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ABSTRACT

THE DEVELOPMENT AND TESTING OF AN INSTRUCTIONAL MODEL FOR LABORATORY EXPERIMENTS ON ELECTRONIC CIRCUITS IN COLLEGE-LEVEL ENGINEERING

By

Shlomo Waks

The purpose of this study was to create an instructional model which would improve a student's understanding of the operation and application of electronic circuits, and to increase his laboratory skills through the use of a systematic approach involving audio-tutorial techniques. A model for laboratory experiments on electronic circuits was suggested for implementing this systematic approach.

There are eleven main components of the model developed:

1. Preliminary work by a student based on handouts and assigned reading, including calculations of electrical performance that will be measured in the laboratory experimentation.

2. Use of audio-tutorial techniques in the theoretical analysis of the circuit and its applications.

3. Use of an oscilloscope as a powerful medium in studying electronic circuits for scanning the output characteristics, displaying waveshapes at various points in

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the circuit, or scanning the actual transfer characteristic of the circuit; that is, the output voltage as a function of the input voltage.

4. Use of guides and flow charts describing the experiment procedure (optional).

5. Creation of conditions for a student's active involvement in the experimenting process--letting him take part in the "design" of the circuit by calculating some missing components and providing immediate feedback for reinforcement. Measuring the circuit operation and getting expected results during the experimental process frequently provides a student with successful experience; this increases his involvement.

6. D.C. (Direct Current) and A.C. (Alternating Current) measurements of the circuit's operation and comparison to precalculated values of voltage, current, or amplification.

7. The use of an experimental analysis of the circuit; a combination of laboratory and theoretical investigation of the circuit's reaction to external or internal changes imposed on it, like changing feeding voltages, loading, environmental circumstances (temperature), or changing the values of its internal components. If an integrated circuit is under experiment, only external changes are investigated.

8. To keep in touch with the real world, a student is shown a few typical practical applications of the circuit at this stage; the newly learned details of the circuit are investigated under real conditions. It is recommended that

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media be utilized for application demonstrations if "live" practical circuits are unavailable.

9. College-level students are asked at this stage to design adequate modifications to be introduced into the circuit in order to satisfy newly imposed conditions of operation.

10. The posttest in any format (oral, written, performance, or in a combination of the three testing forms) is to be taken right after the experiment procedure.

11. The modular structure of the model enables its use at different levels (i.e., engineering, community college, technical school).

The model was applied to the "Electronic Devices Laboratory" E.E. 484 (senior level) in the College of Electrical Engineering at Michigan State University during Fall Term, 1972. A total of 108 students was divided into ten lab sections. Five of the sections (treatment groups) used the suggested model to perform their lab experiment: The Schmitt Trigger--Theory and Applications. This lab experiment was scheduled to last two weeks, for three hours weekly. The other five sections, comparison groups, performed the same experiment under the traditional method of experimentation. The treatment groups had three instructors, and the comparison groups had two other instructors.

The following items were prepared to be used in the Schmitt circuit experiment:

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1. Theory Sheets, including the Schmitt circuit theory and applications.

2. Experimental Procedure Sheets.

3. A slide-tape presentation of the Schmitt analysis and applications.

The experiment was evaluated by four tests: a pre-test, a posttest, a retention test (given one month after the posttest), and a student attitude test. An instructor's evaluation form was filled out by the three treatment group instructors. The results of the four student tests were analyzed statistically, utilizing the CDC 3600 computer at the Michigan State University Computer Center. The Finn Multivariate Analysis of Variance program was employed in the analysis.

Three hypotheses were formulated in the experimental testing of the model, two in the cognitive domain and a third in the affective domain. It was expected that members of the treatment groups would achieve higher mean scores on the posttest and retention test than would members of the comparison groups. It was also expected that members of the treatment groups would have a more positive attitude toward the experimental method (the suggested model) than the comparison group students would have toward the conventional method of experimentation.

The main findings of the statistical analysis were summarized:

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1. No significant difference ($p<0.9544$) was found in the mean scores of the pretest when comparing the treatment and comparison groups, indicating equivalence of groups at the beginning of the lab experiment.

2. Significant difference in the posttest ($p<0.0004$) and retention test ($p<0.0001$) between the treatment and comparison groups indicated that the members of the treatment groups learned and retained more than students in the comparison groups.

3. No significant difference was found in the mean scores within the treatment groups ($p<0.8151$) and within the comparison groups ($p<0.7023$) in any of the three tests (pretest, posttest, and retention test).

4. Members of the treatment groups held a significantly ($p<0.0120$) more positive attitude toward experimentation by means of the model than members of the control groups held toward experimentation through the conventional method.

In the Instructor's Evaluation Form, the treatment groups' instructors reported a favorable reaction regarding the application of the model in the electronics laboratory.

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THE DEVELOPMENT AND TESTING OF AN INSTRUCTIONAL MODEL FOR LABORATORY EXPERIMENTS ON ELECTRONIC CIRCUITS IN COLLEGE-LEVEL ENGINEERING

By

Shlomo Waks

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Secondary Education and Curriculum

1973

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DEDICATION

To Ayala:

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ACKNOWLEDGMENTS

The writer wishes to acknowledge:

The assistance and friendship freely given by his doctoral committee:

Dr. Stephen L. Yelon, Chairman

Dr. Julian R. Brandou

Dr. David P. Fisher

Dr. James L. Page

The cooperation of the Science and Mathematics Teaching Center and the Department of Electrical Engineering and System Science at Michigan State University.

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CHAPTER I

INTRODUCTION

Statement of the Problem

The main objective of this thesis is to develop an instructional model for laboratory experiments on electronic circuits and to test this model in the College of Electical Engineering at Michigan State University.

Successful experimentation with electronic circuits means bringing constructed circuits into operation according to predetermined expectations. In some cases, the experimentation also includes constructing the circuit under experiment. Furthermore, at the college level, students have to acquire the ability to introduce necessary modifications into the circuit in order to fit it into a given new system with specific requirements. This kind of training is a key factor in becoming a good electronic technician or engineer.

Some of the problems in traditional laboratories are:

1. Forcing all the students in a group to proceed at the same rate is boring to the fast students and leads to failure for the slow ones.

Goldon H. Flammer, from Stanford University, asked among other questions:

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> How can we individualise instruction, that is, allow the student to move at his own speed? Why should a brilliant student be forced to make four years of his B.S. and the handicapped (in most cases due to accumulated ignorance) student be forced to meet a quarter deadline or flunk out?
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> Individualized or self-paced instruction appears to have the answer to most of the questions posed above in a way which is acceptable to students and teachers alike.[1]

2. Instead of dealing with meaningful difficulties arising during the accomplishment of the experiment, an instructor spends most of the time reiterating technical instructions.

3. The student's lack of physical and mental involvement in the process of experimentation in the electronics lab lowers the chances that he will learn the amount of knowledge he should.

At the Third Annual Audio-Tutorial System Conference, which took place at Purdue University in November, 1972, a team from the Engineering and Technology Department at Western Michigan University worte in their conference paper:

> Engineering curricula is continually under pressure to increase the amount of knowledge transferred to the student without decreasing the quality of education. One of the best ways to increase this

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[1] Gordon H. Flammer, "A Behavioral Analysis Design of an Engineering Course Using Individualized Instruction," Stanford University, n.d., p. 2.

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transfer of knowledge is through student involvement which demands initiative reactions from the student.[1]

4. A student's over-dependence on an instructor's help while working on the experiment in the laboratory is another problem encountered in the traditional group laboratory. Many of the circuit malfunctions that usually require a student to wait for an instructor's help can be corrected by the student himself if appropriate guidance is provided.

Importance of the Study

Modern industry, computers, automation, communication by telstar, transportation, radio, television, instructional technology, modern medical treatment and research, space exploration, national security, and other modern accomplishments would be impossible without a highly developed science of electronics. More and more people are needed in this field. In the Technical Education Program Series, a prediction of further dissemination of this field is stated: "Meanwhile, science promises that future development using applied electronics will be even more dramatic than the developments witnessed during the past three decades."[2] Thus,

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[1] Jerry H. Hamelink, James Kauppi, and Gary Roberts, "The Multi-Media Approach to Learning at Western Michigan University" (paper presented at the Third Annual Audio-Tutorial System Conference, Purdue University, Lafayette, Indiana, November 1-2, 1971).

[2] U.S. Department of Health, Education, and Welfare, Office of Education, Electric Technology: A Suggested 2-Year Post High School Curriculum, Technical Education Program Series No. 2A (Washington, D.C.: U.S. Government Printing Office, 1969).

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it might be helpful to develop appropriate instructional tools in order to enable increasing numbers of students to become competent electronic engineers or technicians.

The subject matter in electronics is abstract in nature. A man's senses are not constructed to feel (without harm) any electrical quantities like voltage or current. He can only observe the result of electrical activity--light, sound, or movement. This abstract character of the subject limits a student's ability to master electronics.

A desirable method of learning electronics should include software based on both an understanding of the teaching-learning process and a knowledge of electronics as subject matter. Hardware should include varied forms of media. The resulting ease in experimenting with electronic circuits may help to increase the concreteness and usefulness of many applications of electronic circuitry.

The audio-tutorial method of instruction, which has the feature of combining practice with theory, may be the channel through which electronics will reach those potential students who would not otherwise become acquainted with this field.

The audio-tutorial approach to college-level electronics has been implemented at Texas A&M University. The results are strongly in favor of the audio-tutorial method of teaching electronics. James L. Boone, Jr. and William F. Smith wrote in their paper:

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> After one year of operation it has been found that the electronics students have achieved higher grades and have progressed through the course material faster than during the previous year when conventional methods were used. Furthermore, each student has become skilled in the use of electronic measuring instruments. This has not always been accomplished in previous semesters, as the weaker students lean on the stronger students. The audio-tutorial system eliminates lab partners--each student is on his own.
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> We are convinced that the audio-tutorial system of instruction is an excellent approach to teaching electronics. Time is needed to develop more visual materials and software to supplement the system. The task at hand is to develop these materials, . . . We encourage other electronic instructors to try the audio-tutorial system of instruction.[1]

In high school level electronics, audio-tutorial instruction turned out to be successful at Jonesboro High School, Jonesboro, Arkansas, where a course of "Basic Electronics" has been taught since 1969.[2] Almost 90 per cent of the students chose to continue learning about electronics using the audio-tutorial technique, while only about 10 per cent preferred to proceed through the conventional method of learning electronics.

Definitions

Terms used in the study with which the reader may not be familiar are defined below:

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[1]James L. Boone, Jr. and William F. Smith, "Audio-Tutorial Electronics Instruction" (College Station, Texas: Texas A&M University, n.d.). (Mimeographed.)

[2]John S. Morgan, "High School Basic Electronics (Modified Audio-Tutorial Style)." (Mimeographed.)

Electric (Electronic) Circuit--The entire course traversed by an electric current.

Oscilloscope--An electronic instrument for projecting the graphic presentation of the voltage at a measured point as a function of time (or other voltage).

Waveshape--The graphic presentation of voltage at a certain point in an electrical circuit as a function of time.

Instructional Model--An isomorphic representation of certain aspects of a larger and more complicated instructional system.

Purpose of the Study

The purpose of this study is to improve a student's understanding of the operation and application of electronic circuits, and to increase his laboratory skills through the use of a systematic approach involving audio-tutorial techniques. A model for laboratory experiments on electronic circuits is suggested for implementing this systematic approach.

The Behavioral Objectives

Objectives in a curriculum design describe the student's behavior at the end of a course or another learning unit. The learner's behavior is characterized by his demonstrated visible or audible action according to specified conditions and standards for adequacy of performance.

In a technical field of education like electronics, introducing behavioral objectives into the curriculum might be as helpfu

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be as helpful to the teacher as it is to the student, in clarifying an instructional destination.

More and more technical institutions are beginning to use behavioral objectives. One of the most active institutes in this field is the nonprofit educational corporation, The Instructional Objectives Exchange,[1] which prepared a booklet of behavioral objectives in electronics.

In Chapter III of the present study, the reader will find a sample of the behavioral objectives specific to the circuit under experiment (Schmitt Trigger). These objectives are in accordance with the general behavioral objectives for any electronic circuit under experiment, and are stated in the following order.

Given a diagram of the electronic circuit under experiment, the student will be able to do the following:

1. Explain (orally or in writing) the operation of the circuit and the roles of the various components of the circuit.

2. Point out the expected waveshapes of the voltages at the various points in the circuit.

3. Predict the possible changes in the circuit operation as a result of a great change (over 70 per cent) of one of its component values or feeding sources.

Examples of acceptable answers: The circuit will not operate; the transistor will be in saturation (or in cut off).

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[1]The Instructional Objectives Exchange, P.O. Box 24095, Los Angeles, California, 90024.

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4. Perform a series of measurements according to given tables.

5. Realize how theory "works" by comparing the measured results with the calculated ones. The maximum acceptable difference between measured and calculated values is 30 per cent.

6. The student will point out possible reasons for the differences between the calculated and measured results.

7. The student will name at least two applications of the circuit.

8. Given a new situation (different supply voltages or driving level, environmental changes like rising temperature, additional loading, or increasing frequency of operation), the student will point out the necessary modifications which have to be introduced in order for the circuit to operate correctly under the new circumstances.[1]

The Model for Electronic Circuit Experiments--in Brief

A detailed description of the model for electronic circuit experiments and the philosophy behind it is given in Chapter III. Only a brief presentation is given below. The development of this model is based on the following factors:

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3. Knowledge in the electrical engineering field.

A condensed presentation of the model is given in the block diagram in Figure 1. The sequence and roles of the various blocks are described as follows:

1. Prepare Preliminary Work

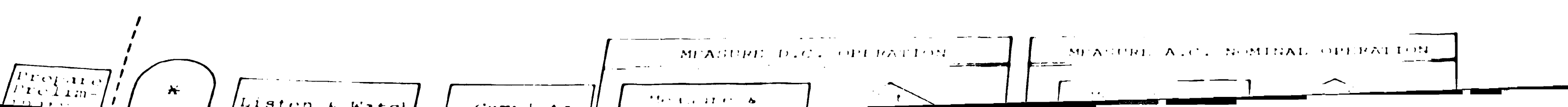
At least a week before the laboratory experiment, a student is informed about the topic of the experiment. He is supposed to come to the laboratory after completing the assigned reading and calculating some of the circuit components and expected outcomes of the lab measurements. These calculations will be used as comparison references of the measured outcomes of the experiment. Some instructors may require a student to hand in preliminary work before starting the experiment.

2. Enter

The student "enters" the lab with an incomplete practical circuit, a lab manual, a set of varied media, and electronic equipment and materials.

3. Listen and Watch, Audio-Tutorial

In this stage, a student gets to know the circuit under experiment. Its operation and applications have to be demonstrated through multi-media means like a tape-slide presentation, or a closed loop film. An effort has to be made to arouse a student's curiosity and interest in the circuit, by posing a problem which might be solved by this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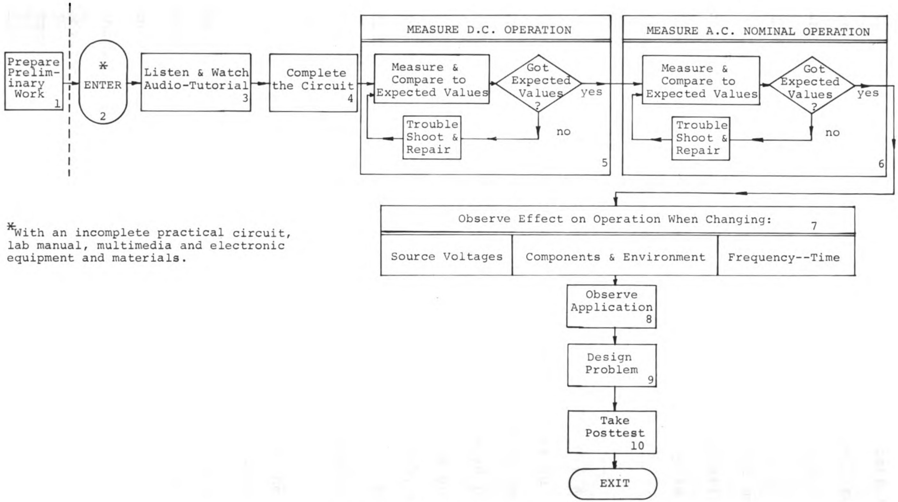

*With an incomplete practical circuit, lab manual, multimedia and electronic equipment and materials.

Figure 1.--A model for electronic circuits experiments.

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circuit, for instance. In this stage, a student gets an overview of the whole experiment procedure in brief, so he knows where he is going and what he is supposed to do.

4. Complete the Circuit

The student can't really operate the circuit unless he completes the circuit under experiment by calculating and connecting components purposely missing. This step is used to check if prerequisites are met.

5. Measure D.C. Operation

The first operation is Direct Current (D.C.) measurement, i.e. the D.C. conditions of the circuit. As in the following steps, a student gets natural feedback by comparing some of the measured results with the calculated ones. In case of malfunction of the circuit, a student is guided through a self-correcting trouble shooting procedure, which in itself, is a very important learning experience. Details of this unit may be found in the Experiment Procedure, Appendix A.

Only after trying unsuccessfully to locate the problem and resolve it by himself through self-guided trouble shooting, does a student call for the instructor's help. This procedure not only increases the practical experience of a student, but also increases his satisfaction and self-confidence, while it frees an instructor to deal with meaningful difficulties arising during the accomplishment of the experiment.

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It must be emphasized here that merely operating the circuit successfully and getting reasonable comparisons between the calculated and measured values is a process of continuing evaluation. The student gets continuous evaluation from the operational behavior of the circuit; this is actually natural evaluative feedback, which may result in strong reinforcement.

6. <u>Measure A.C. Nominal Operation</u>

After establishing and measuring the D.C. conditions of the circuit, the dynamic (A.C.) nominal operation is performed, measured, and compared with some expected values. At this point, some instructors, especially at the high school level, may introduce some application presentations and finish up with the final evaluation step, i.e. a post-test. However, for a college and community college student, the model offers some additional steps in the experimentation procedure, namely further analysis and synthesis options of the experiment.

7. <u>Observe Effect on Operation</u>

In this stage, a student investigates the effect of changes in source voltages, component values, and environmental conditions on the operation of the circuit. Frequency and time response of the circuit are also investigated in this stage.

8. <u>Observe Application</u>

In the application step, several block diagrams, illustrating actual applications of the circuit, are presented t

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9. Design Problem

The design stage is primarily a college-level stage. It is actually a part of the evaluation. Here a student is asked to suggest appropriate modifications to be introduced into the experimented circuit to make it compatible with a given system having new conditions of loading, feeding voltages, environmental restrictions, etc.

10. Take Posttest

Right after finishing an experiment procedure, a student has to submit a written report, including his precalculations and measurement results of the experiment. A posttest might be given in written, oral, or performance form, or even in some combination of the three forms.

The main points of the model might be summarized as follows:

1. Use of audio-tutorial techniques.

2. Utilizing the oscilloscope as a powerful medium in studying electronic circuits; for instance, scanning the output characteristics of a transistor, or scanning the waveshapes at various points in the circuit or scanning the actual transfer characteristic of the circuit, that is,

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3. Use of guides like flow charts for the experiment procedure (optional).

4. Having a student discover by calculating the values he is going to measure.

5. Some features of "programmed experimentation." It is a combined series of mental and motor activities performed by a learner. A student is exposed to an ordered sequence of stimulus items to which he responds. His responses are immediately reinforced by the natural feedback he gets through measuring the circuit operation.

6. The modular structure of the model enables its use at different levels, i.e. engineering, community college, technical schools.

It is important to maintain weekly sessions of the instruction team and the whole group of students performing the electronic circuits experiments. These sessions are to be dedicated to discussing the preceding and forthcoming experiment, to surveying special problems, to exchanging recent learning experiences among the students, to stating conclusions, and to administering oral exams.

Developmental Sequence of the Model

An overview of the developmental sequence of the model is shown in Figure 2 in a block diagram format.

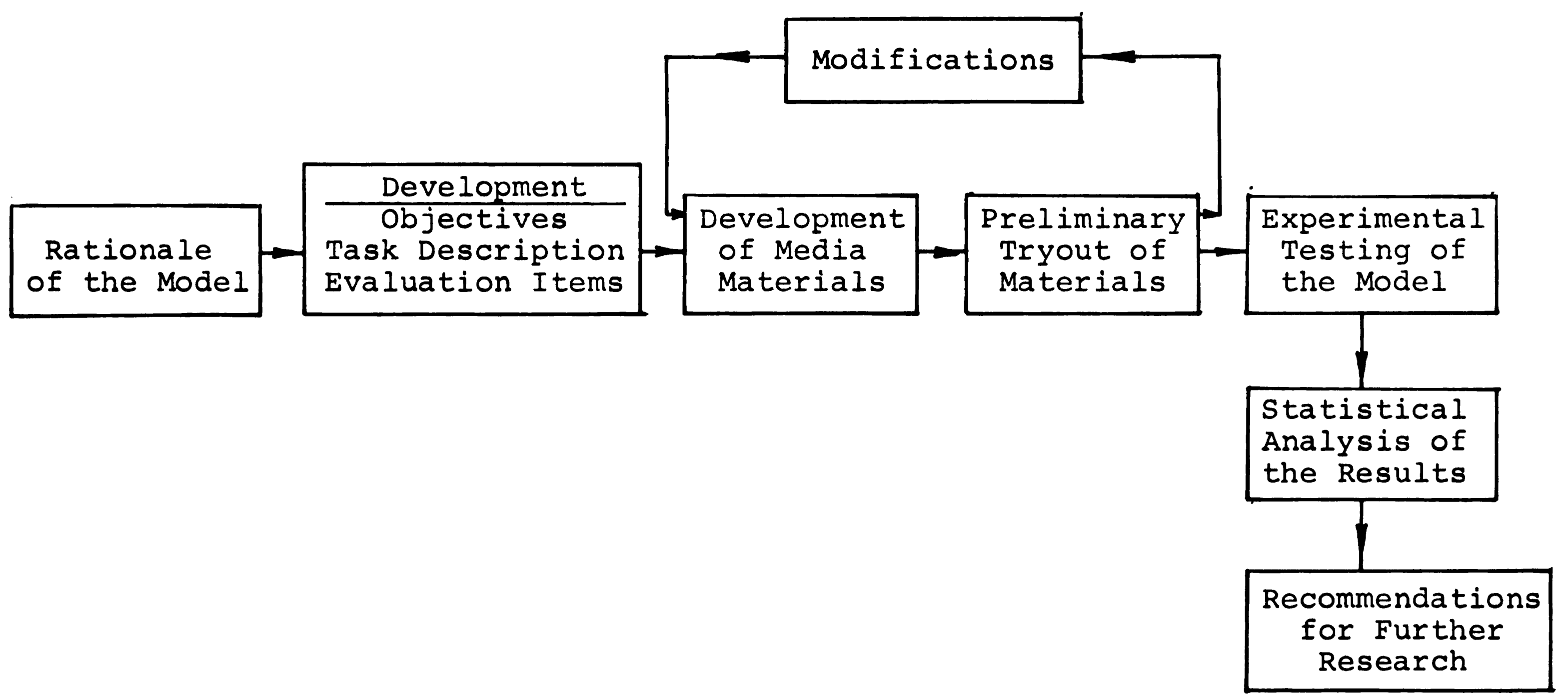

Figure 2.--Developmental sequence of the model for electronic circuits experiments.

The rationale includes the reasoning behind the model, its importance and purpose.

The second stage includes the development of terminal objectives, task descriptions, and tests. The behavior described is that which the student is to perform when completing the experiment on a given electronic circuit. A task description includes detailed guidance for the student during the experiment procedure.

The evaluation used in this study includes four tests: pretest, posttest, retention test, and attitude test. These four are not necessarily the only evaluation tools for an instructor using this model. These four tests were used by the researcher to evaluate a partial representation of the model. Other instructors who use the model may use different evaluation methods, like student reporting or oral testing.

The development of media materials includes creation and selection of both hardware and software. A great deal of time and money can be saved by selecting from existing materials rather than by making them.

In order to try out the model, the researcher was given permission to apply its requirements to the "Electronic Devices Laboratory" course, E.E. 484 (senior level) in the College of Electrical Engineering at Michigan State University during the first two weeks of fall term, 1972 (three hours weekly). The topic of the scheduled experiment was: "The Schmitt Trigger--Theory and Application." For this topic, the

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topic, the researcher wrote the Theory Sheets and Experiment Procedure for the students who would use the suggested model.[1] Two presentation forms were prepared by the writer--a slide-tape presentation of circuit theory and applications, and an oscilloscope to be used as a diagnostic tool of the circuit's practical operation.

In the preliminary tryout, the materials were submitted separately to an electrical engineering instructor and a student from the selected population. After getting their remarks, necessary modifications were introduced to improve the media materials.

A total of 108 students was divided into ten lab sections. Five of the sections (treatment groups) used the suggested model to perform their lab experiment on the "Schmitt Trigger" three hours weekly for two weeks. The other five sections (comparison groups) performed the same experiment under the traditional method of experimentation. The treatment groups had three instructors and the comparison groups had two other instructors.

As has already been mentioned, the model was evaluated by four tests: pretest, posttest, retention test (given one month after the posttest), and a student attitude survey. The three treatment group instructors filled out an Instructor's Evaluation Form concerning the model (Appendix D5).

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[1]See Appendices A and B for a copy of the Theory Sheets and Experiment Procedure.

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The results of the four tests were statistically analyzed utilizing the computer at Michigan State University (Finn program). According to the findings of the study, recommendations for further research are stated.

The model should never be completely finalized; it must remain open to further changes and improvements according to future necessities.

Use of the suggested model of experimentation is not restricted to certain electronic circuits. It may be used for a great variety of circuits, like amplifiers, oscillators, multivibrators, and other switching dircuits. The circuits may be constructed of discrete components or integrated ones like those used when dealing with the more modern portion of electronics.

The model does not impose a rigid system of experimentation. On the contrary, the instructor and students are encouraged to change or add their own modules, or use those media which will result in optimum results for the learner.

The suggested instructional model for experimenting in electronics was prepared for college-level students. However, since this model is constructed of small modules, it may also be used for lower level students, i.e. at the community college or high school level. For instance, high school students do not have to work on the "synthesis" part of the experiment. Design capabilities are required only at the college level.

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The Hypotheses

The hypotheses for the tryout of the model are of a general nature. At this stage of development the purpose is to get an overall idea of the characteristics and effects of the model in comparison with a conventional method of instruction. Consequently, three hypotheses were formulated, two in the cognitive domain and a third in the affective domain.

The hypotheses are given in testable form in Chapter IV, and are stated only briefly below. First, it is expected that members of the treatment groups will achieve higher scores on the posttest (Appendix D2) than students in the comparison groups. It is also expected that there will be a significant difference in achievement test scores between the treatment and the comparison groups one month after the students have completed their experiment (Retention Test, Appendix D3). Finally, it is expected that there will be a significant difference in positive attitude toward the methods of experimentation with electronic circuits, between the members of the treatment groups and the members of the comparison groups. For instance, a smaller percentage of the treatment group members will prefer to use the conventional method of experimentation in the future than the percentage of the comparison group members preferring the conventional method.

In Chapter VI, specific hypotheses are made available for the ongoing experimental research of the model, concerning specific in

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specific independent variables of interest like efficiency, timing, or use of different multi-media setups.

Assumptions

1. The sample of 108 students from the Department of Electrical Engineering at Michigan State University did not differ from similar populations in other colleges of engineering.

2. It was assumed that no student had had an opportunity to practice the questions included on any examination.

3. There was no interaction between students of the treatment and comparison groups, nor between instructors of the comparison and treatment groups. Since the comparison groups had different instructors than the treatment groups, there was no carry-over of the model's methods of experimentation to the groups.

4. There was no teacher effect. (This can be shown by finding no significant differences when comparing the scores within the treatment groups and within the comparison groups).

Limitations

The study was limited by the number of students (108) in the course E.E. 484--Electronic Devices Laboratory I at Michigan State University.

The statistical analysis of the results of the three tests (pretest, posttest, and retention test) involved only 80 subjects because only those students who took all the three tests were included in this statistical analysis.

Equipment, manpower, and space limitations made it impossible for the student to perform the experiment at his own convenience. Each of the ten lab sections had its fixed three weekly laboratory hours of experimenting in the electronic lab.

Limited quantities of electronic equipment prevented the testing of the model in completely individualized format, so in this experimental test of the model the students worked in pairs.

The time elapsing between the posttest and retention test (retention period) chosen was only one month because the researcher suspected that during this period some of the students might pick up additional information concerning the Schmitt Trigger in other electrical engineering courses.

According to the Cornfeld-Tukey argument, the population of this study might be considered those students in courses similar to the ones taken by electrical engineering seniors at Michigan State University. In order to expand the population, further field studies should be carried out to investigate the external validity of the model, as suggested in detail in Chapter VI. Conclusions concerning external validity--i.e. application of the study to other student populations--should account for the limitations mentioned.

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Overview

In Chapter II, the background of the problem of electronics instruction is given. The traditional method of experimentation in electronics is reviewed.

Chapter III contains a detailed description of the model, including an example to be used in the experimental test. A report of the development of media materials is also included in this chapter.

The experimental test of the model, description of the sample, statistical design of the study, and the process of "running" the model are described in Chapter IV.

Chapter V consists of the analysis of the collected data. Included are results and interpretation of the data collected from the attitude survey and instructor's evaluation form.

Discussed in Chapter VI are the conclusions based on the results of the analysis and recommendations for further research.

CHAPTER II

BACKGROUND

Introduction

Curriculum modification is a continuing process, especially in such a dynamic field as electronics. During the short history of this field, many changes in content have occurred, mainly since World War II. It seems that methods of electronics instruction are far behind the needs of those who would like to be acquainted with this field.

The search for better means of instruction has been and should continue to be one aim of education in general. The changes in physics content and the amount of research in instruction of physics at various levels serve as examples of this continuous process.

The value of reviewing past work (even in less dynamic fields than electronics) to improve instruction was pointed out by Dewey: "The way out of scholastic systems that make the past an end in itself is to make acquaintance with the past a means of understanding the present."[1] Therefore, we must not be content with the status quo. We

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[1] John Dewey, quoted in Sidney Hook, Education for Modern Man--A New Perspective (New enlarged edition; New York: Alfred A. Knopf Publishing Co., 1966), p. i.

must examine the past accomplishments as well as future needs for methods of improving the teaching of electronics.

A brief review of the ever-growing field of electrical engineering and a description of traditional and non-traditional ways of experimenting in an electronics lab will aid in understanding the reasons for developing the suggested model. In this chapter the reader will also find a short literature review in three areas that are closely connected with this study: audio-tutorial instruction, individualized instruction, and mastery learning.

Background of the Problem--The Spread of Electricity and Electronics

Electrical engineering is less than 100 years old, but magnetism and electricity have been known and observed for thousands of years.

Chinese emperors about 2000 B.C. used a lodestone for pointing always to the South. Later, the Greeks knew about amber ("elektron" in Greece) attracting light objects after being rubbed in a certain way.

Dunsheath wrote about the first compass:

> King Solomon, Son of David, is said to have employed the compass and indeed to have invented it, while certain verses in Homer's Oddyssey are interpreted as evidence that the properties of the lodestone were understood and applied in his time.[1]

Dunsheath also wrote about the first description of magnetic induction in iron:

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[1]Percy Dunsheath, A History of Electrical Engineering (London: Faber and Faber, 1962), p. 22.

Lucretius (55 B.C.) for example, considered that the lodestone had hoods on its surface which engaged with rings on the surface of the attracted iron. This same poet, in his "De Rerun Natura" vividly describes magnetic induction in iron by the lodestone in the following lines:

When without aid of hinges, links or springs
A pendant chain we hold of steely rings
Dropt from the stone; the stone the binding source
Ring cleaves to ring, and owns magnetic force;
Those held superior, those below maintain
Circle neath circle downward draws in vain.[1]

Not until the nineteenth century did the discovery of the close relationship between electricity and magnetism bring about the foundation of electrical engineering.

The great push for the expansion of electrical engineering came with World War II. The electrical engineering departments began to turn away from teaching power electricity emphasizing machinery and tramsmission, and moved beyond offering only a few elective courses in electronics and communication.

Van Valeknburg wrote about this change:

> The technical developments of World War II emerged as fruits of the labors of engineers and scientists from a variety of backgrounds: antennas and propagation, microwaves and microwave electronics, servomechanisms (later called controlled systems), pulse techniques, radar, network synthesis, communications and accoustics (especially underwater sound). To accommodate all of these new subjects, it was obvious that an upgrading of the curriculum was urgently required. This was accomplished by the adoption of the option system. The older work in power was retained as power option. The newer fields were included in electronics and communications options.[2]

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[1] Ibid.

[2] M. E. Van Valkenburg, "Electrical Engineering Education in the U.S.," IEEE Transactions on Education, E15, 4 (November, 1972), 242.

Van Valkenburg named additional important fields (increasing in quantity) like: automation (or cybernetics), nonlinear theory, information theory, millimeter tubes, plasmas, transistors and other solid state devices, radio astronomy, quantum electronics, bioengineering and computer science. One of the important curriculum elements is the laboratory. Professor Van Valkenburg wrote in this regard:

> Laboratories have traditionally followed cookbook procedures. We have not enjoyed a tradition of interesting and valuable laboratory experiences. Project laboratories, with considerable student flexibility and initiative, have been slow to develop.[1]

His more general comment was: "We should give increased attention to educational techniques."[2]

The development of electronics industries has taken place in many countries besides the United States, especially during the last two decades. Such development, however, is impossible without adequately trained technicians and engineers.

The November, 1972, edition of the IEEE Transactions on Education is a special issue on international engineering education.[3] Robert C. Winton, Chairman of the Manpower and Training Advisory Committee of the Electronic Engineering

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[1] Ibid.

[2] Ibid., p. 243.

[3] The interested reader may find in this edition of the IEEE Transactions on Education a very interesting review of electrical engineering education in the United States, Scandinavian countries, the United Kingdom, Australia, India, Japan, and Latin America.

Association in England, described how the Industrial Training Act, enacted to raise the quality and quantity of training in the United Kingdom, is implemented. He outlined some training recommendations in the electronic and electrical industries.[1] Great emphasis on cooperating with related industries in training provides relevant subject matter. Unfortunately, in many countries, including the United States, there is little contact between industry and universities.

Electronic Circuits Laboratory Experiments--Past and Present

In the 1940's, the lab experiment began to play an integrated role in the electronics curriculum at the technical school and college levels. Most of the lab manuals edited by many manufacturers of electronic equipment intended for training purposes were written in "cookbook" style. Unfortunately, in most cases both the hardware and software have not been student oriented.

Schulz, Anderson, and Leyer published a laboratory textbook for college-level courses in electronics, communication networks, basic radio and television circuits, and transmission systems including antennae.[2] Concerning the

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[1] Robert C. Winton, "Some Aspects of Industrial Training in the U.K. and Their Impact on Education," IEEE Transactions on Education, E-15, 4 (November, 1972), 205-211.

[2] E. M. Schulz, L. T. Anderson, and R. M. Leyer, Experiments in Electronics and Communication Engineering (2nd ed.; New York: Harper & Brothers Publishers, 1954).

purpose of laboratory work, the authors stated:

> Familiarity with laboratory equipment is as essential to an electronic or communication engineer as an understanding of the theory behind the equipment. This familiarity can be gained only by working with the equipment in the laboratory. The student should keep the following objectives in mind in any engineering laboratory course:
> 1. To become familiar with the equipment and its behavior.
> 2. To become familiar with standard methods of tests and operation.
> 3. To learn to work with tools and equipment.
> 4. To become familiar with practical considerations which prevent a circuit from behaving as a theoretical treatment might indicate that it should.[1]

The usual procedure of implementing an experiment in electronics has been, and in most cases continues to be, as follows:

The instructor assigns a topic for a forthcoming lab experiment and hands out some brief description of the circuit and preliminary work. A week later, when time for the experiment comes, the students construct the circuit (or get it already assembled on a board) and begin to experiment by turning knobs, pushing buttons, and recording data. The student has to fill out a report including experimental procedure, measured data curves, and sometimes answers to specific questions concerning the circuit.

Usually, the students work in pairs with one set of equipment. When three or more students are working together on the same experiment, the efficiency of experimentation turns out to be quite low. In these situations, a "job

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[1] _Ibid._, p. 1.

distribution" is often established; e.g., one student reads the instructions from the lab manual, another turns the knobs, and the third records the data.

Evans' book, Experiments in Electronics, consists of 100 experiments on 50 different subjects, most of which are in the "circuits" area.[1] The pattern of the experiment procedure is similar to the experimentation procedure described.

The procedure mentioned assumes responsible lab instructors who make the necessary arrangements to keep the lab equipment in operative condition, maintain a current check on the student's prelims and reports, supply "theory sheets" when necessary, and assign adequate readings for the upcoming experimental topics. An important problem for the instructor is the synchronization between lectures on theory and lab experiments, e.g., to make sure the student has already been acquainted with the circuit with which he is going to experiment.

After nine years' experience in instructing and supervising in technical institutions at the junior college level, the writer cannot state that the circumstances are always such as to satisfy these assumptions.

During the past decade, laboratory work has assumed a much more important role in many technical schools and engineering colleges. Instructors in electronics and

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[1]W. H. Evans, Experiments in Electronics (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1959).

electrical engineering faculty members have spent a large amount of time and effort developing new programs and laboratory facilities.

The laboratory experience at the college level may be divided into three major levels: introductory, intermediate, and project. The student is first introduced to the basic skills necessary to use electronic instrumentation and equipment and use a variety of measurement techniques. The intermediate laboratory work exposes the student to a variety of electronic circuits, their operation modes, and factors affecting their performance. At this stage, the student is given an opportunity to explore and see if he wishes to enter a given technical area. The laboratory project enables the highly motivated students to attack some challenging professional problems.

A special issue of the IEEE Transactions on Education was dedicated to exploring the place of the laboratory in a modern electrical engineering curriculum.[1] This issue illustrates many innovative approaches that have been developed to provide various types of electronic laboratory facilities. It might be worthwhile to look at some of these innovative approaches.

Oswald and Sloan described one innovative approach:

> . . . A senior electronics laboratory at Michigan Technological University which operated for more than a year with 100 students each term working individually

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[1] IEEE Transactions on Education, Special Issue on Undergraduate Laboratories, E-14, 3 (August, 1971), 90-94.

> on an open laboratory basis. The objectives of the laboratory are to teach theory and practice of experimentation and supplement engineering theory presented in the classroom. Students schedule time in two-hour blocks and perform experiments alone without direct supervision. . . . Each student is assigned to an experimental advisor (a faculty member).[1]

Senior students from the same course are responsible for safety, obtaining new equipment, and circuit trouble shooting. The authors stated that "student and faculty acceptance of the program has been enthusiastic"; and:

> This laboratory has increased development of experimental skills for all students compared with the traditional group operation. The laboratory has functioned on a small budget with no new equipment in the first year and no increase in instructor time. . . .
>
> All the instructor's time is now spent in one-to-one relationship with students or in critical review of student reports, rather than laboratory lecture or trouble shooting in laboratory.[2]

In the same issue of <u>IEEE Transactions on Education</u>, Banks presented a paper on the topic: "The Junior Electronics Laboratory: Opportunities for Invention."[3] In this kind of circuit design laboratory, creativity and problem solving are emphasized. Pairs of students design, construct, and measure their project. On an oral examination, they demonstrate the working circuit and defend the design. There are only two weekly scheduled requirements: a lecture on Tuesday

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[1] Oswald and Sloan, "An Economical Self-Supervised Operated Open Electronics Laboratory," <u>IEEE Transactions on Education</u>, E-14, 3 (August, 1971), 90.

[2] <u>Ibid</u>.

[3] Banks, "The Junior Electronics Laboratory: Opportunities for Invention," <u>IEEE Transactions on Education</u>, E-14, 3 (August, 1971), 86-89,

to acquaint the students with the following week's project, and a 20-minute private oral examination given by the lab staff on the previous week's project. The average time a student puts into this project lab is ten hours per week. The students compete in solving the same problem, which has many solutions. This type of laboratory is implemented in the Electrical Science Division of the School of Engineering, Case Western Reserve University, Cleveland, Ohio. The three-credit-hour course involves about 65 students each year. Banks stated that "Many students have credited their working knowledge of electronics to this laboratory program."

In a rapidly changing industrial world, much emphasis is placed on thorough and continuous in-plant education and training programs. In keeping with this dynamic development, the training activities in large industrial enterprises are often replanned and reorganized to ensure a current and future professional work force. In fact, training schools in industrial plants might be more up-to-date than colleges. However, it is difficult to review such programs, since these in-plant training schools generally don't report their curricula or methods of instruction.

In the United States, The Bell System is considered to have the largest educational institution outside the government. Sever (Engineering Director--Education and Training, American Telephone and Telegraph Company) and Kotch published an article concerned with The Bell System Center for

Technical Education.[1] In this article, they discussed, among other things, the systematic course development process based on learning principles such as task analysis, establishment of behavioral objectives, valid evaluation, and computer-aided individualized learning. In their conclusion, they stated: "It is through utilization of a sound behaviorally based course-development system that we can be assured the results of training are effective." Unfortunately, this article was written in general terms, and is not as valuable as more detailed information.

The use of the digital computer as a teaching tool is an important educational innovation. The extra dimension provided by the computer is now widely recognized, and its almost unlimited instructional potential is being tapped by many curriculum designers. It is only natural that a profound impact of computers on the electrical engineering curricula is becoming increasingly apparent.

There seems to be great potential in Computer-Guided Experimentation (CGE) in the electronics lab. The computer is an extremely efficient tool that automatically provides feedback information about a student's laboratory activities, like the interconnections he makes between the terminals of his experimentation equipment and his settings of instrument dials. The student's experimentation activities can be

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[1] Sever and Kotch, "The Bell System Center for Technical Education: One Industry's University," IEEE Transactions on Education, E-15, 2 (May, 1972), 103-108.

transferred to a time-shared, computer-aided instructional system, so he can get automatic guidance through a lesson in any manner preprogramed by an instructor.

Neal and Meller presented a paper dealing with Computer-Guided Experimentation at the 1971 Symposium on Applications of Computers to Electrical Engineering Education.[1] In this paper, the authors reported about ". . . the development, operation, and initial performance of an Electrical Engineering laboratory station equipped for Computer-Guided Experimentation." The study was carried out in the computer-based Education Research Laboratory at The University of Illinois, Urbana. Since 1968, members of the CGE team have been devising, programing, and testing lessons in experimentation. These activities are based on educational psychology, Computer-Aided Instruction (CAI), and experience in laboratory instruction. Neal and Meller described the Computer-Guided Experiment station as follows:

> This CGE station consists of electronic experimentation equipment and a student terminal of the PLATO time-shared computer aided instructional system mounted side by side on a large laboratory table (3'0" x 7'8"). The rack-mounted electronic equipment consists of a dual-track wide-band oscilloscope, a square, triangle, ramp or sine wave voltage generator, a constant current-voltage supply and a vacuum tube voltmeter. A general purpose circuit board and various alternate printed circuit boards are equipped with automatic terminal sensing connections cabled to connectors that can be plugged in at the front of the equipment

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[1] James P. Neal and David V. Meller, "Computer-Guided Experimentation--A New System for Laboratory Instruction," IEEE Transactions on Education, E-15, 3 (August, 1972), 147-152.

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panel. The present PLATO station equipment consists of a portable television set and a cable-connected table-top keyset.[1]

The authors of the article included an evaluation of two programed lessons. The results were positive in both the cognitive and affective domains.

Regarding community-college level electronics instruction, two significant curriculum programs for a two-year electronics technology course (post high school) might be mentioned. The first is Electronic Technology: A Suggested 2-Year Post High School Curriculum.[2] This thorough and widespread curriculum suggests a program intended to educate highly skilled electronic technicians. The program was prepared by a team of engineers, industrialists, educators, administrators, and technical specialists.

The second program, a more recent, sophisticated, and updated two-year Electronics Technology course, is the Report of the Electronics Technology Curriculum Development Project, which was conducted by the University of Illinois at Urbana-Champaign in cooperation with seven community colleges.[3]

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[1] Ibid., p. 148.

[2] U.S. Department of Health, Education, and Welfare, Office of Education, Electronic Technology: A Suggested 2-Year Post High School Curriculum, Technical Education Program Series No. 2A (Washington, D.C.: Government Printing Office, 1969).

[3] Daniel S. Babb, Project Director, Report of the Electronics Technology Curriculum Development Project (Urbana, Illinois: Department of Electrical Engineering, University of Illinois at Urbana-Champaign, 1971).

The members of the Project Staff and the Steering Committee are electronics instructors, coordinators, or heads of college electronics departments. The contents of this lengthy report include the objectives and philosophy of the project, and subject matter for the core courses of an Electronics Technology Curriculum with recommended instruction techniques, facilities, equipment, and costs. The appendices of the report include detailed information regarding summer institutes, conferences, multimedia sources, suggested texts, references, and bibliography.

Review of Literature on Learning Principles and Instruction Methods

Learning Principles

The present study deals with the development of an instructional model for experimentation in the electronics laboratory. The related professional literature has already been reviewed in the preceding pages. Related instructional literature will now be reviewed.

Concerning the modern conceptions of learning, Gagné wrote:

> Many modern learning theorists seem to have come to the conclusion that conceiving learning as a matter of strengthening connections is entirely too simple. Modern conceptions of learning tend to be highly analytical about the events that take place in learning, both outside the learner and also inside. The modern point of view about learning tends to view it as a complex of processes taking place in the learner's

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nervous system. This view is often called an "information-processing" conception.[1]

According to Gagné, modern conceptions of learning lead to a new view of what instruction is all about. He concluded in this article:

> In the most general sense, instruction becomes not primarily a matter of communicating something that is to be stored. Instead, it is a matter of stimulating the use of capabilities the learner already has at his disposal and of making sure he has the requisite capabilities for the present learning task, as well as for many more to come.[2]

Hilgard and Bower stated that learning principles are:

> . . . summarizations of empirical relationships that hold rather widely, although many of them are not stated with sufficient precision to consider them to be "laws" of learning.[3]

These writers distinguished between three orientations of learning principles: the orientation toward S-R (Stimulus-Response) theories, toward cognitive theories, and toward principles from motivation and personality theory.

The principles emphasized within S-R theory are:

1. Activity of the learner (his responses).
2. Frequency of repetition--to guarantee retention.
3. Reinforcement--positive reinforcements (rewards) are preferred to negative reinforcements (punishments).

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[1] R. M. Gagné, "Some New Views of Learning and Instruction," IEEE Transactions on Education, E-14, 1 (February, 1971), 28.

[2] Ibid., p. 30.

[3] Ernst R. Hilgard and Gordon H. Bower, Theories of Learning (3rd ed.; New York: Appleton-Century-Crofts, 1966), p. 562.

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4. Generalization and discrimination--learning becoming appropriate to a wider range of stimuli.

5. Novelty in behavior.

6. Drive conditions--motivational conditions are important.

7. Conflict and frustrations--irrelevant motives have to be recognized and their resolution or accommodation provided for.

The main points of several related theories of learning will be pointed out next.

According to Bruner's theory of cognitive development, there are three ways of knowing: (1) enactive--through doing, (2) ikonic--through seeing, and (3) symbolic--through a symbolic means.[1] Bruner also formulated three levels of thinking: concept formation, interpretation of data and inference, and applications of principles. In 1960, Bruner proposed the spiral curriculum to identify basic concepts and principles of a discipline, and to teach at increasing levels of difficulty (sequential and cumulative).

In Gagné's hierarchy of learning model, eight learning categories are arranged in order from simple to complex. This hierarchy is based on the assumption that each higher order of learning depends upon the mastery of the one below it. The eight types of learning cited by Gagné are:

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[1] J. S. Bruner, "The Act of Discovery," Harvard Educational Review, XXXI, 1 (1961); J. S. Bruner, Toward a Theory of Instruction (Cambridge, Mass.: Harvard University Press, 1966).

1. Signal learning--a general response to a signal.
2. Stimulus-response learning--a precise response to a discriminated stimulus.
3. Chaining--linking several responses by reinforcing the responses done in sequence, continuously increasing the number of responses linked together.
4. Verbal association--learning of verbal chains.
5. Multiple discrimination--n different identifying responses to n different stimuli.
6. Concept learning--acquiring the capability of making a response that identifies an entire class of experiences, objects, or processes.
7. Principle learning--describing relationships between events to be used for prediction. It may be verbalized in a rule form like: "If A, then B" where A and B are concepts.
8. Problem solving--a strategy from problem sensing and formulation to the search and implementation of a solution. Requires thinking to combine two or more principles.[1]

Skinner's reinforcement theory is based on the following principles:

1. Operant conditioning--first respond, then reward. "Operant" is a behavior which changes frequency as a function of its consequences.

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[1]Hilgard and Bower, op. cit.

2. Information is best assimilated in small steps.
3. Student should be actively involved in the learning process.
4. Immediate reinforcement of correct answers.
5. Self-pacing.[1]

According to Mager's theory of behavioral objectives, a behavioral objective is a precise description of the behavior (visible or audible action) a student is expected to exhibit after instruction under specified testing conditions and standards for adequacy of performance.[2] Thus the behavioral objective has three factors:

1. Behavioral term (measurable).
2. Conditions under which behavior is to occur.
3. Criterion of acceptable performance.

Mager once commented, with reference to objectives: "If you don't know where you are going, you are certain never to get there." Mager's main points concerning learning in general are:

1. Focus student attention.
2. Achievement is increased when teachers and students understand objectives.
3. Emotional atmosphere is improved if more pleasant

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[1]B. F. Skinner, "Why We Need Teaching Machines," Harvard Educational Review, XXXI, 4 (1961); B. F. Skinner, "The Science of Learning and the Art of Teaching," Harvard Educational Review, XXXIV (1967).

[2]R. F. Mager, Preparing Instructional Objectives (San Francisco: Fearon, 1962).

emotional reactions are elicited and more time is used in helping students deal with emotions.[1]

Taxonomy of Educational Objectives

The two domains in the taxonomy of educational objectives are the cognitive and the affective domains. Cognitive behavior is internal, unseen behavior, including thinking. It usually takes the form of problem solving and conceptual or verbal behaviors.

The main aspects of cognitive domain are: knowledge, comprehension, application, analysis, synthesis, and evaluation.[2]

Affective behavior is neither related to verbal processes nor to skilled action. It is emotional behavior. Affective behavior may be expressed by persistent approach or avoidance in reference to a particular set of events.

The main aspects of the affective domain are: reception, response, valuation, organization, and characterization.[3] These factors may be regrouped as personality components: interests, attitudes, and values.

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[1]R. F. Mager, Speech before the 1970 Convention of the National Society of Programmed Instruction, Anaheim, California, 1970.

[2]B. S. Bloom, et al., Taxonomy of Educational Objectives (New York: David McKay, 1956).

[3]D. R. Krathwohl, et al., Taxonomy of Educational Objectives, Affective Domain (New York: David McKay, 1964).

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As a conclusion of the review on learning principles, a "block diagram" presentation of the Hierarchy of Knowledge is shown in Figure 3.

Instructional Methods

After briefly reviewing the current literature on learning principles, it seems to be reasonable and logical to proceed with a review of literature regarding instruction methods related to this study. Three areas were searched: individualized instruction, programed instruction, and audio-tutorial instruction.

Individualized instruction.--The idea of individualizing instruction is not new. Plato, in his Republic, mentioned the need for recognizing individual differences in learning. In modern times, several people have pointed out the need to individualize instruction. White indicated that only through individualized instruction can appropriate lessons be given for each learner, and thus minimize the possibility of increasing students' problems through unrealistic expectations and demands.[1]

Many voices have been heard in favor of individualized instruction, but at present not many courses fulfill this objective. Wilhelm pointed out that:

> . . . The common grouping system will tend to hold two kinds of danger. First, there is a danger of stereotyping. With reference especially to the sectioning of classes into ability groups it is notorious

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[1]Verna White, Studying the Individual Pupil (New York: Harper and Brothers, 1968), p. 12.

DISCRIMINATION LEARNING

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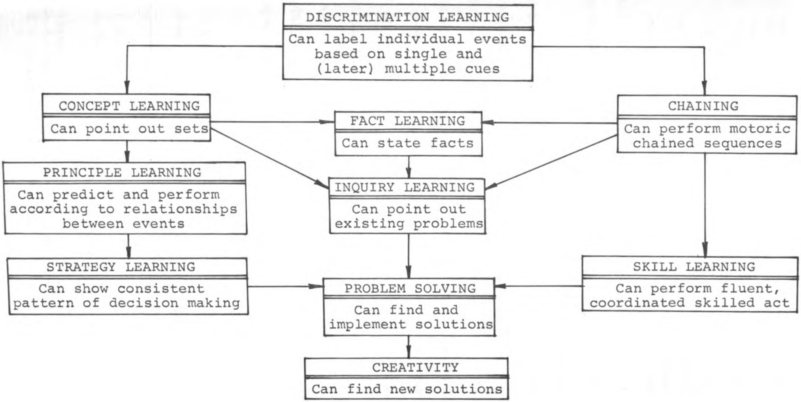

Figure 3.--Hierarchy of Knowledge.

Source: Taken from Stephen L. Yelon, Instructional Design and Technology, College of Education, Michigan State University, 1971.

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> that administrators and teachers fall into thinking of each section as "homogeneous." The teacher often speaks of his "slow" group or his "fast" group as if all the members of each were the same. It is frequently obvious that his satisfaction with the system corresponds precisely with his relief at no longer having the bother of adapting his teaching to a range of differences.
>
> Second, specialized courses designed for particular groups introduce another danger. Being designed to do one job especially well, such courses are often narrow in scope and offer few internal choices.[1]

This is to say that offering students different routes of learning even the same subject matter might be desirable.

Efforts have been made to individualize instruction at the various levels of education. Commercial companies are producing methods of instruction designed to individualize teaching. The Philips Company in Eindhoven, Netherlands, produces an individualized experimental kit and a study guide in basic electricity and electronics. The commercial name of this kit is "Practronics." The kit is battery operated and includes a direct current voltage supply, a multimeter, a sinus-square audio generator (in a very compact and portable form), experiment materials, and a lab manual including adequate theory background for every experiment.

This portable electronic laboratory "station" enables individualized learning not only at the school, but the student can also carry out a large part of individualized laboratory experimenting at home. Now the learner can do more experimentation on electronic circuits than in a

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[1] Fred Wilhelm, "The Curriculum and Individual Differences," in Individualizing Instruction, Sixty-First Yearbook of the National Society for the Study of Education, Part I (Chicago: University of Chicago Press, 1962), p. 102.

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conventional laboratory period. The audio-tutorial studies mentioned in Chapter I and the "Economical Self-Supervised Operated Open Electronics Laboratory" discussed in this chapter also are obviously concerned with individualized instruction in electronics laboratory experimentation.

Programed Instruction

Programed instruction consists of learning experiences in which a "program" replaces a tutor for the student and guides him through a systematic, sequenced set of specified behaviors to make him behave in a given desired way in the future. That is how Schramm explained the meaning of Programed Instruction.[1] The program itself is sometimes housed in a "teaching machine" or in a "programed textbook."

Concerning the "program," Schramm pointed out:

> The program is the important thing about programed instruction. It is usually a series of items, questions, or statements to each of which, in order, the student is asked to make a response. His response may be to fill in a word left blank, to answer a question, . . . to solve a problem and record the answer. As soon as he responds to the item he is permitted to see the correct response that he can tell immediately whether his response has been the right one. But the items are so skillfully written and the steps are so small between them that the student practices mostly correct responses, rather than errors, and the sequence of items is skillfully arranged to take the student from responses he already knows, through new responses he is able to make because of the other responses he knows, to the final

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[1]Reproduction of part of Schramm's book, Programmed Instruction, Today and Tomorrow (1962), published by the Fund for the Advancement of Education (out of print). The partial reproduction can be found in Programed Instruction (New York: Fund for the Advancement of Education, 1964), pp. 98-99.

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> responses, the new knowledge it is intended that he should command.[1]

It is easy to realize that the above description is a Skinnerian type of program. The main points of Skinner's reinforcement theory were pointed out earlier in this chapter.

Hilgard and Bower[2] pointed out that programed learning began with the appearance of the "teaching machine" as a technological aid introduced by Pressey[3] in 1926, but the main impetus to the idea of automatic self-instruction was given by Skinner,[4] who was already known in the field of learning through his operant conditioning work.

Hilgard and Bower emphasized that" "The essence of learning by means of a teaching machine lies not in the machinery but in the material to be presented. . . ."[5]

There is a wide range of literature on programed instruction. These are a few important, useful publications.

Skinner's article on "Teaching Machines" pointed out the common points between good programed instruction and qualified individual tutoring:

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[1] Ibid.

[2] Hilgard and Bower, op. cit., p. 555.

[3] S. L. Pressey, "A Simple Apparatus Which Gives Tests and Scores--and Teaches," School and Society, XXIII (1926), 373-376.

[4] B. F. Skinner, "The Science of Learning and the Art of Teaching," Harvard Educational Review, XXIV (1954), 86-97.

[5] Hilgard and Bower, op. cit., p. 556.

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1. Beginning where the pupil is, not moving beyond his comprehensive capabilities.
2. Moving at a rate that is consistent with the pupil's ability to learn.
3. Not permitting false answers to remain uncorrected.
4. Not lecturing; questioning and giving hints to the pupil to find and state answers for himself.[1]

Lumsdaine and Glaser edited a collection of papers, including the famous articles by Skinner of 1954 and 1958, and gave a good introduction to the state of the art at the end of the 1950's.[2]

Schramm collected abstracts of all the research on programed instruction carried out and reported prior to spring, 1963.[3]

What about programed instruction in the engineering field? Plants and Venable claimed that engineers can apply many of their skills to the design of instructional materials in programed learning because of its similarity to engineering design in general. In both cases, the designer formulates his objectives and specifications before laying

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[1]B. F. Skinner, "Teaching Machines," Science, CXXVIII (1958), 969-977.

[2]Arthur A. Lumsdaine and Robert Glaser, eds., Teaching Machines and Programmed Learning (Washington, D.C.: National Education Association, Division of Audio-Visual Instruction, 1960).

[3]U.S. Office of Education, The Research on Programed Instruction, by Wilbur Schramm (Washington, D.C.: U.S. Government Printing Office, 1964).

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out the detailed design. After design work comes prototype testing, revision, and then field testing before production.[1]

The power of any programed learning is based on a student's active response to the designed sequence of items. The authors are highly in favor of programed learning.[2] As they stated:

> The claims made for programed learning are many. In our experience they are mostly true. Students using programed materials have been able to perform very well. Each is able to work at his own pace, review as much as is needful and be confident of his results.
>
> . . . For the teacher the advantages have been considerable reduction in routine work and a certainty of a reasonable performance by the students.
>
> . . . Those of us who have used it, both as students and teachers, are convinced that programed instruction is the most effective educational tool yet devised.[3]

As to the use of programed instruction in the electronics laboratory, one experimental study carried out at the University of Illinois, Urbana, involving programed learning has already been discussed on pp. 33-34 of this chapter.[4]

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[1]Helen L. Plants and Wallace S. Venable, "Programed Instruction: An Application of the Engineering Method," IEEE Transactions on Education, E-14, 2 (May, 1971), 41-44.

[2]Plants and Venable are with the Department of Theoretical and Applied Mechanics, West Virginia University, Morgantown, West Virginia.

[3]Plants and Venable, op. cit., pp. 43-44.

[4]Neal and Meller, op. cit.

Roth reported about utilizing programed instruction to teach use of the oscilloscope in the junior electrical engineering laboratory course at the University of Texas, Austin. He wrote:

> A programed text was developed that breaks down the process of operating a scope into a series of logical steps starting with deflection of the electron beam. . . .
> . . . .
> Results from practical examinations and observation of student performance in later courses indicate that students learn to use the oscilloscope more effectively from the program than from conventional laboratory instruction.[1]

Audio-Tutorial Instruction

In the present study, the researcher has tried to utilize modern instructional methods as well as modern hardware to enable a student to achieve optimum results from his lab experiments. That is the reason for a student-oriented audio-tutorial approach. In this study, audio-tutorial technique of instruction means the use of audiotape and slides in conjunction with presentation of the subject matter concerning the circuit under experiment.

One of the important pioneers in the field of audio-tutorial instruction is Professor S. N. Postlethwait from Purdue University. At the very beginning of Postlethwait's work, the following statement appears:

> A fundamental guideline which must be given prime consideration is that "learning is an activity done

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[3]Charles H. Roth, "Programmed Instruction for Use of the Oscilloscope," IEEE Transactions on Education, E-14, 3 (August, 1971), 138.

by an individual and not something done to an individual." The structuring of an educational system should be done on the basis that the program must involve the learner. The teacher at best can only create a situation conducive to learning by providing the direction, facilities and motivation to the individual learner. Immediately, it becomes apparent that the program must allow for individual differences in interests, capacity, and background.[1]

Some of the activities that result in learning in an informal situation (as in the audio-tutorial case) are:

1. Repetition.
2. Concentration.
3. Association (involve maximum senses during the learning experience through association).
4. Appropriately sized units of subject matter.
5. Use of a communication vehicle appropriate to the objective.
6. Use of multiplicity of approaches (multi-media).
7. Use of an integrated experience approach.[2]

In the conclusion of their work, the authors listed the advantages of the audio-tutorial approach:

1. Emphasis is placed on student learning rather than on teaching.
2. Students can adapt the study pace to their ability to assimilate the information. Exposure to difficult

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[1]S. N. Postlethwait, J. Novak, and H. T. Murry, Jr., The Audio-Tutorial Approach of Learning Through Independent Study and Integrated Experiences (2nd ed.; Minneapolis: Burgess Publishing Company, 1969), p. 1.

[2]Ibid., pp. 3-4.

[illegible]

[illegible]

subjects is repeated as often as necessary for any particular student.

3. Better students are not a "captive audience," and can use their time most effectively. Their interests are not dulled by unnecessary repetition of information already learned, but they are free to choose those activities which are more challenging and instructive.
4. The student can select a listening time adapted to his individual efficiency peak.
5. Tapes demand the attention of the student. Students are not distracted by each other.
6. Students have more individual attention, if they desire it.
7. Scheduling problems are simplified. The four hours of scheduled time from which the students are relieved under the new system can now be distributed throughout the week as necessary to adjust to the students' activities.
8. More students can be accommodated in less laboratory space and with fewer staff.
9. Make-up labs and review sessions can be accommodated with a minimum of effort.
10. The student feels more keenly his responsibility for his own learning.
11. Each student is essentially "tutored" by a senior staff member.

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12. Opportunity for research on learning processes is enhanced.[1]

The audio-tutorial approach makes use of the learning principles mentioned earlier in this chapter (i.e., those of Gagné, Bruner, and Skinner). It can be used to achieve behavioral objectives (Mager) at any level of the three domains: cognitive, affective, and psychomotor (Bloom, Krathwohl). This concept of learning stresses the need for providing optimum conditions to achieve the maximum development of each individual's learning capacity.

One of the recent developments in audio-tutorial techniques is the Minicourse, a self-contained unit of instruction that tutors a student through an integrated experience and optimizes the conditions for learning. The instructional package deals with a single unit of subject matter. The minicourse usually involves portable materials, so the student can carry out the learning process in the library, study carrel, or at his residence.[2]

Development of minicourses has been carried out at Purdue University, Lafayette, Indiana. The minicourse appears to be the unit (or module) through which various subjects will be learned in the future. The great flexibility

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[1] Ibid., p. 96.

[2] James D. Russell (Minicourse Project Coordinator, Purdue University, Lafayette, Indiana), "A Systematic Approach for Developing Minicourses for Science Students" (paper presented at the National Science Teachers Association Convention, Washington, D.C., March 29, 1971).

of the minicourse may be the main factor of its potential applications in the ever-changing circumstances of modern instructional needs.

The audio-tutorial approach of instruction was begun in the early 1960's. The approach was originated in the botany field, in an attempt to make some adjustments for the diversity of student backgrounds in a freshman botany course. Most of the study reports at the Third Audio-Tutorial System Conference were in the field of biology; only two presentations out of 39 were from the electrical field.

Rainey presented an audio-tutorial method in electrical and electronics laboratories that is being applied in the Department of Electrical Technology at Purdue University.[1] Audiotapes, color slides, and other audio-visual materials that are supplied to the students enable self-paced, individualized instruction in electrical and electronics technology. Some useful points of this experience given by Rainey are:

> Slides and tapes used in the audio-tutorial method do not take the place of the instructor, but free the teacher to teach! Students obtain the technical information and instructions from the audio-tapes and slides, which leaves the instructor free to work with the students on real problems. . . .
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> . . . .
>
> The control of the instructional materials, freedom to schedule time in the laboratory and the removal of time deadlines for the performance of the experiment

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[1]Gilbert L. Rainey, "Audio-Tutorial Learner Controlled Laboratory" (paper presented at the Third Annual Audio-Tutorial System Conference, Purdue University, Lafayette, Indiana, November 1-2, 1971).

> changed the attitudes of the students toward the laboratory course.
>
> . . . The open laboratory does result in better utilization of equipment. . . .
>
> . . . Vigorous development work from many dedicated teachers will be required to implement this dynamic teaching method.[1]

A presentation of utilizing audio-visual instrumentation in electrical engineering and technology was given by Hamelink at the Third Annual Audio-Tutorial System Conference.[2] The audio-tutorial approach was used to teach electronic instrumentation (especially for industry) like bridge amplifiers, strip chart recorder, teletronix oscilloscope 503 potentiometers, and slide rule. Encouraged by positive results, the team that developed the audio-visual instrumentation at Western Michigan University started expanding the audio-tutorial approach to instruction for other industrial electronic devices like strain-gauges, thermocouples, and transducers.

Two other studies in applying audio-tutorial instruction in electronics at the college level[3] and high school level[4] were already discussed in Chapter I.

In all these studies the researchers appealed to electronics instructors to try the audio-tutorial system in

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[1]*Ibid.*, pp. 2-5.

[2]Jerry H. Hamelink, "The Multi-Media Approach to Learning at Western Michigan University" (paper presented at the Third Annual Audio-Tutorial System Conference, Purdue University, Lafayette, Indiana, November 1-2, 1971).

[3]Boone and Smith, *op. cit.*

[4]Morgan, *op. cit.*

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electronics instruction, because this approach seemed to be suitable and promising in this field.

Lindenlaub tried audio-tutorial techniques in laboratory instruction in the Electrical Engineering School at Purdue University. He also found the "unscheduled arrangement of an open laboratory advantageous, efficient and economical." Regarding the relative roles of the instructor, audiotapes, and notes, Lindenlaub pointed out:

> Audio tapes can be used effectively to present the introductory remarks and background material of an experiment to the students. This function is more traditionally handled by the instructor at the beginning of the period, or in a separate laboratory preparation session. Audio-tutorial instruction has the advantage, in this case, of presenting the material at that point in time and space when it is most useful to the student and when he is most interested in receiving it: that is, as he sits in front of the equipment and is about to begin the experiment.
>
> . . . .
>
> One of the functions of the senior instructor, . . . , is to prepare an audio-tutorial tape which can be made available to the student as he is about to begin his work. . . .
>
> . . . The main function of the notes is to present material that is more readily conveyed visually than audibly.
>
> . . . By posing questions on the tape, guidelines by which a student can judge his progress and departure points for independent study can be integrated into the experiment.[1]

Student reaction to this project was very favorable. All but one of a group of 57 students preferred to continue the audio-tutorial method rather than the traditional way of learning. Lindenlaub reported that:

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[1]John C. Lindenlaub, "Applying Audio-Tutorial Techniques to Laboratory Instruction," IEEE Transactions on Education, E-12, 2 (June, 1969), 92-95.

> It has been found that the effectiveness of the audio tapes is increased if their use is carefully coordinated with that of other materials such as written notes, laboratory equipment, and equipment instruction manuals.[1]

Summary

In Chapter II, a brief description of the spread of electronics in many areas of life was given. The past and present curricula of electronic circuits laboratories were reviewed and analyzed. The state of electronic experimentation was described. Regarding educational concerns, a review of literature on learning principles and instructional methods relating to this study was reported.

Some conclusions from the analysis are:

1. Electronics has become a factor in modern life, involving great portions of total professional manpower including all levels of ability.
2. Research and design of new instructional technology have to be carried out in order to enable adequate study and training in electronics.
3. Modern research in learning principles and theories has led to development of instruction methods like individualized learning, programed instruction, and the audio-tutorial approach. The main assumption in all these developments is that the heart of education is the student learning.

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[1] *Ibid.*, p. 96.

4. Experimental studies have pointed out that substantial improvements in instructing electronics can be achieved through tight cooperation between available technological means and serious concern with the learning process.

An attempt has been made by the researcher to utilize the principles of learning reviewed in this chapter, in the development of the instructional model for laboratory experiments on electronic circuits. Behavioral objectives (Mager) were established prior to the instructional unit (the electronic circuit under experimentation) at the beginning of every experiment. Skinner's reinforcement theory, including the idea of student self-pacing while learning the operation of the circuit and the laboratory experimental procedure, was incorporated in this model. Also, following Skinner, the materials elicit involvement of the learner in the experimental process.

Gagné's hierarchy of learning guided the researcher in developing the various stages of the model. For example, "to progress from simple to complex," in this experiment the learner moved from the simple D.C. measurements to the solving of the design problem.

The strategy of using a modular approach was intended to not only improve student performance in laboratory experimentation, but also to allow an evaluation of the model itself. The "Design Problem" module, for instance, could be eliminated if the model were being used at the community college level, or other modules substituted to suit particular situations and/or levels of learning.

An assumption has been made by the writer, and not tested in the experimental study, concerning the sequence required to learn an electronic circuit. The essence of this assumption lies in the following sequence:

1. To acquaint a student with the general application of the circuit, the instruction should include a general presentation of a technological application where a circuit like that under experiment is necessary and a step-by-step analysis (theoretical and experimental) of the circuit--from simple to complex.
2. To expose a student to a specific detailed application of the circuit, the instruction should include an electronic system involving the circuit under experiment as one of its components.

CHAPTER III

DEVELOPMENT OF THE MODEL AND PREPARATION OF EXPERIMENTAL MATERIALS

Introduction

By forcing a student to follow a series of instructions in experimenting on a certain electronic circuit without understanding them, an instructor might get a "nice looking" report from a student who is interested in high grades, but the learner won't benefit greatly from the experiment. On the contrary, due to boredom he might develop some negative feelings toward the subject of the experiment and the whole environment, i.e., toward working with electronics equipment.

One of the goals of the laboratory experimentation model is to create a more positive student attitude toward the subject under experiment, as well as toward general involvement and work in the electronics laboratory. The goal of improving a student's attitude toward the subject is achieved through increasing his active involvement in the process and providing immediate reinforcement of correct answers (Skinner's Reinforcement Theory). Active student involvement is enhanced by two factors: challenge and immediate reinforcement. How are these goals accomplished? A student has to complete the "design" of the circuit by calculating and connecting the "missing" components before he can actually start the experiment procedure. This is one challenge to a learner. This kind of learning activity is the highest in Gagné's hierarchy of learning; it is "problem solving." It involves more than two principles and produces new capability.

A student gets immediate reinforcement by operating the circuit at his own pace and measuring the results. He might feel great satisfaction in seeing that his "design" really works; this is his reward.

In this chapter, a detailed description of the development of the model is given. The learning theory supporting the steps is pointed out. Because the development of media materials is an integral part of the model, the types of media are also described in this chapter.

The Schmitt Trigger experiment, which happened to be used in the experimental test, is used as an example of the implementation of this instructional model for laboratory experiments on electronic circuits.

Description of the Model Components, Their Rationales and Sequence

It is assumed that students have already learned the circuit they are going to experiment with, in former lectures on the theory of electronics.

Frequently, it is difficult to keep optimal synchronization between theory and related laboratory experiments, e.g. to have the student work on the experiment, approximately

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one week after covering the theoretical portion of the subject.

In many cases students forget most of the theory concerning the circuit they are going to work on in the laboratory. In other cases, lectures may lag behind laboratory work, so a student finds himself working with unknown circuits. In such cases, a student will not get all possible benefits from the activity.

A number of ways of avoiding faulty results are suggested in the proposed model. Students must be informed about the topic of the experiment at least a week before the laboratory work is scheduled. Provide students with a detailed list of experiments to be carried out during the term in the first week of classes. This is usually done in the traditional method of experimentation. Also, the following procedures should be added:

1. Hand out behavioral objectives including what a student is supposed to be able to do as the result of completing the lab work, complete with conditions and acceptable level of performance (Mager, 1962).
2. It is desirable to have a student make some calculations of expected values like voltage, current, or amplification in order to make comparisons between measured and expected operation of the circuit (Skinner).

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The student must have some source (besides the teacher) to refer to, so he will not derive absurd and frustrating conclusions. The lab manual can serve as another source of information concerning theory and practice, and can serve as a guide for conducting the experiment. It should include often-used circuits for reference.

What if a student comes to the laboratory unprepared? This situation can be prevented:

1. Require a student to submit his preliminary work (exercises) before starting the experiment.
2. Require a student to take a pretest.
3. Construct the experiment so that only a prepared student can complete it. This procedure requires a student to calculate some missing component (or driving voltages) in order to activate the circuit under experiment. For example, have the student calculate the load resistor when an amplifier is being experimented.

Because experimentation with electronic circuits may be considered problem-solving, concepts and principles have to be mastered before the experiment is started; the prerequisites have to be fulfilled.

A student has two alternatives in meeting the prerequisites of the experiment:

1. He may learn the subject at home from the "Theory Sheets" (Appendix A) and/or he may learn from assigned reading, and solve the preliminary problem.

2. He may learn the experimental topic in the laboratory using varied forms of media. This activity refers to the "Listen & Watch, Audio-Tutorial" step in Figure 1 (page 10). At the end of this step, the student solves the preliminary problem. Otherwise, he can't proceed.

The Theory Sheets

Theory Sheets are that portion of the student's lab manual which includes theory and applications of the circuit to be experimented upon. This important handout must be delivered to the student at least one week before the experiment, so he may have an opportunity to become acquainted with the circuit with which he is going to work.

The purpose of the experiment and the terminal objectives must be stated at the start. After all, the learner has to know where he is going and why, in order to get there (Mager). An example of behavioral objectives for a specific circuit (Schmitt Trigger) is given in Appendix A.

In order to get the student's active involvement in the subject, his interest in it has to be stimulated. An attempt is made in this model to provide the student with stimulation throughout the whole experimentation process, by means of challenges, variations in media, and rewards. For example, the comprehensive portions of the Theory Sheets do not begin with the theoretical explanation of the circuit nor do they start with its applications. Instead, the comprehensive portions are introduced by demonstrating the need for the circuit. In the Schmitt circuit, a block diagram of an automatically controlled street lighting arrangement (twilight switch) is presented, as shown in Appendix A, Figure 1. Since the Light Dependent Resistor (LDR) is unable to activate the relay which turns the street lights on and off through the power switch, an electronic circuit (x) with certain characteristics is needed. The Schmitt Trigger is capable of fulfilling this requirement. But what is this circuit? How does it operate? That is precisely what this experiment is about. Students are given further instructions: "Let's analyze this circuit and see how we can utilize it for various applications."[1] A similar strategy may be used when experimenting with other electronic circuits. For example, regarding an audio amplifier circuit, for a microphone which does not have enough power to operate a loudspeaker appropriately can be presented; some power amplification must be provided. That is precisely what the audio amplifier does.

The thoughtful and experienced instructor can find a way to rationalize most electronic circuits, because there is usually a reason for the existence of a practical circuit.

Referring to the hierarchy of knowledge (page 43), this strategy is an example of "Inquiry," pointing out existing problems, and "Problem Solving," trying to find

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[1]Appendix A, p. 139.

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adequate solutions. Lower steps of the hierarchy of knowledge must be fulfilled too. For instance, in the case of the Schmitt Trigger, the student has to master electrical and basic electronic circuits, devices and theory including concepts and principles; if he doesn't, remedial material must be provided to help him fill some "knowledge vacancies." Only after mastering the prerequisites should he proceed with the experiment.

An example from the writer's experience may demonstrate the damage caused by nonfulfillment of the prerequisite requirements. The concept "Loop Gain" was not clear to many students, and this caused difficulties in understanding the experimental process. Mastery of this concept by the students shouldn't have been taken for granted, even if the "try-out" student was vaguely familiar with this concept.

A good idea might be to administer a special pretest to check a student's degree of mastery of the prerequisites. This pretest should be taken enough in advance of the experiment (more than a week), to enable the student to obtain remedial help. The student should be provided with adequate remedial material.

The Theory Sheets include the following main items (Appendix A):

1. Purpose and behavioral objectives.
2. Rationale to provide a functional view through practical application examples.

3. Generalized qualitative analysis of the circuit under experiment.
4. Specific quantitative analysis of the circuit.
5. Summary of the circuit analyses and some relevant remedy notes.
6. Examples of various versions (transistorized, integrated circuit) of the circuit.
7. Practical application examples of the circuit.
8. Detailed solved problem which includes the circuit and the results of the above analyses.
9. Preliminary work including precalculations of some of the components and values that are going to be measured during the experiment. This is one of the problem-solving tasks in which the learner is to find and implement solutions which will be used as comparison to the forthcoming measures in the laboratory.

The specific quantitative analysis of the circuit (item 4) is the longest section in the Theory Sheets. Those students who have already mastered the circuit theory may skip this section.

The Experiment Procedure Sheets[1]

The Experiment Procedure Sheets constitute the second portion of the laboratory manual. They include systematic layout of the experimental procedure using flow charts and

[1]Appendix B.

comments. The advantage of the flow chart is in getting an easy, immediate overview of the procedure.

An example of a generalized initial portion of an Experiment Procedure flow chart is shown in Figure 4. The numbers in some of the blocks in this diagram refer to corresponding checklists and notes. Such a specific flow chart with the checklists for the Schmitt Trigger experimental procedure is shown in Appendix B, Figure 1.

Referring to Figure 4, the various blocks will now be interpreted.

Enter.--Regarding the circuit under experiment, there are two possibilities of "enter" status:

1. A student is given all the materials and components except those "missing components" which he has to determine by himself in the prelim work. He has to construct the circuit according to the given circuit's schematic diagram and start experimenting. This is usually the procedure in technical schools.

2. A student is given the practical circuit already mounted on a board. Those components he has to determine by himself are missing. This procedure is used mostly in engineering colleges.

In either case, at the "enter" stage a student is provided with the necessary tools, equipment, and media sources to enable him to carry out the experiment. The equipment is usually assembled at the working station. All sorts of media may be used:

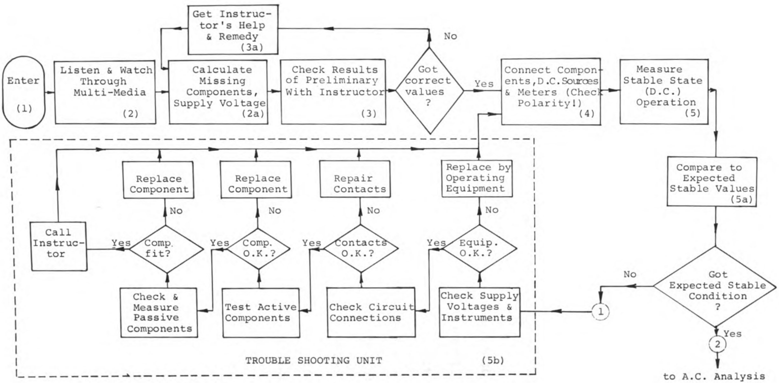

Figure 4.--Introduction and "stable-state operation" experimenting procedure.

Printed (texts, journals, study guides)

Graphic (charts, graphs, diagrams)

Pictures (flat, film strips, slides, film loops)

Audio tape player (and tapes)

Films, film loops

Television (monitor)

Video tapes

Realia (an actual circuit or model)

Computer terminal

Electronic calculators

Electronic instrumentation (an oscilloscope)

Which media to incorporate is contingent on the circumstances; primarily budget considerations. However, this model may be implemented with a very low budget for media equipment in addition to the regular electronic instrumentation. In the experimental test of this study, the cost of the additional media station for two students, including audio tape player, slide projector, projector viewer, and two headphones, runs about $180.

Listen & Watch Through Multi-Media.--The importance of increasing a student's involvement in the experimental process was stressed earlier in this chapter. It was also stated that stimulating a student's interest in the circuit will contribute to an increase in his active involvement. The learner, as every living creature, is stimulated through his senses, so it seems reasonable to appeal to as many senses as possible during the learning process. The multi-media approach may be used as an efficient communication vehicle, because it enables involvement of more than one sense during the learning process.

In the stage of "Listen & Watch Through Multi-Media," a student may use media facilities to proceed at his own pace through a detailed analysis and application of a circuit. In essence, it is the same analysis as in the Theory Sheets, but more applications and audio-visual explanations can be provided through a slide-tape or video tape presentation. In this study, a slide-tape presentation was used.

To get a learner's attention and involvement, the introductory pictures or slides of the presentation must consist of concepts (objects or processes) with which the student is already familiar and, if possible, which cause pleasant associations. Next the presentation proceeds toward the subject matter itself: analysis, problem solving, and at the college level the highest level of knowledge is reached--namely, creativity--where the learner is capable of finding new solutions for a given problem.

For the first slide in the slide-tape presentation in this study dealing with the analysis of the Schmitt Trigger, the researcher selected a color picture from a weekly journal showing street lights in a Texas town. Through this slide, the student is introduced to the problem of Automatic Street-Light Control. The second slide shows the block diagram of the twilight switch (Appendix A, Figure 1). It should be noted that the student is familiar with all the

items shown in this block diagram, excluding the new concept (the x block, which is going to be investigated). The learner is getting to know the problem in a sequence of small steps, so when the "solution" is presented, e.g., the Schmitt Circuit itself, he is more likely to accept it and try to understand its functioning. It is the belief of the researcher that this gradual introduction to the analysis of a circuit contributes more to a student's involvement in the learning process than exposing a learner to the schematic diagram right at the beginning of the circuit analysis. Experimental research has to validate the researcher's beliefs.

The multi-media may also be used for modeling[1] purposes, especially when the experiment involves complicated performance. A good model includes verbal explanations at the time the model is demonstrated. Not only can the instructor demonstrate some important portions of the experimental procedure, but a video tape, film loop, or even slide-tape presentation of the modeling may provide a student with repetitive self-paced opportunities to check out ambiguous points in the experimental procedure.

The serious instructor can always update the circuit's applications by videotaping new developments from

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[1]A. Bandura, "Social Learning Through Imitation," in Nebraska Symposium on Motivation: 1962, ed. by M. R. Jones (Lincoln: University of Nebraska Press, 1962), pp. 211-269; A. Bandura, "Vicarious Processes: A Case of No-Trial Learning," in Advances in Experimental Social Psychology, II, ed. by L. Berkowitz (New York: Academic, 1965), pp. 534-536.

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industry or laboratory, or adding new slides with adequate explanations.

It might be fair to a student to let him use the multi-media phase of analyzing the circuit as an option. If the student enters the laboratory after he has studied the theory and applications of the circuit and has correctly prepared the preliminary work, he is eligible to skip the stage of "Listen & Watch Through Multi-Media" and start the experimental work on the circuit. Most students will choose to use the media, if it is incorporated with meaningful and understandable explanations so they can benefit from it.

Proceeding with the blocks in the flow chart (Figure 4), the following procedures will be carried out:

Calculate Missing Components and Supply Voltage.--This calculation is a part of the preliminary work. If a student has not completed his work at home, he has to do it in the laboratory after studying the circuit's theory and applications with or without the aid of media presentations.

Check Results of Preliminary Work With Instructor.--There are two main reasons for an instructor's check of a student's status at this stage:

1. To find out if a student has acquired the essential prerequisites (knowledge and skills).
2. To check calculated values of the missing components and supply voltages, and to make sure that these

values will not cause any damage or endanger the student when applied to the circuit.

Get Instructor's Help & Remedy.--If an instructor finds out from the preceding step that a student doesn't meet the required prerequisites, he has to guide the learner to remedial sources and facilities. It is strongly recommended that these sources be available inside the laboratory where the experiments are carried out. The remedial material should include the electronic equipment manuals (for operating equipment), as well as textbooks, handbooks, diagrams, and catalogues. Varied forms of media may be used for this remedial learning purpose. If the instructor's monitoring is eliminated for any reason during this stage, the student should be given safe component and voltage values.

Connect Components, D.C. Sources & Meters.--After having checked the correctness of calculated values of missing components and supply voltage, a student may connect all D.C. sources and instrumentation (according to a detailed checklist) and activate the circuit.

Measure Stable State (D.C.) Operation.--A student carries out a series of Direct Current (D.C.) measurements at various points of the circuit determined by the instructor. These points are listed in a table which includes the calculated and expected values of voltages. This is done for comparison purposes (5a in Figure 4). Such a table for the Schmitt experiment is shown in Appendix B, Table 1.

This procedure provides natural feedback for the student concerning his predictive calculations.

In case the circuit under experiment has no D.C. stable state, like an oscillator, the student may skip this step (5) and proceed directly to the next step, which involves A.C. measurements.

What if the circuit malfunctions? The traditional approach to answer this problem is to ask for an instructor's help. But if all the students having trouble with the circuit (which could be a large portion of the group working in the laboratory) called for the instructor's aid, he would be too busy to supply all the help necessary. This is usually the case if the students and instructor really care about what is happening in the laboratory. Why shouldn't the student carry out some trouble shooting in the circuit by himself before he calls for an instructor's help? In order to assist the student to help himself, a trouble shooting guidance unit is suggested.

Trouble Shooting Unit.--Trouble shooting is the procedure for finding the exact location of and reason for the factor causing malfunction of a piece of equipment. This kind of activity is problem solving. There is no reason why a student shouldn't be guided to trouble shoot while experimenting with an electronic circuit. By being involved in this kind of activity, the student will develop his laboratory skills further, and acquire self-confidence in handling electronic circuits.

The trouble shooting procedure proposed has been used by the researcher for years while instructing electronics laboratory courses at the community college level. This "Trouble Shooting Unit" (see Figure 4) consists of a systematic sequence of generalized steps. These steps have to be carried out when trying to determine why the electronic circuit malfunctions. It includes steps which are to be accomplished in order to bring the circuit to nominal operation. Only after being unable to get satisfactory results does a student call for an instructor's help. From the writer's experience, most of the students following this procedure find the malfunction and repair it before calling for the instructor's assistance.

Measure A.C. Nominal Operation.--After establishing and successfully measuring the D.C. operation of the circuit, the dynamic nominal operation has to be measured. The procedure is similar to that in the D.C. measurements, as one may notice in Figure 1. In this dynamic operation, the oscilloscope may be used as an extraordinary medium. Instead of the usual time-consuming and boring procedure of recording the transfer characteristics of the Schmitt Trigger, and drawing the curve when preparing the report, a student can view the whole curve immediately on the oscilloscope's screen. The oscilloscope was used successfully in the Schmitt Trigger experiment (see Appendix B, Figure 6). The researcher has been motivated to further develop this technique of getting immediate, natural, displayed feedback. The use of this instrument provides reinforcement.

As can be seen in the Experiment Procedure Sheets (Appendix B), the "media power" of the oscilloscope is utilized throughout all the dynamic experiment with the Schmitt circuit, for waveshape recording, as well as for the transfer characteristics recording.

The reader probably noticed that the A.C. measurement procedure (Figure 1) also has a "Trouble Shoot & Repair" unit like the D.C. procedure has. These two units are basically the same.

Observe Effect on Operation.--This stage may be designated as the experimental A.C. analysis procedure.

Given the circuit under experiment, external restrictions like loading (R_L), driving sources (V_{CC} and V_S), or certain environmental conditions are imposed on the circuit (see Figure 5). A student has to investigate the effect of these external restrictions on the performance of the circuit.

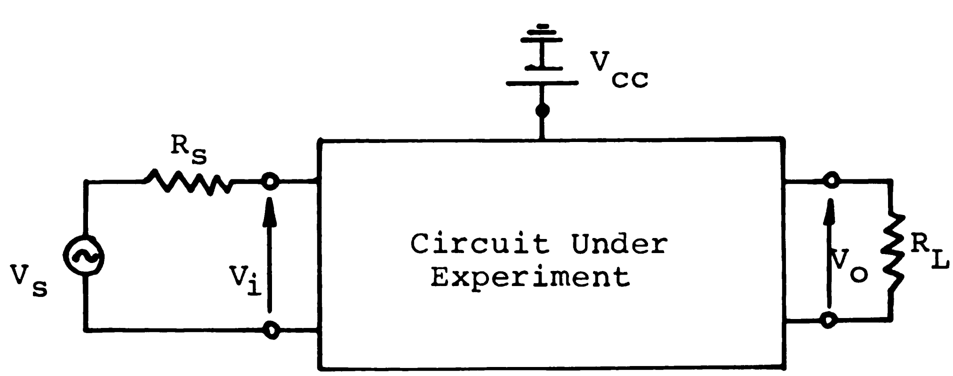

Figure 5.--Investigating external effects on the circuit's operation.

Frequency and time response of the circuit are also investigated at this stage. It must be stressed that the circuit under experiment can be constructed of discrete components or an integrated circuit (I.C.). In the case of an integrated circuit only external voltages can be varied and measured; then the circuit has to be considered a "black box" as depicted in Figure 5.

In searching for effects and changes in the operation of the circuit, the use of the oscilloscope as an instructional feedback device is very efficient, reliable, and convenient. That is why the researcher has incorporated this apparatus to such a great extent in the Schmitt Trigger experiment (Appendix B).

Observe Application.--At this time a student is exposed to an electronic system involving the experimental circuit as one of its components. His newly acquired knowledge may be applied to understand the integrating aspects of the circuit within the greater system; how impedance matching, driving, or environmental problems are handled in practice. In contrast to the introductory examples given in general terms at the beginning of the experiment, these examples have to be presented in more detail and must illustrate how specific characteristics of the circuit are utilized for practical purposes. This experience may help a student to remember and apply what he has learned.

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home appliances, in addition to other detailed applications. In most cases, it might be impossible to gain access to an electronic system because of technical difficulties. Then it is even more important to show some applications through a short film, videotape, or other media. Using a demonstration to represent a certain application is also possible at this stage.

In the case of the Schmitt Trigger, a detailed diagram of a practical street light control system incorporating a Schmitt Trigger[1] was shown in a slide-tape presentation.

Design Problem.--This is the highest stage in the hierarchy of knowledge (see page 43) because it can be labeled in the Creativity category, where new solutions to problems are found. This is primarily a college-level stage. A student is asked to introduce appropriate modifications into the experimental circuit in order to optimize its performance under new conditions of loading, feeding voltages, or environmental restrictions. Preferably, this stage should be included within the experimental procedure rather than merely asking a student to answer a theoretical synthesis question. An example will clarify this point: A student may be asked to design necessary modifications to be carried out in the circuit in order to maintain the same output swing voltage, when the loading at the output

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[1]"Automatic Twilight Switch," Electronic Application News, VI, 6 (November/December, 1969), 30-35.

terminals is doubled. Such a problem may be included even in the preliminary work and the student can take his time to implement his design and compare the measured results with his predictions. The discrepancies between his own designed expectations and the actual measured values will make him aware of some problems which occur between practice and theory.

Take Posttest.--The posttest may be given in written, in oral, or in performance form. A combination of these three techniques of evaluation is also possible. A student has to submit a written report right after completing the experiment, including his precalculations and measured results as well as answers to, and comments on, questions asked throughout the experimental procedure. It should be kept in mind that merely by operating the circuit and measuring its performance successfully the student has already demonstrated, in behavioral terms, some mastery of the enabling and even terminal behavioral objectives. He has been evaluated along the whole route of the experimental process through the programed-oriented procedure.

It is important to maintain weekly sessions of the instructional team and the whole group of students. These sessions should be dedicated to a discussion concerning the preceding and forthcoming experiments, a survey on special practical problems, and conclusions. Some instructors may use these sessions for oral or written exams.

The posttest in the experimental portion of this study was given in written form, right after the student had completed his experiment procedure.

The Development of Media Materials for the Experimental Study

The variety of media available for the electronics laboratory in this era of modern technology has already been discussed in this chapter. The quality of a laboratory course in electronics is determined by the program of experimentation as well as by the electronic instrumentation and media equipment. A good experimental program has to take maximum advantage of the available equipment. One fact is obvious: A poor experimental method will result in few benefits for the students in any laboratory course, no matter how expensive or sophisticated the electronic and media equipment.

The development of media in the test of the model has been carried out in two areas:

1. The professional area--oscilloscope display.
2. The general media area--slide-tape presentation.

The "Media Power" of the Oscilloscope

The oscilloscope is an integral part of the electronics laboratory equipment, and can be used as a display system as well as a measuring instrument.

This piece of equipment is capable of illustrating by display on a screen relationships between any variables

which can be measured in terms of voltage. For instance, the load line of a transistor (say a common emitter configuration)--that is, the graphic presentation between the collector current and collector-to-emitter voltage--can easily be displayed on the screen of an oscilloscope. A student can immediately see how this line changes its slope or location when the values of the collector load resistor and the collector supply voltage are changed, respectively. If a dual trace oscilloscope is available, the media power increases even more. The media facilities of the oscilloscope may be utilized in addition to the waveshape display which describes voltage patterns as a function of time (e.g. sinusoidal voltage).

In developing this approach of utilizing the scope as a display system, the researcher used the electronics laboratory facilities in the Department of Electrical Engineering at Michigan State University. Pictures of the various output waveshapes and transfer characteristics describing the actual operation of the Schmitt circuit were taken during the experiment's accomplishment (see Appendix E).

Preparing the Slide-Tape Presentation

Although a description of the slide-tape presentation was presented in a previous section of this chapter, a brief discussion concerning the materials used is in order.

All the diagrams and pictures for the slides were prepared and drawn by the author. These items were supplied to the Instructional Media Center at Michigan State University, where photographs were taken. The price of each slide was 35¢. The slide projector was made by Kodak (Model B2). The headsets were of the Telex type. The recordings were made by the author (see manuscript in Appendix C). Multiple copies ($2.50 each 60-minute tape) were made at the Instructional Media Center, Michigan State University. A 3M (Wallensak, model 2520) tape-recorder-player was used.[1]

Each laboratory station was set up for two students. The audio-visual materials (besides electronic instrumentation) for such a station included the equipment above (two headsets). As has already been mentioned, the cost of the multi-media materials per two students does not exceed $200, excluding the labor.

A preliminary try-out of the materials was conducted by having an instructor and later a student from the study population perform the whole experiment. After getting their remarks, appropriate modifications were introduced to improve the materials.

Summary

The development of the instructional model for laboratory experiments on electronics circuits was described in this chapter. This development was based on learning

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[1]A cassette player may be used, and would be much less expensive than the 3M tape recorder, which is the standard piece of equipment at the Instructional Media Center.

principles and modern instructional methods reviewed in the preceding chapter.

The main components of the suggested method are as follows:

1. Preliminary work by the student based on handouts (Theory Sheets), assigned readings, and precalculations of values that are going to be measured.
2. An audio-tutorial system.
3. A circuit which the student can't operate unless he "completes the circuit" by calculating and connecting some missing circuit components.
4. Stable State D.C. establishment and measurements of the circuit.
5. Measurements of the A.C. nominal operation.
6. Experimental A.C. analysis of the circuit.
7. Observing advanced and detailed applications of the circuit.
8. Solving a design problem (college level); suggesting modifications in the circuit to meet new conditions of operation.
9. Taking a posttest (oral, written, or performance) right after completing the experimental procedure.

The Schmitt Trigger experiment is used as an example. The following items were prepared to be used in the Schmitt circuit experiment:

1. Theory Sheets: The Schmitt Trigger--Theory and Applications.

2. Experimental Procedure Sheets--including special guidance in using the oscilloscope as a display system.

3. Slide-tape presentation of the Schmitt analysis and applications.

The experiment was tried separately on an instructor and a student, prior to being applied to the members of the electronics laboratory course (E.E. 484) in the Department of Electrical Engineering at Michigan State University.

CHAPTER IV

THE EXPERIMENTAL TESTING OF THE MODEL

Introduction

The suggested model for experimenting with electronic circuits was applied to the "Electronic Devices Laboratory" course, E.E. 484, in the Department of Electrical Engineering at Michigan State University. The course was supposed to provide limited experimental testing of the model; suggestions for further tests will be made in Chapter VI, Recommendations for Further Research. The general operating procedure of the experimental test was given on pages 17 and 18 of this thesis; the reader may wish to review these pages before continuing.

Chapter IV contains: a description of the sample, a description of the population, the statistical design of the experimental testing, the testable hypotheses, a description of running the model in practice, and a chapter summary.

The Sample

Students taking the "Electronic Devices Laboratory I" course (E.E. 484) are seniors in the Department of Electrical Engineering at Michigan State University. This course, which carries one credit a term, offers three hours a week of experimentation in the electronics lab, and is to be taken concurrently with the three-credit lecture course, E.E. 474: "Physical Properties of Electronic Devices I."

The electricity and electronics background of these students will now be reviewed on the basis of the prerequisites required of participants in the course (E.E. 484).[1] It is assumed that all the students have probably met the prerequisites in mathematics, physics, and chemistry, because these are included in the college and department requirements.

Briefly, the background of the students in electricity includes: current, voltage, and power; DC, AC, and transient RLC (resistance, inductance, capacitance) circuit analysis; resonance phenomena; bridges; nonlinear circuitry; two-part networks and their equivalent circuits; and computer-aided analysis and design of circuits.

The electronics background of the students taking E.E. 484 is summarized as follows: volt-ampere characteristics of the transistor; voltage, current, and power amplification; logic circuits; design, analysis, and evaluation of monostable, astable, and bistable multivibrator circuits, logic circuits, and systems.

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[1]The information concerning the background of the senior students in the Department of Electrical Engineering at MSU was collected from "The Undergraduate Program in Electrical Engineering" (East Lansing: Department of Electrical Engineering and System Science, Michigan State University, September, 1971), pp. 1-2.

In the framework of laboratory work, the students have covered the topics in electricity and electronics through experimental and measurement procedures, in addition to lecture coverage of these topics.

The laboratory course (E.E. 484) is usually divided into small lab sections (10-12 students per section). The total number of students (all males) enrolled in this course at the beginning of fall term, 1972, was 121. Because of student withdrawal from the course or nonattendance in lab sessions due to illness, a total of 108 students participated in the study. There were five treatment sections with three instructors, and five comparison sections with two other instructors. The reason for not having the same instructor for comparison and treatment groups was the researcher's suspicion that some instructional techniques would be carried over from the treatment to comparison group by the instructor. The laboratory instructors participating in the study were graduate students, as usually is the case in engineering colleges. All of them were students working toward their second or third degree in electrical engineering.

The number of students per section varied from section to section; the number ranged from four to eleven.

The Population

The population may be described using the Cornfield-Tukey argument for significance. According to this argument, even if a sample is selected nonrandomly, the statistical inferences may be generalized to a population of subjects similar to those included in the sample, provided this sample is carefully described. Cornfield and Tukey pointed out:

> In almost any practical situation where analytical statistics is applied, the inference from the observations to the real conclusion has two parts, only the first of which is statistical. A genetic experiment on Drosophila will usually involve flies of a certain race of a certain species. The statistically based conclusions cannot extend beyond this race, yet the geneticist will usually, and often wisely, extend the conclusion to (a) the whole species, (b) all Drosophila, or (c) a larger group of insects. This wider extension may be implicit or explicit, but it is almost always present.[1]

Therefore, after carefully describing the sample and the background of its subjects included in this experimental study (students enrolled in E.E. 484 at Michigan State University), the population may be inferred as follows: The population for the study may be considered to be all students in similar courses and of similar background, now in existence or that will be in existence, in electrical engineering colleges.

Although the use of the suggested model may easily be adapted to the junior college or technical school level, this has still to be validated by further experimental research at the respective levels.

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[1]J. Cornfield and J. Tukey, "Average Values of Mean Squares," Annals of Mathematical Statistics, XXVII (1956), 913.

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The Statistical Design of the Experimental Testing

The purpose of this study was to improve the student's mastery of electronic circuits and increase his laboratory skills by employing an instructional model for laboratory experiments on electronic circuits.

The validity of this model has to be tested by running it in practice, in a current electronics laboratory course. An experimental study has to be conducted to show the causal relationship between the achievements of the members using the suggested model (treatment groups) and the treatment they received through this model. A comparison study then has to be made to the achievement of members (comparison groups) accomplishing the same experiment through the traditional method. Thus, for comparison purposes, the ten sections of the laboratory course were divided into five treatment groups (sections) and five comparison groups. In Table 1, the arrangement of the various sections assigned to the instructors is shown.

Table 1.--Sections assigned to instructors.

Instructor	Sections
A	1, 2, 3
B	6, 10
C	4
D	7, 8, 9
E	5

The researcher was in no position to assign the instructors to treatment or comparison sections. This was arranged among the instructors themselves, according to personal course and work schedules. All instructors were masters and doctoral students in the electrical engineering department.

Therefore, this procedure was not a process of random assignment, and this assumption was violated. By using analysis of covariance in the study, the anticipated decrease in the external validity was thus avoided.

The schedule of the various sections in the electronics laboratory course (E.E. 484, Fall, 1972), as arranged by the Department of Electrical Engineering, is shown in Table 2.

Table 2.--Weekly schedule of laboratory sections.

Hour / Day	08:00-11:00	11:30-14:30	15:00-18:00	19:00-22:00
Monday			Sec. 6 C (6)	Sec. 10 C (8)
Tuesday	Sec. 1 T (9)	Sec. 3 T (10)	Sec. 7 C (9)	
Wednesday			Sec. 8 C (4)	
Thursday	Sec. 2 T (6)	Sec. 5 T (11)	Sec. 9 C (7)	Sec. 4 T (10)

In this table, "T" stands for treatment section and "C" stands for comparison section. The number of students per section who participated in all the steps of this experimental study and took all the tests is shown in parentheses.

According to the material presented by Dr. A. Porter in the class, Experimental Design in Education (Ed. 969c) at Michigan State University, in a causal study like the present one, two criteria have to be met for a good comparison group:

1. All systematic differences between the treatment and comparison groups have to be defined as treatment differences.

It was assumed this criterion was met by applying the model for experimenting only to the treatment groups.

2. At the start of the study, the subjects in the treatment groups are not systematically different from the subjects in the comparison groups.

This requirement was met by conducting a pretest. It indeed turned out that there was no significant difference in the mean scores between the treatment and comparison groups in the pretest, indicating equivalence of groups at the beginning of the lab experiment.

The purpose of the experimental study was to test the impact of the suggested instructional model on the learner in two domains: the cognitive and affective domains. The measuring tools for testing this impact in the cognitive domain were three tests: pretest, posttest, and retention test (Appendices D1, D2, and D3, respectively).

In a consultation with Dr. Porter, he pointed out to the writer that the outcomes of the retention test, taken at a certain period of time (e.g. a few months) after the posttest, might be more important than those of the posttest taken right after completing the experiment, so it seemed quite vital to make every possible effort to include a retention test in the study. The researcher did not want to bother the students with long tests (in order not to lose the subjects' cooperation), so all three tests were relatively short, including ten multiple-choice questions each. This form of test was chosen because of the following advantages:[1]

1. Versatile
2. Reliable
3. Valid
4. Suitable for item analysis
5. Unambiguous
6. Open to illustration
7. Objectively scored
8. Liked by students

One purpose of giving the pretest was to show that there was equivalence of groups at the beginning of the laboratory experiment. Another purpose of the pretest was to get a score to be used as a covariable in the analysis of covariance (ANCOVA). There was no intention in this study

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[1]William D. Hedges, Testing and Evaluation for the Sciences (Belmont, Calif.: Wadsworth Publishing Company, Inc., 1968), pp. 113-115.

to use the pretest scores for reference to calculate how much knowledge the various groups had "gained" regarding the Schmitt Trigger during the laboratory experimentation procedure. Therefore, most of the questions in the pretest dealt with prerequisite material, rather than with the Schmitt Trigger itself.

The posttest and retention test were identical. The retention test was taken by all the students (treatment and control) one month after the experiment was completed.

The length of the retention period was chosen to minimize the possibility of some students picking up additional relevant information regarding the Schmitt Trigger in lectures or literature--this might have confounded the interpretation of the retention test outcomes.

An experimental unit in a study is the smallest group of subjects that receive the treatment independently of all other groups. The experimental unit also has to be the unit of analysis. In this study, every section is taken as the experimental unit.

If an experimental test has internal validity, it has no confounded variables. Every variable (excluding the dependent variable) that is related to an independent variable in an experimental (statistical) study is considered a confounding variable.

Nonsignificant difference in the mean scores within the treatment and within the control groups in the various tests will indicate that the instructors have not been a confounding variable. This has to be checked while analyzing the data.

The affective reaction of the students was assessed by means of an attitude test (Appendix D3). Members of the comparison groups were asked to answer seven questions (1-7), and the treatment group members were given three additional questions (8-10) concerning some treatment details. In the analysis of the data, the students' answers to every single question as well as to the whole test have to be analyzed, in order to get a general idea of the students' perception of the suggested model.

Through an Instructor's Evaluation Form (Appendix D4), an attempt was made to find out the problems elicited by the use of the model, activities the instructors had been involved in during the experimentation, the students' difficulties, and the instructors' attitudes toward the new model. This form was submitted only to the instructors of the treatment groups. Because of the few instructors (three) involved in this part of the study, no statistical analysis was made regarding the outcomes of the Instructor's Evaluation Form.

The Testable Hypotheses

In Chapter VI, in the section Recommendations for Further Research, the reader will find a variety of independent and dependent variables on which new hypotheses can be established. Further experimental studies may find the nature of the relationship between some of these variables.

In this experimental test, only the general potential of the suggested model, in comparison with the traditional method of experimentation, is being investigated. This is the rationale for establishing the following two general-achievement hypotheses and the attitude hypothesis.

The null form of the first hypothesis tested in the cognitive domain is:

> Ho_1: There will be no difference between the mean scores of the treatment groups and comparison groups on the posttest (Appendix D2).

The null form of the second hypothesis tested deals with retention of material acquired in the experimenting process, one month after completing the experiment:

> Ho_2: There will be no difference between the mean scores of the treatment groups and comparison groups on the retention test (Appendix 2).

An attempt has been made to formulate an hypothesis in the affective domain in such a manner that quantitative data analysis would be feasible (see data analysis in Chapter V). The null form of the student attitude hypothesis is:

> Ho_3: There will be no difference in the positive attitude of the students toward the method of experimenting with electronic circuits, between the treatment groups and comparison groups (Attitude test, Appendix D3).

Under the circumstances of this experimental test, there was no way to prove that the assumptions of the analysis of covariance (ANCOVA) were met. In any case, the results of the analyses ($p<0.0004$) do decrease some anxiety regarding possible violations of those assumptions.

Running the Model in Practice

A critical stage in developing a new instructional model is its first implementation in practice. The problems linked with this stage are more severe when the new model has to be integrated into an existing traditional system, and is only one of the system's components.

In this study, the model was integrated into the conventional laboratory course in electronics at Michigan State University. Dr. D. Fisher, of the Department of Electrical Engineering at Michigan State University, assisted in implementing the experimental test of the model.

As has already been mentioned, the model was applied to the "Electronic Devices Laboratory" course, E.E. 484 (senior level) at MSU for two weeks (September 26 to October 6) during fall term, 1972. In the week before the laboratory experiment began, students in this course took the pretest (Appendix D1) in their lecture session of the concurrent course, E.E. 474 (Physical Properties of Electronic Devices I). On this occasion, the purpose of the study was explained in a few sentences to all the students of the course. By this time, all the laboratory materials, equipment, media means, evaluation items (tests), and student handouts had been completed and were ready for the students' use. The development, design, and preparation of all these materials had been accomplished mainly during spring and summer, 1972.

When taking the pretest, the students had already been assigned to the five treatment groups and five comparison groups. The writer maintained contact with the three instructors of the treatment groups during the two weeks that the experiment was run. Problems which arose, like misprints or vague points in the lab manual, were clarified. In the week before the experiment began, a meeting was held in order to acquaint the treatment groups' instructors with the subject matter and experiment procedure through the suggested model. These instructors were also provided with a detailed solution of the preliminary work and a complete record of laboratory measurements of the Schmitt Trigger.

One of the responsibilities of all laboratory instructors in the Department of Electrical Engineering at Michigan State University is to perform every experiment they are going to monitor, at least three days ahead of the scheduled time of the experiment. The measurement results of pre-experimentation are used as reference during the laboratory session. It is very important for the instructor, as well as for the success of the experiment, that he accomplish the pre-experimentation by <u>himself</u>. So the instructors of the treatment groups (as well as those of the comparison groups) carried out the experiment procedure prior to the students' experimentation.

Details concerning the assignment of instructors to the various treatment and comparison groups were discussed earlier in this chapter.

Right after taking the pretest, the members of the treatment groups received the Theory Sheets and Experimental Procedure Sheets (Appendices A and B, respectively).

Six lab stations of the Schmitt Trigger experiment were set up in the electronics laboratory (Room 360, Engineering Building, MSU). Each station consisted of electronic instrumentation (as described in Appendix A, page) and media materials (as described previously in this chapter). Each station served two students at a time.

The instructors were given the option of briefly explaining the Schmitt circuit and experimental procedure, including a demonstration of some measurements of the circuit.

The Schmitt circuit experiment was supposed to last two weeks, three hours every week. Most of the students spent the first laboratory session (three hours in the first week) on the slide-tape presentation and the preliminary work. Only a few of them got to start the practical experimentation on the circuit at this first session.

The measurements and laboratory analysis of the experiment on the Schmitt Trigger were carried out substantially during the second three-hour laboratory session the following week.

Right after completing the experiment, every student (treatment and comparison groups) took the posttest and attitude test (Appendices B and C, respectively). The attitude test included seven questions for members of the comparison groups. Members of the treatment groups were asked three additional questions regarding the use of the media used.

The retention test, which was identical to the post-test in content but with different question arrangement, was taken by the students in the same manner as the pretest (at lecture sessions) one month after the experiment period. All the sections were given the same length of time when taking the tests.

Summary

The experimental test of the suggested model for laboratory experiments with electronic circuits, which was described in this chapter, consists mainly of the statistical design of the study and the implementation of this model in practice. The statistical analysis is based on the data derived from this tryout.

The sample of students participating in the study was carefully described; it consisted of all the seniors taking the "Electronic Devices Laboratory" course (E.E. 484) in the College of Electrical Engineering at MSU. A review of their background in electricity and electronics was based on the prerequisites required by the Department of Electrical Engineering at Michigan State University.

On the basis of this carefully described sample, the Cornfield-Tukey argument was applied to generalize the statistical inference of this study to the population of subjects similar to those included in the sample.

The purpose of the experimental test was to evaluate the effectiveness of the suggested model in the affective domain as well as in the cognitive domain.

Three multiple-choice tests (pretest, posttest, and retention test) were designed to be used as measuring tools in evaluating the model in the cognitive domain, while an attitude test was used as a measuring device in the affective domain.

Ten sections of the E.E. 484 laboratory course (a total of 108 students) were divided into five treatment groups using the suggested model to perform the Schmitt circuit lab experiment, while the other five sections (comparison groups) performed the same experiment under the traditional method.

The two testable null hypotheses of this experimental study in the cognitive domain were: There will be no difference between the mean scores of the treatment and comparison groups on the posttest and retention test. The null form of the hypothesis in the affective domain was: There will be no difference in the positive attitude of the students toward the method of experimenting between the treatment and comparison groups.

The model was applied to the "Electronic Devices Laboratory" course during two weeks in fall term, 1972 (three weekly hours of lab). The number of students in the experimental units (the various lab sections) was unequal. The treatment groups had three instructors, while the control groups had two different instructors. The schedule of the lab sessions was determined by the Electrical Engineering Department.

The facilities of the laboratory where the experiment was implemented included six lab stations equipped with the necessary electronic instrumentation and media.

The posttest and attitude test were conducted immediately after completing the experiment, and the retention test was given one month later.

CHAPTER V

ANALYSIS OF RESULTS OF THE EXPERIMENTAL TEST

Introduction

Data were collected for the statistical analysis of the experimental test, from the pretest, posttest, retention test, and attitude test.

One hundred eight students were involved in the study. In order to carry out the statistical analysis of the study with only those subjects who had participated in all the stages of the study and had written all four evaluation tests, the researcher eliminated those students who had taken fewer than the four tests. Thus, the final number of subjects in the statistical analysis of the study dropped to 80.

The data were run on the Control Data Corporation 3600 computer in the Michigan State University Computer Center, employing the Finn[1] program.

This chapter contains: a description of the statistical analysis of cognitive domain measures, a description of the statistical analysis of affective domain measures, the instructors' evaluation of the model, and a chapter summary.

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[1]Jeremy Finn, "Multivariate Analysis of Variance," State University of New York at Buffalo.

Statistical Analysis of Cognitive Domain Measures

The hypotheses tested involved scores for each class section; there were five treatment sections and five comparison sections. For this reason, the mean scores on all three measures in the cognitive domain (pretest, posttest, and retention test) are reported in Table 3.

Table 3.--Means for pretest, posttest, and retention test.

Source	Section	# Students per Sec.	Pretest	Posttest	Retention Test
Treatment	S1	9	4.666	5.555	3.888
	S2	6	4.500	6.000	5.666
	S3	10	4.600	5.400	4.800
	S4	10	4.200	5.300	5.100
	S5	11	4.818	5.454	4.454
Total	(T)	46	4.56	5.55	4.73
Compar-ison	S6	6	5.666	4.500	3.333
	S7	9	4.777	3.777	2.888
	S8	4	4.750	3.750	3.250
	S9	7	3.286	4.571	3.000
	S10	8	4.625	3.750	2.750
Total	(C)	34	4.60	4.07	3.00

The maximum possible individual (not section) score was ten. A possible reason for the relatively low scoring in the pretest is that three of the ten questions were related to the Schmitt circuit, whose operation was not yet mastered by the students at the time they took the pretest. A look at the posttest and retention test (Appendix D2) reveals that these tests are quite difficult. This was done on purpose; the writer suspected that an easy test would result in high scores in both the treatment and comparison groups, which might cause difficulties in distinguishing between the achievements of the two groups.

The Analysis of Variance--Pretest

In the preceding chapter, it was stated that one of the purposes of conducting the pretest was to show that there was equivalence of groups at the beginning of the laboratory experiment. This was accomplished by running an analysis of variance (ANOVA) test on the CDC 3600 computer through the Finn program. Because the scores on the posttest and retention test were punched on the same cards with the pretest data, the ANOVA procedure was applied to all three tests. The null hypotheses tested in this case were: Ho: There will be no difference between the mean scores of the treatment groups and comparison groups on the: (1) pretest, (2) posttest, and (3) retention test. The analysis yielded the results presented in Table 4.

Table 4.--ANOVA treatment vs. comparison results.

Variable	Between Mean Squares	F Ratio	p less than
Pretest	0.0104	0.0033	0.9544
Posttest	40.6051	13.1305	0.0006
Retention Test	57.6614	21.4786	0.0001
D.F. for hypothesis = 1 D.F. for error = 70			

The null hypothesis regarding the pretest was not rejected; i.e., no significant difference ($p<0.9544$) was found in the mean scores of the pretest between the treatment and comparison groups, indicating equivalence of groups at the beginning of the lab experiment.

The null hypotheses regarding the posttest and retention test were rejected; i.e., significant difference in the mean scores of the posttest ($p<0.0006$) and retention test ($p<0.0001$) between the treatment and comparison groups indicated that the treatment groups learned and retained more than the comparison groups. These findings are in accordance with the forthcoming ANCOVA analysis findings concerning the same posttest and retention test.

The Analysis of Covariance--Posttest and Retention Test

A test concerning the statistics for regression was carried out. It turned out that the covariate, the pretest, was indeed correlated with the posttest and retention test, in spite of the fact that the pretest included three questions (out of ten) concerning the forthcoming unknown topic--The Schmitt Trigger. So it was justifiable to use the analysis of covariance in this part of the study. The computer's report on this matter is shown in Table 5. (R is a correlation coefficient.)

The null hypotheses regarding the posttest and retention test were: $Ho_{1,2}$: There will be no difference between the mean scores of the treatment groups and comparison groups on the (1) posttest and (2) retention test.

Table 5.--Statistics for regression analysis with one covariate.

Variable	Square Mult. R	Mult. R	F	p less than
Posttest	0.0914	0.3023	6.9413	0.0104
Retention Test	0.0479	0.2189	3.4733	0.0667

D.F. for hypothesis = 1
D.F. for error = 69

Chi square test of hypothesis of no association between dependent and independent variables = 7.0225

D.F. = 2 p less than 0.0299

The data were assembled, and using ANCOVA the analysis yielded the results presented in Table 6.

Table 6.--ANCOVA of the cognitive domain measures.

Variable	Between Mean Squares	Mean Squares	F Ratio	p less than
Posttest	40.99	2.85	14.38	0.0004
Retention Test	57.97	2.59	22.36	0.0001

D.F. for hypothesis = 1
D.F. for error = 69

The decisions were to reject null hypothesis Ho_1 and to reject null hypothesis Ho_2.

The results recorded in Tables 3 and 6 show that the students using the model in the lab experiment retained the material learned through this experiment to a greater extent than did the members of the comparison groups who used the traditional way of experimentation. The results of the retention test point out good external validity of the model in the time domain (over a period of time).

To conclude the results of the statistical analysis so far: The treatment groups learned and retained more than the comparison groups.

The Analysis of Variance--Within Groups

The purpose of this analysis of variance (ANOVA) was to check the homogeneity within the treatment groups and within the comparison groups using the mean scores on the pretest, posttest, and retention test. Nonsignificant differences within the two categories of groups (treatment and control) might indicate consistency in the suggested model's contribution to the lab experimentation with electronic circuits. Nonsignificance might also minimize the concern that the instructor is a confounding variable in this experimental testing.

The ANOVA testing was accomplished similarly to that of the "ANOVA--Pretest, Treatment vs. Control Groups" test (detailed earlier in this chapter). The null hypothesis in the ANOVA--within the groups was: Ho: There will be no difference within the treatment groups' and within the comparison groups' mean scores on the (1) pretest, (2) posttest, and (3) retention test. The analysis of the within groups scores yielded the results presented in Table 7.

Table 7.--Analysis of variance--within treatment groups.

Source	Variable	Between Mean Sq.	Within Mean Sq.	F Ratio	p less than
Treatment	Pretest	0.5420	3.1440	0.1724	0.9519
	Posttest	0.5126	3.0924	0.1658	0.9551
	Retention	3.4691	2.6846	1.2922	0.2815
Comparison	Pretest	4.8232	3.1440	1.5341	0.2018
	Posttest	1.2156	3.0924	0.3931	0.8130
	Retention	0.3819	2.6846	0.1423	0.9659
D.F. of hypothesis = 4 D.F. of error = 70					

The null hypotheses in all three tests were not rejected, in either group; i.e., no significant difference was found in the mean scores within the treatment or comparison groups on all three tests (pretest, posttest, and retention test), indicating homogeneity within treatment and within comparison groups. The various p levels are shown in Table 7.

Multivariate Analysis of Covariance (MANCOVA)

To conclude the statistical analysis of the cognitive domain measures, the results of a multivariate analysis of covariance are presented in Table 8. The posttest and retention test results were pooled in the computerized analysis.

Table 8.--Multivariate analysis of covariance results.

Source	D.F.	F	p less than
Treatment/Comparison	2,68	12.706	0.0001
Treatment	8,136	0.862	0.5507
Comparison	8,136	0.384	0.9277

The null hypotheses tested were:

Ho_1: There will be no difference between the treatment groups' and comparison groups' mean achievement scores (including posttest and retention test scores).

Ho_2: There will be no difference within the treatment groups' mean achievement scores.

Ho_3: There will be no difference within the comparison groups' mean achievement scores.

The decisions were: fail to reject Ho_1, and reject Ho_2 and Ho_3.

Statistical Analysis of Affective Domain Measures

The main tool in evaluating the suggested model in the affective domain was the Attitude Test (Appendix D3). This test included seven questions to be answered by the student right after completing the lab experiment, in the form of an "agreement scale," on which:

(1) SD - Strongly Disagree
(2) D - Disagree
(3) N - Neutral
(4) A - Agree
(5) SA - Strongly Agree

In order to carry out quantitative statistical analysis, the "agreement levels" have been labeled by numbers as indicated above (SD=1, D=2, N=3, A=4, SA=5).

Regarding the model to be evaluated, this scale corresponds from absolute disfavor of the model, labeled 1, to strongly positive attitude toward the model, labeled 5. Thus, the data were coded on the computer-punched cards in the numerical form (from 1 to 5). The data were run on the CDC 3600 computer, through the Finn program. Two types of analyses were employed:

1. Univariate ANOVA--applying analysis of variance to each of the seven questions separately--analyzing one question at a time, by investigating the difference in mean scores of the answers to this particular question, between treatment and comparison groups.

2. Multivariate ANOVA--applying analysis of variance to the pooled data of all the seven questions.

The univariate analysis of variance results and the distribution of the students' answers (in per cent of the total number of students in the treatment or control groups) are shown in Table 9. Every question will now be analyzed separately. The order of the questions--Q1, Q2, . . . Q7--in this discussion corresponds to the order of these questions in the Attitude Test (Appendix D3). The reader may find it advantageous to read every question in Appendix D3 right before reading its analysis.

Referring to Table 9:

Q1: 46.7 per cent of the comparison group members are quite satisfied with the conventional method of experimentation in the electronics laboratory, as it is done at

Table 9.--Distribution of student attitude answers and univariate ANOVA results (treatment vs. comparison groups).

Question	Distribution of Students' Answers				Univariate Analysis of Variance			
	Comparison Groups		Treatment Groups		Between Mean Sq.	Within Mean Sq.	F Ratio	p less than
	A or SA[a]	D or SD[b]	A or SA	D or SD				
Q1	46.7%	11.1%	76.2%	11.1%	3.3560	0.6846	4.9023	0.0301
Q2	80.0%	4.4%	82.6%	6.3%	0.0676	0.5582	0.1212	0.7289
Q3	51.1%	28.9%	65.1%	12.7%	1.0824	0.9408	1.1504	0.2872
Q4	68.9%	8.9%	77.8%	3.2%	2.1611	0.5610	3.8520	0.0537
Q5	8.9%	71.1%	6.4%	82.6%	2.7633	0.5323	5.1911	0.0258
Q6	42.2%	13.3%	57.1%	12.7%	1.0243	0.4856	2.1095	0.1509
Q7	13.3%	48.9%	41.3%	27.0%	10.6804	0.8838	12.0842	0.0009

D.F. for hypothesis = 1
D.F. for error = 70

[a]Agree or Strongly Agree

[b]Disagree or Strongly Disagree

MSU, while 11.1 per cent are dissatisfied with this method. The remaining 42.2 per cent of the students in the comparison groups answered "Neutral" to the first question.

In the treatment groups, 76.2 per cent would prefer to use the suggested model of experimentation in the future, while 11.1 per cent would not. The univariate analysis of variance on this question resulted in significant difference between the treatment and comparison groups ($p<0.0301$) in their willingness to continue experimenting by the same method they used in this experiment.

Q2: A vast majority of the students (80%) in both categories (treatment and comparison) admitted that calculating the expected values to be measured before the experiment made the experiment more understandable and interesting.

Q3: 51.1 per cent of the comparison group members stated that the conventional experimental procedure enabled work without waiting for the instructor, while 28.9 per cent of these groups claimed that this procedure had not enabled self-help. In the treatment groups, 65.1 per cent were positive while only 12.7 per cent were negative in this matter. No statistically significant difference was found between answers to this question by treatment and comparison groups.

Q4: 68.9 per cent of the comparison group students felt a positive reinforcement in knowledge and interest in switching circuits (the category of electronic circuits to which the Schmitt Trigger belongs) as a result of working on the Schmitt experiment, while 8.9 per cent of these groups did not have such a feeling. The corresponding distribution of the treatment groups' answers to this question was 77.8 per cent positive and 3.2 per cent negative.

Q5: The weight of the various answers to this question was reversed in the univariate ANOVA; e.g., SD→SA, D→A, N→N, A→D, and SA→SD, because this question is stated in a negative way.

The results of the ANOVA analysis regarding this question indicate that more comparison group members followed the experiment procedure without understanding it than did the members of the treatment groups. The significant difference was at the $p<0.0258$ level.

Q6: 57.1 per cent of the treatment groups' members felt more confident being able to deal with the Schmitt circuit after experimenting on it, while 42.2 per cent of the comparison groups felt the same way.

Q7: The greatest significant difference ($p<0.0009$) appeared on the answer to this question, indicating that more members from the treatment groups than those from the comparison groups felt they had <u>learned more from this Schmitt experiment (using the model) than from any other experiment in electronics so far</u>.

The null hypothesis regarding the affective domain was: There will be no difference in the positive attitude of the students toward the method of experimenting with electronic circuits, between the treatment groups and comparison groups.

In order to investigate this general hypothesis on the basis of the Attitude Test's outcomes, a multivariate analysis of variance was carried out. The results are presented in Table 10. The mean scores of the treatment and comparison groups on all the seven questions in the attitude test were employed, using the Finn program.

Table 10. Multivariate attitude ANOVA.

Source	Multivariate F Ratio	D.F.	p less than
Treatment vs. Comparison Groups	2.84	1,64	0.012
Treatment Groups Difference	1.11	28,232	0.329
Comparison Groups Difference	1.18	28,232	0.248

The decision was to reject the null hypothesis. The conclusion is that there is a significant difference ($p<0.012$) in the positive attitude of the students toward the method of experimentation with electronic circuits, between the treatment groups and comparison groups. This indicates that the members of the treatment groups held a significantly more positive attitude toward experimentation by means of the model than members of the comparison groups held toward experimenting through the conventional method.

It can be seen in Table 10 (treatment and comparison groups within results) that some homogeneity exists among the treatment groups' attitudes toward the model, as well as among the comparison groups' attitudes toward the conventional method of experimentation in the electronics lab.

Three additional questions were submitted to the members of the treatment groups on the Attitude Test form (see Appendix D3). The answers of the students were distributed as follows:

Q8: 46.1 per cent of the treatment groups' members stated that the flow charts describing the experimental procedure had helped in proceeding by themselves while working on the experiment; 15.9 per cent of the students disagreed with that.

Q9: 57.1 per cent of the treatment groups' members admitted that the slide-tape presentation of the Schmitt circuit had been helpful, while 22.2 per cent had had no benefits from this medium (according to their own statements).

Q10: 44.5 per cent of these students would like to have additional slide-tape presentations of the Schmitt Trigger applications, and 19.1 per cent were opposed to having additional presentations.

It seems that a certain learning aid which is good for one student is not necessarily good for another; therefore, the student should be given alternative learning aids so he can choose the one that best fits his personality.

The Instructors' Evaluation of the Model

The instructors of the treatment groups were asked to fill out a form concerning the application of the model during the laboratory sessions they had monitored (Appendix D4). Here are their answers:

1. All three instructors chose not to demonstrate the circuit operation to their groups.

2. All of the instructors stated they had not been occupied with students' problems during the experiment, any more than in the usual electronic lab experiment. (It has to be kept in mind that these instructors were not professionals; they were graduate students.)

3. All instructors reported no lack in student prerequisite material.

4. Vagueness of the loop-gain concept was mentioned as difficult for students and instructors.

5. One instructor introduced remedial material, just for one individual. The other two did not introduce any remedial material.

6. Two instructors preferred to use the suggested model rather than the "classical" method of experimenting with electronics circuits. The third instructor stated that the use of the model depends on the specific objectives desired.

7. It was the writer's perception that the instructors' attitude toward applying the model, although reluctant and cool at the beginning, became warmer and more positive as

the experiment went on, during the two-week experimental period.

Summary

The statistical analysis of the study has been presented in this chapter. Measures in the students' cognitive and affective domains were carried out and analyzed using the computer facilities at Michigan State University. Instructors' attitude toward applying the instructing model in the electronics laboratory was searched and the results presented. The decisions made on the basis of the statistical analysis are listed in Table 11.

Table 11.--Statistical decisions.

For No Difference Between or Within Groups	Source of Comparison (Groups)	Decision	p less than	Test
Pretest	Treatment vs. Comparison	Fail to Reject	0.9544	ANOVA
Posttest	Treatment vs. Comparison	Reject	0.0004	ANCOVA
Retention Test	Treatment vs. Comparison	Reject	0.0001	ANCOVA
Pretest	Treatment Within	Fail to Reject	0.9519	ANOVA
Posttest	Treatment Within	Fail to Reject	0.9551	ANOVA
Retention Test	Treatment Within	Fail to Reject	0.2815	ANOVA
Pretest	Comparison Within	Fail to Reject	0.2018	ANOVA
Posttest	Comparison Within	Fail to Reject	0.8130	ANOVA
Retention Test	Comparison Within	Fail to Reject	0.9659	ANOVA
Attitude Test	Treatment vs. Comparison	Reject	0.0120	ANOVA

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Discussion

The essence of the development of the instructional model of experimenting with electronic circuits is the audio-tutorial approach. The central idea of the audio-tutorial approach is that the learning activity is done _by_ the student and not _to_ him. If a student is supposed to learn, he must be given conditions to do so in the most beneficial manner. The model suggested is an attempt to set conditions in the electronics laboratory which will lead to learning.

The elements of the model may be considered as independent variables. The word "variable" implies that these conditions of learning may vary, so at least two alternative conditions have to exist. Some of the _independent variables_ in a learning system may be:

1. Type of instruction--lecture-based teaching, individualized tutorial instruction, programed instruction, or audio-tutorial instruction.
2. Media--presence or absence of media.
3. Types of media employed.
4. Timing between elements--timing between a laboratory schedule and corresponding theory lectures.

5. Integration of elements--integrating theory and lab experiments versus separating them.
6. Student options versus teacher choices.
7. Evaluation based on mastery or on relative standards.
8. Type of evaluation--written, oral, or performance tests, or a combination.
9. Type of instructor--in the electronics lab, the professor in charge of theoretical portion parallel to the lab course, a graduate student, or a professional specialist from industry.
10. Student's choice of time to learn--choice in experimentation time (open laboratory) versus scheduled procedure.
11. Mediated and live demonstrations--demonstration of the experimental process by the instructor (modeling) versus demonstration by media or no demonstration at all.
12. Upgrading the program (every year, for instance).
13. Order of presentation and experimentation--i.e., to start with A.C. measurements and then check the D.C. conditions.

The outcomes of the learning process may be labeled as <u>dependent variables</u>. The following outcomes may be considered variables of this category:

1. Amount of material learned in a period of time (concepts, principles, skills).
2. Degree of student's mastery of the subject matter.

3. Degree of student's retention of the material studied.
4. Extrapolation capabilities of the students in applying the learned material to meet needs of the real world (transfer).
5. Efficiency of the instructional method concerning the following components:
    a. Development and material preparation of the lab experiments.
    b. Equipment and laboratory facilities--investment and maintenance.
    c. Instructors' time and wages.
    d. Students' time consumption.
6. Students' attitude toward the learned subject.

There are no precise rules or laws which express a quantitative mathematical relationship between the dependent and independent variables of an instructional system. Often it is difficult to identify all the independent variables affecting a set of dependent variables. Since there is no mathematical formula expressing the dependent variable as some function of independent variables, it is practically impossible to find the precise nature of the independent variable through differentiating procedure as used in calculus.

Experimental testing must be employed to determine the approximate relationship between the two types of variables. Prediction of outcomes may be made only for those future cases where the independent variables will be similar to those used in the study. For this reason, the sample has to be precisely described.

In the experimental testing of the model used in this study, only a generalized search of its instructional potential has been carried out so far.

Summary

Since electronics has become a factor in everyday life, many people face the need of professional mastery in this field, which is abstract in nature. Research and development of instructional methods must be carried out to accommodate students who are interested in this profession. Some experimental studies carried out in this field during the past several years have pointed out the potential of applying modern learning theories in electronics studies to improve instruction.

There are eleven main components of the model developed:

1. Preliminary work by a student based on handouts and assigned reading, including calculations of electrical performance that will be measured in the laboratory experimentation.

2. Use of audio-tutorial techniques in the theoretical analysis of the circuit and its applications.

3. Use of an oscilloscope as a powerful medium in studying electronic circuits for scanning the output

characteristics, displaying waveshapes at various points in the circuit, or scanning the actual transfer characteristic of the circuit; that is, the output voltage as a function of the input voltage.

4. Use of guides and flow charts describing the experiment procedure (optional).

5. Creation of conditions for a student's active involvement in the experimentation process--letting him take part in the "design" of the circuit by calculating some missing components and providing immediate feedback for reinforcement. Measuring the circuit operation and getting expected results during the experimental process frequently provides a student with successful experience; this increases his involvement.

6. D.C. (Direct Current) and A.C. (Alternating Current) measurements of the circuit's operation and comparison to precalculated values of voltage, current, or amplification.

7. The use of an experimental analysis of the circuit; a combination of laboratory and theoretical investigation of the circuit's reaction to external or internal changes imposed on it, like changing feeding voltages, loading, environmental circumstances (temperature), or changing the values of its internal components. If an integrated circuit is under experiment, only external changes are investigated.

8. To keep in touch with the real world, a student is shown a few typical practical applications of the circuit at this stage; the newly learned details of the circuit are

investigated under real conditions. It is recommended that media be utilized for application demonstrations if "live" practical circuits are unavailable.

9. College-level students are asked at this stage to design adequate modifications to be introduced into the circuit in order to satisfy newly imposed conditions of operation.

10. The posttest in any format (oral, written, performance, or in a combination of the three testing forms) is to be taken right after the experiment procedure.

11. The modular structure of the model enables it to be used at different levels (i.e., engineering, community college, technical school).

The model was applied to the "Electronic Devices Laboratory" course, E.E. 484 (senior level) in the Department of Electrical Engineering at Michigan State University. A total of 108 students were divided into ten lab sections. Five of these sections (treatment groups) used the suggested model to perform their lab experiment, which happened to be "The Schmitt Trigger--Theory and Applications." This lab experiment was scheduled to last two weeks, three hours weekly. The other five sections (comparison groups) performed the same experiment in the conventional way of experimenting in the electronics laboratory. The treatment groups were monitored by three instructors and the comparison groups were guided by two different instructors.

The following items were prepared to be used in the Schmitt circuit experiment.

1. Theory Sheets--including the Schmitt Trigger's theory and applications.
2. Experimental Procedure Sheets--including flow charts and special guidance in using the oscilloscope as a display medium.
3. A slide-tape presentation of the Schmitt analysis and applications.

These items had been tried out on an instructor and on a student before being applied to the treatment groups.

The model was evaluated by four tests: pretest, posttest, retention test (given one month after the posttest), and student attitude test. An Instructor's Evaluation Form (of the model) was filled out by the three treatment group instructors.

The results of the four tests were analyzed statistically utilizing the CDC 3600 computer at the Michigan State University Computer Center. The Finn Multivariate Analysis of Variance program was employed in the analysis.

Three hypotheses were formulated in the experimental testing of the model, two in the cognitive domain and one in the affective domain.

It was expected that members of the treatment groups would achieve higher mean scores on the posttest and retention test than members of the comparison groups. It was also expected that members of the treatment groups would have a more positive attitude toward the specific method of experimentation they used than members of the comparison groups would have regarding the traditional approach.

The main results of the statistical analysis were as follows:

1. No significant difference ($p<0.9544$) was found in the mean scores of pretest between the treatment and comparison groups.

2. There was evidence of significance in the mean scores of the posttest ($p<0.0004$) and retention test ($p<0.0001$) between the treatment and comparison groups.

3. No significant difference was found in the mean scores within the comparison groups ($p<0.7023$) and within the treatment groups ($p<0.8151$) in any of the three tests (pretest, posttest, and retention test).

4. There was a significant difference ($p<0.0120$) in the positive attitude of the students toward the specific method of experimentation between the members of the treatment groups and members of the comparison groups.

Conclusions

The development of the instructional model for electronic circuits laboratory experiments and the performance of the experimental testing led to the following conclusions:

1. By using modern technological means, based on theories of learning, the improvement of learning in the electronic circuits laboratory is possible.

2. Students using the suggested model in experimentation with the Schmitt circuit learned more than those who used the traditional method of experimentation.

3. Students using the model retained the material they learned better than students who learned the same material by the traditional method.

4. Students using the model held a significantly more positive attitude toward experimentation in the electronics lab than did students using the traditional method of experimentation.

5. Learners using the model acquired a feeling of successful progress in the laboratory experiment (question 7, page 113). This feeling is considered to be one of the most important factors in motivation.

6. Learning aids are not uniquely advantageous to different students. (51 per cent of the treatment groups members found the slide-tape presentation helpful, while 46.1 per cent stated that the flow charts describing the experiment procedure had helped in self-proceeding during the lab experimentation.)

Recommendations for Further Research

The experimental test of the model carried out in this study can be considered as a source of hypotheses for experimental research to be conducted to reach the goal of improving learning in the electronics laboratory. An instructional model for experimenting with electronic circuits cannot be developed by theory alone, without experimental research, and still be valid and helpful in practice. The development of such a model is a continuous process of introducing improvements into the basic prototype and testing their validity.

Relationships between various combinations of instructional independent variables and dependent variables might be considered hypotheses to be investigated through experimental research. Some of the instructional variables were discussed at the beginning of this chapter.

The model can be extended by conducting appropriate research. Researchers may investigate the extent of retention periods, application to courses at other levels in the engineering college (juniors) and at the community college or technical school level, other laboratory experiments in electronics and electricity, and its application in the realm of techniques of instruction like computer-guided instruction. Each of these investigations would extend the model's external validity.

The internal validity of the model might be strengthened in further research by meeting all the assumptions of the employed statistical analysis.

The efficiency of the model as an instructional tool can also be investigated in further experimental studies.

Researchers may wish to investigate the use of an integrated lecture-laboratory situation in learning electronic circuits, by incorporating a lecture with laboratory experiences (involving audio-tutorial techniques, programed texts, desk calculators, or computer-aided instruction).

Some of the model's features, like the cost efficiency of open laboratory procedures, could not be tested, due to restricted circumstances. These, too, might be a worthwhile subject for further research.

This model includes a variety of instructional factors like individualized learning, programed experimentation, and self-evaluation facilities (getting natural feedback through the oscilloscope), which provided the statistical results of the study. There were probably some interactions between these various factors. The effect of a certain independent variable might be evaluated by conducting a study in which the treatment groups get the maximum possible variables incorporated in the model, while the comparison groups perform the laboratory experiment through the same model with the tested variable missing. The writer considers the use of the oscilloscope and the systematic student-oriented procedure for experimentation as the primary means through which student involvement is being increased.

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APPENDICES

APPENDIX A

THEORY SHEETS

Michigan State University
Department of Electrical Engineering and Systems Science

Electronic Devices Laboratory I
EE 484 -- Fall 1972

THE SCHMITT TRIGGER -- THEORY AND APPLICATIONS

Shlomo Waks

THEORY SHEETS 1972

Michigan State University
Department of Electrical Engineering and Systems Science

THE SCHMITT TRIGGER--THEORY AND APPLICATIONS

Purpose

To improve the understanding of the student in the operation and application of the Schmitt Trigger and increase his laboratory skills.

Objectives

Given a diagram of the Schmitt Trigger, you will be able to do the following after completing the experiment.

1. Explain (orally or written) the operation of the Schmitt Trigger and the role of every single component in the circuit.
2. Point out the expected waveshapes of the voltages at the various points of the circuit in the stable and triggered states.
3. Predict possible changes in the operation of the circuit as a result of a great change (over 70%) in one of its component values or sources. Predictions like: "the output transistor Q_2 will not change its saturation state" are acceptable.
4. Point out possible reasons for differences between calculated and measured voltages at various points in the circuit.
5. Suggest necessary modifications to be carried out in order to adapt it to new operating conditions with

different supply or driving voltages, change in loading or in environmental conditions.

Applications of the Schmitt Trigger

To automatically control street lighting or neon sign switching an automatic twilight switch is required to switch the artificial lighting on or off, depending upon the intensity of the daylight.

The following block diagram shows the basic components of such an automatic twilight switch (Figure A1).

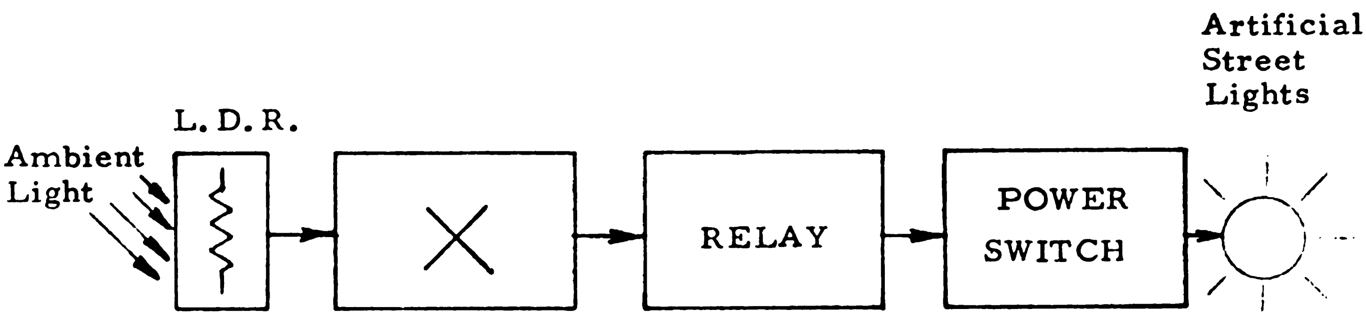


Figure A1.--Block diagram of a twilight switch.

In the evening when ambient light intensity drops, the resistance of the Light Dependence Resistor (L.D.R.) increases. When this occurs, the artificial street lights have to be turned on automatically by the power switch which is operated by the relay. The relay is activated by a definite supply of current through its coil. Since the L.D.R. changes its resistance gradually (as a result of gradual change in ambient light) there is need for a device x (see Figure A1) which will transfer slow changes in the voltage across the L.D.R. into fast changes of voltage (or current) in order to activate the relay at a definite ambient light level. The Schmitt Trigger circuit can fulfill the above requirements for the device x.

Let's analyze this circuit and see how we can utilize it for various applications.

The Schmitt Trigger is an electronic circuit which gives an accurately shaped, constant-amplitude-rectangular pulse output for any input pulse above a predetermined triggering level. This circuit can be used as a d-c signal-level detector or an amplitude comparator, to produce an abrupt change in voltage when an arbitrary waveform reaches a particular reference level.

Squaring of arbitrary input signals is one of the frequent uses of the Schmitt Trigger, as Figure A2 illustrates. Some of the applications of the Schmitt Trigger circuit are in:

1. Radiation counters,
2. Opto-electronic aparatus such as optical counters,
3. Liquid-level sensor,
4. Automatic lighting controls, and
5. Square wave generators, to "square off" a sinusoidal input.

In the above-mentioned applications, as well as in other cases, the Schmitt circuit uses as a "trigger" circuit which translates the slow-changing voltage accepted for instance from a transducer (photo sensitive device, radiation counting tube, etc.) into triggering signals which activate the relay or electronic counter.

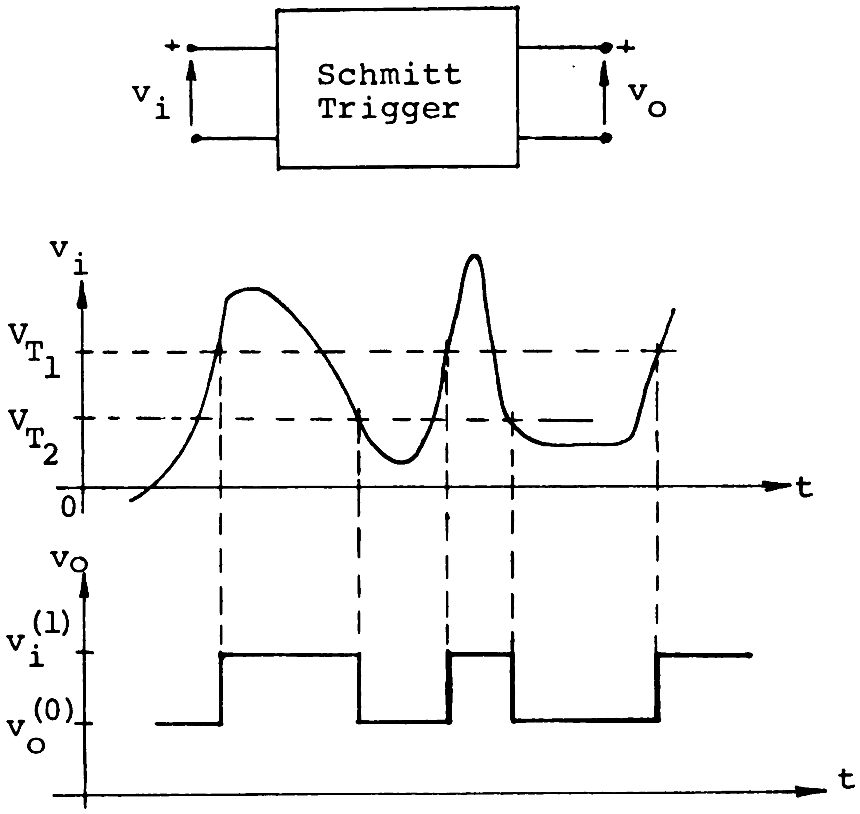


Figure A2.--Input (v_i) and output (v_o) waveshapes of a Schmitt Trigger.

Let us now see how the Schmitt circuit functions and find the key factors affecting its operation.

Analysis of a Schmitt Trigger Circuit

The basic Schmitt Trigger circuit consists of two inverting amplifier stages, A_1 and A_2, connected to deliver positive feedback as shown in Figure A3. The feedback is positive only when regarding the closed loop B_2, E_2, E_1, C_1, B_2.

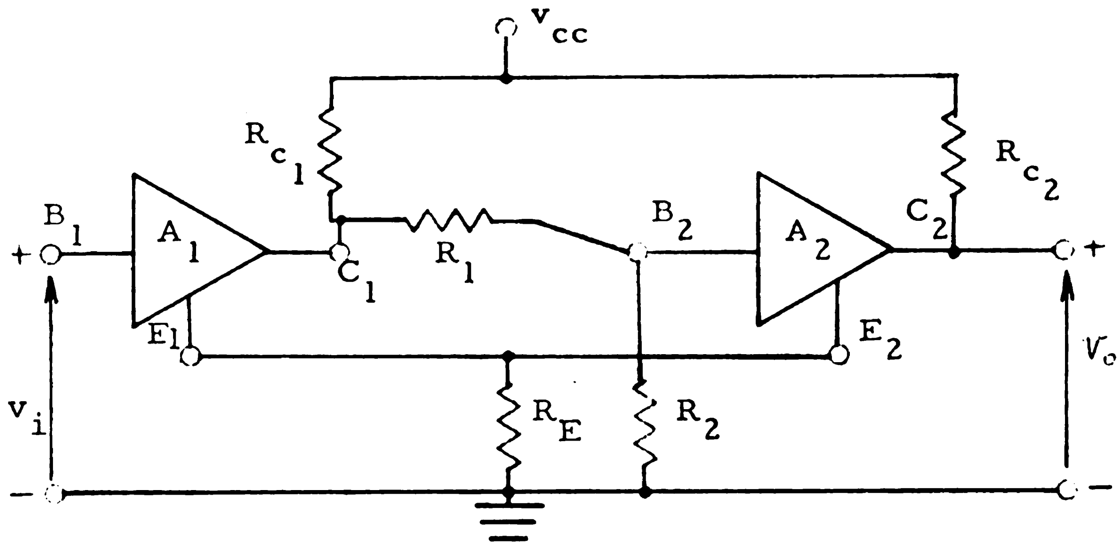


Figure A3.--Basic circuit of the Schmitt Trigger.

Any type of inverter may be used as active component in the amplifier stages A_1, A_2, such as vacuum tubes, bipolar transistors, field effect transistors, or integrated circuit operational amplifiers.

Quantitative Analysis of the Transistorized Schmitt Trigger Circuit

Figure A4 shows a transistorized Schmitt trigger circuit. Let's see what happens in the circuit when v_i starts raising from Ov. When v_i = Ov, transistor Q_1 is forced into the cut-off state because its base-emitter junction is reversed biased by the voltage drop on R_E. Transistor Q_2 is in conduction because it is biased adequately via R_{C_1}, R_1 and R_2.

Neglecting the leakage currents of the transistor in cut-off (Q_1), the circuit may be described as in Figure A5a. After applying Thevenin's theorem at point B_2 (looking to

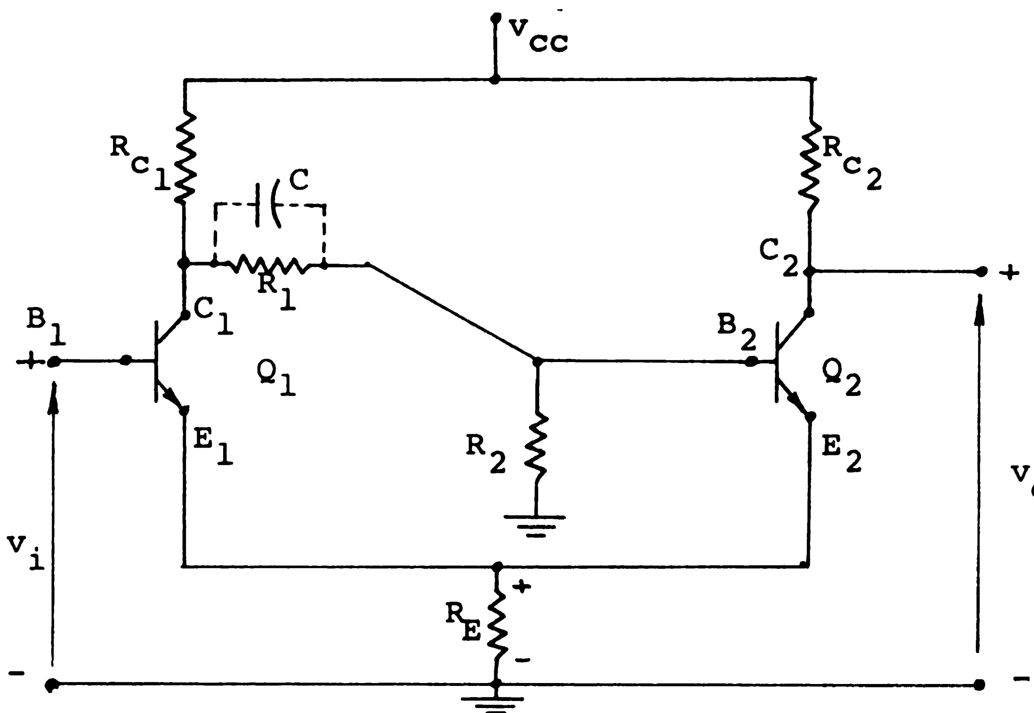


Figure A4.--Transistorized Schmitt Trigger circuit.

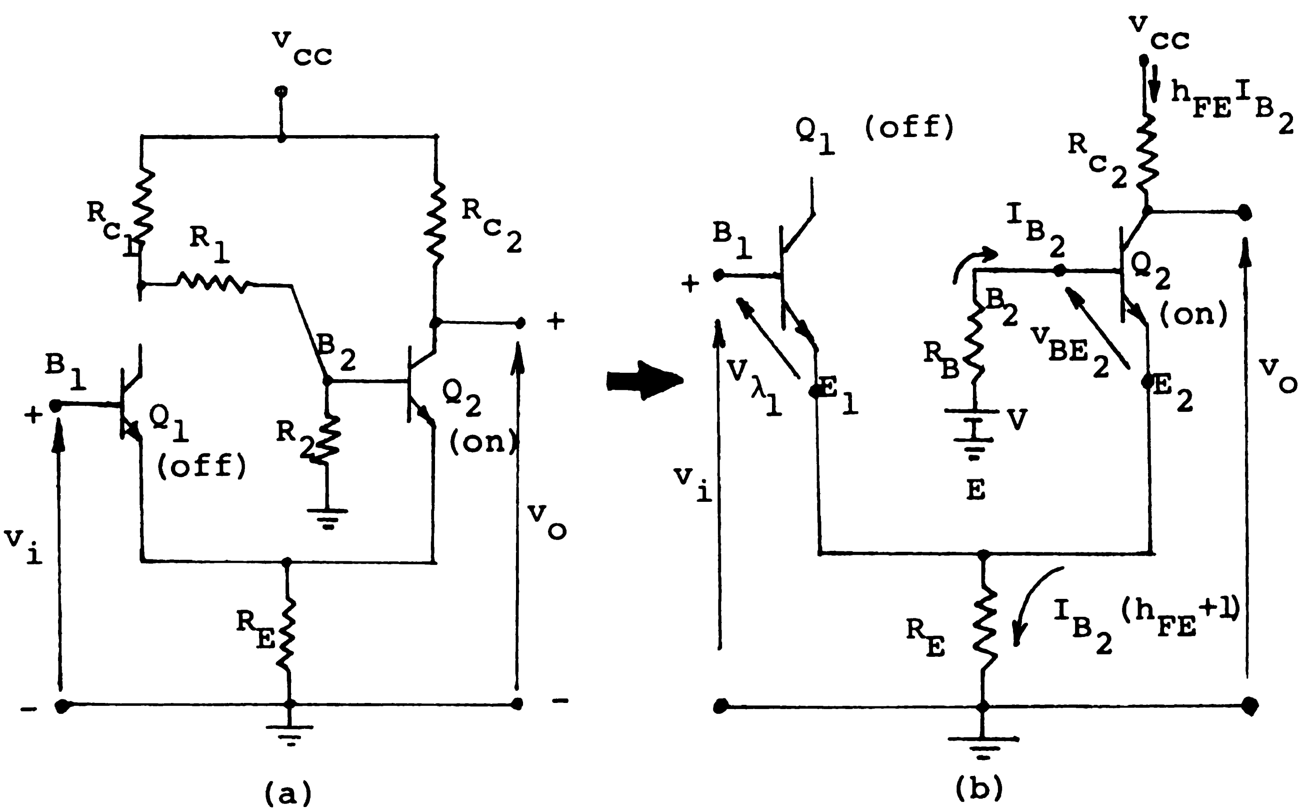


Figure A5.--Equivalent circuits of the Schmitt Trigger when Q_1 is in cut-off and Q_2 is in conduction.

the left) we get the circuit depicted in Figure A5b.

Here:

$$V' = \frac{V_{CC} \cdot R_2}{R_{C_1} + R_1 + R_2} ; \qquad R_B = \frac{R_2(R_1 + R_{C_1})}{R_1 + R_2 + R_{C_1}} \qquad (1)$$

In order to calculate the voltages and currents in the circuit, let's remember that the input characteristics of a transistor might be described approximately as in Figure A6. For our analysis, let's consider the more general case where the transistors are not necessarily driven into saturation.

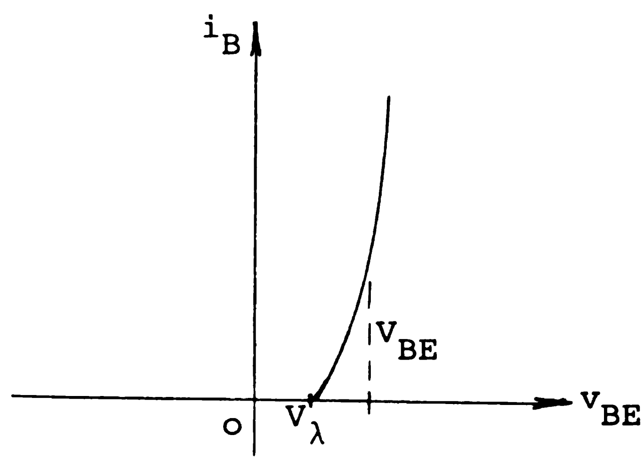


Figure A6.--Input characteristics of a transistor.

The operating currents and voltages can be calculated from the equivalent circuit shown in Figure A5b.

According to Kirchhoff's voltage law applied to the base emitter circuit of Q_2:

$$V' - I_{B_2}R_B - V_{BE_2} - I_{B_2}(h_{FE} + 1)R_E = 0 \qquad (2)$$

$$I_{B_2} = \frac{V' - V_{BE_2}}{R_B + (h_{FE} + 1)R_E} \qquad (3)$$

As long as Q_1 stays in the cut-off state, the output voltage will be:

$$v_1 = V_o^{(0)} = V_{CC} - h_{FE} I_{B_2} R_{C_2} \qquad (4)$$

Increasing the input voltage v_i will cause Q_1 to start conducting. If we define V_{T_1} as the input voltage which causes Q_1 to start conducting, then:

$$v_i = V_{T_1} = V_E + V_{\gamma_1} = I_{B_2}(h_{FE} + 1)R_E + V_{\gamma_1}$$

$$= (V' - V_{BE_2}) \frac{(h_{FE} + 1)R_E}{R_B + (h_{FE} + 1)R_E} + V_{\gamma_1} \qquad (5)$$

$$V_{T_1} = \frac{V' - V_{BE_2}}{1 + \frac{R_B}{(h_{FE} + 1)R_E}} + V_{\gamma_1} \qquad (6)$$

Consider the closed loop B_2, E_2, E_1, C_1, B_2 in Figure A6. The loop gain of the Schmitt in Figure A4 is the overall voltage gain of the whole loop. In our case, for instance, when a signal of Δv is delivered to base B_2, this signal is transferred through Q_2 and appears at E_2 uninverted (in the same phase as at B_2), now it is delivered through E_1 to transistor Q_1 that operates as a common base amplifier (because the input signal is delivered to the emitter while the base B_1 can be considered grounded). From collector C_1 the amplified (and noninverted) signal is transferred back to base B_2 via a voltage attenuator involving R_1, R_2, and R_{C_1}. If the loop gain in this circuit is less than unity, the circuit will operate for $v_i > V_{T_1}$ as a simple direct coupled two stage amplifier with positive feedback. The increase in the input voltage v_i causes a decrease in collector voltage of Q_1 which in turn lowers the voltage supplied to the base of Q_2, thus causing an increase in the output voltage v_o. Further increase in v_i lowers the base voltage of Q_2 till finally Q_2 is driven into cut-off. Additional increase in v_i does not effect the output voltage which is now at a constant value $v_o = V_o^{(1)} = V_{CC}$.

The transfer characteristic $v_o = f(v_i)$ of the circuit is shown in Figure A7. The slope $\frac{\Delta v_o}{\Delta v_i}$ of the transfer function in Figure A7a represents the overall voltage gain of the circuit. Increasing the loop gain by raising the value of R_{C_1}, for instance, will cause a steeper slope. When the loop gain is unity, the slope will be infinite, and the circuit will begin to regenerate. No more linear amplification will be available.

Further increase in loop gain results in a negative slope and the transfer function assumes the hysteresis shown in Figure A8.

Since the Schmitt circuit is mostly used as a fast regenerative triggering device, loop gain greater than unity is established; therefore, the transfer function in Figure A8 usually appears in application notes, data sheets, and chapters in books dealing with the Schmitt Trigger.

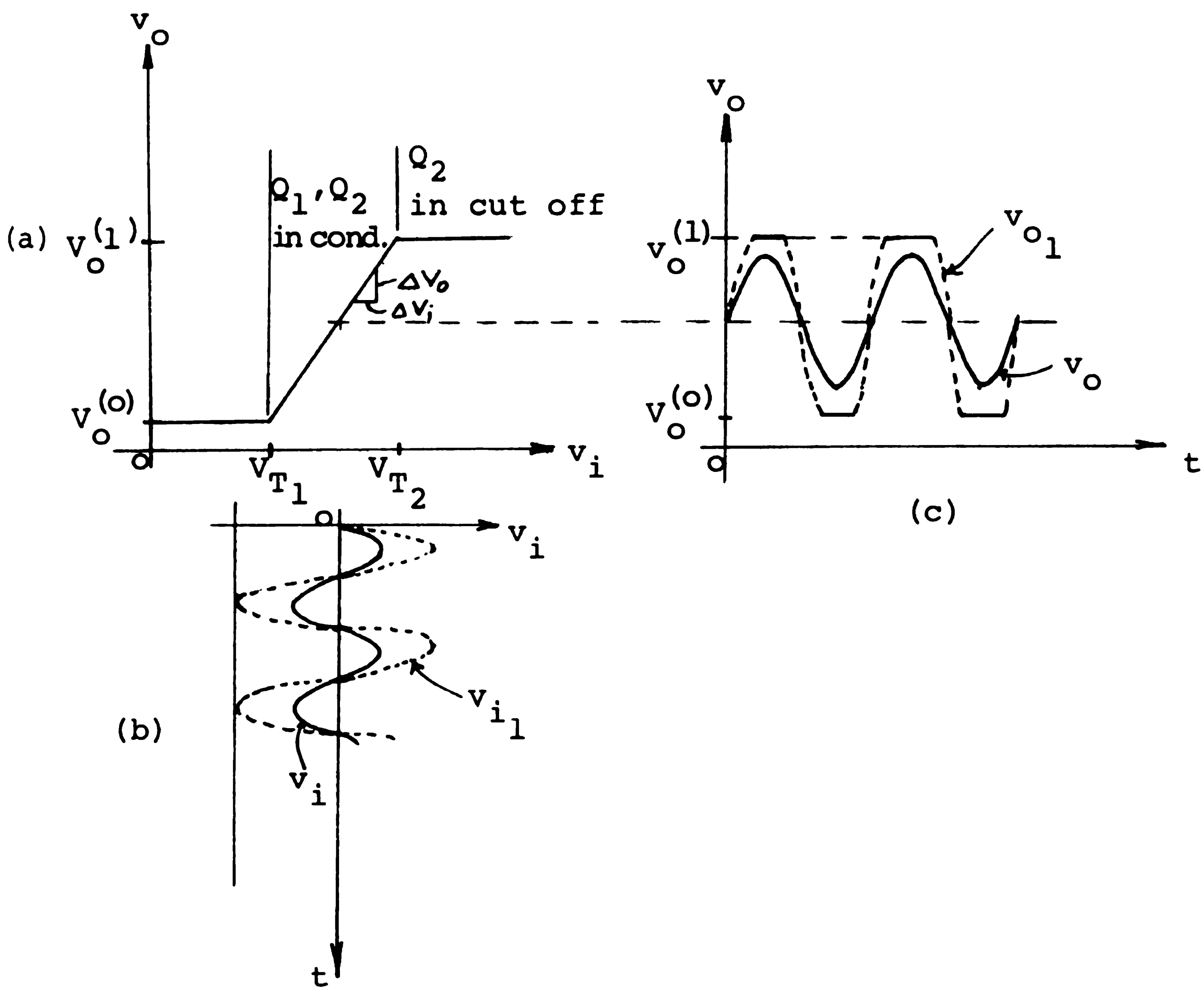


Figure A7. (a) Transfer function of the Schmitt Trigger when (loop gain) < 1.
(b) Input sinusoidal voltage.
(c) Output voltage waveshapes, v_O--operating in the linear region, v_O'--output voltage clamped.

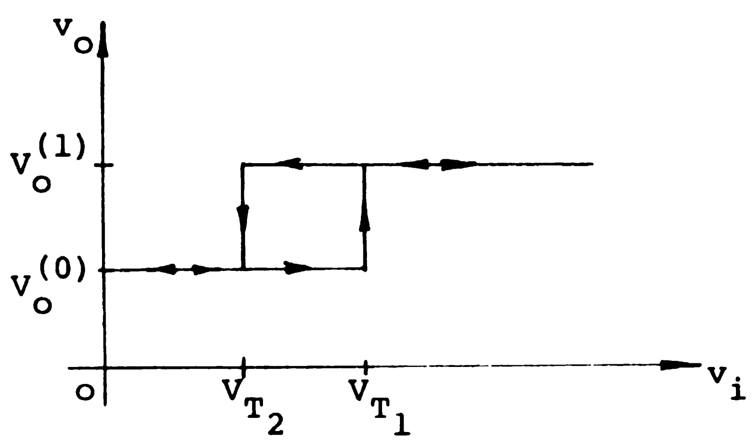


Figure A8.--Transfer function of the Schmitt Trigger for (loop gain) > 1.

To Conclude:

Raising v_i from zero volts will initially hold the Schmitt Trigger in its "low" stable state: $v_o = v_o^{(0)} = V_{CC} - I_{B_2}(h_{FE} + 1)R_{C_2}$ (Q_1 off, Q_2 conducting). When v_i reaches the value V_{T_1} (Eq. 6) the circuit switches over rapidly to the "high" stable state, where $v_o = v_o^{(1)} = V_{CC}$ (Q_1 conducting, Q_2 off). Further increase in v_i will have no effect on the output voltage v_o. Now, when decreasing v_i, starting from values higher than V_{T_1}, the circuit won't switch back to the low stable state $v_o^{(0)}$ as v_i reaches the value V_{T_1}. The reverse transfer of the circuit from the high stable state $v_o^{(1)}$ to the low state $v_o^{(0)}$ will happen at $v_i = V_{T_2} < V_{T_1}$.

The difference (V_H) between the two triggering voltages V_{T_1} and V_{T_2} is known as the hysteresis voltage of the Schmitt Trigger:

$$V_H = V_{T_1} - V_{T_2} \tag{7}$$

We will prove the existence of the hysteresis voltage by developing equations for V_{T_1} and V_{T_2}, and then investigate the factors affecting this voltage.

We have already developed an equation for V_{T_1}; the result was (Eq. 6):

$$V_{T_1} = \frac{V' - V_{BE_2}}{1 + \frac{R_B}{(h_{FE} + 1)R_E}} + V_{\gamma_1}$$

Refer to the Schmitt circuit in Figure A6, where

$$V' = \frac{V_{CC}R_2}{R_1 + R_2 + R_{C_1}} ; \quad R_b = \frac{R_2(R_1 + R_{C_1})}{R_1 + R_2 + R_{C_1}}$$

V_{γ_1} -- cut in voltage of Q_1

The effect of the resistor R_E on V_{T_1} is easily seen in Eq. 6; when R_E is increased V_{T_1} decreases.

In many cases, $R_B << (h_{FE} + 1)R_E$, so then Eq. 6 can be written in the following form:

$$V_{T_1} \cong V' - V_{BE_2} + V_{\gamma_1} \quad (8)$$

Usually, in silicon or germanium transistors

$V_{BE} - V = 0.1v$, so

$$V_{T_1} = (V' - 0.1)v \cong \frac{V_{CC}R_2}{R_1 + R_2 + R_{C_1}} - 0.1v \cong \frac{V_{CC}R_2}{R_1 + R_2 + R_{C_1}} \quad (9)$$

In this case, V_{T_1} is independent of h_{FE}.

It is possible to design the Schmitt Trigger so that the transistor Q_2 (Figure A4) will be in saturation (when Q_1 is in cut-off) instead of being in the active region. In this case switching time will increase.

Calculation of V_{T_2}

V_{T_2} is the input voltage which causes the reverse transition of the Schmitt Trigger from the high state ("1") back to the low state ("0"), by cutting off Q_1 and driving Q_2 into conduction.

Referring to the transistorized Schmitt circuit in Figure A6, Q_1 is now conducting (active region) and Q_2 is in cut-off. v_i is being decreased. We want to calculate the voltage $v_i = V_{T_2}$ which will cut off Q_1. The equivalent circuit of the "high" state of the Schmitt Trigger is shown in Figure A9.

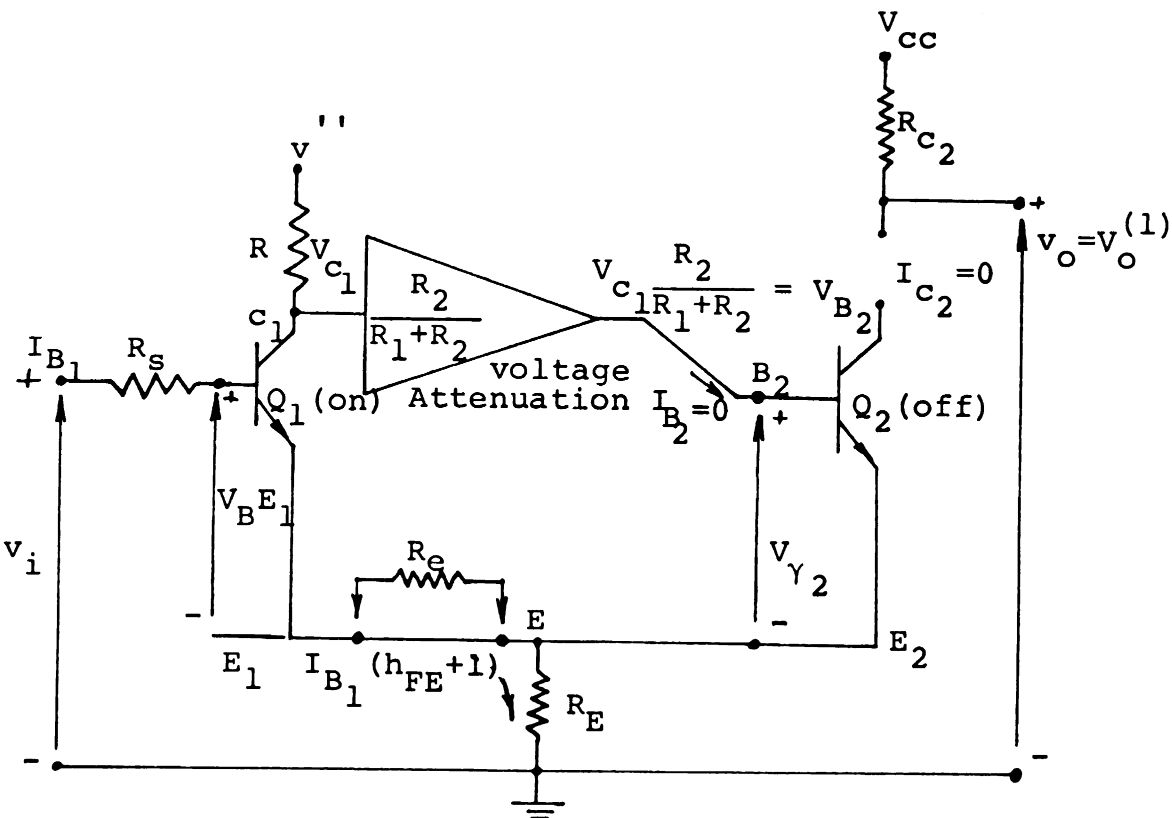


Figure A9. Equivalent circuit of the Schmitt Trigger when Q_1 is on and Q_2 is cut off.

Figure A10 shows the Thevenin equivalent circuit of the collector C_1 and base b_2 circuits. V" is a Thevenin voltage source:

$$V'' = V_{CC} \frac{R_1 + R_2}{R_1 + R_2 + R_{C_1}} \tag{10}$$

with an internal resistance

$$R = \frac{R_{C_1}(R_1 + R_2)}{R_1 + R_2 + R_{C_1}} \tag{11}$$

Note: Meanwhile ignore R_e assume points E_1 - E being shorted.

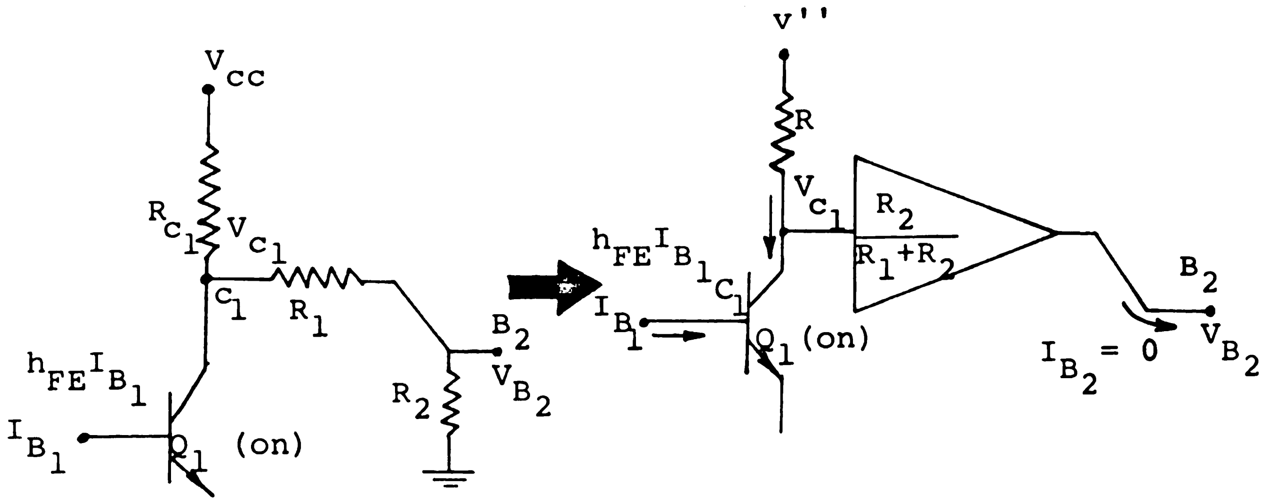


Figure A10.--Thevenin equivalent representation of collector C_1 and base b_2 portion (Q_1 on, Q_2 off).

Applying Kirchhoff's voltage law to the base emitter circuit of Q_2 just before it begins to conduct, we get:

$$V_{C_1} \frac{R_2}{R_1 + R_2} - V_{\gamma_2} - I_{B_1} R_E(h_{FE} + 1) = 0 \tag{12}$$

$$(V'' - h_{FE}I_{B_1}R)\frac{R_2}{R_1 + R_2} - V_{\gamma_2} - I_{B_1}(h_{FE} + 1)R_E = 0 \tag{13}$$

$$\frac{V_{CC}\cancel{(R_1 + R_2)}R_2}{(R_1 + R_2\, R_{C_1})\cancel{(R_1 + R_2)}} - h_{FE}I_{B_1}\,\frac{R_{C_1}(R_1 + R_2)R_2}{(R_{C_1} + R_1 + R_2)(R_1 + R_2)}$$

$$- V_{\gamma_2} - I_{B_1}R_E(h_{FE} + 1) = 0 \qquad (14)$$

$$I_{B_1} = \frac{V' - V_{\gamma_2}}{h_{FE}\,\dfrac{R_{C_1}\;R_2}{R_{C_1} + R_1 + R_2} + R_E(h_{FE} + 1)} \qquad (15)$$

Now, writing Kirchhoff's voltage law for the base-emitter circuit of Q_1 we get:

$$v_i = V_{T_2} = I_{B_1}\,R_S + V_{BE_1} + (h_{FE} + 1)I_{B_1}R_E \qquad (16)$$

$$V_{T_2} = V_{BE_1} + \frac{(V' - V_{\gamma_2})[R_S + (h_{FE} + 1)R_E]}{h_{FE}\,\dfrac{R_{C_1}\;R_2}{R_{C_1} + R_1 + R_2} + R_E(h_{FE} + 1)} \qquad (17)$$

In many practical circuits $R_S << (h_{FE}+1)R_E$ and $h_{FE} << 1$, then the input voltage V_{T_2} which causes the reverse transition of the Schmitt Trigger (from "1" to "0" state) is:

$$V_{T_2} \cong V_{BE_1} + V_{CC}\,\frac{R_2}{R_1 + R_2 + R_{C_1}} - V_{\gamma_2}\,\frac{R_E}{\dfrac{R_{C_1}\;R_2}{R_{C_1} + R_1 + R_2} + R_E} \qquad (18)$$

If the above assumptions are met, V_{T_2} is independent of the source impedance R_S and h_{FE}.

Sometimes, a further approximation is made, namely, $V_{BE_1} \cong 0$; $V_{\gamma_2} \cong 0$, in this case:

$$V_{T_2} \cong \frac{V_{CC}R_2}{\frac{R_{C_1} R_2}{R_E} + R_{C_1} + R_1 + R_2} \qquad (19)$$

The Hysteresis and Its Elimination

Equation (7) defines the hysteresis voltage V_H of the Schmitt Trigger circuit; substituting the approximate values of V_{T_1} (Eq. 9) and V_{T_2} (Eq. 19) we get:

$$V_H = V_{T_1} - V_{T_2} = \frac{V_{CC}R_2}{R_1 + R_2 + R_{C_1}} - \frac{V_{CC}R_2}{\frac{R_{C_1} R_2}{R_E} + R_1 + R_2 + R_{C_1}}$$

$$V_H = \frac{V_{CC}R_2^2 R_{C_1}}{R_E[R_1 + R_2 + R_{C_1}] \left[\frac{R_{C_1} R_2}{R_E} + R_1 + R_2 + R_{C_1}\right]} \qquad (20)$$

In cases where the hysteresis is undesirable it might be eliminated by adjusting the loop gain to be unity (then $V_{T_1} = V_{T_2}$). There are several ways to adjust the loop gain:

1. Increasing the gain by increasing R_{C_1} (See Figure A11).
2. Decreasing the gain by adding a resistor R_e in series with the emitter E_1 (See Figure A9). This resistor will increase V_{T_2} because of its own voltage drop: $(h_{FE}+1) I_{B_1} R_e$. If necessary, R_e may cancel the entire voltage. If I_{B_1} (Figure A9) remains unchanged, then:

$$V_H = V_{T_1} - V_{T_2} = I_{B_1} R_e (h_{FE} + 1) \quad (21)$$

The value of R_e required to cnacel the hysteresis voltage V_H will be:

$$R_e = \frac{V_H}{(h_{FE} + 1) I_{B_1}} \quad (22)$$

where I_{B_1} is determined by Eq. (15).

R_e affects only V_{T_2} (when Q_1 is conducting) and does not affect V_{T_1} at all. (Why?)

3. The gain may be adjusted also by varying the ratio $\frac{R_2}{R_1 + R_2}$, Figure 4. Decreasing R_2 or increasing R_1 decreases the loop gain. To maintain a loop gain value of precisely unity, frequent readjustment is necessary. However, loop gain less than unity results in loss of speed in the response of the circuit. As a trade-off then, a slight hysteresis is tolerated in many practical cases.

The time elapsed from the moment that v_i hits V_{T_1} (or V_{T_2}) to the moment that the output has "settled" at its new level is called the switching time. Switching time is sometimes decreased by shunting R_1 with a speed-up capacitor C (See Figure A4). This capacitor easily transfers the voltage transients from the collector of Q_1 to the base of Q_2, thus avoiding their attenuation by resistor R_1. Detailed computation of the Schmitt circuit operation is presented in the next example. This example is also an outline of the experiment to follow.

Example: Given the Schmitt Trigger circuit in Figure A11.

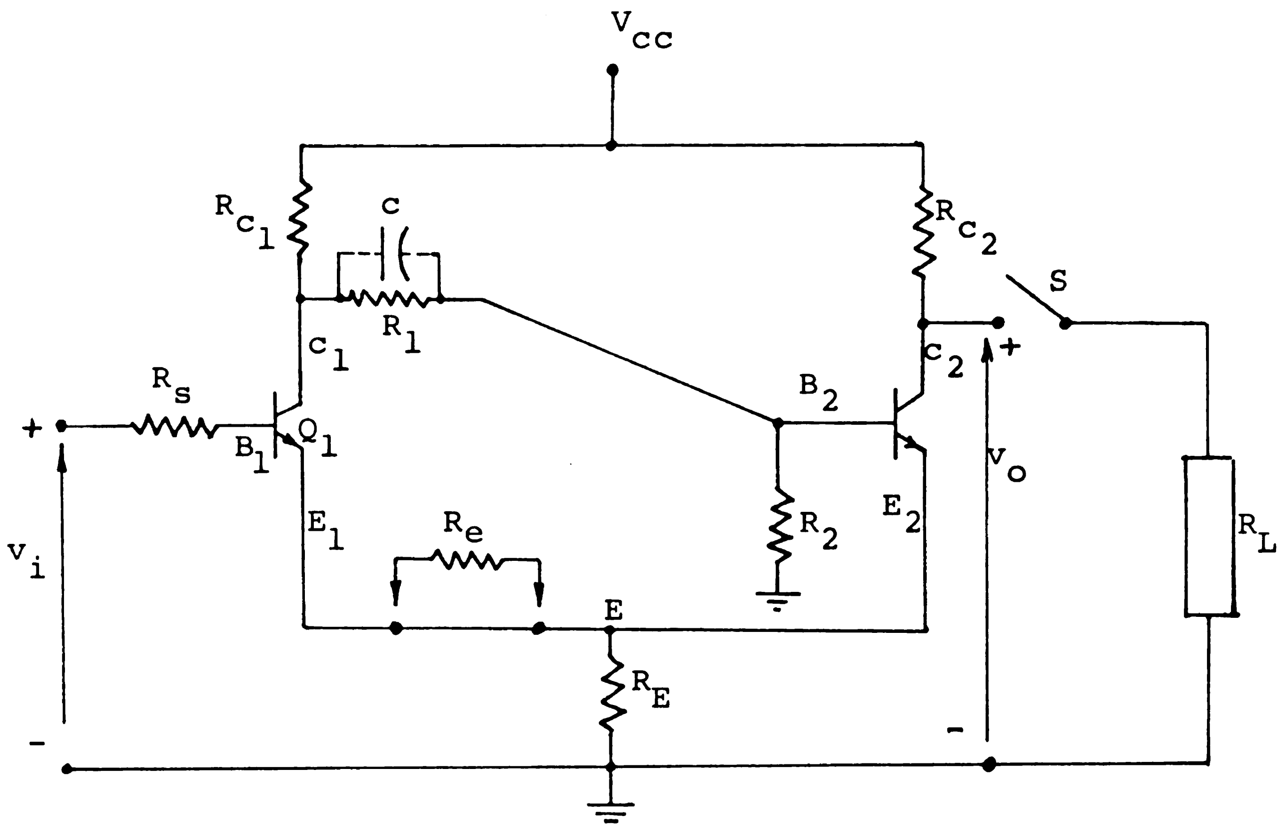


Figure A11.--Calculating example of the Schmitt Trigger.

$V_{CC} = 12v$ $\quad$ $C = 100pF$

$R_{C_1} = 4K\Omega$

$R_1 = 2K\Omega$

$R_2 = 6K\Omega$

$R_E = 3K\Omega$

$R_S = 1K\Omega$

$Q_1;Q_2$ silicon transistors with $h_{FE} = 30$.

$V_{BE} = 0.6v$. $\quad V_{\gamma} = 0.5v$.

Calculate the following:

1. Base current of Q_2.
2. R_{C_2}, when S is open. The output swing voltage has to be 4 volts.
3. <u>Loading Effect</u>:

   After connecting the load $R_L = 5K\Omega$ by closing the switch S, to what value must R_{C_2} be changed in order to maintain the output voltage swing unchanged?
4. Calculate $V_{(0)}^{(0)}$ and $V_{(0)}^{(1)}$ when S is closed.
5. <u>Triggering Level</u>:

   Calculate V_{T_1} and V_{T_2}.
6. <u>Hysteresis</u>:

   Calculate the hysteresis voltage V_H.
7. <u>Effect of D.C. Voltage Supply, V_{CC}</u>:

   Repeat steps (1), (2), (5) and (6) with $V_{CC} = 6v$.
8. <u>Effect of Triggering Source (v_i)</u>:

   Which of the calculated values, V_{T_1}, V_{T_2} is affected by the internal resistance R_S of the triggering source v_i? Why? Calculate this value when $R_S = 5K\Omega$ (and $V_{CC} = 12v$). Compare to your result for $R_S = 1K\Omega$.
9. <u>Effect of Circuit Components</u>:

   Repeat steps (1), (2), (5) and (6) with $R_E = 500\Omega (V_{CC} = 12v)$. Is now the Schmitt circuit operation more dependent on the h_{FE} of the transistor than in the case when $R_E = 3K\Omega$?

10. Explain in your own words the effect of R_{C_1}, R_1, R_2 and C on the loop gain and hysteresis of the Schmitt circuit in Figure 11.

11. Hysteresis Elimination:

Calculate the value of a resistor R_e connected in series with E_1, required to eliminate hysteresis.

Note: You will benefit very much if you try to solve the above example, step by step, before looking at the solution.

Solution

1. Base current calculation: (I_{B_2})

By Eq. (1),

$$V' = \frac{12 \cdot 6}{4 + 2 + 6} = 6v \qquad R_B = \frac{7(4 + 2)}{4 + 2 + 6} = 3K$$

Substituting into Eq. (3),

$$I_{B_2} = \frac{6 - 0.6}{3 + (30 + 1)3} = \frac{5.4}{96} = 0.056 \text{ ma}$$

2. Calculation of R_{C_2}: (S open)

In the "1" state:

$$v_o = V_0^{(1)} = V_{CC} = 12v.$$

The output swing voltage is:

$$V_0^{(1)} - V_0^{(0)} = 4v.$$

By eq. (4),

$$V_0^{(0)} = V_{CC} - h_{FE} I_{B_2} R_{C_2} = V_0^{(1)} - 4 = 12 - 4 = 8v.$$

$$R_{C_2} = \frac{V_{CC} - 8}{h_{FE} I_{B_2}} = \frac{12 - 8}{30 \cdot 0.056} = \frac{4}{1.68} = 2.38K$$

3. <u>Loading Effect:</u> (S closed)

Thevenin's equivalent circuit at the collector of Q_2 when S is closed is shown in Figure A12b. The swing voltage $V_0^{(1)} - V_0^{(0)}$ is actually the voltage drop across the equivalent collector resistance R'. Since the base current I_B does not depend on the collector resistance, I_{B_2} remains as before, and $R' = R_{C_2} = 2.38K$.

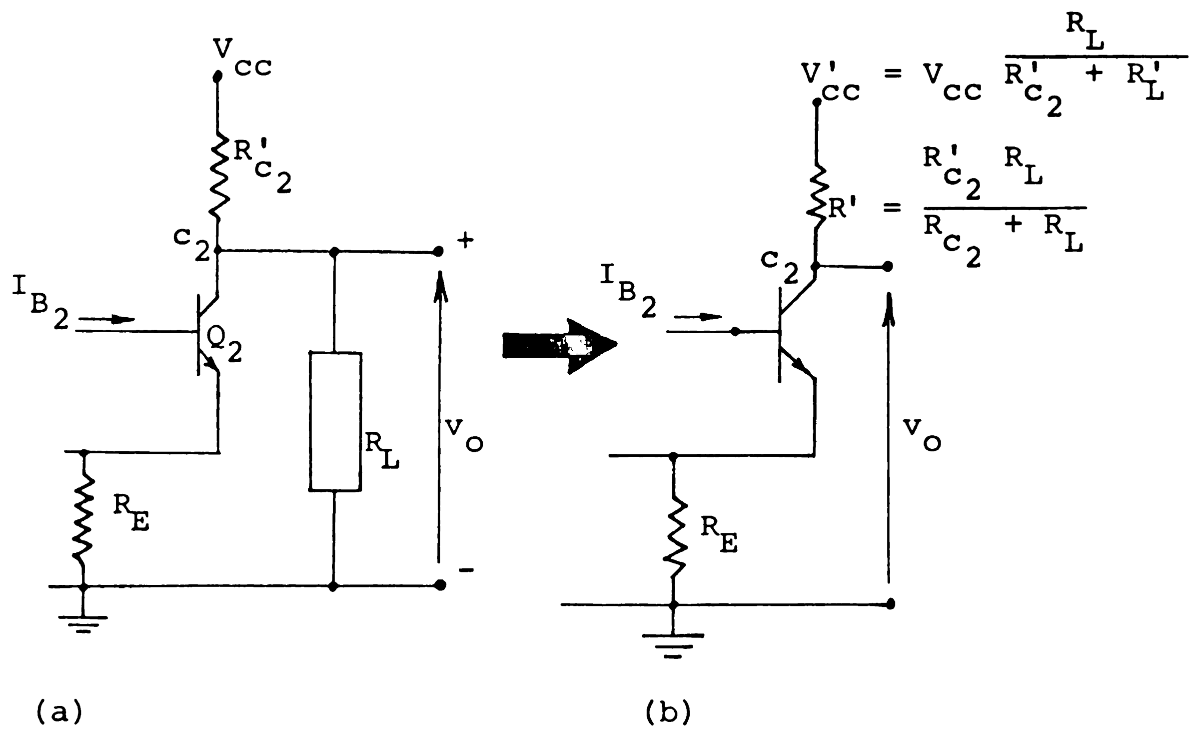


Figure A12.--(a) Output circuit of the Schmitt, loaded by R_L; (b) Thevenin's equivalent circuit of (a).

The required collector resistor R'_{C_2} will be:

$$R' = \frac{R'_{C_2} R_L}{R'_{C_2} + R_L} \qquad R'_{C_2} = \frac{R_L \cdot R'}{R_L - R'} = \frac{5 \cdot 2.38}{5 - 2.38} = 4.54K$$

4. The "1" state output level of the Schmitt when S is closed is:

$$V_0^{(1)} = V'_{CC} = V_{CC}\frac{R_L}{R'_{C_2} + R_L} = 12\frac{5}{0.525 + 5} = 10.9\text{v}.$$

The "0" state output voltage will be:

$$V_0^{(0)} = 10.9 - 4 = 5.9\text{v}.$$

5. Triggering Level.

By Eq. 6:

$$V_{T_1} = \frac{6 - 0.6}{1 + \frac{3}{31 \cdot 3}} + 0.5 = 5.2 + 0.5 = 5.7\text{v}.$$

Using the approximate formala for V_{T_1}, Eq. (9), assuming: $R_E(h_{FE} + 1) \gg R_B$:

$$V_{T_1} \cong V' - 0.1 = 6 - 0.1 = 5.9\text{v}.$$

Here: $R_E(h_{FE} + 1) = 3.31 = 93K \gg R_B = 3K$.

So, a relative error of $\frac{R_B}{R_E(h_{FE} + 1)} \times 100\% = 3.2\%$ caused a close error in V_{T_1} of $\frac{5.9 - 5.7}{5.9} \times 100 = 3.4\%$.

By Eq. (17):

$$V_{T_1} = 0.6 + \frac{(6 - 0.5)(1 + 31 \cdot 3)}{30\frac{4.6}{4 + 2 + 6} + 3.31} = 0.6 + 3.4 = 4.0\text{v}.$$

Applying the approximate formula for V_{T_1}, Eq. (19), when assuming:

$(h_{FE} + 1)R_E \gg 1$, $V_{BE_1} \cong 0$ and $V_\gamma \cong 0$: we get for V_{T_2}:

$$V_{T_2} \cong \frac{12.6}{\frac{4.6}{3} + 4 + 2 + 6} = 3.6v.$$

6. Hysteresis.

The hysteresis voltage V_H, Eq. (7), is:

$$V_H = 5.7 - 4.0 = 1.7v.$$

7. Effect of a D.C. voltage supply, V_{CC}.

Base current calculation: I_{B_2}

$$V' = \frac{6.6}{4 + 2 + 6} = 3v. \qquad R_B = \frac{6(r + 2)}{4 + 2 + 6} = 3K\Omega$$

$$I_{B_2} = \frac{3 - 0.6}{3 + (30 + 1)} = \frac{2.4}{96} = 0.025 \text{ ma.}$$

Output voltage swing: calculation of R_{C_2}

$$V_0^{(1)} - V_0^{(0)} = 4v; \quad V_o^{(1)} = V_{CC} = 6v. \quad V_0^{(0)} = V_0^{(1)} - 4 = 2v.$$

$$R_{C_2} = \frac{4}{30 \cdot 0.025} = 5.34K.$$

Applying Eq. (6):

$$V_{T_1} = \frac{3 - 0.6}{1 + \frac{3}{31 \cdot 3}} + 0.5 = 2.32 + 0.5 = 2.82v.$$

Or approximately by Eq. (9):

$$V_{T_2} \cong 3 - 0.1 = 2.9v.$$

Using Eq. (17):

$$V_{T_2} = 0.6 + \frac{(3 - 0.5)(1 + 31.3)}{30\frac{4.6}{4 + 2 + 6} + 3 \cdot 31} = 0.6 + \frac{2.5 \cdot 94}{153} = 2.14v.$$

The approximate value of V_{T_2}, using Eq. (19), is:

$$V_{T_2} \cong \frac{6 \cdot 6}{\frac{4 \cdot 6}{3} + 4 + 2 + 6} = 1.8\text{v}.$$

The hysteresis voltage is:

$$V_H = 2.82 - 2.14 = 0.68\text{v}.$$

8. <u>Effect of Triggering Source (v_i).</u>

V_{T_1} is not affected by R_S, because this triggering voltage is determined when Q_1 is in cut-off (no current flows through R_S, $I_{B_1} = 0$). When calculating V_{T_1}, Q_1 is conducting (see Figure A9) and the voltage drop across R_S has to be taken into account when calculating V_{T_2} [see Eq. (16)]. With $R_S = 5K\Omega$, V_{T_2} will be, according to Eq. (17):

$$V_{T_2} = 0.6 + \frac{(6 - 0.5)(5 + 31 \cdot 3)}{30 \frac{4 \cdot 6}{4 + 2 + 6} + 3 \cdot 31} = 0.6 + 3.52 = 4.12\text{v}.$$

V_{T_2} raised by 0.12v when replacing $R_S = 1K\Omega$ by $R_S = 5K\Omega$.

9. <u>Effect of Circuit Components</u>

$$R_E = 500\Omega = 0.5K$$

Substituting into Eq. (3), the base current in Q_2 is:

$$I_{B_2} = \frac{6 - 0.6}{3 + (30 + 1) \cdot 0.5} = \frac{5.4}{18.5} = 0.29 \text{ ma}.$$

Applying Eq. (4), the collector resistance of Q_2 is:

$$R_{C_2} = \frac{4}{30 \cdot 0.29} = 0.46K\Omega.$$

The triggering voltage V_{T_1} [Eq. (6)]

$$V_{T_1} = \frac{6 - 0.6}{1 + \frac{3}{31 \cdot 0.5}} + 0.5 = \frac{5.4}{1.194} + 0.5 = 4.5 + 0.5 = 5v.$$

By Eq. (17):

$$V_{T_2} = 0.6 + \frac{(6 - 0.5)(1 + 31 \cdot 0.5)}{30 \frac{4 \cdot 6}{4 + 2 + 6} + 0.5 \cdot 31} = 0.6 + 1.2 = 1.8v.$$

The hysteresis voltage is:

$$V_H = V_{T_1} - V_{T_2} = 5 - 1.8 = 3.2v.$$

Now, with $R_E = 0.5K$ the operation of the Schmitt Trigger circuit is more dependent on the h_{FE} of the transistor than in the case where $R_E = 3K$ because the assumptions $(h_{FE} + 1)R_E >> R_B$ and $(h_{FE} + 1)R_E >> R_S$ are more valid when R_E is higher.

Only after accepting these assumptions with the approximate equations for V_{T_1} and V_{T_2} [Eq. (9) and Eq. (19)] show independence in h_{FE}.

10. Referring to the Schmitt Trigger circuit shown in Figure A11, R_{C_1} is part of the collector load resistance of the first amplified stage Q_1. Hence, lowering R_{C_1} will decrease the amplification, thus decreasing the loop gain. As a result the hysteresis voltage V_H will become smaller. R_1 and R_2 are connected as an attenuator while transferring the signal from the collector of Q_1 to the base of Q_2. It is a simple voltage divider with a ratio $\frac{R_2}{R_1 + R_2}$. This voltage divider is part of the closed loop $B_2\ E_2\ E\ E_1\ C_1\ B_2$, so when R_1 increases or R_2 decreases there is more attenuation, causing a decrease in loop gain and in hysteresis voltage V_H.

Connecting a speed up capacitor C in parallel with R_1 is like lowering R_1 during the transition period (which is of A.C. character). Thus, loop gain is increased when transitions occur. The hysteresis voltage V_H = $V_{T_1} - V_{T_2}$ is determined by the two stable D.C. conditions of the Schmitt; therefore, the capacitor won't affect the hysteresis voltage V_H. Too large a capacitance of C might require an excessively long discharge time, thus lowering the maximum frequency of operation of the circuit.

11. Hysteresis Elimination

From Eq. (15):

$$I_{B_1} = \frac{6 - 0.5}{30 \frac{4 \cdot 6}{4 + 2 + 6} + 3(31)} = \frac{5.5}{153} = 0.036 \text{ ma.}$$

Hysteresis might be eliminated by inserting a resistor R_e in series with emitter E_1. If we want the current I_{B_1} to remain unchanged with R_e connected V_{T_2} has to be increased by the amount of the voltage drop across R_e. Since we want to eliminate the hysteresis voltage $V_H = V_{T_1} - V_{T_2}$ we will choose such a resistor R_e that will cause an increase in V_{T_2} so that $V_{T_2} = V_{T_1}$. (V_H will then be zero.) Therefore, according to Eq. (22):

$$R_e = \frac{V_H}{I_{B_1}(h_{FE} + 1)} = \frac{5.7 - 4}{0.036 \cdot 31} = \frac{1.7}{0.036 \cdot 31} = 1.5\text{K}\Omega$$

Various Types of Schmitt Trigger Circuits and Applications

1. FET Increases Schmitt Input Impedance.

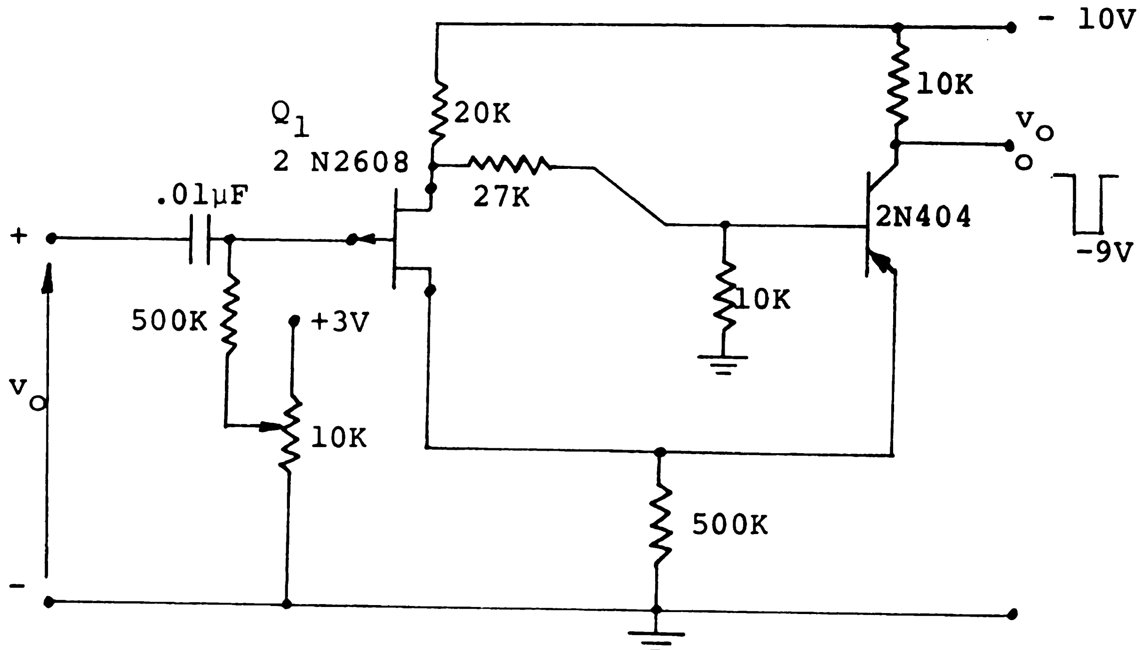


Figure A13.--High impedance Schmitt.

Use of a FET for input stage gives high input impedance, as required, for some threshold detector circuits. Output pulse is square wave at up to 100 Kc triggering rate. Turn-off threshold is about 0.2v. below turn-on.

L. R. Lott, Electronics, 38:15, p. 65.

2. Diode and Resistor Increase Input Resistance of Schmitt

Addition of R_b and D_1 reduces loading on driving circuit when Q_1 is on, thereby preventing input signal from being clamped. Same signal may therefore drive other Schmitt Triggers having higher trigger levels. (Figure A14)

J. Gaon, Electronics, 39:12, p. 110.

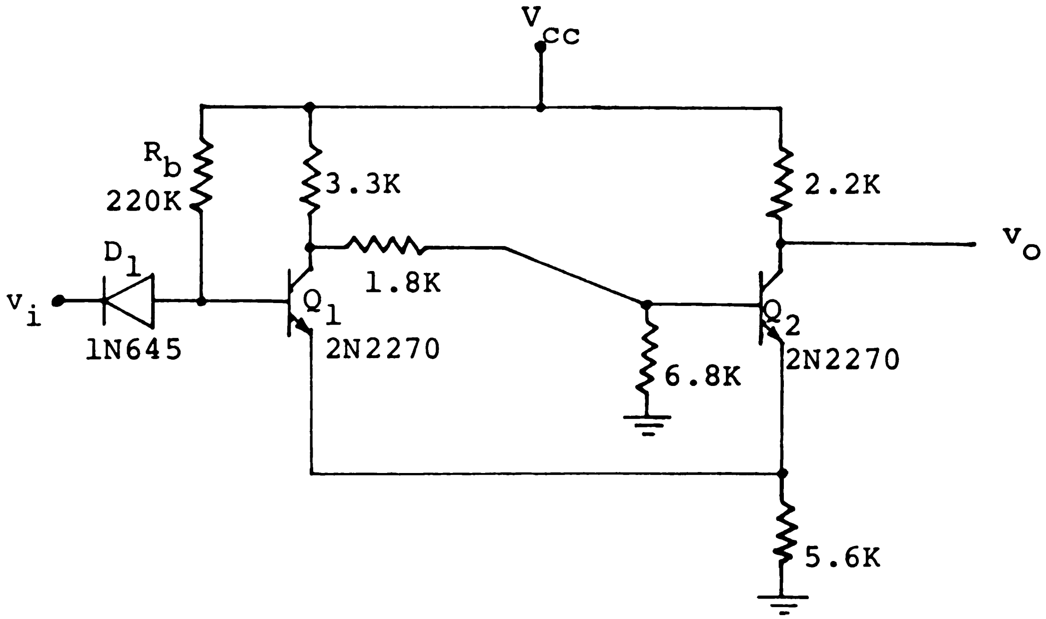


Figure A14.--Diode modified Schmitt.

3. <u>An Integrated Circuit Operational Amplified Schmitt Trigger</u>

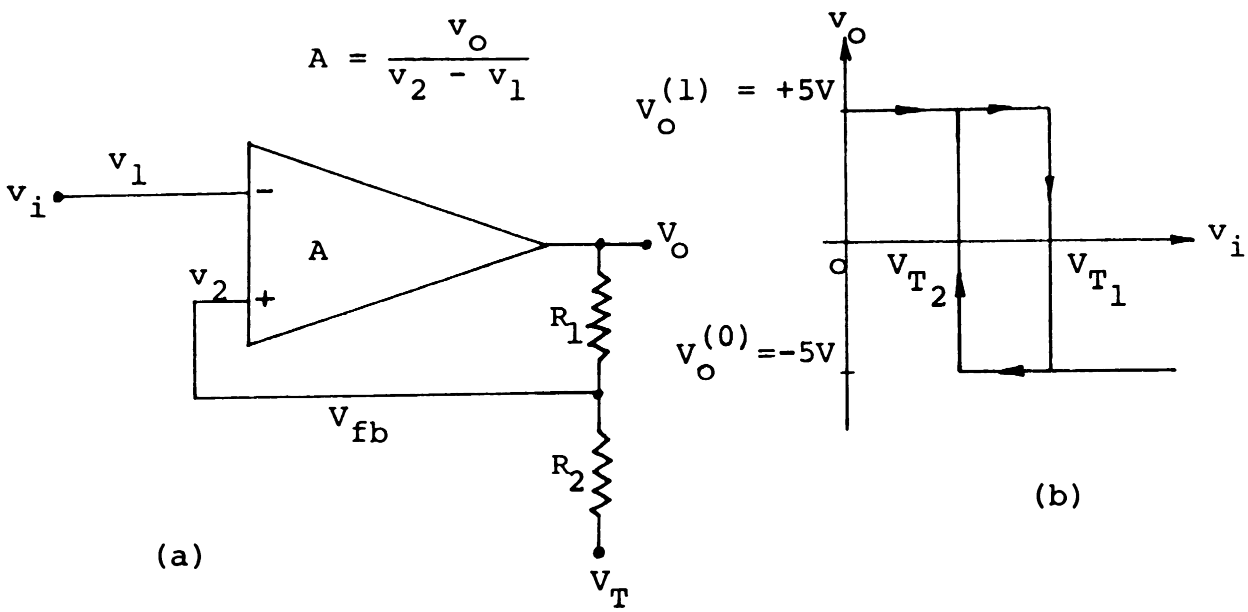


Figure A15.--(a) Op-amp Schmitt.
(b) Input-output transfer function.

Since the operational amplifier has at least two amplifying stages (two inverters), a positive feedback loop may be established easily. Such a feedback arrangement is shown in Figure A15(a). When using appropriate component values, a Schmitt Trigger operation is established as depicted in Figure A15(b).

Let's analyze an Op-amp Schmitt incorporating a typical operational amplifier with the following characteristics:

$A \cong 5000$

$Z_{in} > 20K$

$Z_o < 25$

Output Swing = ±5v peak; i.e., $V_0^{(1)} = 5v$. $V_0^{(0)} = -5v$.

Referring to Figure A15(a), R_1 and R_2 are chosen in such a manner that $R_1 >> Z_o$ and $\frac{R_1R_2}{R_1 + R_2} << Z_{in}$. Voltage V_T is supplied externally--it sets the (threshold) trigger level of the Schmitt.

$$\text{Feedback loop gain} \cong A \frac{R_2}{R_1 + R_2} \tag{23}$$

If this loop gain is greater than unity the output is forced into saturation at either +5v or -5v. The (positive) feedback voltage V_{fb} is:

$$V_{fb} = V_T + (V_o - V_T) \frac{R_2}{R_1 + R_2} = \frac{V_TR_1 + V_oR_2}{R_1 + R_2} \tag{24}$$

In the "1" state of the Schmitt, $v_o = V_0^{(1)}$, so:

$$V_{fb_1} = \frac{V_T R_1 + V_0^{(1)} R_2}{R_1 + R_2} \tag{25}$$

and $(V_{fb_1} - V_{in})A \geq V_0^{(1)}$ (26)

When $V_{in} = V_{T_1}$ then the triggering voltage V_{T_1} is obtained:

$$(V_{fb_1} - V_{T_1})A = V_0^{(1)}$$

$$V_{T_1} = \frac{A\,V_{fb_1} - V_0^{(1)}}{A} = V_{fb_1} - \frac{V_0^{(1)}}{A} \cong V_{fb_1} \tag{27}$$

Similarly, in the "0" state, $v_o = V_0^{(0)}$,

$$V_{fb_2} = \frac{V_T R_1 + V_0^{(0)} R_2}{R_1 + R_2} \tag{28}$$

The triggering voltage V_{T_2} (which transfers the Schmitt from the "0" to the "1" state when v_i decreases) is:

$$V_{T_2} = V_{fb_2} - \frac{V_0^{(0)}}{A} \cong V_{fb_2} \tag{29}$$

The hysteresis voltage $V_H = V_{T_1} - V_{T_2}$ may be decreased by decreasing the loop gain by lowering R_2. If the loop gain is then unity the circuit will operate as a differential amplifier with a linear region, as in a discrete transistorized Schmitt.

Using the above-mentioned typical operational amplifier in a Schmitt circuit depicted in Figure A15(a), with: R_1 = 10KΩ, R_2 = 50Ω, V_{Th} = 2v the following operation results are obtained:

Feedback Loop Gain = 25 > 1.

$V_{fb_1} \cong 2.025$ v ; $V_{fb_2} \cong 1.975$ v.

$V_{T_1} = 2.024$ v ; $V_{T_2} = 1.976$ v. $V_H = 48$ mV.

Preliminary

The circuit under experiment is given in Figure A16.

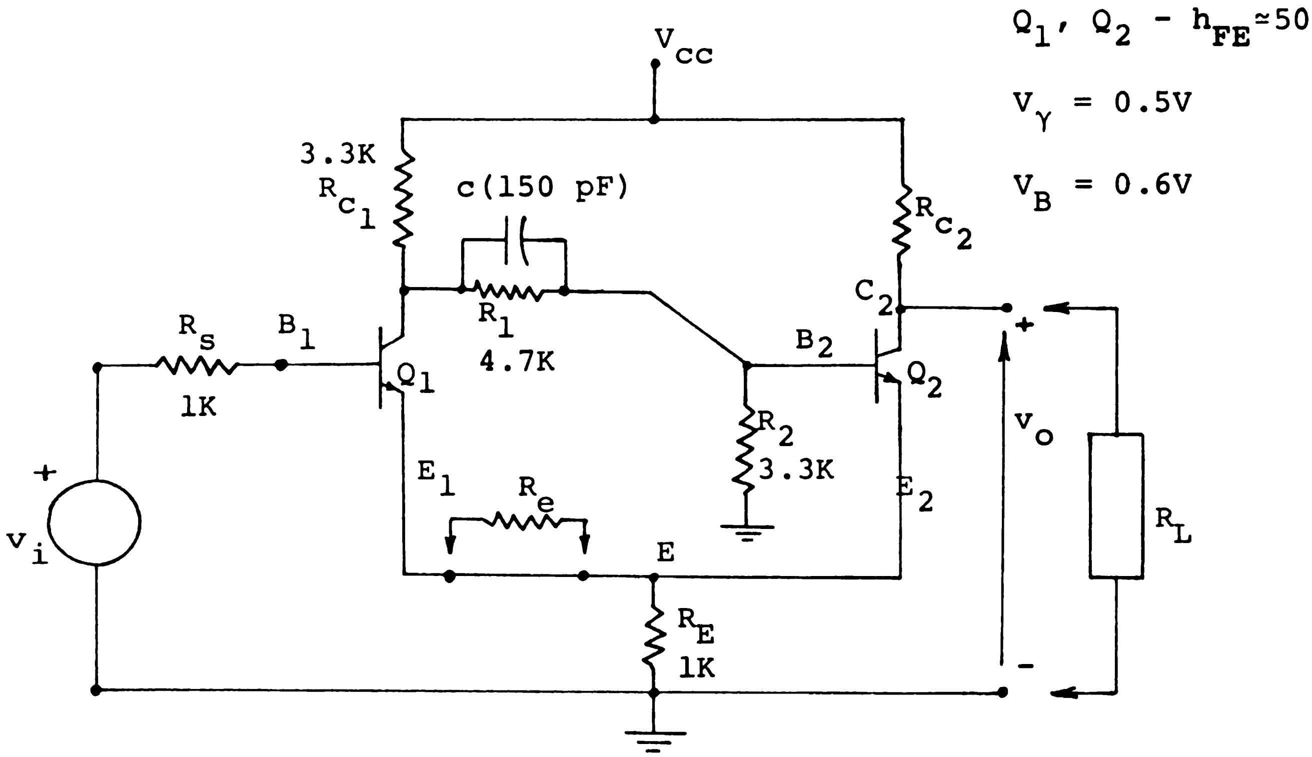


Figure A16.--The Schmitt Trigger circuit under experiment.

In the "high" state of the Schmitt the required output voltage level is 12 v. Leakage currents of the transistors may be neglected.

Calculate the following (and write down the results in the Experiment Procedure sheets):

1. Supply voltage V_{CC}.
2. R_{C_2} (when R_L is disconnected) to get an output swing voltage of 3 volts.
3. Given $v_i = 0v$, calculate the voltages at the following points in Figure A16: B_1, E_1B_2, C_2. Write down the results in Table B1 in the experiment sheet.
4. Calculate the triggering voltages V_{T_1}, V_{T_2} and the hysteresis voltage V_H.
5. Draw down the output voltage shape of the Schmitt if the input voltage is a half sinusoide as shown in Figure A17.

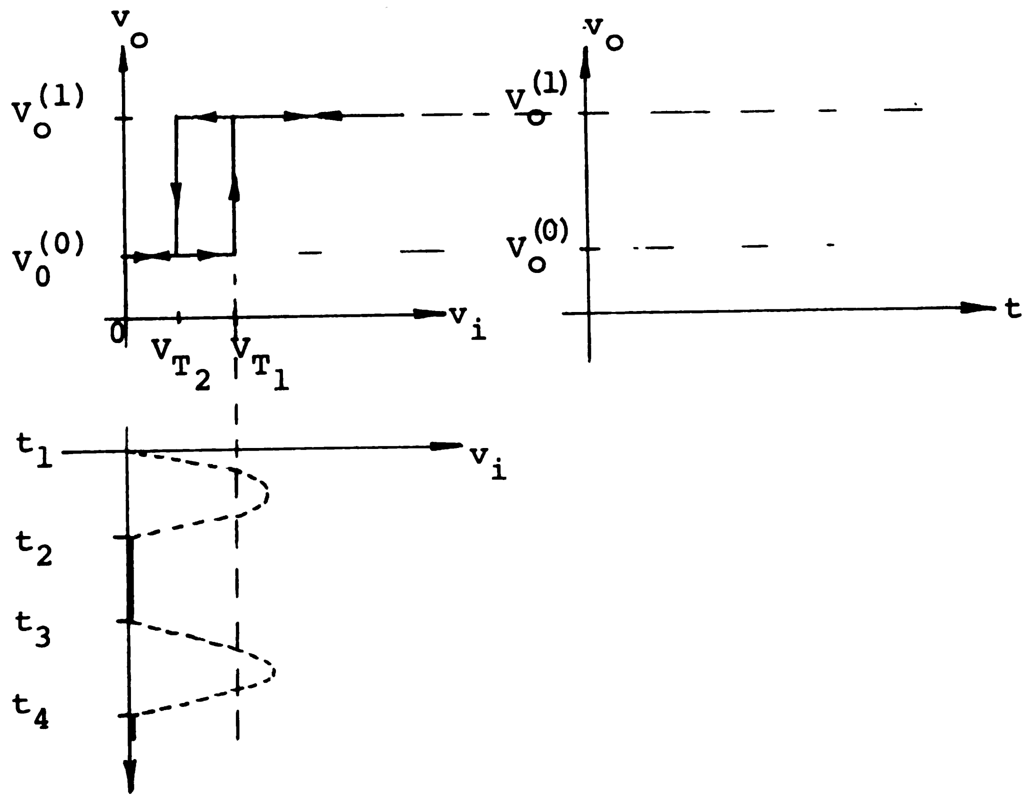
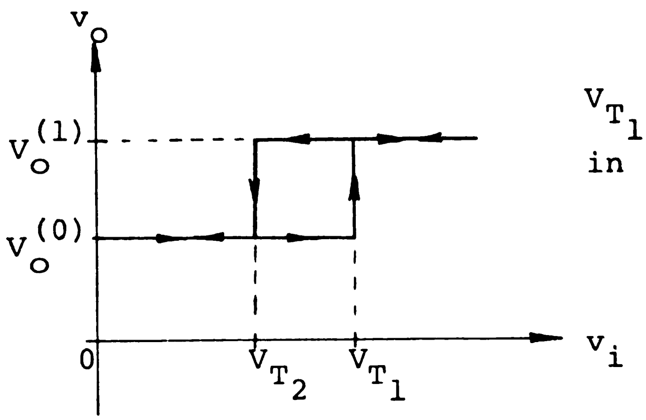


Figure A17.--Determining the output waveshape of the Schmitt.

6. Repeat steps (3) and (4) when $R_L = 1K\Omega$ is connected at the output (Figure A16). What is now the swing voltage?
7. Replace V_{CC} by $V'_{CC} = \frac{V_{CC}}{2}$. Repeat steps (2), (3) and (4). (R_L disconnected).
8. Assuming V_{CC} as calculated in step (1) and R_L disconnected (See Figure A16), calculate V_{T_2} when the value of R_S is 5K.
9. Calculate R_e to be connected in series with the emitter of Q_1 in order to eliminate hysteresis.
10. Assume that the transfer characteristics of the Schmitt circuit are as shown in Figure A18.



V_{T_1}, V_{T_2} values as calculated in step (4).

Figure 18.--The transfer characteristics of the Schmitt Trigger.

Sketch the transfer characteristics and output waveshape in each of the following cases, when (Input voltage v_i is the same as in Figure A17) only one component value is changed at a time, while the others remain in their nominal values as in Figure A16.

a. R_{C_2} increased ($R'_{C_2} = 2R_{C_2}$)

b. R_{C_1} decreased ($R'_{C_1} = 0.5R_c$)

c. R_1 decreased ($R'_1 = 0.5R_1$)

d. R_2 decreased ($R'_2 = 0.5R_2$)

e. R_E decreased ($R_E = 0.5R_E$).

What happens in every case with: V_{T_1}, V_{T_2}, V_H, $V_0^{(0)}$ and $V_0^{(1)}$? Do we have in all the cases a bi-stable operation of the Schmitt or does the circuit operate also as an amplifier within a certain linear region? Give descriptive answers (numerical values unnecessary).

Selected References

Pulse, Digital and Switching Waveforms
by J. Millman, H. Taub
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Digital Electronics With Engineering Applications
by T. P. Sifferlen, V. Vartanian
Prentice-Hall, Inc., Englewood
Cliffs, New Jersey, 1970

APPENDIX B

EXPERIMENT PROCEDURE

Michigan State University
Department of Electrical Engineering and System Science
E.E. 484 - Fall 1972

Schlomo Waks

The Schmitt Trigger - Experiment Procedure

The procedure of the experiment is laid out in a flow chart depicted in Figure B1. It may be very helpful to proceed step by step according to this flow diagram while referring to the attached tables and briefings pointed out by the number in parentheses fixed at the lower right corner of some blocks in Figure B1.

Introduction and "Stable-State-Operation" Experimenting Procedure

Refer to Figure B1.

(1) [Enter] Given the practical Schmitt circuit (shown in Figure B2) mounted on a board, 2 D.C. power supplies (Trygon Electronics, Mod. HR40v.-750ma), one audio generator (hp Mod.200 CD), one oscilloscope (hp. Model 130A), VTVM (hp. Model 410B). This equipment is assembled on your working bench in the electronic laboratory.

(2) A slide-tape presentation of the Schmitt Trigger (analysis and applications) will help you to understand the operation and possible applications of the Schmitt circuit. You may use the slide projector and tape explanations not only in this stage (before you start the experiment), but also later during the various steps of experimenting.

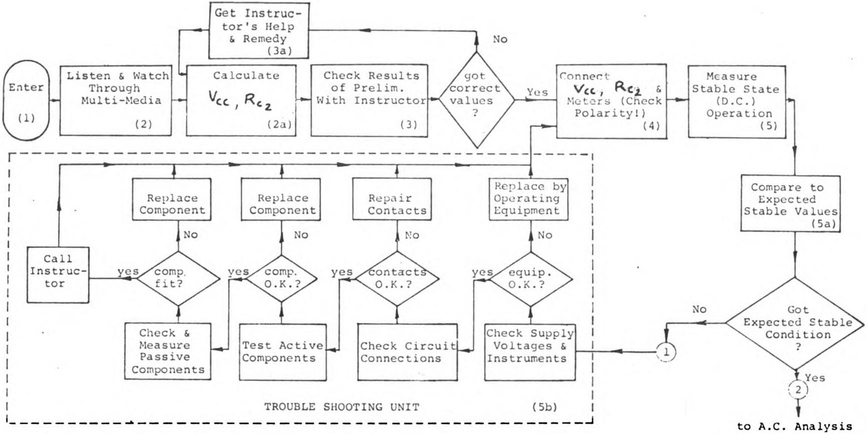

Figure B1.--Introduction and "stable-state operation" experimenting procedure.

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Figure B2 shows the diagram of the circuit under experiment.

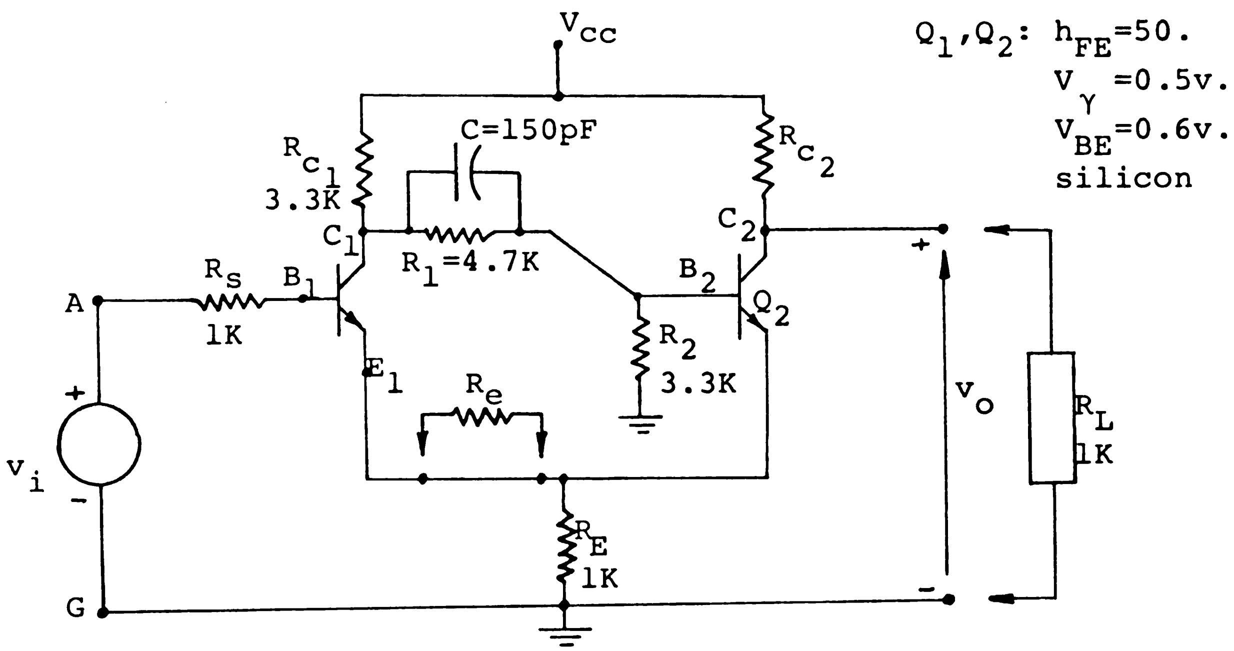


Figure B2.--The practical Schmitt Trigger under experiment.

(3) If you have already calculated V_{CC} and R_{c_2} in your preliminary work, use those results. Check these values with the instructor before connecting R_{c_2} and V_{CC} to the circuit. Present your whole prelim. to the instructor.

(4) Carry out the following measurements (R_L not connected yet). (a) The expected voltage values are those you have already calculated in your preliminary work--write them down in the "calculated" portion of Table B1.

Table B1. Stable State ("Low") Voltages in the Schmitt Trigger.
$V_i = 0v.$

	Calculated $(V)c$	Measured $(V)_M$	$(V)c-(V)_M$
V_{B_1} (v)			
V_E (v)			
V_{B_2} (v)			
V_{C_2} (v)			

(b) Start increasing the input voltage and fill out Table B2.

Table B2. Transferring the stable state of the Schmitt.

V_i(v)	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
V_o(v)									

Note where V_o has changed, measure the precise value of V_i that causes transition: V_{T_1} =

(c) Measure V_{T_2} - the input voltage that brings back the Schmitt to its original state ("low"). V_{T_2} =

(d) Make comparison according to Table B3.

Table B3. Comparison between calculated and measured triggering voltages.

	Calculated $(V_T)_c$	Measured $(V_T)_M$	$(V_T)c-(V_T)_M$
V_{T_1} (v)			
V_{T_2} (v)			

(e) Determine the hysteresis voltage V_H. (Table B4).

Table B4. Calculated and measured hysteresis voltage.

	Calculated $(V_H)c$	Measured $(V_H)M$	$(V_H)c-(V_H)M$
V_H (v)			

"A.C. Nominal Operation" Procedure

After completing the D.C. measurements described in Figure B1, proceed from step 2 according to the procedure laid out in Figure B3. Now you will investigate the A.C. nominal operation of the Schmitt circuit.

Note: Don't forget to connect D_1 and R = 3.3K as shown in Figure B4.

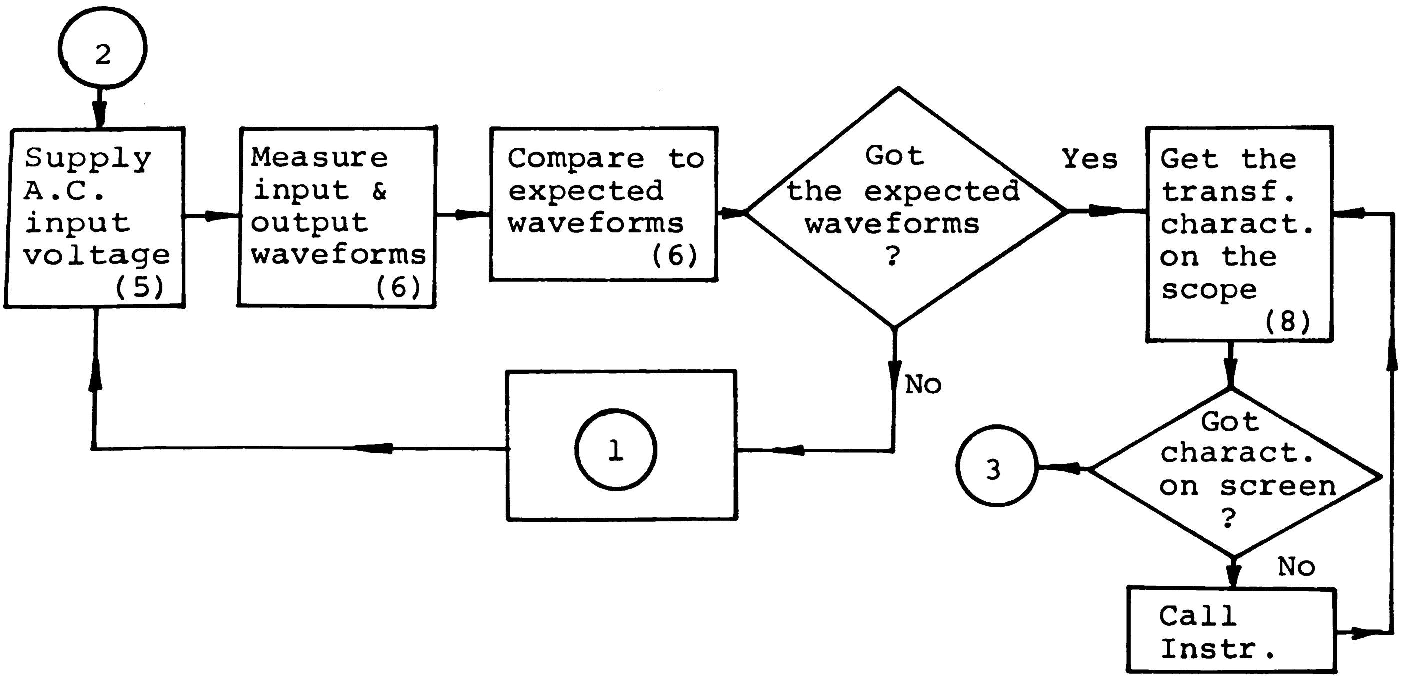


Figure B3.--"A.C. Nominal Operation" experimentation procedure.

(5) Deliver a sinusoidal input voltage from the audio generator through a "half wave rectifying" arrangement as described in Figure B4.

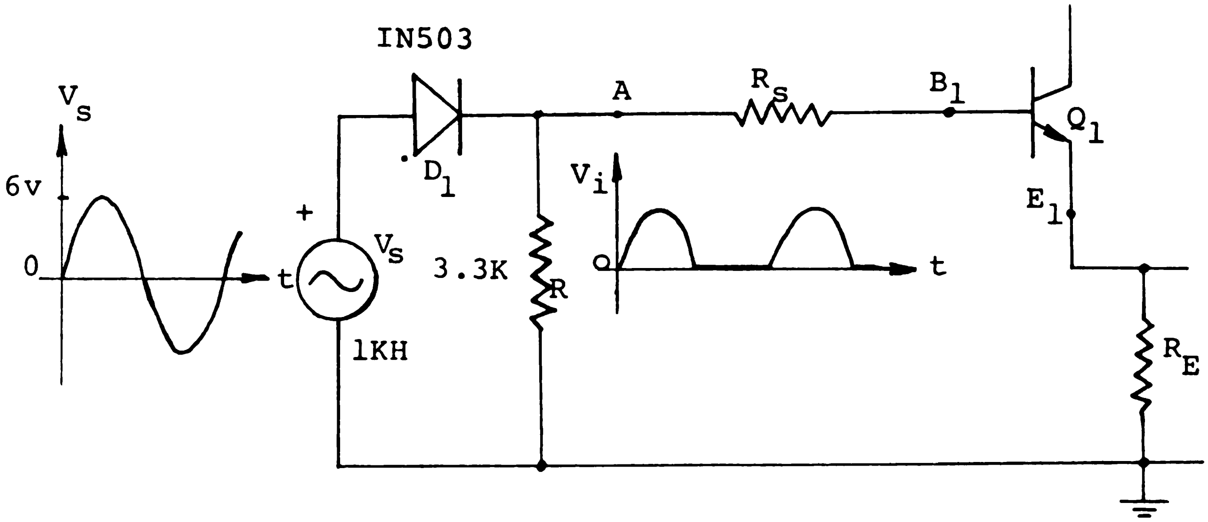


Figure B4.--Triggering the Schmitt with half a sinusoidal voltage.

(6) Connect the output voltage V_o (Figure B2) to the vertical input of the oscilloscope. Make necessary alignments of the scope to get the output waveshape on the screen. Draw the required output shapes in Figure B5.

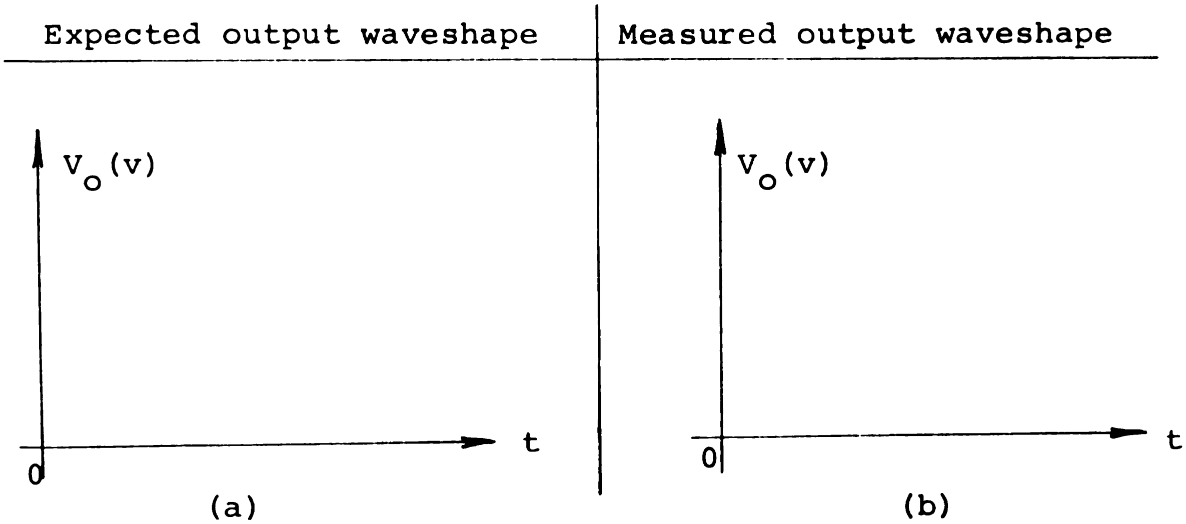


Figure B5.--Expected (a) versus measured (b) output waveshapes.

(7) If you didn't get the expected output waveforms start following the "Trouble Shooting Unit," as described in Figure B1, but first check the new connected contacts and components (V_i, D_1, R in Figure B4).

(8) Getting the Transfer Characteristics of the Schmitt Circuit on the Oscilloscope. Leave the same input-voltage arrangement as shown in Figure B4 and connect the input and output terminals of the circuit to the oscilloscope as depicted in Figure B6.

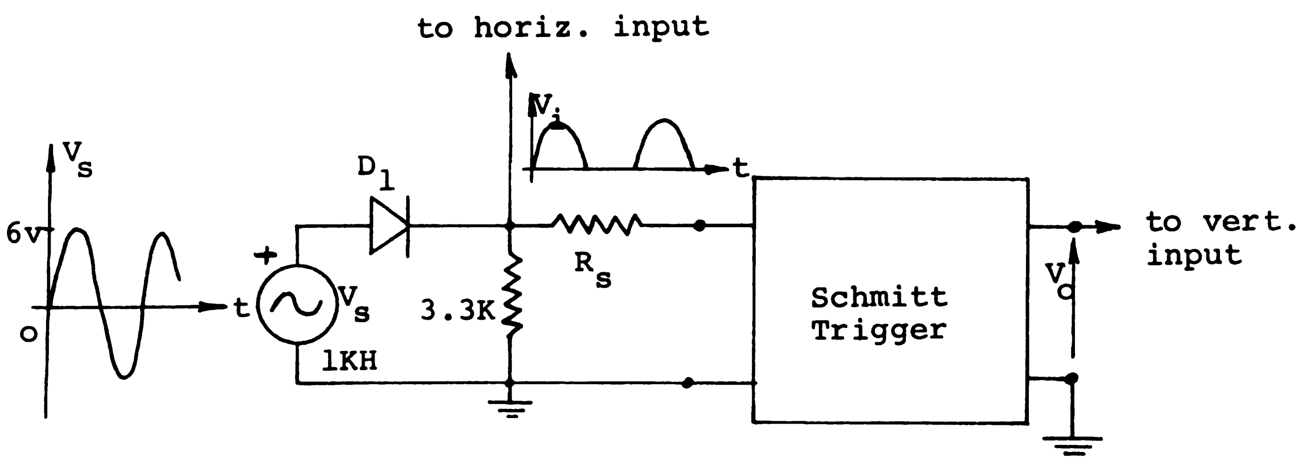


Figure B6.--Getting the transfer characteristics on the oscilloscope.

Notes

(a) Don't forget to disconnect the internal sweep of the oscilloscope by turning the "Horiz. Sensitivty" knob to some horizontal sensitivity value (say 1 volt/cm.).

(b) In order to get the true voltage values (including the D.C. component), set the "input" knobs (switches) to D.C. position.

Make necessary alignments of the scope to get the transfer characteristics on the screen.

Draw the expected (dashed line) and measured (solid line) transfer characteristics in Figure B7.

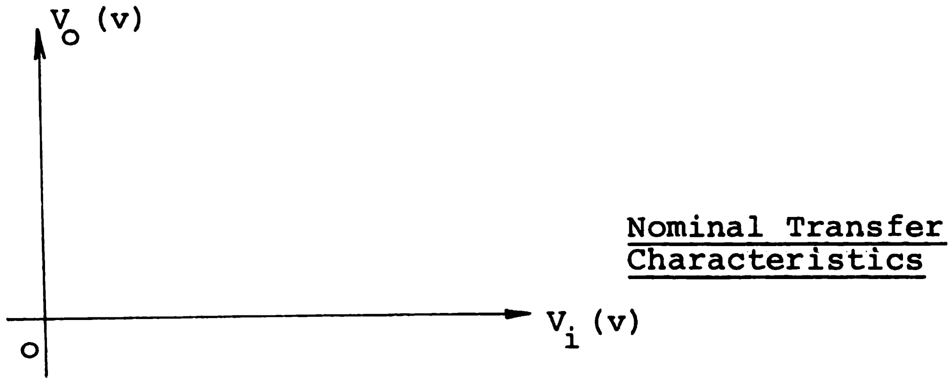
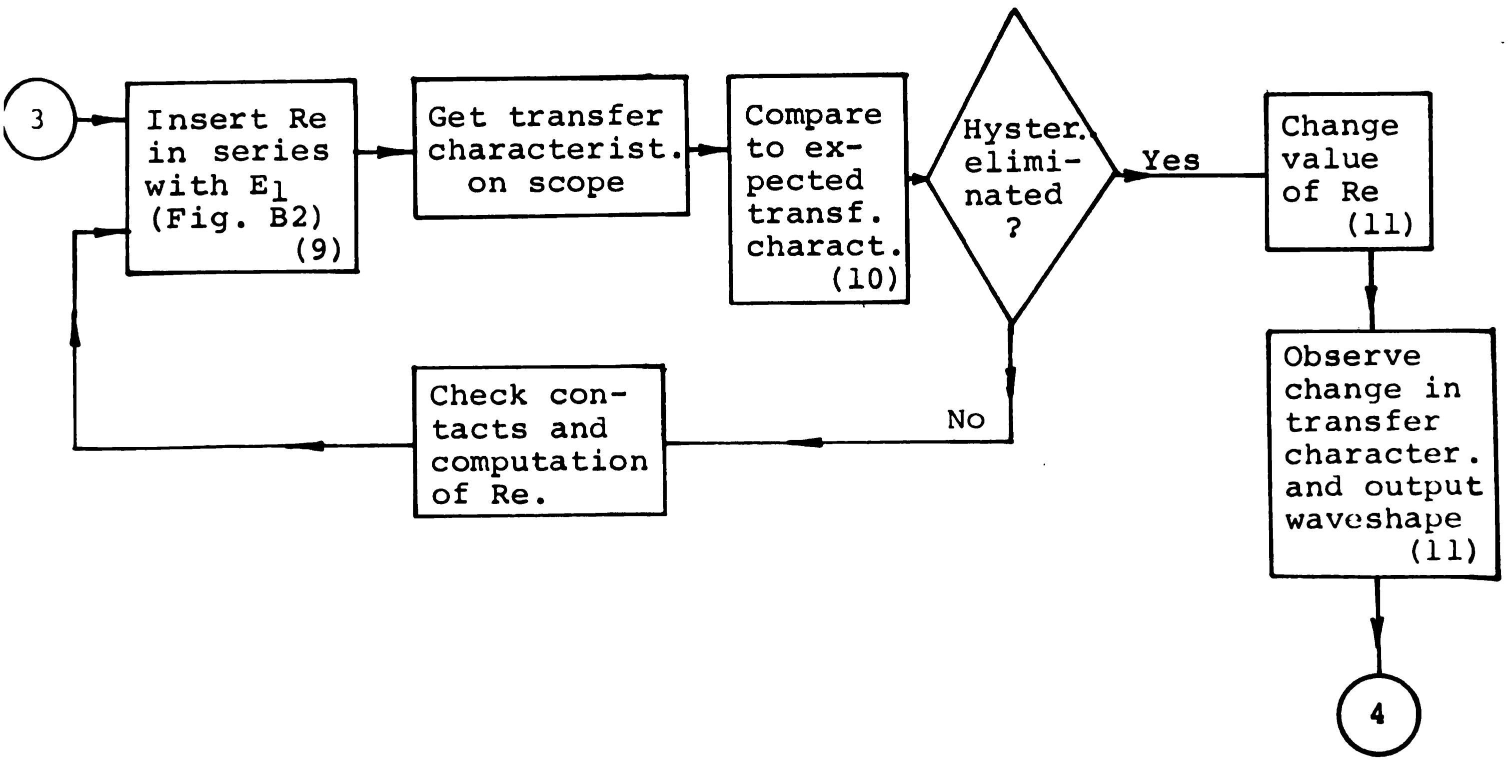


Figure B7.--Expected (dashed line) and measured (solid line) transfer characteristics of the Schmitt.

Hysteresis Elimination.

Proceed according to flow chart shown in Figure B8.



(9) Use the value you have calculated for Re, in your preliminary work.

Use a decade resistor box for Re.

(10) Draw the transfer characteristics in Figure B9.

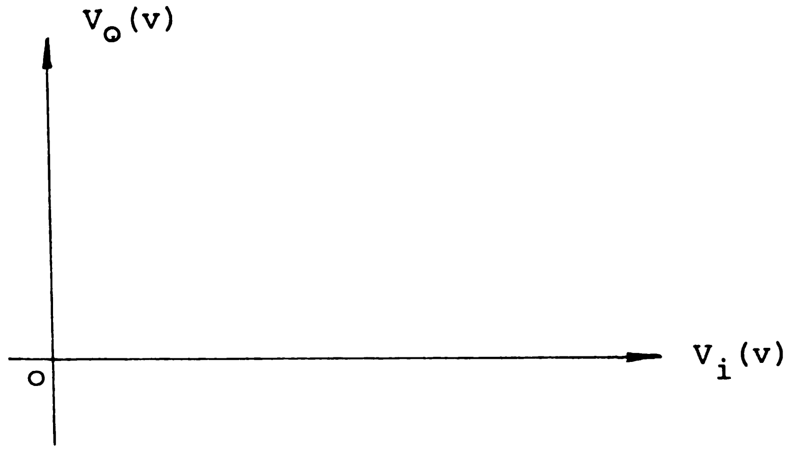


Figure B9.--The expected transfer characteristics (dashed line) and the measured transfer characteristics (solid line).

Adjust Re to obtain minimum hysteresis voltage. Write down this value. Re =

(11) Draw down approximately, in Figure B10, the shapes of the expected and measured transfer characteristics and the output waveform in the following two cases:

(I) $Re_1 \simeq \frac{Re}{3}$ (Re_1 is the new resistor replacing Re=1K, the resistor required to eliminate the hysteresis).

(II) $Re_1 \simeq Re_1 + 0.33K$

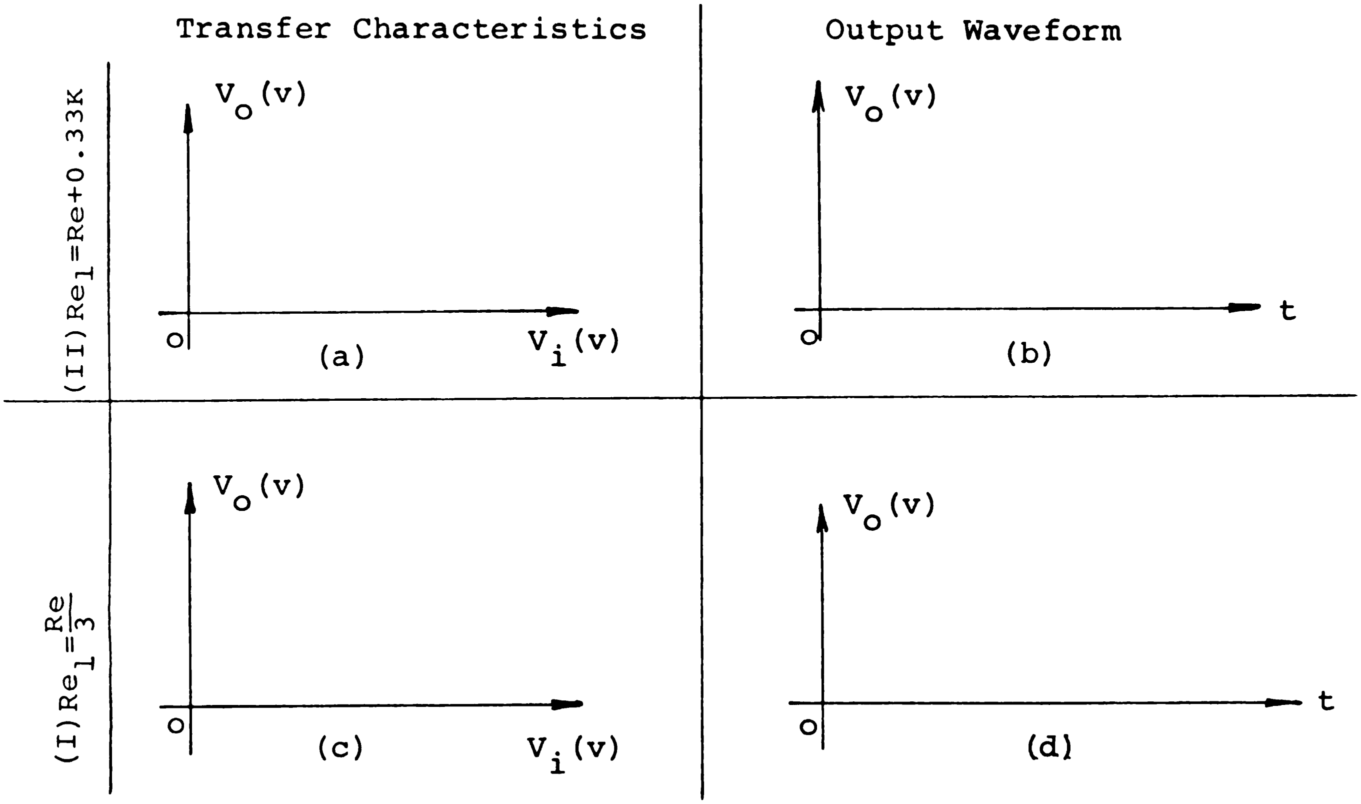


Figure B10.--Effect of Re on the transfer characteristics on output waveform (dashed line--expected curves) (solid line--measured curves).

Is Re affecting the loop gain? Is this the reason for the difference in the transfer characteristics and output waveform when Re is changed? Discuss this with your partner and write down your conclusion.

Factors Affecting Circuit Operation

Let's look on the Schmitt Trigger as on a "black box" where excess is provided only to the feeding voltages (V_{CC}, V_i) and load connection as depicted in Figure B11. This might indeed be the case when dealing with an Integrated Circuit Schmitt Trigger.

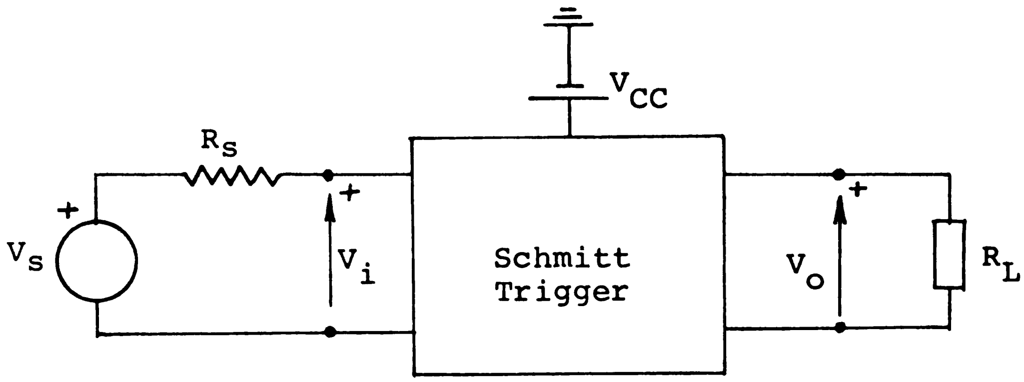


Figure B11.--"Black box" presentation of the Schmitt.

Let us investigate the effect of the feeding voltages and loading on the operation of the Schmitt Trigger.

Notes: I. Only one factor will be changed at a time, when investigating its effect on the circuit operation. The other factors (components and voltages) will remain in their nominal values as indicated in Figure B2.

II. In order to get the image of the transfer characteristics on the scope, the arrangement shown in Figure B6 of driving the Schmitt will be used whenever this image of the transfer characteristic is required (on the scope).

Loading Effect

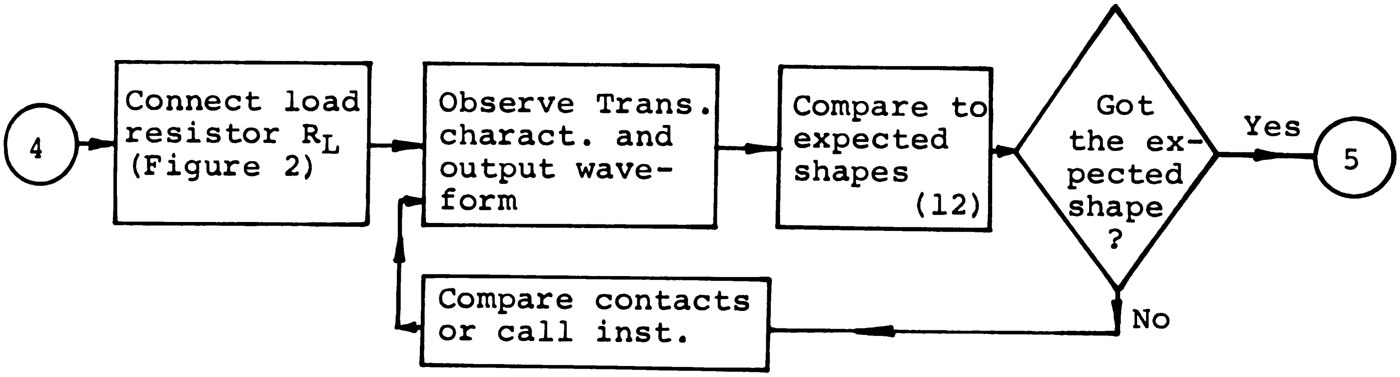


Figure B12.--Checking "loading effect" procedure.

(12) Use the calculated values of the transfer charact. (V_{T_1}, V_{T_2}, $V_O^{(0)}$, $V_O^{(1)}$ from your preliminary work to draw the "Expected Transfer Charact." in Figure B13(a) below in dashed line. Draw down (from the scope) the "Measured Transfer Charact." (Figure B13(a) and "Output Waveform" in Figure B13(b) in solid lines). For comparison purposes you may add the nominal transfer function from Figure B7 on Figure B13(a).

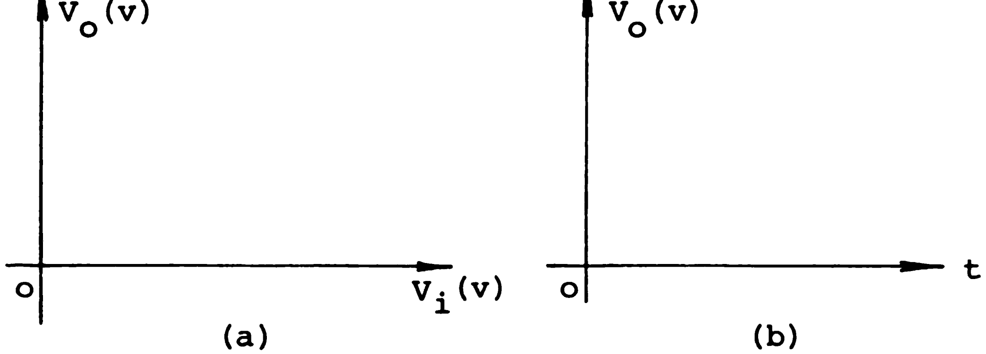


Figure B13.--Transfer characteristics (a) and output waveform (b) of the Schmitt with load R_L=1K connected.

D.C. Voltage Supply (V_{CC}) Effect

Disconnect R_L. Decrease V_{CC} to $\frac{V_{CC}}{2}$. Follow the procedure outlined in Figure B12 (with R_L disconnected), including paragraph (12). Draw the transfer characteristics and output waveform in Figure B14. Add the nominal transfer characteristics from Figure B7 on Figure B14(a).

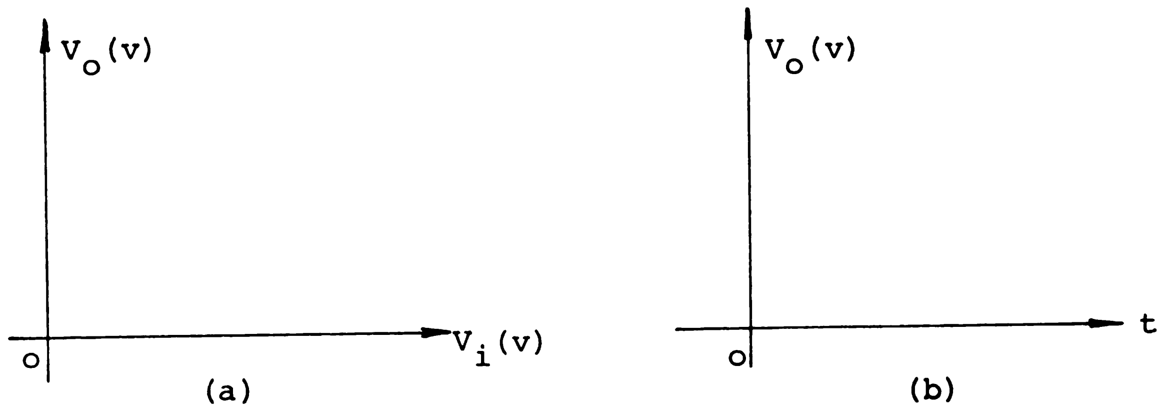


Figure B14.--Transfer characteristics (a) and output waveform (b) of the Schmitt circuit with decreased V_{CC} $(\frac{V_{CC}}{2})$.

Change V_{CC} by turning the "voltage" knob on the D.C. power supply and observe the ongoing changes in the transfer characteristics and output waveform on the scope. Discuss the phenomena with your partner and/or instructor.

Driving Source (V_S) Effect

Set V_{CC} to 12v.

(a) Decrease the input voltage from the audio generator. Observe the output voltage on the scope. Go on decreasing the input voltage; what happens finally with the output voltage? Why?

(b) Let Rs represent the internal resistance of the driving source Vs in our circuit. Replace the existing Rs=1KΩ by R_s^1=5KΩ.

Repeat the procedure outlined in Figure B12 (R_L disconnected).

Draw the expected and measured transfer characteristics in Figure B15. Add the nominal transfer characteristics from Figure B7.

If this value of Rs (5K) hasn't affected the transfer function, increase Rs until it begins to affect the transfer characteristics. What are the practical implications of this?

Figure B15.--Effect of Rs on the transfer characteristics of the Schmitt.

Component Effects on the Operation of the Schmitt

Make the following changes in the components' value (one change at a time!). Draw down in Figure B16 the adequate nominal transfer charact. (from Figure B7) and the measured transfer characteristics after a change in a component value was carried out as depicted in Figure B16. (Use a "decade resistor box" for convenience to connect the various resistor values).

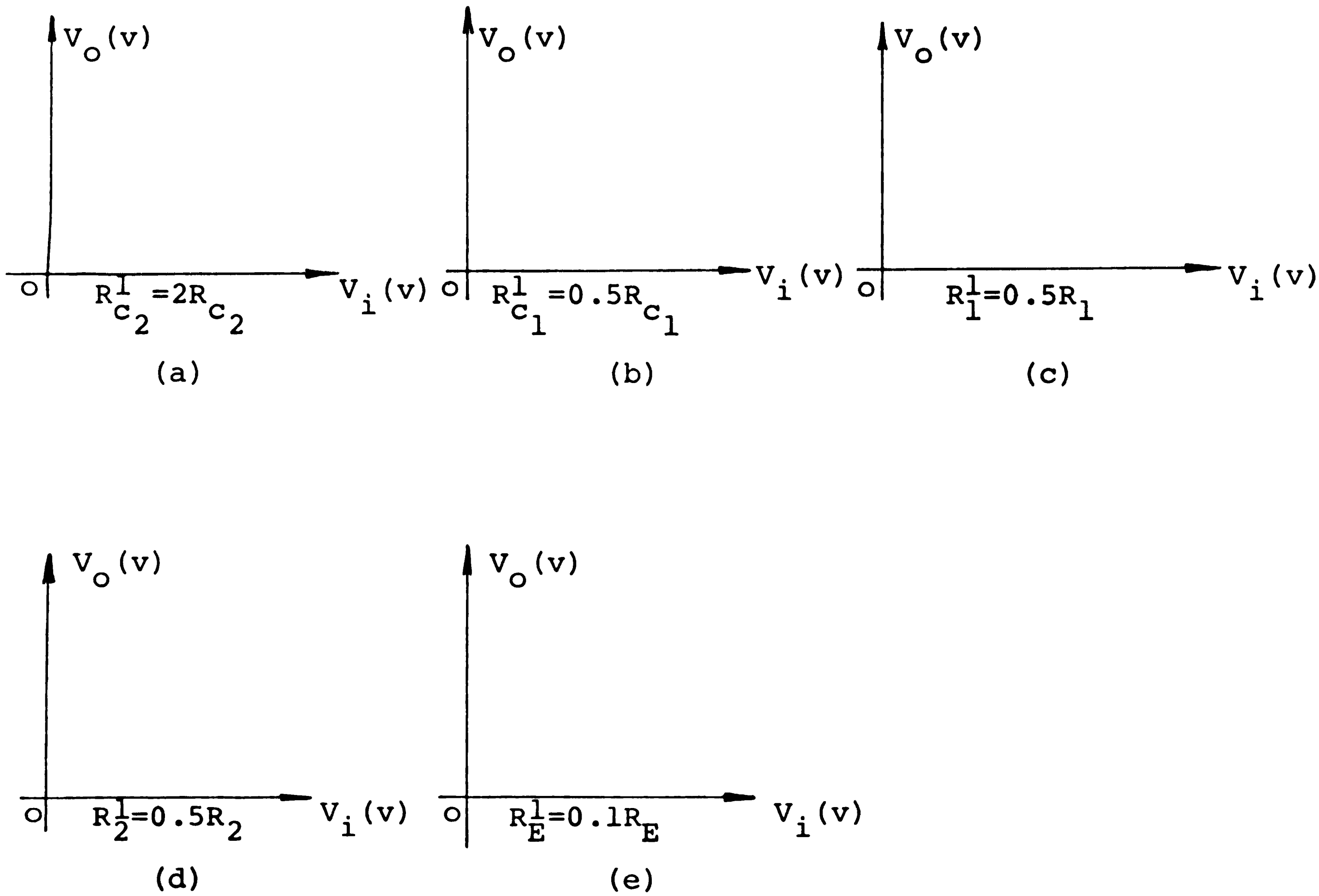


Figure B16.--Nominal transfer characteristics (dashed line) versus the transfer characteristics when one of the component values of the Schmitt is changed (as pointed out).

Does transistor Q_2 remain in the active region (when conducting) if $R^1_{C_2} = 10R_{C_2}$? Explain.

The Report

At the end of the laboratory period of the experiment, you should hand in a report including the following:

(a) The experiment procedure sheets with the tables and waveshapes filled out (expected and measured values).

(b) Answers to all the questions asked along the experiment procedure.

(c) Give possible reasons for differences you've got between the expected and measured values.

(d) Solution to the following design problem.

What changes are to be introduced into the Schmitt Trigger circuit in Figure B2 in order to feed an electronic decimal counter that has a high input impedance and requires driving rectangular pulses of 6v swing. Calculate the necessary changes. Explain what modification has to be carried out in the Schmitt circuit of Figure B2 if the driving source can hardly be loaded.

APPENDIX C

THE SCHMITT TRIGGER--ANALYSIS AND APPLICATIONS

THE SCHMITT TRIGGER--ANALYSIS AND APPLICATIONS

(Manuscript--recorded on tape)

Hello. A new approach to experimenting in electronic circuits at the college level will be presented to you through the accomplishment of the Schmitt Trigger experiment.

My name is Shlomo Waks and I am developing a model for electronic circuit laboratory experiments. The purpose is to improve your understanding of the operation and applications of electronic circuits, in this case the Schmitt circuit. By use of a systematic approach, I'll try to make you understand the reasoning of the events which will occur during your experimenting process.

This model will provide you with means for self-experimenting and learning using slides, audio-tape, flow charts, the oscilloscope facilities, and most of all, make you use your own brains to calculate the circuit operation and then investigate experimentally the validity of your design calculations and expectations. When you feel it's necessary, call the instructor for help, but you are encouraged to try to solve the arising problems first by yourself.

Time to start. Please open your Theory Sheets on page 1. If you would like to know where you are heading, what you are going to achieve--read the objectives. The posttest you will be given at the end of the experiment is going to find out if these objectives have been reached. Please turn off the tape, and come back as you finish reading the objectives.

Look at slide #1. All these street and road lights--are they turned on and off by a man, or is it done automatically according to the intensity of ambient light? The answer is that these lights are automatically controlled. In the evening when light intensity drops, the artificial lights are turned on, and at dawn they are turned off. Slide #2 shows a block diagram of such an arrangement. Please turn off the tape, and come back after reading pages 2 and 3.

It turns out that the Schmitt Trigger is an electronic circuit which gives an accurately shaped constant amplitude rectangular pulse output for any input pulse above a predetermined triggering level. Slide #3 shows the Schmitt operation in terms of the multishape input voltage and the unique rectangular output waveform. Notice that V_{T_1} and V_{T_2} are triggering voltages that determine the two output voltage levels--the "high" state $Vo^{(1)}$ and the "low" state $Vo^{(0)}$.

As we have already seen, the Schmitt is usually a portion of an electronic apparatus like a Radioactive Radiation Counter. What is actually happening inside the Schmitt that enables it to square arbitrary input voltage shapes? Let us see how this circuit functions. Look at the basic Schmitt circuit shown in slide #4. The general notation of the two amplifier stages A_1 and A_2 has been chosen on purpose to show that these may be any kinds of amplifiers--transistors, tubes, field effect transistors, or an integrated circuit operational amplifier. These two amplifiers have to be inverting stages. This basic Schmitt Trigger is a two-stage amplifier with positive feedback provided by the presence of the emitter resistance R_E, as you can see in the basic circuit.

Let us analyze one of the most used versions of the Schmitt: the transistorized Schmitt Trigger Circuit as it appears on slide #5. In this case, two NPN transistors, Q_1 and Q_2, are the two active components mentioned before in the basic Schmitt as A_1 and A_2. If the input voltage is zero, that means that the input terminal B_1 is assumed to be shorted to ground. The voltage drop on R_E reverse biases the emitter base junction of Q_1, thus keeping it in the cut off state. Under these circumstances, transistor Q_2 has the proper biasing through R_{C_1}, R_1, and R_2 to maintain conduction. It would be worthwhile to use Thevenin's equivalent presentation for the collector circuit of transistor Q_1. Slide #6 describes it in detail. Notice the expression of Thevenin's equivalent voltage and resistnace in equation (1). Please turn off the tape, and come back after reading pages 4 through 10 in the Theory Sheets.

Let's see on slide #7 some formulas we have just derived through our analysis: The base current I_{B_2} of Q_2; the output voltage Vo of the Schmitt in the "low" state, which equals simply the supply voltage V_{CC} minus the voltage drop on the collector resistor R_{C_2} of transistor Q_2; and finally the triggering voltage V_{T_1}, which is the value of the input voltage that transfers the Schmitt from its "low" state into its "high" state by driving Q_1 into conduction and Q_2 into cut off.

Slide #8 shows the transfer characteristics and the input and corresponding output waveforms of the Schmitt. Notice the three regions of the transfer characteristics, which are determined by the value of the input voltage V_i.

1. for $V_i < V_{T_1} \Rightarrow V_o = V_o^{(0)}$ = Constant low state,
2. for $V_{T_1} < V_i < V_{T_2} \Rightarrow$ the linear region, and
3. for $V_i < V_{T_2} \Rightarrow V_o = V_o^{(1)} = V_{CC}$ = Constant high state.

Since there is no current flow through R_{C_2}, there is no drop voltage on it and the output voltage equals simply the supply voltage V_{CC}.

Notice that we get linear amplification when working in the linear region with a small enough input signal, but when raising the amplitude of the input signal as indicated by the dashed-lined input sinusoid we enter the nonlinear portions of the transfer characteristic. This causes the clipping of the output waveform shown in dashed lines on our slide.

By adjusting the loop gain, the slope of the transfer characteristics in the linear region can be changed. If the loop gain is less than unity, the slope ΔV_o over ΔV_i

is positive. If the loop gain equals unity, the slope has an infinite value, which means that we have got enough positive feedback just to start oscillations which results in driving the circuit into a stable state by cutting off one of the transistors.

For loop gain that is equal to or greater than unity, the linear portion of the transfer characteristics disappears, and now the circuit operates as a bistable device with two stable states. This is the reason that the Schmitt Trigger belongs to the family of bistable circuits.

The Schmitt is mostly used when operating with a loop gain greater than unity, so the transfer characteristic has the form as described in slide #9. Notice that the triggering voltage V_{T_1} which transfers the state of the Schmitt from low to high is greater than the triggering voltage V_{T_2} that causes the reverse transfer from high to low state. The difference between these two voltages $V_{T_1} - V_{T_2}$ is called the hysteresis voltage (V_H) of the Schmitt.

Please turn off the tape, read pages 10 through 13, and come back to hear me right after that.

Since we have already got an expression for V_{T_1}, we should start developing the equation for V_{T_2}--the input voltage which causes the reverse transition of the Schmitt from the high state back to the low state. In order to do this, let us have a look at slide #10, which shows the equivalent circuit of the Schmitt in the "high" state.

Now transistor Q_1 is conducting and Q_2 is in cut off. That's why the output voltage, without loading, is now equal to the D.C. supply voltage V_{CC}.

We neglect the collector cut off current. This is illustrated in our equivalent circuit by the opened collector circuit of transistor Q_2. Since the cut off transistor currents are neglected, the base of transistor Q_2 has no loading effect on the collector circuit of transistor Q_1. So the equivalent circuit shown in slide #10 was derived by using Thevenin's theorem. Look at slide #11 to see the way in which this equivalent circuit was obtained. Notice that the triangle between the collector of transistor Q_1 and base of transistor Q_2 denotes the attenuator operation of the voltage divider $\frac{R_2}{R_1 + R_2}$.

Turn off the tape and come back after reading pages 13 and 14.

By developing equations for V_{T_1} and V_{T_2}, we have already proved that there exists a hysteresis in the Schmitt action because we have got the value of V_{T_2} different from the value of V_{T_1}, and the hysteresis voltage is defined as the difference between these two voltages.

Let us now see on slide #12 a brief summary of the Schmitt Trigger analysis. You will obtain a great deal of clarification by careful reading of the worked out example on pages 15 through 22. Turn off the tape and come back after studying the example.

Now let us see some of the various types of the Schmitt Trigger circuits. Slide #13 shows a Schmitt Trigger circuit with a high input impedance. This feature is achieved simply by using a field effect transistor for the input stage of the Schmitt with adequate bias arrangements for the FET.

In the transistorized Schmitt Trigger, the input terminal is almost clamped to the voltage drop on the common emitter resistor plus V_{bE_1}, when Q_1 is on. Slide #14 shows an arrangement which prevents the input signal from being clamped. When Q_1 is in cut off D_1 is conducting, but when Q_1 conducts D_1 is being cut off, thus disconnecting the input signal from the Schmitt. Therefore, the same signal source may drive other circuits with higher trigger levels.

In order to get acquainted with the integrated circuit operational amplifier Schmitt Trigger, please read pages 24 through 26 of the Theory Sheets. After you finish reading, come back. Let us summarize the analysis of the operational amplifier Schmitt Trigger. Look at slide #15: by means of R_1, R_2, and V_T we determine the triggering voltages V_{T_1} and V_{T_2}, as seen from the shown equations, of the feedback and triggering voltages.

Take a look at the transfer characteristic. When increasing the input voltage from zero, the green line characteristic holds, but when decreasing the input voltage from values greater than V_{T_1} the red line characteristic is valid.

Let us now see a practical industrial circuit that involves a Schmitt Trigger. Please take a look at slide #16. You can see the complete diagram of a twilight switch picked up from the Electronic Application News journal, Volume 6, #6, edited by Inbelec--Electronic Components Division of Philips India. For details you may refer to this journal.

Looking at our slide #16, the portion with the yellow background shows the Schmitt Trigger. In general, an automatic twilight switch serves to switch artificial lighting on or off, depending upon the intensity of the daylight. An essential requirement of automatic twilight switches is a suitable time delay in their operation. That is to say, the switch should not be sensitive to transient light variations such as lightening flashes or passing clouds. During a storm at night, for instance, a sudden flash of lightening would switch off street lights controlled by an automatic twilight switch--if the switch did not incorporate a time delay. In the circuit under consideration, a time delay of about 20 seconds is achieved by incorporating the Monostable Multivibrator shown in our slide. The switch operates in the following manner: Changes in ambient light conditions vary the resistance of the L.D.R.--the light dependent resistance. This controls the state of the Schmitt Trigger, which, through a suitable triggering circuit, controls a one shot multivibrator. The states of the Schmitt Trigger and the monostable are linked to two AND gates and an OR gate, which operate a relay through its driver. The lamp load is switched on, not directly by the relay, but by a power contactor driven by it.

Now let us have an overview of the procedure of the upcoming experiment. Look at slide #17. It shows a general flow chart of the suggested model for electronic circuits experiments. It is recommended to read the theoretical analysis and prepare the preliminary work before coming to the lab to experiment with the circuit. The preliminary work is actually a quantitative analysis and calculations of the expected values you are going to measure in the lab during the experimenting.

If for some reason you haven't prepared the prelim before coming to work on the experiment, you can complete this after utilizing the audio-tutorial facilities right before beginning your measurements on the circuit. As a matter of fact, you can't start experimenting without doing the prelim work because it includes the computation of some components you have to connect to the uncompleted circuit in order to carry out the required measurements.

As you may see on the flow chart, there are three steps of measuring and observation; namely, measuring the D.C. operation, the A.C. nominal operation, and observing the effect of source voltages, component values, environment like temperature, and frequency on the operation of the circuit.

At this stage it is recommended to observe a detailed application of the circuit under experiment, like that of the twilight switch in our case. After solving a design problem, completing your report, and taking the posttest, the whole experiment procedure is completed.

Let me remind you that a great deal of help can be obtained by following the worked-out example in the Theory Sheets. I wish you good luck and successful experimentation.

APPENDIX D

D_1--Pretest

D_2--Posttest

D_3--Attitude Test

APPENDIX D_1

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E.E. 484
Fall 1972

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PRETEST

Circle the correct answer.

1. In a saturated transistor:

    1. The collector-base junction is forward biased and emitter-base junction is reverse biased.
    2. The collector-base junction is reverse biased and emitter-base junction is forward biased.
    3. Both transistor junctions are forward biased.
    4. Both transistor junctions are reverse biased.

2. The collector current Ic in transistor Q (Figure 1) is approximately:

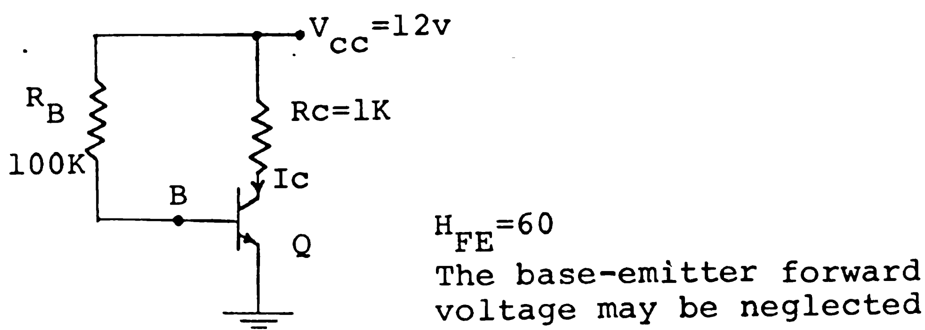

Figure 1

    1. 12 ma.
    2. 5.9 ma.
    3. 7.2 ma.
    4. 0.012 ma.

3. The base resistor R_B (Figure 1) is shunted by a 2.2K resistor; as a result transistor Q will be in:

1. Saturation
2. Active region
3. Cut off
4. Impossible to determine (from the givens)

4. The voltage between the collector of transistor Q (Figure 1) and ground is:
   1. 7.2 v
   2. 12 v
   3. 0.1 v
   4. 4.8 v

5. Adding a resistor (4.7KΩ) between the base B of transistor Q and ground will:
   1. Increase the collector current Ic.
   2. Drive the transistor into saturation.
   3. Stabilize the collector current Ic concerning ambient temperature changes.
   4. All the above answers are incorrect.

6. The Schmitt Trigger can be considered as a flip-flop circuit because it:
   1. Has never two stable states.
   2. Can be designed to have two stable states.
   3. May be operated as a free running multivibrator.
   4. Operates as a differential amplifier when the loop gain is less than unity.

7.

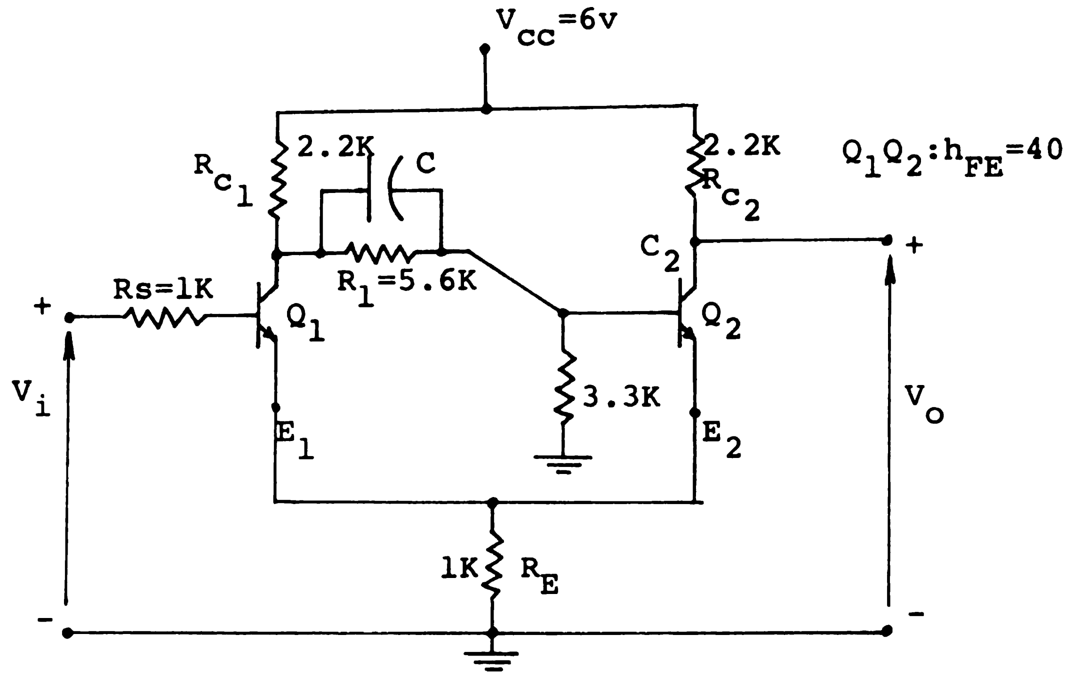

Figure 2

If Vi = 0 (Figure 2) then:

1. $V_o = V_{cc}$
2. Q_1 and Q_2 are in cut off
3. Q_1 is in conduction and Q_2 in cut off
4. Q_1 is in cut off and Q_2 in conduction

8. The circuit in Figure 2 is a:

1. Monostable multivibrator
2. A stable multivibrator
3. Schmitt Trigger
4. Two-stage amplifier with negative feedback provided by R_E.

9. The hysteresis voltage in a Schmitt Trigger circuit can be eliminated by:
   1. Decreasing the loop gain.
   2. Increasing the loop gain.
   3. Raising the supply voltage V_{CC}.
   4. Neither of the above answers is correct.

10. Among the three configurations of a single stage transisterized amplifier (C.E., C.B., C.C.),
    1. The C.E. has the highest power amplification.
    2. The C.C. has the lowest voltage amplification.
    3. The C.B. has the lowest input resistance,
    4. All the above answers are correct.

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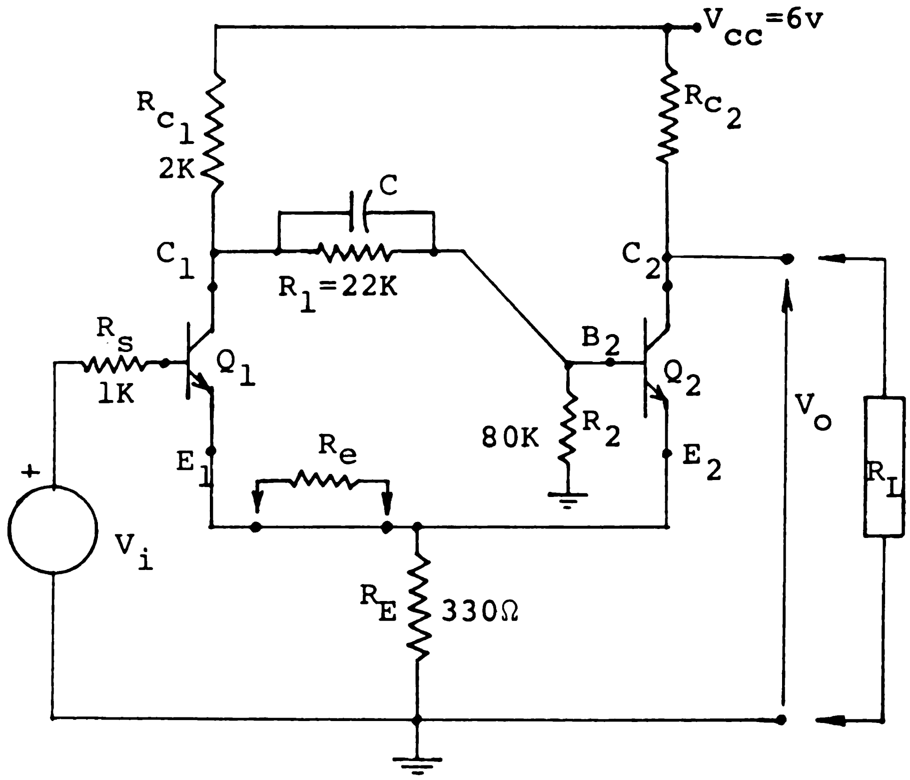
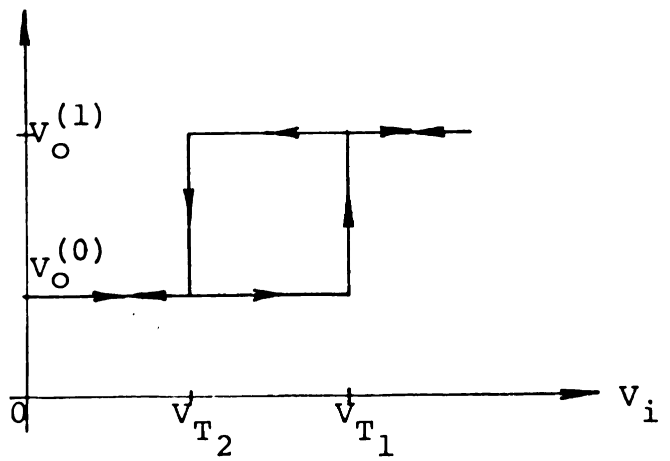
POSTTEST (Schmitt Trigger)



(a)



(b)

Figure 1.--The Schmitt Trigger circuit (a) and its transfer characteristics (b).

*The Retention Test is identical to the posttest.

Circle the most correct answer.

Given the Schmitt circuit in Figure 1.

1. The role of resistor R_E is:
    1. To provide negative feedback to the circuit.
    2. To provide positive feedback to the circuit.
    3. To eliminate the hysteresis of the Schmitt.
    4. To provide saturation of transistor Q_1 whenever it conducts.
2. The hysteresis voltage of the Schmitt (in Figure 1a) can be adjusted by:
    1. R_{c_1}
    2. R_{c_2}
    3. R_2
    4. Answers 1 and 3 are correct.
3. The triggering voltage (V_{T_1}) for the Schmitt in Fig. 1a is approximately:
    1. 3.6v
    2. 4.5v
    3. Impossible to determine V_{T_1} even approximately because R_{c_2} is not given.
    4. Neither of the above answers is correct.
4. The triggering voltage V_{T_2} (see Fig. 1b) depends on the values of the following components (refer to Fig. 1a):
    1. R_{c_1}, R_{c_2}, R_1, R_2, R_s
    2. R_{c_1}, R_s, R_1, R_2, R_E
    3. R_{c_1}, R_s, R_{c_2}, R_E, R_1, R_2
    4. R_{c_1}, R_s, R_1, C, R_E, R_2

5. If v_i = 0v, then:
   1. Q_1 is in conduction and Q_2 in cut off, therefore the output voltage $V_o=V_{cc}=6v$.
   2. Both transistors Q_1 and Q_2 are in cut off.
   3. Both transistors are in their active region provided that the loop gain is less than unity.
   4. Impossible to calculate V_o because R_{c_2} is not given.

6. Inserting resistor R_e in series with E_1 (Fig. 1a) will:
   1. Increase V_{T_1} (see Fig. 1b)
   2. Decrease V_{T_1}
   3. Increase V_{T_2}
   4. Decrease V_{T_2}

7. Given the Schmitt Trigger in Fig. 1, which of the following modifications would you have introduced in order to meet the requirement of high input impedance (above 0.5MΩ):
   1. Raise Rs.
   2. Replace Q_1 by a tube and make necessary bias arrangements.
   3. Replace Q_1 and Q_2 by tubes and make the necessary bias arrangements.
   4. Replace Q_1 by a field effect transistor and make necessary bias arrangements.

8. If the Schmitt in Fig. 1 is supposed to maintain the same output swing voltage and the same triggering voltages when loaded at the output by R_L, which of the following modifications would you introduce in the circuit?
   1. Increase R_{c_2}
   2. Decrease R_2
   3. Increase R_E
   4. Decrease R_{c_2}

9. Lowering R_E to 10 percent of its value will result in a change of the following values: (see Fig. 1b)
   1. V_{T_1}, V_{T_2}, and $V_o^{(0)}$
   2. Only in $V_o^{(1)}$ and V_{T_1}
   3. Only in $V_o^{(1)}$ and V_{T_2}
   4. V_{T_1}, V_{T_2}, $V_o^{(1)}$ and $V_o^{(0)}$

10. The input voltage supplied to the Schmitt is shown in Fig. 2a. Sketch the output voltage in Fig. 2b.

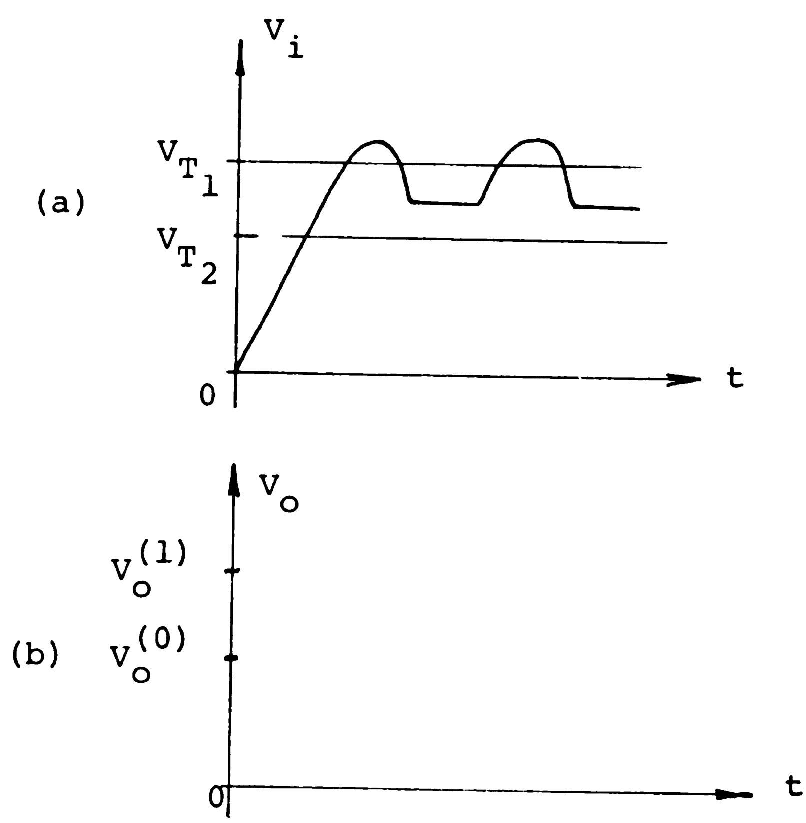


Figure 2

APPENDIX D_3

M.S.U.
E.E. 484
Fall 1972

ATTITUDE TEST

Mark your answer in the square under the number of every question according to the following notation:

SA - Strongly Agree
A - Agree
N - Neutral
D - Disagree
SD - Strongly Disagree

1. ☐ I would like to take some other experiments in the electronic lab using the same method as I have used in experimenting the Schmitt circuit.

2. ☐ Calculating ahead the expected values to be measured during the experiment made the experimenting more interesting and understandable.

3. ☐ The experiment procedure enabled me to proceed by myself without waiting for the instructor.

4. ☐ Switching circuits appear to me more understandable and interesting than they did before this experiment of the Schmitt Trigger.

5. ☐ I spent the experimentation time in the lab mainly following the instructions from the experiment-procedure sheets without understanding exactly what I was doing.

6. Now, after experimenting with the Schmitt circuit I am confident of being able to handle the Schmitt Trigger by adapting it to new required conditions or locate any malfunctions in its operation. ☐

7. I have learned more from the Schmitt Trigger experiment than from any other lab experiment in electronics so far. ☐

Have you any comments concerning the Schmitt Trigger experiment? Please write them down.

8. The flow-charts describing the experiment procedure helped me to proceed by myself during the experiment. ☐

9. The slide-tape presentation of the Schmitt circuit was helpful. ☐

10. I would like to have some additional slide-tape presentations of the Schmitt Trigger applications. ☐

APPENDIX D_4

M.S.U.
E.E. 484 Sec.____
Fall 1972

INSTRUCTORS' EVALUATION FORM

(Schmitt Trigger Experiment)

Instructor's name_______________________________

Number of students in section____________________

1. Number of students that finished the preliminary work before the first session (3 hours) was over: ________

2. Number of students that didn't complete the experiment: _________________

3. Have you demonstrated to the whole group the circuit operation? yes___ no___

4. Were you occupied with students' problems during the experiment more than in the usual electronics lab experimenting? yes___ no___

5. Had the students substantial lack of some prerequisite material or skills? yes___ no___
   What are they?

6. Difficulties of the students:

7. Had you any difficulties in instructing this experiment? yes___ no___. If yes, what were the difficulties?

8. Have you introduced some necessary remedial material to individual students or to the whole group? yes___ no___ If yes, what material?

9. Would you prefer this suggested "Model" of experimentation instead of the "classical" method of experimentation in electronic circuits? yes___ no___

10. Have you any suggestions to improve this "Model" of experimentation in electronic circuitry? Please write them down. Thank you.

APPENDIX E

MEASURED RESULTS OF THE SCHMITT CIRCUIT OPERATION

MEASURED RESULTS OF THE SCHMITT CIRCUIT OPERATION

In the following pictures:

1. When waveform is shown, the horizontal axis denotes time (0.2 in/cm).

2. When transfer characteristics are shown, the horizontal axis denotes input voltage v_i (1v/cm).

3. The vertical axis denotes, in all the pictures, output voltage v_o (5 v/cm).

Figure E5b.
Output waveform (Re_1=280Ω).

Figure E7.
Transfer characteristics of the Schmitt.

Figure E9a.
Transfer characteristics of the Schmitt with Re≃1.1kΩ.

Figure E9b.
Transfer characteristics of the Schmitt with Re=840Ω.

Figure E10a.
Effect of Re on transfer characteristics of the Schmitt with Re_1=1.17kΩ.

Figure E10b.
Effect of Re on the output waveform of the Schmitt with Re_1=1.17kΩ.

Note: If not mentioned otherwise, V_{cc}=12v, R_{c_2}=1.11k.

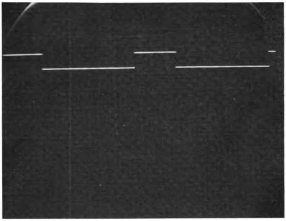


Figure E5b.

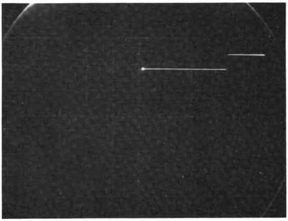


Figure E9b.

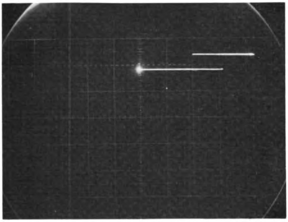


Figure E7.

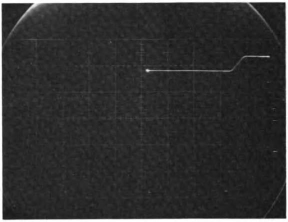


Figure E10a.

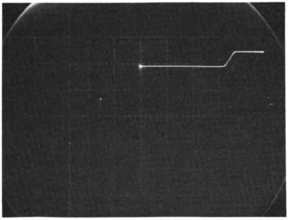


Figure E9a.

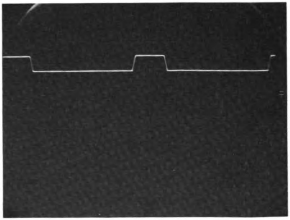


Figure E10b.

Figure E10c.
Effect of Re on the transfer characteristics of the Schmitt with Re_1=280Ω.

Figure E10d.
Output waveform of the Schmitt with Re_1=280Ω.

Figure E13a.
Transfer characteristics of the Schmitt with load R_L-1kΩ connected.

Figure E13b.
Output waveform of the Schmitt with load R_1=1kΩ connected.

Figure E14a.
Transfer characteristics of the Schmitt with $\frac{Vcc}{2}$ volts.

Figure E14b.
Output waveform of the Schmitt with $\frac{Vcc}{2}$ volts.

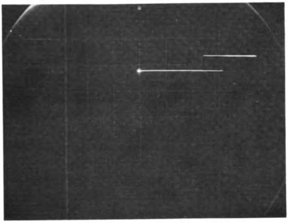


Figure 10c.

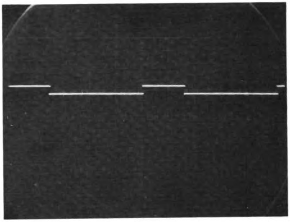


Figure E13b.

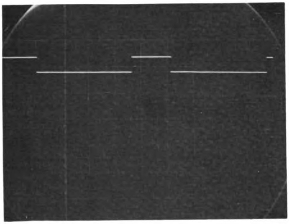


Figure E10d.

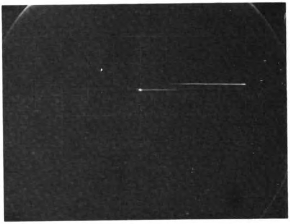


Figure E14a.

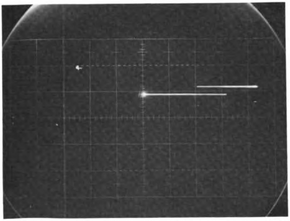


Figure E13a.

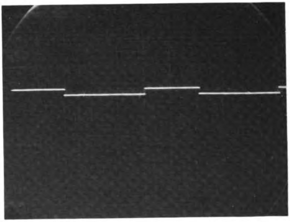


Figure E14b.

Figure E15.
Transfer characteristics of the Schmitt with $R_s'=5k\Omega$.

Figure E16a.
Transfer characteristics of the Schmitt with $R_{c_2}'=2R_{c_2}$.

Figure E16b.
Transfer characteristics of the Schmitt with $R_{c_1}'=0.5R_{c_1}$.

Figure E16c.
Transfer characteristics of the Schmitt with $R_1'=0.5R_1$.

Figure E16d.
Transfer characteristics of the Schmitt with $R_2'=0.5R_2$.

Figure E16e.
Transfer characteristics of the Schmitt with $R_E'=0.1R_E$.

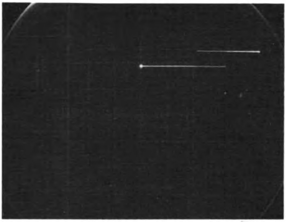


Figure E15.

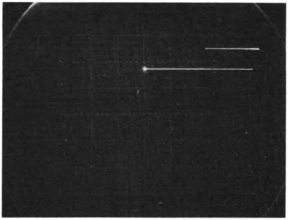


Figure E16c.

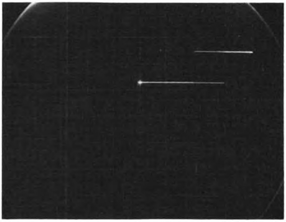


Figure E16a.

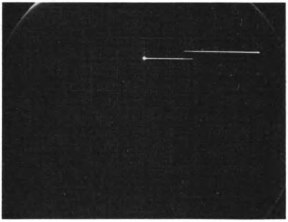


Figure E16d.

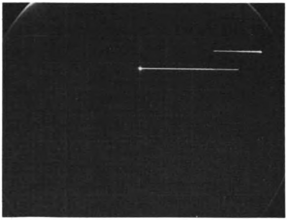


Figure 16b.

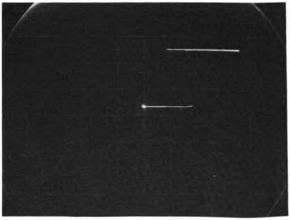


Figure E16e.

APPENDIX F

IMPLEMENTING THE MODEL IN THE LABORATORY

IMPLEMENTING THE MODEL IN THE LABORATORY

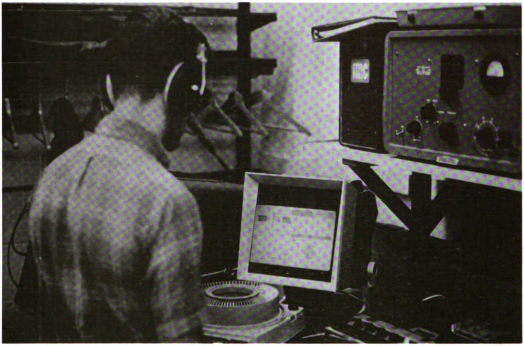


Figure F1.--Using the slide-tape presentation.

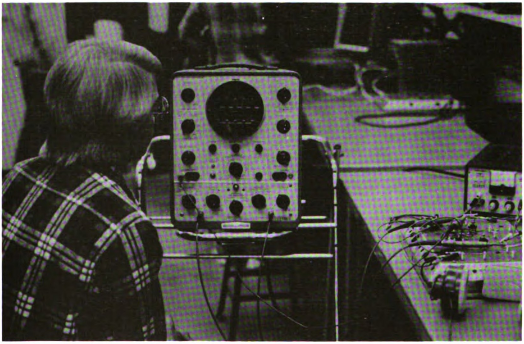


Figure F2.--Utilizing the oscilloscope as a measuring instrument as well as a media means.

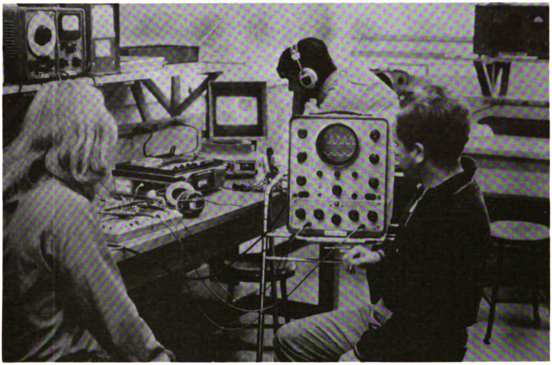


Figure F3.--Getting the input and output waveshapes of the Schmitt circuit on the oscilloscope screen (the writer is seen on the right).