

LEARNING ELECTRONICS

THEORY AND
EXPERIMENTS
WITH
COMPUTER-AIDED
INSTRUCTION
FOR THE
COMMODORE
64TM/128TM

R. Jesse Phagan and William Spaulding

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**Dedicated to Our Children:
Bettina and Barrett Phagan
and to
Daniel Spaulding**

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TAB BOOKS Inc.

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FIRST PRINTING**

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Contents

| | |
|---|-----------|
| Preface | ix |
| Introduction | xi |
| Using the Programs for the Commodore 64—Hands on Experience | |
| 1 Introductory Topics | 1 |
| Electronics Terms—Job Market—Electrical Safety—Computer Assisted Instruction (CAI)—Using the Programs in this Book—Student Projects—Safety Test | |
| 2 Tools of the Trade | 9 |
| Basic Hand Tools—Soldering | |
| 3 Shop Math | 13 |
| Shop Math Pretest—Fractions—Arithmetic with Fractions—Decimals—Percent Tolerance—Positive and Negative Numbers—Solving Equations—Solving Formulas—Programs for this Chapter—Shop Math Competency Test | |
| 4 Engineering Notation | 35 |
| Significant Figures/Rounding Numbers—Scientific Notation—Engineering Notation—Arithmetic Operations with Powers of 10—Programs for this Chapter—Engineering Notation Competency Test | |
| 5 Introduction to DC Circuit Components | 47 |
| DC Voltage Sources—Conductors—Switches—Fuses and Circuit Breakers—Resistors—Resistor Color Code—Introduction to Schematic Diagrams—Programs for this Chapter—DC Circuit Components Competency Test | |

| | | |
|-----------|--|------------|
| 6 | Use of an Ohmmeter | 63 |
| | Construction of an Ohmmeter—Ohmmeter Range Switch—Ohmmeter Scale—Hands-On Experience—Programs for this Chapter—Ohmmeter Written Competency Test | |
| 7 | DC Circuits: Relationships, Formulas and Measurements | 81 |
| | Electrical Relationships—Ohm's Law—Power Formulas—Connecting Single-Load Circuits—Using a Voltmeter—Using an Ammeter—Meter Construction—Programs for this Chapter—DC Circuits: Relationships, Formulas and Measurements Competency Test | |
| 8 | Oscilloscope Familiarization | 103 |
| | What the Oscilloscope Does—Oscilloscope Screen—Understanding Oscilloscope Controls—Vertical Controls and Adjustments—Horizontal Controls—Trigger—Measuring dc Voltages—Hands-On Practice with dc Voltages—Programs for this Chapter | |
| 9 | DC Circuit Analysis | 111 |
| | Series Circuits—Hands-on Practice: Series Circuit Measurements—Parallel Circuits—Hands-on Practice: Parallel Circuit Measurements—Series-Parallel Combinations—Programs for this Chapter—DC Circuit Analysis Test | |
| | Exam #1. DC Building Block | 143 |
| | Safety—Engineering Notation—Resistor Color Code—Schematic Symbols—Use of an Ohmmeter—Ohm's Law—Power Formulas—Use of a Multimeter and an Oscilloscope—DC Circuits | |
| 10 | Magnetism and Inductance | 149 |
| | Magnetism—Inducing Voltage—Electro-Magnets—Properties of Inductance—Inductors in Series—Inductors in Parallel—Programs for this Chapter—Magnetism and Inductance Competency Test | |
| 11 | Sine Wave Analysis | 159 |
| | Alternating Current (ac)—AC Line Voltage—Producing a Sine Wave—Plotting a Sine Wave—Units of Amplitude—Units of Time—Using an Oscilloscope to Measure a Sine Wave—Hands-On Practice with Sine Waves—Programs for this Chapter—Sine Wave Analysis Competency Test | |
| 12 | Transformers | 183 |
| | Transformer Construction—Transformer Ratios—Power and Efficiency—Variations of Transformers—DC Voltage with the Transformer—Hands-On Testing of Transformers—Programs for this Chapter—Transformer Competency Test | |
| 13 | Capacitors and Time Constants | 197 |
| | Properties of Capacitance—Capacitors in Parallel and Series—Practice Problems: Capacitance—Universal Time Constant Curve—L/R Time Constant—RC Time Constant—RC Waveshaping—Hands-On Practice: Time Constants and Waveshaping—Programs for this Chapter—Capacitors and Time Constants Competency Test | |
| 14 | AC Circuits | 223 |
| | Reactance—Phasor Analysis—Reactive Circuits—AC Power—Measuring Phase Angle with an Oscilloscope—Hands-On Practice: Measuring Phase Angle—Programs for this Chapter—AC Circuits Competency Test | |
| 15 | Resonance | 249 |
| | Net Reactance—The Resonant Effect—Series Resonance—Parallel Resonance—Bandwidth—Programs for this Chapter—Resonance Competency Test | |
| | Final Exam DC and AC Building Blocks | 259 |
| | Engineering Notation—Ohm's Law—Power Formulas—DC Circuits—Sine Wave Analysis—Transformers—Inductors and Capacitors—Time Constants—Reactance, Impedance and AC Power—Resonance | |

| | |
|----------------------------|------------|
| A Glossary | 263 |
| B Formulas | 267 |
| C Schematic Symbols | 271 |
| D Answers to Exams | 275 |
| E Computer Programs | 295 |
| Index | 343 |

Preface

When learning a technical subject such as electronics, there are three important approaches to the learning process that must be followed: theory, math, and hands-on experience. Each of these should be directly tied together in order to achieve maximum learning efficiency.

As an electronics teacher, it has been my responsibility to order the books for students and to make recommendations on which books would be good for them to buy on their own. I have never been able to find a book that covers all three of the important learning approaches.

By using the theory to explain how things work, the math to perform the necessary calculations, and

the hands-on practice to make everything fit together, this book does all three. To top it all off, there are computer programs to assist in the learning process.

It is recognized by teachers everywhere that the computer can be a great help in the learning process because the computer requires student involvement in the learning process. The more different aspects that the student is involved with, the more information will be retained.

Students using this book will be involved through the use of plenty of practice problems, hands-on exercises, and computer-assisted instruction.

R. Jesse Phagan

Introduction

Student-managed learning is the main emphasis of this book, with the key being involvement by the student in the learning process. The major learning units contain worked-out sample problems, followed by practice problems. There are hands-on practice exercises designed to help with the learning of meters and oscilloscopes. At the end of the chapters, there are tests that have been used in an actual classroom. There are also two main examinations. The student learns with practice.

One of the major highlights to provide student involvement are the computer programs. Each chapter, starting with Chapter 3, has computer programs designed to quiz the student in the important concepts of electronics theory, math, and use of test equipment. There are also programs that provide practice and experience with ohmmeters, voltmeters, ammeters, and the oscilloscope.

The field of electronics technology is constantly changing. Although the basics of dc and ac remain the same, the methods of learning have changed. The effort placed on the various basic subjects needs

to reflect the applications of the advanced electronics. The math areas studied in the basics help with a complete understanding and are used to predict circuit behavior. To study electronics in the last part of the 20th century requires student involvement and a book that puts the emphasis on subject matter where it belongs—to provide a sound foundation in the building blocks.

USING THE PROGRAMS FOR THE COMMODORE 64

Chapters 3 through 15 have BASIC programs listed for them in Appendix E. In order to use them, you must enter each of the programs, including the main menu program, and save them on a disk. Once you have the programs entered, the following instructions will help you load and run them:

1. Enter **LOAD** ● , 8, 1
2. When the computer's **READY** prompt appears, enter **RUN**

(The ● symbol is made by holding down the Shift Key while pressing “Q”.) The main menu will appear and you can then select the program quiz you desire. Further instructions are supplied by the program as necessary.

At the end of each chapter for which there is a program, there is a description of the program and some instruction. Each of the programs is an interactive quiz on the material covered in the chapter. A grade can be acquired by typing “N” at any time. This will also return you to the main menu. Make certain that the disk drive is turned on whenever you return to the main menu.

The names of all the programs are:

- | | |
|-------------------------|--------------------|
| A) Introduction | I) Dc Analysis |
| B) Shop Math | J) Oscilloscope Ac |
| C) Engineering Notation | K) Phase Angle |
| D) Color Code | L) Time Constants |
| E) Ohmmeter | M) Magnetism |
| F) V&A Meter | N) Transformers |
| G) Ohmmeter | O) Reactance |
| H) Oscilloscope Dc | P) Resonance |

HANDS-ON EXPERIENCES

The hands-on experiences throughout this book have been designed to use a minimum of equipment and parts. They have also been designed so the actual component values are not crucial.

Equipment

- Multimeter.
- Variable dc power supply (6-volt battery may be substituted).
- Oscilloscope.
- Audio function generator (sine waves and square waves).

Parts

- 10 different values resistors including 10 kilohm.
- 2 different variable resistors.
- Switch.
- Transformer.
- .001 microfarad capacitor.

Chapter 1

Introductory Topics

Chapter Objective: To become familiar with common technical words used in the electronics trade, types of jobs available, and safety practices. Also included in this chapter will be an explanation of what “computer assisted instruction” is and how to make use of it.

Chapter Outline:

- Electronics Terms
- Job Market
- Electrical Safety
- Computer Assisted Instruction (CAI)
- Using the Programs in this Book
- Student Projects
- Safety Test

INTRODUCTION

It is obvious that electronics is used throughout any modern household. Including appliances using only electricity, it becomes overwhelming to think of how much people in the late 20th century

depend on electricity and electronics. Try to imagine how well your own house would function without electricity for a short period of time, say one week.

The study of electronics begins with the study of electricity. The student should make every effort to understand the principles of electricity that are presented.

ELECTRONICS TERMS

In every field there are words that are used to describe things that are unique to that field. This is especially true when dealing with technical subject areas. A student needs to adopt the technical words of his/her field as part of the normal thought process. In this section a few words will be mentioned. Throughout the remainder of the book other words will be introduced and applied. The purpose of this section is to introduce some of the words that the student may have already come in contact with.

Electronics is a very broad term used to describe devices that use electricity in more advanced ways than just light, heat or motors. Exam-

ples are: radio, TV, computers, calculators, quartz clocks, robots, etc.

Electricity is the flow of electrons through a conductor. Electricity is generally used to produce heat, give off light (as in the case of an incandescent light bulb), operate motors, and operate electronic devices. Examples of devices using electricity: refrigerator, toaster, electric stove, clothes dryer, etc.

Conductor is the medium through which electricity flows. A good conductor is copper wire. A poor conductor is usually called an insulator. An example of an insulator is plastic.

Resistance is a term used to describe opposition to the flow of electricity. Resistance is the property of a conductor that causes heat when electricity flows.

Voltage is the term used to describe an electrical force. Voltage is a potential to perform work. Work, in electrical terms, is such examples as: heat, motors, operation of a radio, etc. In the United States, household voltage is 120 volts (also referred to as 110 or 117 depending on the local tradition). Most cars use a 12 volt battery. Although these examples are of quite different forms of electrical energy, the size of the numbers describes the amount of potential electrical energy.

Current is the term used to describe the amount of electrical energy (electrons) flowing through the wire. The unit for current is ampere. It can be measured and a number can be assigned to show its relative size for comparison to other measurements of current. As an example: the circuit breaker or fuse for an average household circuit is 15 or 20 amps. The current of a 120 watt light bulb is approximately 1 amp.

Power is a term used to describe the amount of electrical work performed. The unit of measure is watt. The best example is the wattage rating of a light bulb. The higher wattage gives a brighter light and gives off more heat. The higher power bulb also uses more current than a smaller wattage bulb.

Other terms: there are many other terms used in both electricity and electronics, which will be introduced with the appropriate subject matter. The purpose of the discussion now is only to mention

some of the common words a new electronics student may already be familiar with.

JOB MARKET

The job market in the electronics field varies considerably depending on the geographical location. Since the location can not be discussed in a book, what can be discussed is the level of jobs and the relationship of education. This section will deal in great generalities with the level of education.

There is no question that the opportunities in the electronics related fields will continue as more products are developed and require servicing.

Bachelor's Degree

A four-year degree or higher opens up a vast number of opportunities. Generally speaking, a higher education means considerably more money. The type of work acquired with a B.S. degree is usually considered "engineering" in some form. It could be developing new products, updating older products, and sometimes more advanced levels of servicing. Computer related jobs usually require a four-year degree or higher, especially programming.

Associate Degree

The associate degree is a two-year degree intended for a junior engineer or a technician. The associate degree will provide the student with a well rounded education, including English skills, and good technical skills. Many companies prefer the AS degree for their technicians because they also have some engineering training.

Post-Secondary Technical Schools

Technical schools, after high school, are an excellent way to receive the necessary skills to be a technician. This type of education somewhat limits the advancements of a technician only because many companies prefer an AS degree and it is also difficult to receive college transfer credits if a further education is ever desired. However, if an individual knows that being a technician is what he/she wants, the technical schools usually do a much better job of developing the necessary technical skills.

Technical High School

Technical high schools are an excellent way to get a “starting” education in order to enter the field of electronics. Most technical high schools will prepare the student with many of the same types of skills as a post-secondary school. Usually the big difference is the depth of study and understanding.

Technician vs Engineer

Engineering is usually thought of as a “desk” job. This isn’t necessarily true, but usually engineers are responsible for more paper work than a technician. Usually the engineer is considered to have a more in-depth understanding of how the circuits operate, because their education level is somewhat higher.

A technician usually performs the “hands-on” jobs. A technician’s job includes operation of test equipment, repair and maintenance of equipment and assisting engineers. Technicians are often involved in design work, but the majority of technician duties will involve repair and maintenance. Usually the jobs with the title of “field engineer” are filled by skilled technicians.

It is possible for self-taught individuals to find a place in the field of electronics. The reason for this is the fact that hands-on jobs and repair of equipment seems to be a talent and it is possible for someone to teach himself. Often, self-taught technicians find it necessary to either work at their own business or for a small company that hires on ability rather than education.

ELECTRICAL SAFETY

Safety needs to be considered in every aspect of a person’s life. Generally speaking, safety is a matter of knowing the dangers, being trained in dealing with them and using common sense.

A technician deals with many of the common dangers such as ladders, falls, cuts, etc. Tools present a special problem because a technician’s job depends on the skillful and constant use of both hand and power tools. The items that are discussed in the following sections have been selected because they address the most common issues.

Also, keep in mind that safety glasses are often recommended when using many tools or being in the vicinity of flying particles. Use your safety glasses!

Hand Tools

Many of the hand tools that are in use by technicians perform very specific functions, some of which are cutting, pinching, twisting, heating, etc. Tools of this nature can cause very serious injury to a person’s skin. Not only is the tool’s normal working edge dangerous, but the handle itself can cause injury, especially where the two handles come together.

Another cause of injury with seemingly harmless tools, such as a screwdriver, is when the tool is being used improperly. If a screwdriver slips from the screw and strikes a person’s hand, a very serious cut can result.

The reason for mentioning this type of danger with hand tools is to try to impress the idea on the student that proper training and common sense are both required to maintain safety on the job.

Power Tools

Power tools, such as an electric drill or electric saw, present dangers and safety problems from both the tool itself and from the electricity to operate it.

All power tools are intended to operate in a specified manner. Do not try to force the tool to perform a function that it is not intended to do. For example; a drill is designed to have pressure down on the drill bit NOT sideways on the bit. When some people find a hole is slightly too small, they try to enlarge the hole by placing pressure on the side of the drill bit to enlarge the hole. This practice is extremely dangerous.

One major problem with any device that uses electricity is the fact that the outside can become electrically “hot.” This happens for a variety of reasons. If the outside portion is metal, a person touching it can receive a shock that could be fatal.

All new power tools are either “double insulated” or they have a three prong plug. If the tool is double insulated it will have a two prong plug and all of the outside of the tool will be made of heavy

plastic. All tools with a metal outside must have a three prong plug. If the tool becomes defective and a wire from the inside touches the outside, the ground prong (ground wire) will cause the circuit breaker to trip and prevent shock. It is, therefore, extremely important for the round prong to be connected to electrical ground. If a three prong electrical outlet is not available, an adapter plug can be used provided the adapter plug's ground wire is connected to the outlet box screw. Under no circumstances is it safe to use a two wire extension cord with a tool with three prongs.

Electrical Shock

The amount of electrical shock necessary to kill a human being is surprisingly low. It is the electrical current flowing through the person's body and the path it flows that determines the severity of the shock. It is not the voltage, as most people think, that kills in a shock. Whenever a person comes in contact with a voltage source, current will flow through the person's body and the amount of current will depend on two items: voltage and body resistance.

A person's body resistance depends on many factors. For example; examine the skin of your hand. There are places where the skin is dry and tough, which offers high resistance, and there are places where the skin is moist and soft, such as between the fingers, which offers low resistance. If the skin is broken, due to an injury or puncture, the resistance of blood and inside tissue is very low. When a piece of wire is snipped with cutting pliers, it usually has a sharp edge. If that sharp edge contacts the skin in such a manner as to cut it and the wire has voltage, a fatal shock is likely.

A person's body resistance is also affected by environmental conditions, such as moisture in the air, or standing in water. Any time the skin is moist, it will have much lower resistance than normal. A lower body resistance requires a much lower voltage to cause serious shock.

If the path of current flow is through the heart, such as passing from one hand, through the arm and chest and out the other arm and hand, the danger

is much more severe than just through the hand. Taking everything into consideration, a voltage as small as 40 volts can cause a fatal shock to a normal, healthy person. Voltages as high as the household voltage of 120 volts are certainly enough to kill a person.

Some people feel that household voltage of 120 volts isn't dangerous because they have had shocks and not been killed. A shock is an accidental injury, and like any accident, it should be avoided whenever possible . . . it only takes one fatal accident.

Most electrical shocks will cause the victim to suddenly jump clear of the voltage source. However, a shock that could lead to a dangerous situation happens when the person can not release on his own.

If you observe a person receiving an electrical shock, you must protect yourself from shock and remove the person from the electrical supply. The best way to do this is to use an insulated object such as a piece of dry wood to push the person off the electrical source. Keep in mind, fatal shocks happen when the person becomes paralyzed from the electricity flowing through the body.

Safety Rules

1. Wear safety glasses whenever there is danger of flying particles or liquids.
2. Never use a tool for a job that it was not intended to perform.
3. Be certain power tools are properly grounded or double insulated.
4. Do not rely on electrical safety devices, since they often fail.
5. Do not assume an electrical circuit is dead because a wire is not connected.
6. Avoid wet or moist conditions when working around electricity.
7. Avoid the use of jewelry when near electricity.
8. Never defeat a safety or interlock device.
9. Use a CO₂ fire extinguisher, rather than water on electrical fires.
10. When observing another person receiving a shock, push him/her from the electrical source with something insulated, or disconnect the electricity at its source.

11. Always act with common sense and never take unnecessary chances.
12. Do not work near electricity or operate power tools when taking medicine or alcoholic beverages.
13. Always follow the instructions provided by the manufacturer.

COMPUTER ASSISTED INSTRUCTION (CAI)

The personal home computer has made great changes in teaching and learning techniques. When we consider that school systems all over the country have placed computers in the classrooms and a vast number of people have computers of their own at home, it only makes sense that the computer should be put to work in teaching.

In a Classroom

The computer has made it possible to introduce a concept called "student managed learning". This has not replaced the teacher, but instead allows the teacher to concentrate more on one-to-one teaching. This method of teaching in a classroom atmosphere is still in the beginning stages. It also allows for another approach called "competency based learning", which is based on the fact that most people learn the best when they teach themselves at their own pace and use the classroom teacher to answer questions and solve problems.

Learning at Home

Many people have found that they can teach themselves, with the use of computers and books, almost any subject they want to know about. Programs are written for every level of learning and there are new programs coming out all the time.

There are many advantages to teaching oneself at home. For example; it is a relatively inexpensive way to learn a new subject and find out exactly how much interest one has in the subject. If a student is involved with both a school and teaching oneself at home, the learning process is much easier and the student retains much more and does better in school.

Some colleges are now willing to recognize self-taught individuals and give them a chance to take bypass examinations to receive college credits. This is especially true of the basic subject areas.

What CAI Is Not

Computer Assisted Instruction is not a way of replacing books or good study habits. It will not replace memorizing certain concepts, such as formulas, or definitions.

Computers, like books, are programmed or written by someone who makes every effort to answer all the questions that could be thought of by a student. This obviously is an impossible task. The student must learn to interpret the information that the computer is offering. When a student is reading a book, if there is something not understood fully, he or she needs to read it again or ask someone else. This is also the case with using computer programs.

What CAI Is

Computer Assisted Instruction is an alternate method of learning. Books by themselves are hard to learn from and to retain information from. The programs selected for the computer are intended to get the student involved in the teaching/learning process.

The key phrase is student involvement. Most people feel they "learn the hard way." What is "the hard way?" When someone says that, they usually mean that they must "do it themselves" in order to retain the information.

CAI allows the student to participate. The programs will offer some instructional material, some question/answer practice, some tests. If the student reads through the necessary material in the book first, then goes to the computer and allows the computer to reinforce what the book says, there will be a winning combination.

This Book and CAI

For each chapter, from chapter 3 to 15, there will be at least one computer program. The listings are in Appendix E. The material selected for the pro-

gram has been taken from the text material and is intended to challenge the student in the learning process.

All of the programs are intended to have the student read the text first, then try the programs. It may be necessary to re-read the text in order to get full understanding.

At the end of each chapter will be a list of the programs available for that chapter and a brief discussion of what they are and how they will help the student.

All of the student projects, practice exercises, and tests try to cover every angle of the material. When the student finishes a chapter, he or she should feel competent in that subject area.

USING THE PROGRAMS IN THIS BOOK

The programs included in this book are written in BASIC and, if the student desires, he/she can copy the program from the book directly into the computer.

Many of the programs include graphics to help the student to better see the more complicated concepts.

Read the Book First

It is very important for the student to read the complete chapter before starting on the programs. In this way, the student has a good idea of what is expected in the chapter and has some practice before starting the programs.

Load the program for the particular chapter and try to perform the tasks the computer asks for. It will probably be necessary for the student to return to the proper section of the book to assist with understanding the programs.

Programs and Book Go Together

Studying a technical subject, such as electronics, is a very difficult task. It is not the same thing as reading a novel. With a novel, if the reader does not understand a certain point, it usually doesn't matter. With a technical subject, every point is important and must be understood fully.

Therefore, allow the book and the programs to work together to teach the subject matter. It will be very easy for the student to want to only use the programs since many of them will be "fun". Do not allow yourself to get caught in the trap of only depending on one source of teaching/learning experience.

STUDENT PROJECTS

The projects for this chapter are intended to help the student be better introduced to the subject of electronics technology.

1. Make a list of electrical/electronic terms that you can remember hearing at some time. Make a brief definition and give an example of any words that you are familiar with.
2. Using the newspaper from your area, or preferably a big city, look in the help wanted section to find out what jobs are available and the education level required.
3. Visit a high school guidance counselor to obtain information on what types of jobs are available in the electronics field and what education level is required.
4. Check in your own home for safety hazards. Make a list of the hazards and have them fixed as soon as possible.
5. Do some research on the subject of electrical shock: what it is, how to avoid it, how to perform first aid on a victim.
6. Make a list of the common sources of electrical shock and how to avoid them.
7. Make a list of safety rules to include many of the common safety problems.
8. Make a safety poster with the top 10 or more safety rules.

SAFETY TEST

The following safety test is to highlight some of the safety points. **Remember: Safety Requires Common Sense.**

Select the one best answer for each of the following multiple choice questions.

1. When using an electric drill:
 - a. never plug the three conductor drill cord into a two conductor extension cord.
 - b. side pressure on the drill bit is acceptable at slow speeds.
 - c. never allow the drill to be grounded.
 - d. safety glasses are not required.
2. When an electric wire is disconnected:
 - a. it is safe to handle the wire.
 - b. voltage may still be present.
 - c. there is no danger of shock.
 - d. the circuit breaker will trip.
3. In case of a fire in or near electrical equipment:
 - a. use water to extinguish.
 - b. use CO₂ (carbon dioxide) to extinguish.
 - c. turn off the power and allow the fire to burn itself out.
 - d. trip the circuit breaker by hand and the fire will go out.
4. A double insulated tool:
 - a. has a three prong plug.
 - b. has a two prong plug.
 - c. cannot give electrical shock.
 - d. has a metal handle.
5. When observing a victim receiving an electrical shock:
 - a. wait until the victim falls clear before turning off power.
 - b. do not move the victim.
 - c. immediately give artificial respiration.
 - d. first remove the source of electrical power or move the victim.
6. When using electrical equipment, be sure you're standing on a dry floor. Water and electricity cause:
 - a. electrical shock
 - b. gas
 - c. explosion
 - d. rust
7. If there's an emergency you may have to use a fire extinguisher. It's important to know where the fire extinguishers are located and to:
 - a. test them
 - b. read the instructions posted on them
 - c. keep one near you at all times
 - d. store flammables under them
8. Always protect your eyes when you're working with power equipment, an air hose or soldering. To prevent eye injury or blindness, wear:
 - a. safety glasses or face shield
 - b. a cap with a visor
 - c. sun glasses
 - d. waterproof clothes
9. Serious muscle and back injuries can result from lifting something incorrectly. The right way to lift something from the floor is:
 - a. with your back
 - b. slowly
 - c. with your leg muscles
 - d. with your arm muscles
10. It's dangerous to leave tools or materials sticking out over the edge of the work bench or table because:
 - a. the tools could be damaged
 - b. they could damage the table surface
 - c. someone could bump into them
 - d. it looks messy
11. When handling electrical equipment, be sure:
 - a. that you're grounded
 - b. the wires are exposed for inspection
 - c. your hands are dry and you're standing on a dry floor
 - d. the polarity is positive
12. If you need to use an extension cord, always check to see that the cord is:
 - a. in good condition

- b. the right color
 - c. well worn with frayed ends
 - d. light weight
13. Another important safety rule for power cords is:
- a. put in the middle of the floor where it can be seen
 - b. keep them out of the way of traffic
 - c. hide them under a carpet
 - d. none of these
14. The best way to hold a drill is:
- a. firmly and comfortably, away from your face
 - b. with a very tight grip
 - c. without bending your elbows
 - d. with one hand on the cord
15. As you begin to work with any electronic equipment, if you are not sure if the wiring is "hot" or not, always:
- a. assume that it's dead
 - b. smell the wire for heat
 - c. turn off the power at its source first
 - d. feel the wire
16. The only *right* way to test wiring is:
- a. with a metal object
 - b. with an insulated object
 - c. with your fingers
 - d. with proper testing equipment
17. All connections must be completed:
- a. before the power is turned on
 - b. before you examine the wiring
 - c. only by a qualified technician
 - d. after the power is turned on
18. To pass a hot soldering iron to someone else:
- a. lay it down so the other person can pick it up
 - b. hand it tip first so he/she can see it's hot
 - c. hold it by the tip so he/she can take the handle
 - d. pass it holding the cord
19. A good way to test if a soldering iron is hot is:
- a. on a piece of paper
 - b. on a piece of solder
 - c. on a wet sponge
 - d. touch with a wet finger
20. It is important that the area you are soldering in is:
- a. wet so it won't burn
 - b. clean and dry
 - c. near a water source
 - d. kept dark to help see any sparks

Chapter 2

Tools of the Trade

Chapter Objectives: To identify some tools of the electronics trade and know their common uses. To learn basic soldering techniques.

Chapter Outline:

- Basic Hand Tools
- Soldering

INTRODUCTION

The list of tools available to the technician is endless. Some are general purpose and used by most everyone and others are specialty tools that are only used in certain applications.

This chapter will present some of the very basic general purpose tools that would be used by most all technicians. The emphasis here will be clearly on an introduction, knowing that as the student technician develops knowledge of the electronics subject, skill with tools will also develop.

BASIC HAND TOOLS

Hand tools are used by skilled technicians to make it possible to repair circuits and all types of machinery. The tools discussed here are a sample of the more common tools available.

Cutting Pliers

A pair of diagonal cutters, nicknamed “dykes”, is especially useful for cutting wire. The cutters are available in many different sizes and it is often necessary to keep a small and large pair to cut the wide range of wires that are encountered.

The wire is placed in the diagonally shaped cutting jaws for the purpose of cutting the wire. This tool is intended to cut through the wire and should not be used for the purpose of removing only the insulation.

Safety practices must be observed in the vicinity of the cutting edge. Extreme caution should also be observed if cutting near other wires that are not intended to be cut.

Long Nose Pliers

Long-nose pliers are used for a wide range of operations. However, the primary purpose is to hold a piece of wire, bend, pull and push wire.

The shape of the nose ranges from long and skinny to short and not-so-skinny. The size and shape is usually a matter of personal preference and the size of the wire being worked with. Some long nose pliers also have cutters built in. It is usually best, however, not to use "combo" tools because it will result in a compromise that may be unfavorable.

Caution when using long nose pliers is usually a matter of not squeezing the insulation on the wire. Squeeze only the wire itself.

Wire Strippers

The primary purpose of wire strippers is to remove the insulation from the wire. The type shown in the drawing can be adjusted to the exact size of the wire with an adjusting screw. By adjusting to the exact size of the wire, the handles can be closed all the way to the adjusted stop and it will not damage the wire.

Caution must be exercised, especially when using stranded wire, not to cut any of the strands and with solid wire not to nick it with the cutting edge.

Slip-Joint Pliers

Slip-joint pliers fall into the category of general purpose pliers, which are available in a wide range of sizes and shapes. The main purpose of these pliers is to hold or squeeze objects.

Pliers are often used to hold nuts on bolts. If the nut is too tight on the bolt, damage to the nut can result.

Caution must also be exercised when holding many objects. Many things are made of plastic, which can be easily damaged by the metal teeth of the pliers. It is often helpful to place a heavy piece of cloth under the teeth to prevent damage.

Crescent Wrench

A crescent wrench often comes as part of a set. Some have different size crescents at each end and

some have the round at one end the same size as the crescent. The fixed crescent wrench is the ideal tool to use to hold a nut. If the crescent is exactly the same size as the nut, there will be little or no damage to a nut that is very tight on the bolt.

Adjustable Crescent

An adjustable crescent wrench is used when the correct size of fixed crescent is not available. A thumb screw is used to adjust the wrench to the size of the nut. When used to hold nuts that are not too tight, one adjustable crescent can be used to replace a complete set of fixed crescent wrenches.

The problem with the adjustable type of crescent wrench is that it may not hold tight enough on a very tight nut and will result in damage to the nut.

SOLDERING

Soldering is a technique used to hold two metal objects together. A metal solder is melted and forms a bond between the two pieces of metal to be joined.

Soldering Tools

In addition to the basic hand tools required for cutting, stripping and holding the wire, soldering requires solder and something to melt the solder.

There are two general groups of tools for melting solder; soldering irons and soldering guns. Both require electricity and use a heating element to heat the tip for the purpose of melting the solder.

The soldering iron is usually fairly small and will produce a lower heat than the soldering gun, which is usually large, with a larger heating element.

Wattage Ratings

The soldering tools have a wattage rating, which give an indication to the amount of heat that will be produced by the tip. A lower wattage rating produces less heat.

Soldering irons have wattage ratings that range from 15 watts to about 60 watts. Some electronic components are easily damaged by heat and need to be installed with very low wattage irons. An iron with a wattage rating to 25 watts is usually low

enough to be used with electronic components. The problem with low wattage irons is that they do not melt the solder very fast and when used with heavy wire, may not produce enough heat.

Soldering guns have wattage ratings that range from 40 watts to 500 watts, or higher. High wattage guns are useful for soldering wires or pieces of metal, not for electronic components.

Solder

Solder is a metal alloy that melts very easily and is used as the "glue" for metal. There are two general types of solder, the kind for plumbing and the kind for wires.

Plumbing solder is solid and it is necessary to use a separate flux. The flux is used for cleaning the two surfaces to be bonded. In plumbing, an acid flux is used which is very effective in cleaning the copper pipes.

Electrical solder is hollow, with the flux inside the core. The flux is a paste and as the solder melts, the flux runs out and cleans the surfaces. The flux used for electrical connections is a rosin and is not corrosive. Acid flux is corrosive and must not be used for electrical connections.

The best all-around solder to use for electronics work is a very thin solder because it melts fast; rosin core with a 60/40 alloy.

Solder Connections

A solder connection must possess one impor-

tant standard; there must be a good electrical connection. Connections are made between two wires, a wire to a terminal, wire to a component, component to a circuit board, wire to a circuit board, etc. All are metal to metal, usually copper, and all connections must be good electrically, that is, they must pass electricity.

During the process of soldering, the two metals to be joined are *both* heated to a point where they *both* can melt the solder. The solder is then touched to the metal and the solder melts. As the solder melts, the flux runs out of the core and cleans away small deposits of dirt and corrosion. The molecules from the solder bond themselves to the molecules of the metal. The solder bond holds the two metals together and provides a good electrical path. The bonded solder also stops any corrosion from taking place and disturbing the bond.

Bad Solder Joints

A bad solder joint, often called a cold or fractured joint, is one where there is not a good electrical connection.

There are three things that cause a bad solder joint; 1) the metals were not *both* hot enough to melt the solder, 2) the joint was moved while the solder cooled causing the joint to crack and the metals to no longer form a good electrical contact, 3) corrosion on the metal was not removed by the rosin flux.

Chapter 3

Shop Math

Chapter Objective: To review the rules of basic math and to demonstrate proficiency in its use prior to the study of electronics. Some students will be able to skip this chapter due to satisfactory training in school. If a grade of 80% correct or better is not received on the pretest, the student should go through the practice exercises to obtain basic math competency.

Chapter Outline:

- Shop math pretest
- Fractions
- Arithmetic with fractions
- Decimals
- Percent tolerance
- Positive and negative numbers
- Solving equations
- Solving formulas
- Programs for this chapter
- Shop math competency test

SHOP MATH PRETEST

A calculator *may not* be used when taking this test. Solve each of the problems as indicated by the instructions for each section.

Part 1. Evaluation of Fractions

Arrange the following sets of numbers in descending order, starting with the largest.

(1) $\frac{1}{4}$ $\frac{2}{5}$ $\frac{3}{10}$ $\frac{1}{8}$

(2) $\frac{3}{4}$ $\frac{9}{16}$ $\frac{7}{8}$ $\frac{17}{32}$

Part 2. Arithmetic with Fractions

Perform the indicated operations, reduce to lowest terms.

(3) $3\frac{5}{6} - 1\frac{1}{3} =$

- (4) $6\frac{2}{5} + 9\frac{1}{3} =$
- (5) $5\frac{2}{3} \times 4\frac{1}{6} =$
- (6) $3\frac{1}{2} \div 4\frac{4}{6} =$
- (7) $4\frac{1}{6} - 2\frac{2}{3} =$
- (8) $5\frac{3}{4} + 6\frac{1}{3} =$
- (9) $1\frac{24}{12} \times 2\frac{39}{13} =$
- (10) $3\frac{4}{5} \div 3\frac{8}{10} =$

- (11) If the numerator of a fraction is made larger, does the value of the fraction increase or decrease?
- (12) If the denominator of a fraction is made larger, does the value of the fraction increase or decrease?

Part 3. Arithmetic with Fractions

Perform the indicated operations with each of the following decimal numbers.

- (13) $53.46 + 3.5 + 2.901 =$
- (14) $12.2 \times 8 =$
- (15) $0.0012 + 5.409 + 9.2 =$
- (16) $49 \div 7 =$
- (17) $56.05 - 23.9 =$
- (18) $25.25 \times 25.5 =$
- (19) $100.0 + 10.001 + 3.059 =$
- (20) $5.6 \div 8 =$
- (21) $0.0035 - 0.0009 =$
- (22) $10 + 100 - .01 + .001 - 01.01 =$
- (23) $7.2 \div 12 =$
- (24) $87.5 \div 0.6 =$
- (25) $12.5 \times 8.752 =$

Part 4. Converting Fractions to Decimals

Change the following fractions to decimals.

Round to three decimal places.

- (26) $\frac{2}{5} =$
- (27) $\frac{7}{8} =$
- (28) $3\frac{6}{7} =$
- (29) $5\frac{4}{5} =$
- (30) $\frac{9}{6} =$
- (31) $\frac{7}{2} =$

Part 5. Converting Decimals to Fractions

Change the following decimals to fractions. Reduce the answer to lowest terms.

- (32) $0.333 =$
- (33) $0.6 =$
- (34) $0.625 =$
- (35) $3.3 =$
- (36) $6.25 =$
- (37) $8.400 =$
- (38) $4.03 =$
- (39) $7.75 =$

Part 6. Arithmetic with Positive and Negative Numbers

Perform the indicated operations with each of the following numbers.

- (40) $-5 + 3 =$
- (41) $(-2)(-3) =$
- (42) $7 - 4 =$
- (43) $(-3)(4) =$
- (44) $2 - 9 =$
- (45) $-5(3) =$
- (46) $0.5 - 0.7 =$
- (47) $6 \times -3 =$
- (48) $-1.5 - -3.6 =$
- (49) $-32 \div 8 =$

$$(50) -\frac{3}{4} - \frac{5}{8} =$$

$$(51) \frac{-4 \times 3}{6} =$$

$$(52) -\frac{3}{5} + \frac{13}{15} =$$

$$(53) \frac{-3 \times -5}{-5 \times 3} =$$

$$(54) 22 + -33 =$$

$$(55) \frac{\begin{matrix} (7) & (-2) \\ (-2) & \end{matrix}}{\begin{matrix} (-3) & (4) \\ (-7) & \end{matrix}} =$$

Part 7. Raising Numbers to a Power

Perform the following indicated operations.

$$(56) 2^2$$

$$(57) -3^2$$

$$(58) -2^3$$

$$(59) 3^3$$

Part 8. Square Root

Take the square root of each of the following numbers. If the numbers given are not perfect squares, approximate to one decimal place.

$$(60) 25 =$$

$$(61) 81 =$$

$$(62) 8 =$$

$$(63) 0.04 =$$

Part 9. Values of Numbers

With each of the following, use the given value to find the two unknown values.

$$(64) \frac{1}{4} \quad \begin{array}{l} \text{decimal} \\ \text{value?} \end{array} \quad \begin{array}{l} \text{percent} \\ \text{value?} \end{array}$$

$$(65) .5 \quad \begin{array}{l} \text{fraction} \\ \text{value?} \end{array} \quad \begin{array}{l} \text{percent} \\ \text{value?} \end{array}$$

$$(66) 33\frac{1}{3}\% \quad \begin{array}{l} \text{decimal} \\ \text{value?} \end{array} \quad \begin{array}{l} \text{percent} \\ \text{value?} \end{array}$$

$$(67) .125 \quad \begin{array}{l} \text{fraction} \\ \text{value?} \end{array} \quad \begin{array}{l} \text{percent} \\ \text{value?} \end{array}$$

$$(68) \frac{3}{8} \quad \begin{array}{l} \text{decimal} \\ \text{value?} \end{array} \quad \begin{array}{l} \text{percent} \\ \text{value?} \end{array}$$

$$(69) .1\% \quad \begin{array}{l} \text{fraction} \\ \text{value?} \end{array} \quad \begin{array}{l} \text{decimal} \\ \text{value?} \end{array}$$

$$(70) .4 \quad \begin{array}{l} \text{fraction} \\ \text{value?} \end{array} \quad \begin{array}{l} \text{percent} \\ \text{value?} \end{array}$$

Part 10. Percent tolerance

With each of the following tolerance problems, determine the minimum and maximum allowable values based on the percent tolerance given.

$$(71) 100 \quad \pm 5\%$$

$$(72) 270 \quad \pm 5\%$$

$$(73) 330 \quad \pm 10\%$$

$$(74) 470 \quad \pm 20\%$$

$$(75) 1000 \quad \pm 1\%$$

$$(76) 2200 \quad \pm 5\%$$

$$(77) 3500 \quad \pm 10\%$$

$$(78) 4900 \quad \pm 15\%$$

$$(79) 8700 \quad \pm 2\%$$

$$(80) 10,000 \quad \pm 10\%$$

Part 11. Solving Equations

Solve each of the following equations.

$$(81) x + 4 = 9$$

$$(82) y + 6 = -4$$

$$(83) a - 5 = 0$$

$$(84) 2a + 3a = 10$$

$$(85) 4y = 3y + 2$$

$$(86) -100 = -5y$$

$$(87) 7(5x - 2) = 6(6x - 1)$$

$$(88) 8(2x + 1) = 4(7x + 8)$$

$$(89) 0(x + 3) = 2x$$

$$(90) x = \frac{4}{x}$$

Part 12. Solving Formulas

With each of the formulas below, substitute the given quantities and solve the formula for the

remaining unknown. Note: π stands for the Greek letter which has the value of 3.14.

$$(91) A = W \cdot P \text{ [Given: } W = 1500, P = .05]$$

$$(92) F = \frac{9}{5} C + 32 \text{ [Given: } C = 20]$$

$$(93) F = \frac{9}{5} C + 32 \text{ [Given: } F = 40]$$

$$(94) d = rt \cdot \text{ [Given: } r = 50, t = 2.5]$$

$$(95) A = \frac{1}{2} bh \cdot \text{ [Given: } A = 32, b = 4]$$

$$(96) P = 2L + 2W \text{ [Given: } P = 200, W = 40]$$

$$(97) E = IR \cdot \text{ [Given: } I = 2, E = 120]$$

$$(98) X_c = \frac{1}{2 \pi f C}$$

$$\text{Given: } f = 60, C = .002$$

Note: all terms are multiplied.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\text{Given: } R_1 = 40, R_2 = 60, R_3 = 80$$

$$(100) X_L = 2 \cdot \pi \cdot f \cdot L$$

$$\text{Given: } f = 50, L = .1$$

INTRODUCTION

The purpose of this chapter, in general, is to ensure that the student is properly prepared in the areas of basic mathematics prior to the study of electronics.

This section deals with a classification called basic math. The objective here will be to provide the rules and show some sample problems in the areas of fractions, decimals, percentages. Keep in mind, the emphasis will be on review of the rules. It is assumed here that the student has already learned basics at some point and needs only to have the rules refreshed.

FRACTIONS

Fractions will be dealt with in two groups; (1) definitions, improper fractions and mixed numbers,

reducing and equivalent fractions, (2) arithmetic with fractions. The groups have been selected so the rules of each group are similar. There will be practice exercises at the end of each group.

Definitions

Fraction. part of a whole. The fraction in mathematics is written as one number over another, which actually means the top number is divided by the bottom number. For example; $\frac{3}{5}$ means 3 divided by 5.

Numerator. the top number of a fraction. The numerator tells how many parts of the whole. A larger numerator represents a fraction with a larger value. For example; $\frac{3}{4}$ is larger than $\frac{1}{4}$.

Denominator. the bottom number of a fraction. The denominator tells how many parts the whole was divided into. If the denominator is increased, the whole was divided into more parts. If the size of the numerator remains the same, the fraction is smaller with a larger denominator. An example is slicing a pie. If the pie is sliced into 8 pieces, each piece is smaller than if it were only sliced into 4 pieces.

Whole Number. a number that does not contain a fractional part. An example is the counting numbers; 1, 2, 3, 4, etc.

Mixed Number. a number that contains both a whole number and a fraction. For example; $2\frac{2}{3}$.

Improper Fraction. the numerator is larger than the denominator. This means the value of the fraction is larger than 1. A proper fraction is always less than 1. Therefore, the improper fraction should be changed to a mixed number as a final answer. For example; $\frac{3}{2}$ is equal to $1\frac{1}{2}$. Note; an improper fraction is used when performing certain mathematical operations.

Reducing Fractions. to lower the size of both numerator and denominator, without changing the value of the fraction. Example; $\frac{2}{4} = \frac{1}{2}$. Reducing to the lowest terms is best.

Equivalent Fractions. to raise (or lower) the size of both numerator and denominator, without changing the value of the fraction. This is necessary to find common denominators or to compare the values of several fractions.

Common Denominator. fractions are changed to have the same denominator, while still retaining their original value. This is necessary with addition and subtraction. Example; $\frac{1}{2} = \frac{3}{6}$, $\frac{2}{3} = \frac{4}{6}$.

Improper Fractions, Mixed Numbers, Reducing and Equivalent Fractions

Addition and subtraction allow the use of mixed numbers or improper fractions. Multiplication and division do not allow mixed numbers, and they must be performed with fractions only. Regardless of which mathematical operation is performed, the final answer should be presented in the form of a proper fraction or mixed number, with the fractions reduced to lowest terms.

Key Point. To change a mixed number to an improper fraction, multiply the whole number times the denominator and add the numerator to this product. Write that result over the original denominator.

Examples: Mixed Numbers to Improper Fractions

$$3 \frac{2}{5} = \frac{17}{5} \quad 3 \times 5 = 15 + 2 = \frac{17}{5}$$

$$2 \frac{1}{3} = \frac{7}{3} \quad 2 \times 3 = 6 + 1 = \frac{7}{3}$$

$$4 \frac{2}{5} = \frac{22}{5} \quad 4 \times 5 = 20 + 2 = \frac{22}{5}$$

$$7 \frac{1}{2} = \frac{15}{2} \quad 7 \times 2 = 14 + 1 = \frac{15}{2}$$

$$8 \frac{3}{4} = \frac{35}{4} \quad 8 \times 4 = 32 + 3 = \frac{35}{4}$$

Key Point. To change an improper fraction to a mixed number, divide the numerator by the denominator. This division will produce a whole number or a whole number and a remainder. The remainder placed over the original denominator will be the fractional part.

Examples: Improper Fractions to Mixed Numbers

$$\frac{22}{11} = 2 \quad 22 \text{ (divided by) } 11 = 2$$

$$\frac{25}{11} = 2 \frac{3}{11} \quad 25 \div 11 = 2 \text{ r } \frac{3}{11}$$

$$\frac{17}{2} = 8 \frac{1}{2} \quad 17 \div 2 = 8 \text{ r } \frac{1}{2}$$

$$\frac{23}{3} = 7 \frac{2}{3} \quad 23 \div 3 = 7 \text{ r } \frac{2}{3}$$

$$\frac{8}{5} = 1 \frac{3}{5} \quad 8 \div 5 = 1 \text{ r } \frac{3}{5}$$

Key Point. To reduce a fraction to lower terms, divide both numerator and denominator by the same number. To find an equivalent fraction, multiply numerator and denominator by the same number.

Examples: Reducing Fractions

$$\frac{4}{8} = \frac{1}{2} \quad \text{Divided both by 4}$$

$$\frac{3}{9} = \frac{1}{3} \quad \text{Divided both by 3}$$

$$\frac{5}{25} = \frac{1}{5} \quad \text{Divided both by 5}$$

$$\frac{16}{18} = \frac{8}{9} \quad \text{Divided both by 2}$$

$$\frac{27}{45} = \frac{3}{5} \quad \text{Divided both by 9}$$

Examples: Equivalent Fractions

Change the fraction on the left to an equivalent fraction with the denominator shown on the right.

$$\frac{7}{8} = \frac{?}{16} \quad \text{Multiply by 2} = \frac{14}{16}$$

$$\frac{2}{5} = \frac{?}{45} \quad \text{Multiply by 9} = \frac{18}{45}$$

$$\frac{3}{4} = \frac{?}{12} \quad \text{Multiply by 3} = \frac{9}{12}$$

$$\frac{1}{9} = \frac{?}{63} \quad \text{Multiply by 7} = \frac{7}{63}$$

$$\frac{5}{8} = \frac{?}{32} \quad \text{Multiply by 4} = \frac{20}{32}$$

$$(11) \frac{19}{4} =$$

$$(12) \frac{37}{6} =$$

$$(13) \frac{28}{3} =$$

$$(14) \frac{37}{8} =$$

$$(15) \frac{28}{7} =$$

$$(16) \frac{34}{25} =$$

$$(17) \frac{47}{9} =$$

$$(18) \frac{11}{4} =$$

$$(19) \frac{18}{2} =$$

$$(20) \frac{40}{10} =$$

Practice Problems: Fractions

A. Change the following mixed numbers to improper fractions:

$$(1) 3 \frac{2}{3} =$$

$$(2) 13 \frac{3}{7} =$$

$$(3) 4 \frac{1}{20} =$$

$$(4) 1 \frac{2}{3} =$$

$$(5) 5 \frac{5}{6} =$$

$$(6) 3 \frac{7}{8} =$$

$$(7) 2 \frac{3}{5} =$$

$$(8) 4 \frac{3}{10} =$$

$$(9) 7 \frac{5}{9} =$$

$$(10) 2 \frac{3}{4} =$$

C. Arrange the following sets of numbers in ascending order, from smallest to largest.

$$(21) \frac{5}{8} \quad \frac{3}{4} \quad \frac{7}{16} \quad \frac{1}{2}$$

$$(22) \frac{3}{32} \quad \frac{3}{16} \quad \frac{1}{8} \quad \frac{5}{64}$$

$$(23) \frac{4}{10} \quad \frac{51}{100} \quad \frac{12}{25} \quad \frac{1}{2}$$

$$(24) \frac{15}{16} \quad \frac{33}{32} \quad 1 \quad 1 \frac{1}{64}$$

$$(25) 5 \frac{1}{4} \quad 5 \frac{3}{64} \quad 5 \frac{1}{3} \quad 5 \frac{4}{9}$$

B. Change the following improper fractions to mixed numbers. Reduce answer to lowest terms.

ARITHMETIC WITH FRACTIONS

The rules for arithmetic with fractions are separated into two sections; multiplication/division and addition/subtraction. When it is thought of in this way, there are only two sets of rules that need to be learned. There will be practice exercises at the end of this section.

Multiplication/Division

Key Point. Mixed numbers must first be changed to improper fractions prior to multiplication or division.

Key Point. Multiply the numerators, then multiply the denominators. Answer must be reduced to lowest terms.

Key Point. With division problems; invert the divisor (the number following the division sign) and multiply.

Sample Problems: Multiplication/Division

SP#3-1 Multiply: $2\frac{3}{4} \times \frac{2}{5} =$

Step 1: Change mixed numbers to improper fractions:

$$2\frac{3}{4} = \frac{11}{4}$$

Step 2: Multiply numerators, then multiply denominators:

$$\frac{11 \times 2}{4 \times 5} = \frac{22}{20}$$

Step 3: Reduce to lowest terms:

$$\frac{22}{20} = 1\frac{2}{20} = 1\frac{1}{10}$$

SP#3-2 Divide: $4\frac{2}{3} \div 3\frac{1}{2} =$

Step 1: Change mixed numbers to improper fractions:

$$4\frac{2}{3} = \frac{14}{3}$$

$$3\frac{1}{2} = \frac{7}{2}$$

Step 2: Re-write the problem to show improper fractions:

$$\frac{14}{3} \div \frac{7}{2}$$

Step 3: Invert the divisor then multiply:

$$\frac{14}{3} \times \frac{2}{7} = \frac{28}{21}$$

Step 4: Reduce to lowest terms:

$$\frac{28}{21} = 1\frac{7}{21} = 1\frac{1}{3}$$

Addition/Subtraction

Key Point. It is not necessary to change mixed numbers to improper fractions, although it is often easier, especially with subtraction.

Key Point. A common denominator is required to add or subtract fractions. A common denominator is when all fractions have the same denominator.

Key Point. The common denominator is found by determining which number all denominators of the fractions can divide into evenly.

Key Point. To add or subtract the numerators, keeping the common denominator. Always reduce the answer to lowest terms.

Sample Problems: Addition/Subtraction

SP#3-3 Add: $\frac{1}{2} + \frac{2}{3} =$

Step 1: The common denominator is 6. Change the

fractions to their equivalent with this denominator:

$$\frac{1}{2} = \frac{3}{6}$$

$$\frac{2}{3} = \frac{4}{6}$$

Step 2: Re-write the problem using the common denominator:

$$\frac{3}{6} + \frac{4}{6} =$$

Step 3: Add the numerators, keeping the common denominator:

$$\frac{3 + 4}{6} = \frac{7}{6}$$

Step 4: Reduce to lowest terms:

$$\frac{7}{6} = 1 \frac{1}{6}$$

SP#3-4 Add: $2\frac{3}{4} + 3\frac{2}{5} =$

Step 1: Find common denominator and change to equivalent. Note: this problem can be done in mixed numbers or with improper fractions. CD = 20

$$2\frac{3}{4} = 2\frac{15}{20}$$

$$3\frac{2}{5} = 3\frac{8}{20}$$

Step 2: Re-write the problem with the common denominator:

$$2\frac{15}{20} + 3\frac{8}{20} =$$

Step 3: Add the whole numbers, then add the fractions:

$$2 + 3 = 5$$

$$\frac{15}{20} + \frac{8}{20} = \frac{23}{20}$$

Step 4: Combine the whole number with the fraction and reduce to lowest terms:

$$5\frac{23}{20} = 6\frac{3}{20}$$

SP#3-5 Subtract: $7\frac{2}{5} - 3\frac{1}{2} =$

Step 1: It is usually best with subtraction to first change to improper fractions:

$$\frac{37}{5} - \frac{7}{2} =$$

Step 2: Common denominator is 10. Change to equivalent:

$$\frac{37}{5} = \frac{74}{10}$$

$$\frac{7}{2} = \frac{35}{10}$$

Step 3: Subtract numerators keeping common denominator. Reduce to lowest terms.

$$\frac{74}{10} - \frac{35}{10} = \frac{39}{10}$$

$$\frac{39}{10} = 3\frac{9}{10}$$

Practice Exercises: Arithmetic with Fractions

Perform the indicated operations. Reduce all answers to lowest terms.

(1) $\frac{1}{2} \times \frac{1}{4}$

$$(2) \frac{1}{2} \div \frac{1}{4}$$

$$(3) \frac{1}{2} + \frac{1}{4}$$

$$(4) \frac{1}{2} - \frac{1}{4}$$

$$(5) \frac{2}{3} \times \frac{3}{5}$$

$$(6) \frac{3}{4} \div \frac{4}{7}$$

$$(7) \frac{5}{6} + \frac{2}{5}$$

$$(8) \frac{6}{7} - \frac{1}{3}$$

$$(9) 6 \times \frac{2}{3}$$

$$(10) \frac{6}{7} \div 3$$

$$(11) 2\frac{2}{6} + 0\frac{3}{9}$$

$$(12) 6\frac{3}{4} - 5$$

$$(13) 2\frac{1}{7} \times 3\frac{4}{3}$$

$$(14) 1\frac{1}{2} \div 4\frac{2}{4}$$

$$(15) 3\frac{3}{10} + 2\frac{2}{15}$$

$$(16) 8 - 2\frac{3}{7}$$

$$(17) \frac{4}{5} \times \frac{6}{7} \div \frac{8}{9}$$

$$(18) \frac{1}{2} \times \frac{3}{4} \times \frac{5}{6}$$

$$(19) \frac{3}{4} + \frac{1}{3} + \frac{5}{8} - \frac{2}{6}$$

$$(20) \frac{1}{2} + \frac{5}{6} - \frac{1}{3} - \frac{1}{4}$$

DECIMALS

Arithmetic with decimals is very similar to using whole numbers, therefore, most people find it fairly easy to work with decimals. Also decimals are more familiar to most people because money is handled in decimal form.

This section on decimals is primarily to review the rules and demonstrate some sample problems in case the student needs the review. Practice problems are available at the end of the section.

Addition/Subtraction with Decimals

Key Point. When adding or subtracting decimals, it is necessary to operate on numbers with the same place value. This is best done by aligning the decimal points in a column.

Sample Problems: Addition/Subtraction

SP#3-6 Add: $2.3 + 3.65 + 10.321 =$

Align the decimal points in a column. If desired, zeros may be added to make an equal number of decimal places for each number. Add the numbers in the same place value columns.

$$\begin{array}{r} 2.3 \\ 3.65 \\ + 10.321 \\ \hline 16.271 \end{array}$$

SP#3-7 Subtract: $4.2 - 1.863 =$

Align the decimal points and place zeros to have equal columns for borrowing during subtraction.

$$\begin{array}{r} 4.200 \\ - 1.863 \\ \hline 2.337 \end{array}$$

Multiplication with Decimals

Key Point. When multiplying numbers with decimals, proceed as if using whole numbers, ignoring the decimal.

Key Point. To determine the decimal place of the answer, count from the right a number of decimal places equal to the *total* decimal places of the numbers multiplied.

Sample Problem: Multiplication

SP#3-8 Multiply: $3.245 \times 2.3 =$

Multiply ignoring the decimals, then count the total number of decimal places. The total number of places is 4; 3 in the top number and 1 in the bottom number. Count from the right, the total number of places.

$$\begin{array}{r} 3.245 \\ \times 2.3 \\ \hline 7.4635 \end{array}$$

Division with Decimals

Key Point. If the number outside of the division bracket has a decimal point; it is necessary to move the decimal to the right enough places to be at the bracket. Move the decimal of the number inside the bracket enough places to equal the move outside.

Key Point. Perform the division placing the answer above the proper place and place the decimal point directly over the corrected decimal inside the bracket.

Sample Problem: Division

SP#3-9 Divide: $36.3 \div .08$

Step 1. Write the problem using the division bracket. Notice (.08) needs to have the decimal point moved to place it at the right of the number, next to the bracket.

$$.08 \overline{)36.3}$$

Step 2. Move the decimal in both (.08) and (36.3) two places to the right. Add zeros to the inside number (36.3) to complete the move.

$$08. \overline{\sqrt{3630.}}$$

Step 3. Divide placing the answer and the decimal in their correct places.

$$\begin{array}{r} 453.75 \\ 8\overline{\sqrt{3630.00}} \end{array}$$

Changing Fractions to Decimals and Decimals to Fractions

Key Point. To change a fraction to a decimal; divide the numerator by the denominator.

Sample Problem: Fraction to Decimal

SP#3-10 Change $\frac{5}{8}$ to a decimal.

$$5 \div 8 = 0.625$$

Key Point. To change a decimal to a fraction; remove the decimal point and write the number over the equivalent place value and reduce to lowest terms. The place value is a multiple of 10 with the same number of zeros as the original decimal number.

Sample Problem: Decimal to Fraction

SP#3-11 Change .75 to a fraction.

$$.75 = \frac{75}{100} = \frac{3}{4}$$

Practice Problems: Decimals

Perform the indicated operations on each of the following.

- (1) $2.8 + 12.19$
- (2) $0.8 - 0.5$

- (3) $.4 \times 3$
 (4) $9.63 \div 3$
 (5) $6.3 + 1.07 + 3$
 (6) $0.28 - .19$
 (7) 0.5×0.043
 (8) $.372 \div .06$
 (9) $2.8 + 1.90 + 51.012$
 (10) $6.9 - 2.47$
 (11) 0.2×0.03
 (12) $1.04 \div 2$
 (13) $49 + .07 + 3.5 - 12.608$
 (14) $100 + .001 - 10.01 + 1.10$
 (15) $16.32 \div 0.008$
 (16) $0.002 \times .0003 \times 1.01$

(17)
$$\frac{1}{2 \times 3.14 \times 100 \times .002}$$

(18)
$$\frac{1}{2 \times \pi \times 50 \times .0000001}$$

(19)
$$\frac{1}{6.28 \times 10000 \times 0.00000005}$$

(20)
$$\frac{.159}{100,000 \times .000000150}$$

Change the following fractions to decimals.

(21) $\frac{3}{8}$

(22) $\frac{2}{5}$

(23) $\frac{3}{16}$

(24) $2\frac{3}{9}$

(25) $5\frac{1}{8}$

Change the following decimals to fractions. Reduce to lowest terms.

(26) 1.3

(27) .667

- (28) .009
 (29) .4
 (30) .3125

PERCENT TOLERANCE

There are many different types of percentage problems. Of these, there is really only type that is used on a regular basis in the field of electronics. That type of percentage problem is "tolerance".

All electronic components, instruments, measurements, calculations and the operation of equipment have a tolerance that is considered acceptable.

It is very important for the student of electronics to understand that, with all the fancy calculations made, there is a range that is considered acceptable.

Most tolerances relating to electronics are stated as a \pm percentage of the ideal. (\pm means "plus or minus".) A tolerance of $\pm 10\%$ means the measurement can be high or low by 10% of the ideal and still be within an acceptable range.

Changing Percents to Decimals and Decimals to Percents

In order to deal with a percentage mathematically, it is necessary to change the percentage to a decimal. Then the mathematical operation can be performed using the decimals.

Key Point. To change a percentage to its decimal form; remove the percent sign and move the decimal to the left two (2) places.

Key Point. To change a decimal to a percent; move the decimal to the right two (2) places and attach the percent sign.

Examples: Percents and Decimals

10% = .10 1.5% = .015

15% = .15 2.5% = .025

20% = .20 7.5% = .075

100% = 1.00 .15% = .0015

235% = 2.35 .25% = .0025

500% = 5.00 .5% = .005

1% = .01 12.5% = .125

2% = .02 15.75% = .1575

5% = .05 20.375% = .20375

Percent Tolerance

Key Point. Tolerance is a percentage of the nominal (ideal) value to allow a calculation of the maximum and minimum acceptable values.

Key Point. Max and min values are calculated by taking the percentage of the nominal value and adding and subtracting from the nominal value.

Sample Problems: Percent Tolerance

In each of the following problems, use the percent tolerance given, and the nominal value, to find the maximum and minimum acceptable values.

SP#3-12 200 +/-10%

Step 1. Change percent to decimal.

$$10\% = .1$$

Step 2. Multiply the decimal times the nominal value to find tolerance.

$$200 \times .1 = 20$$

Step 3. Find the maximum value by ADDING tolerance to nominal value.

$$200 + 20 = 220$$

Step 4. Find the minimum value by SUBTRACTING tolerance from nominal value.

$$200 - 20 = 180$$

SP#3-13 33,000 +/-15%

Step 1. Change the percentage to its decimal equivalent.

$$15\% = .15$$

Step 2. Multiply the decimal times the nominal value to find tolerance.

$$33,000 \times .15 = 4950$$

Step 3. Find the maximum value by ADDING tolerance to nominal value.

$$33,000 + 4950 = 37,950$$

Step 4. Find the minimum value by SUBTRACTING tolerance from the nominal value.

$$33,000 - 4950 = 28,050$$

Practice Problems: Percent Tolerance

With each of the following, determine the maximum and minimum allowable values.

- (1) 100 +/-5%
- (2) 470 +/-10%
- (3) 860 +/-20%
- (4) 1000 +/-10%
- (5) 1500 +/-15%
- (6) 2200 +/-1%
- (7) 3300 +/-2%
- (8) 4700 +/-5%
- (9) 6800 +/-10%
- (10) 10,000 +/-10%

POSITIVE AND NEGATIVE NUMBERS

Both positive and negative numbers are of importance when dealing with subject areas in the electronics field.

Negative numbers have essentially two definitions; (1) numbers with a value less than zero also called minus numbers. An example is a thermometer. (2) opposite positive. Often used in terms of direction. An example is going backwards.

Positive and negative numbers are often called "signed numbers" for simplicity. All numbers, except zero, have either a positive or negative sign. If none is written, the sign is positive. Zero is neither positive nor negative; zero has no sign.

Addition and Subtraction of Signed Numbers

Key Point. When adding; if the signs of the two numbers are the same, add the numbers and keep the same sign.

Key Point. When adding; if the signs of the two numbers are different, subtract the numbers and take the sign of the larger number.

Key Point. When subtracting; change the sign of the number being subtracted and change the subtraction sign to addition. Follow the rules for addition.

Examples: Addition/Subtraction

Addition with same signs:

$$\begin{aligned}6 + 5 &= 11 \\ -3 + -4 &= -7\end{aligned}$$

Addition with opposite signs:

$$\begin{aligned}-7 + 3 &= -4 \\ -1 + 9 &= 8 \\ 8 + -4 &= 4 \\ 2 + -6 &= -4\end{aligned}$$

Subtraction:

$$\begin{aligned}5 - 3 &= 5 + -3 = 2 \\ 6 - -2 &= 6 + +2 = 8 \\ -3 - 1 &= -3 + -1 = -4 \\ -4 - -9 &= -4 + +9 = 5\end{aligned}$$

Multiplication and Division with Signed Numbers

Key Point. The operations of multiplication or division are performed without regard to the signs. The positive or negative sign is placed on the final answer (product or quotient).

Key Point. Same signs produce a positive answer. Opposite signs produce a negative answer.

Examples: Multiplication/Division

Multiplication/division with same signs:

$$\begin{aligned}2 \times 5 &= 10 \\ -3 \times -6 &= 18 \\ 6 \div 2 &= 3 \\ -8 \div -4 &= 2\end{aligned}$$

Multiplication/division with opposite signs:

$$\begin{aligned}3 \times -2 &= -6 \\ -1 \times 4 &= -4 \\ 9 \div -3 &= -3 \\ -12 \div 6 &= -2\end{aligned}$$

Fractions with Signs

Key Point. When dealing with fractions, there are three signs with which to consider; (1) the sign in front or the addition/subtraction sign, (2) the sign of the numerator, (3) the sign of the denominator.

Key Point. A fraction is positive if all three signs are positive or if two of the three signs are negative.

Key Point. A fraction is negative if all three signs are negative or if one of the three signs is negative.

Examples: Positive and Negative Fractions

Positive fractions:

$$+\frac{3}{5} = +\frac{-3}{-5} = -\frac{-3}{5} = -\frac{3}{-5}$$

Negative fractions:

$$-\frac{5}{6} = -\frac{-5}{-6} = +\frac{-5}{6} = +\frac{5}{-6}$$

Practice Problems:

Positive and Negative Numbers

Perform the indicated operations on the following signed numbers.

- (1) $15 + 12$
- (2) $-7 + 0$
- (3) $2 + -4$
- (4) $-5 + -7$
- (5) $6 - 5$
- (6) $2 - 8$
- (7) $-5 - 3$
- (8) $-2 - 7$
- (9) $8 - -1$

- (10) $5 - -15$
- (11) $-9 - -6$
- (12) $-3 - -7$
- (13) 2×4
- (14) 5×-2
- (15) -6×7
- (16) -5×-8
- (17) -1×0
- (18) $9 \div -1$
- (19) $-8 \div 2$
- (20) $-12 \div -6$

Determine if the following fractions are positive or negative.

- (21) $+$ $\frac{1}{3}$
- (22) $\frac{3}{4}$
- (23) $\frac{-3}{-7}$
- (24) $-$ $\frac{2}{-3}$
- (25) $-$ $\frac{4}{7}$
- (26) $-$ $\frac{-5}{-6}$
- (27) $+$ $\frac{-2}{9}$
- (28) $+$ $\frac{3}{-7}$
- (29) $-$ $\frac{-4}{5}$
- (30) $\frac{-2}{5}$

SOLVING EQUATIONS

The study of electronics and most scientific subjects involves the use of many formulas. The proper

use of formulas requires using basic algebra to manipulate the equation and solve for the unknown. This section will concentrate on the skills needed to solve equations.

Variables, Coefficients, and Constants

A variable is a letter used in an algebraic expression to represent an unknown numerical value. Most formulas contain several variables. In order to solve the formula, a numerical value must be known for each variable, except one. The one remaining variable will be solved for using algebra.

A coefficient is a number that is written beside (usually in front of) a variable. It is constant to the formula, because it does not change, but its purpose is to be a multiplier for the variable.

A constant is a number that is part of the equation. It remains the same value regardless of how the variables are changed.

Solving Equations

Key Point. When solving equations, the final goal is to have the unknown by itself on one side of the equation, equal to a number. The equation at this stage does not indicate any arithmetic to be performed. Example: $x = 5$

Key Point. Terms are “transposed” (mathematically moved) from one side of the equation, to the other, by performing arithmetic that is opposite to the operation indicated by the equation. Operations of transposing must be performed equally to both sides of the equation.

Key Point. Only “like terms” can be added or subtracted. Like terms are ones that either do not have a variable or the variables are identical. The coefficients do not have an affect if the variables are identical.

Examples of like terms:

- Any Number by Itself; 1, 2, 3, etc.
- Identical variables; x , $2x$, $3x$, etc.

Examples of unlike terms:

- Nonidentical Variables; x , y , a

Sample Problems: Solving Equations

SP#3-14 Addition; transpose by subtraction.

Step 1. Starting equation:

$$x + 3 = 7$$

Step 2. Notice the indicated addition on the left side. Remove this addition by subtracting 3 from both sides.

$$x + 3 - 3 = 7 - 3$$

Step 3. Perform the subtractions as indicated. Notice the left side will have only the x remaining and the right side has only a number. This equation is now solved.

$$x = 4$$

Step 4. Check the results by substituting the answer into the original equation in place of the variable. $()$ shows the substitution.

$$(4) + 3 = 7$$

SP#3-15 Subtraction; transpose by addition.

Step 1. Starting equation:

$$y - 8 = 4$$

Step 2. The left side of the equation indicates subtraction. Remove this by adding to both sides.

$$y - 8 + 8 = 4 + 8$$

Step 3. Perform the arithmetic and the equation will be solved.

$$y = 12$$

Step 4. Substitute into the original equation to check the answer.

$$(12) - 8 = 4$$

SP#3-16 Multiplication; transpose by division.

Step 1. Starting equation:

$$4a = 20$$

Step 2. Multiplication is indicated by writing a number alongside the variable. This is called a coefficient. Remove by dividing from both sides.

$$\frac{4a}{4} = \frac{20}{4}$$

Step 3. Perform the arithmetic and the equation will be solved.

$$a = 5$$

Step 4. Substitute into the original equation to check the answer. Note: parenthesis $()$ next to a number or variable, without an addition or subtraction sign, indicate multiplication.

$$4(5) = 20$$

SP#3-17 Division; transpose by multiplying.

Step 1. Starting equation:

$$\frac{x}{5} = -2$$

Step 2. The division is removed by multiplying both sides.

$$\frac{x(5)}{5} = -2(5)$$

Step 3. Perform the arithmetic and the equation will be solved.

$$x = -10$$

Step 4. Substitute into the original equation to check answer.

$$\frac{(-10)}{5} = -2$$

SP#3-18 Solving a complex sample equation.

Step 1. Original equation:

$$2x + 7 = 19 - 4x$$

Step 2. First remove addition and/or subtraction. Subtract 7 in one step and then 4x in another step. Do not combine steps because it gets very confusing.

$$2x + 7 - 7 = 19 - 4x - 7$$

Step 3. Simplify by performing the arithmetic shown in step 2.

$$2x = 12 - 4x$$

Step 4. To remove the 4x from the right side, add.

$$2x + 4x = 12 - 4x + 4x$$

Step 5. Simplify by performing the arithmetic shown in step 4.

$$6x = 12$$

Step 6. Solve the equation by dividing by 6.

$$x = 2$$

Step 7. Substitute into the original equation to check answer.

$$\begin{aligned} 2(2) + 7 &= 19 - 4(2) \\ 4 + 7 &= 19 - 8 \\ 11 &= 11 \text{ (checks)} \end{aligned}$$

Practice Problems: Solving Equations

With each of the following equations; solve for the unknown.

- (1) $x + 4 = 9$
- (2) $x + 3 = 7$
- (3) $4 = -6 - y$
- (4) $y + 3 = -1$
- (5) $a - 5 = 0$
- (6) $7 - a = 6$
- (7) $2a + 3a = 10$
- (8) $x + 5 + 3x = 6$
- (9) $4y = 3y + 2$
- (10) $81 = 9x$
- (11) $-100 = -5y$
- (12) $5 + y = 6y - 7 + 5y$
- (13) $100 = 50 + x + 25$
- (14) $(x)(x) = 4$
- (15) $3 - y - 2y = 6 - 6y - 6y$

SOLVING FORMULAS

Formulas and equations are essentially the same as far as the mathematics is concerned. The difference between them is the fact that a formula contains several different unknowns, where the equation contains one unknown. To solve the formula, all of the unknowns will have values given, except one. The formula then becomes an equation, with one unknown. Solving this equation is actually solving the formula for that particular unknown.

Sometimes it is necessary to re-arrange the formula to make it easier to solve for a particular unknown. When this is done, the indicated arithmetic will be transposed from one side of the equation to the other.

Key Point. When arithmetic operations are transposed, they become the opposite on the other side of the equals sign.

Sample Problems: Transposing Formulas

SP#3-19 Solve for C:

$$F = \frac{9}{5} C + 32$$

(This is the formula used to find Fahrenheit degrees when Centigrade is given. Transposing will allow

finding Centigrade when Fahrenheit is given.)

Step 1. Subtract 32 from each side.

$$F - 32 \frac{9}{5} = C$$

Step 2. Multiply both sides by $\frac{5}{9}$. This is the same as dividing by $\frac{9}{5}$.

$$(F - 32) \frac{5}{9} = C$$

Note: it is necessary to enclose the left side in () because every term of that side must be multiplied. When using numbers, it is best to solve inside the () first.

Step 3. The formula can be turned around to have the C on the left side since this is more standard. It is not necessary. The formula is finished the way it is.

$$C = \frac{5}{9} (F - 32)$$

SP#3-20 Solve for L:

$$P = 2L + 2W$$

(This is the formula to find perimeter of a rectangle when length and width are known. Transposing will allow solving for length when perimeter and width are given.)

Step 1. Subtract 2W from both sides.

$$P - 2W = 2L$$

Step 2. Divide both sides by 2.

$$\frac{P - 2W}{2} = L$$

Key Point. When using formulas, usually all of the values will be given except one. When this is the case, simply substitute the given values in place of their respective variables. It is not necessary to transpose the equations prior to substituting values.

Sample Problems: Substituting Values

SP#3-21 Find the value of C; if F = 68

$$F = \frac{9}{5} C + 32$$

Step 1. Substitute the given value.

$$(68) = \frac{9}{5} C + 32$$

Step 2. Subtract 32 from both sides.

$$36 = \frac{9}{5} C$$

Step 3. Multiply both sides by $\frac{5}{9}$.

$$C = 20$$

SP#3-22 Find the value of L; P = 200, W = 40

$$P = 2L + 2W$$

Step 1. Substitute the given values.

$$(200) = 2L + 2(40)$$

Step 2. Simplify by performing indicated arithmetic.

$$200 = 2L + 80$$

Step 3. Subtract 80 from both sides.

$$120 = 2L$$

Step 4. Divide both sides by 2.

$$L = 60$$

Practice Problems: Formulas

With each of the following formulas; substitute the given values and solve for the remaining unknown.

$$(1) I = \frac{V}{R}$$

Find: I
Given: V = 100
R = 25

(This formula is Ohm's law to solve for current, I, with voltage, V, and resistance, R.)

$$(2) I = \frac{V}{R}$$

Find: R
Given: V = 50
I = 10

$$(3) W = Pt$$

Find: P
Given: W = 2500
t = 5

(This formula is used to find work, W, with power, P, and time, t.)

$$(4) W = Pt$$

Find: W
Given: P = 250
t = 10

$$(5) P = I^2R$$

Find: R
Given: P = 160
I = 2

(This formula is used to find power, P, with current, I, and resistance, R.)

$$(6) P = I^2R$$

Find: I
Given: P = 25
R = 1

(Note: to solve for I, it will be necessary to take the square root.)

$$(7) R_T = R_1 + R_2$$

Find: R_T
Given: $R_1 = 10$
 $R_2 = 25$

(This formula is used to find total resistance, R_T , in a series circuit with two resistors, R_1 and R_2 .)

$$(8) R_T = R_1 + R_2$$

Find: R_1
Given: $R_2 = 100$
 $R_T = 350$

$$(9) \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

Find: R_T
Given: $R_1 = 10$
 $R_2 = 25$

(This formula is used to find total resistance, R_T , in a parallel circuit with two resistors, R_1 and R_2 .) Note: it is easiest to use decimals.

$$(10) \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

Find: R_2
Given: $R_T = 10$
 $R_1 = 15$

$$(11) R_T = \frac{(R_1)(R_2)}{R_1 + R_2}$$

Find: R_T
Given: $R_1 = 30$
 $R_2 = 60$

(This is called the "short-cut" formula for finding the total resistance of two resistors in parallel.)

$$(12) R_T = \frac{(R_1)(R_2)}{R_1 + R_2}$$

Find: R_1
Given: $R_T = 100$
 $R_2 = 200$

$$(13) X_L = 2(\pi) f L$$

Find: X_L
Given: $(\pi) = 3.14$
f = 100
L = .2

(This formula is to find inductive reactance, X_L , when given frequency, f, and inductance, L. (π) is a constant in the formula and is always equal to 3.14. Note: all terms are multiplied.)

$$(14) X_L = 2(\pi) f L$$

Find: f
Given: L = .1
 $X_L = 37.68$

$$(15) X_C = \frac{1}{2(\pi) f C}$$

Find: X_C
Given: f = 1590
C = .0000001

(This formula is to find capacitive reactance, X_c , when given frequency, f , and capacitance, C).

PROGRAMS FOR THIS CHAPTER

The programs for this chapter are designed for the student to review and practice the rules of the shop math. The programs are a good way for the student to quickly find out if he or she remembers the rules and can perform the problems.

It is very important to make an honest attempt at solving the problem, rather than just guessing and allowing the computer to tell you the correct answer.

Each program has "help hints" to review the rules, whenever there is a wrong answer.

Upon completion of each quiz, or whenever desired, press N for your score and return to the SHOP MATH menu.

Figure 3-1 shows the shop math program menu and a sample to preview.

Shop Math Menu

- 1 Fraction to decimal
- 2 Decimal to fraction
- 3 Mixed to improper
- 4 Improper to proper
- 5 Evaluation
- 6 Operations
- 7 Percent
- 8 + and - numbers
- 9 Return to main menu

If 9 then disk drive on.

What is the number of your selection ?

Program sample:

1. What is the decimal equivalent of this fraction

$1/2 = ? .5$

Correct

Press space bar to continue, N for new selection.

Fig. 3-1. Shop math program menu and program sample.

- (74) 470 +/- 10%
 (75) 680 +/- 20%
 (76) 1000 +/- 10%
 (77) 5500 +/- 15%
 (78) 8200 +/- 5%
 (79) 10,000 +/- 15%
 (80) 10 +/- 1%

Part 9. Solving Equations

Solve each of the following equations.

- (81) $x + 5 = 9$
 (82) $7 + y = -10$
 (83) $a - 8 = 0$
 (84) $2a + 16 = 4a$
 (85) $12 - 5x = 3x - 12$
 (86) $-x = 16 + 3x$
 (87) $-250 = -25y$
 (88) $125 = -5a$
 (89) $7(5x - 2) = 6(6x - 1)$
 (90) $8(2x + 1) = 4(7x + 8)$

Part 10. Solving Formulas

With each of the formulas below, substitute the

given quantities and solve the formula for the remaining unknown. Note: $\pi = 3.14$

(91) $A = W P$ (Given: $W = 1200, P = .06$)

(92) $F = \frac{9}{5} C + 32$ (Given: $C = -40$)

(93) $F = \frac{9}{5} C + 32$ (Given: $F = 32$)

(94) $d = r t$ (Given: $r = 55, t = 2$)

(95) $A = \frac{1}{2} b h$ (Given: $A = 64, b = 8$)

(96) $P = 2L + 2W$ (Given: $P = 100, W = 20$)

(97) $R_T = \frac{(R_1)(R_2)}{R_1 + R_2}$ (Given: $R_1 = 10, R_2 = 30$)

(98) $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$
 (Given: $R_1 = 10, R_2 = 25, R_3 = 10$)

(99) $X_c = \frac{1}{2 \pi f C}$ (Given: $f = 50, C = .005$)

(100) $X_L = 2 \pi f L$ (Given: $f = 100, L = .1$)

Chapter 4

Engineering Notation

Chapter Objectives: To perform mathematical operations on numbers that are both very large and very small by using powers of 10. Also, to use multiplier names to replace the powers of 10. Exponential notation will also be introduced to simplify use of electronic calculator.

This chapter also provides an ideal opportunity for the student to master use of the electronic calculator.

Chapter Outline:

- Introduction
- Significant figures/rounding numbers
- Scientific notation
- Engineering notation
- Arithmetic operations with powers of 10
- Programs for this chapter
- Engineering notation competency test

INTRODUCTION

Engineering notation, scientific notation and exponential notation are methods of dealing with num-

bers that are either very large or very small. In electronics, as in most scientific fields, numbers at both extremes are quite common.

In this chapter, the task of determining the significant figures of a number and rounding will be discussed. The electronic calculator, the most widely used tool, makes use of exponential notation when accepting keyboard inputs and displaying the answer.

SIGNIFICANT FIGURES/ROUNDING NUMBERS

With all the formulas and calculations an electronics student makes, it is sometimes believed that all those calculations are accurate. Even though mathematics is very precise, with decimal places carried out to extremes, the accuracy of the calculations really depends on the numbers being used.

Numbers have two sources; measured and theoretical. When calculating circuits with either theoretical or measured values, it is important to keep in mind the fact that the components used in the circuit all have tolerances and the instruments used to

measure the circuits have tolerances. All of these tolerances lead to a considerable amount of inaccuracies. There is no sense in having numbers carried to several decimal places if the accuracy is in question. Usually, calculations are made to have three significant figures.

Significant Figures

The significant figures, or digits, of a number are the figures considered reliable. There are two guidelines to follow to determine the significant figures of a number:

1. All nonzero numbers (digits 1 - 9) are significant figures.
2. A zero used as a place holder between two nonzero numbers is significant.

Examples of Significant Figures:

1234 has four significant figures
1230 has three significant figures
1200 has two significant figures
.00123 has three significant figures
0.123 has three significant figures
.2050 has three significant figures
25.5 has three significant figures

Rounding Numbers

Rounding numbers is performed to make working with numbers easier, especially when arithmetic is involved. For example; if a person is counting money stacked in groups of \$1000 an extra \$2 might be considered insignificant. Therefore, \$1002 would be rounded off to \$1000.

Procedure for Rounding Numbers:

1. Determine how many significant figures will appear in the final number. The next digit to the right will determine the outcome of rounding.
2. If the number to the right is 5 or more, add 1 to the last significant figure and drop all the digits to the right.
3. If the number to the right is less than 5, do not adjust the last figure, simply drop all digits to the right.

4. Replace dropped digits with zeros, as place holders, to maintain place values of the significant figures.

Examples of Rounding Numbers

The following are rounded to three significant figures.

806,956 = 807,000
875.5 = 876
.003874 = .00387
.1009 = .101
80.78 = 80.8
98 = 100

Practice Problems: Rounding Numbers

Round each of the following numbers to three significant figures.

- (1) 6408
- (2) 4715
- (3) 5352
- (4) 9880
- (5) 102,589
- (6) 340,301
- (7) 119,815
- (8) 209,280
- (9) 327.09
- (10) 452.11
- (11) 999.99
- (12) 223.51
- (13) 56.257
- (14) 69.5002
- (15) 10.619
- (16) 25.882
- (17) 1.0578
- (18) 3.5266
- (19) 5.9929
- (20) 8.9148
- (21) 0.003599
- (22) 0.002677
- (23) 0.005555
- (24) 0.006666
- (25) 0.003333
- (26) 0.009999

- (27) 0.900356
- (28) 0.870009
- (29) 0.505050
- (30) 0.959595

SCIENTIFIC NOTATION

Scientific notation is a shorthand method of writing numbers that are extremely large or extremely small. The numbers are written as a number between 1 and 10 times a power of 10.

Place Values

The “everyday” system of numbers that we use is based on powers of 10. Each place value is a multiple of 10. Starting at the decimal point, the first place value is the ones column, which is actually 10^0 (10 to the zero power; any number raised to the zero power is 1). The next place value is the tens column, which is actually 10^1 (10 to the 1st power). The next place value is the hundreds column, which is actually 10^2 (10 to the 2nd power or 10 times 10).

Each place value is the next higher power of 10. Numbers below one, on the right side of the decimal point, have a negative power of 10. The 1st decimal place is 10^{-1} and each place to the right is the appropriate negative power of 10. Table 4-1 shows the power of 10 for each place value. Notice, the powers increase in the positive and negative directions.

Scientific notation takes advantage of the place values each having their own power of 10. The most significant digit, the one furthest to the left, even if it is a decimal number, is always a nonzero number (between 1 and 10). When the number is written in scientific notation, the most significant digit will be a number between 1 and 10, the other digits are written as decimals and the number is shown as multiplied by the power of 10 of the most significant digit. In this way, arithmetic is easier to perform because the majority of place holder zeros have been removed and the powers of 10 can be handled separately.

Exponential Notation

In order to further simplify the writing of numbers in scientific notation, an exponential notation is used. This method replaces the indicated multiplication of 10 to a power with “E” followed by the power of 10. For example; if the desired power of 10 is 10^2 the exponential form would be E2.

Writing Numbers in Scientific and Exponential Notation

Numbers larger than 1: are expressed in scientific notation by moving the decimal point to the left enough places to write the number between 1 and 10. The number of places the decimal point is moved is the positive power of 10.

Table 4-1. Place Values.

| Power of 10 | “E” Notation | As a Number | Expressed Verbally |
|-------------|--------------|-------------|----------------------------------|
| 10^6 | E6 | 1,000,000 | ten to the SIXTH power |
| 10^5 | E5 | 100,000 | ten to the FIFTH power |
| 10^4 | E4 | 10,000 | ten to the FOURTH power |
| 10^3 | E3 | 1,000 | ten to the THIRD power |
| 10^2 | E2 | 100 | ten to the SECOND power |
| 10^1 | E1 | 10 | ten to the FIRST power |
| 10^0 | E0 | 1 | ten to the ZERO power |
| 10^{-1} | E-1 | .1 | ten to the NEGATIVE FIRST power |
| 10^{-2} | E-2 | .01 | ten to the NEGATIVE SECOND power |
| 10^{-3} | E-3 | .001 | ten to the NEGATIVE THIRD power |
| 10^{-4} | E-4 | .0001 | ten to the NEGATIVE FOURTH power |
| 10^{-5} | E-5 | .00001 | ten to the NEGATIVE FIFTH power |
| 10^{-6} | E-6 | .000001 | ten to the NEGATIVE SIXTH power |

Examples of Numbers Larger than 1:

$$\begin{aligned}68,500 &= 6.85 \times 10^4 = 6.85E4 \\563,000,000 &= 5.63 \times 10^8 = 5.63E8 \\230 &= 2.30 \times 10^2 = 2.30E2 \\7,602 &= 7.602 \times 10^3 = 7.602E3 \\7.3 &= 7.3 \times 10^0 = 7.3E0\end{aligned}$$

Numbers Less Than 1: are expressed in scientific notation by moving the decimal point to the **right** enough places to write the number between 1 and 10. The number of places the decimal point is moved is the **negative** power of 10.

Examples of Numbers Less Than 1:

$$\begin{aligned}.1 &= 1.0 \times 10^{-1} = 1.0E-1 \\0.023 &= 2.3 \times 10^{-2} = 2.3E-2 \\0.000356 &= 3.56 \times 10^{-4} = 3.56E-4 \\\text{.}000098 &= 9.8 \times 10^{-5} = 9.8E-5 \\0.0000003 &= 3.0 \times 10^{-7} = 3.0E-7\end{aligned}$$

Adjusting Numbers with Powers of 10

Quite often, numbers are already written as a number times a power of 10, or, with the calculator, as a number with the exponent of 10. These numbers often do not have the power of 10 in the most proper form (a good analogy is when dealing with fractions that need to be reduced). This is usually a result of having performed arithmetic. Knowing how to adjust properly is very important, especially when using engineering notation and the electronic calculator.

Key Point: The decimal point moved to the **left** is **Positive**; **Right** is **Negative**.

Key Point: Use the rules of signed numbers to add/subtract powers of 10.

Examples of adjusting powers of 10:

$$\begin{aligned}840,000,000E3 &= 8.4E11 \\0.00035E7 &= 3.5E3 \\0.0075E3 &= 7.5E0 = 7.5 \\0.000062E-3 &= 6.2E-8\end{aligned}$$

Removing the Power of 10

Sometimes it is necessary to remove the power of 10 and return the number to no scientific nota-

tion. This is especially useful when making changes in engineering notation and interpreting answers produced with a calculator.

To remove a **positive** power of 10: move the decimal to the **RIGHT** the same number of places as the power of 10.

Examples of Removing Positive Powers:

$$\begin{aligned}6.7E6 &= 6,700,000 \\7.5E4 &= 75,000 \\80E2 &= 8000 \\\text{.}56 \times 10^1 &= 5.6 \\\text{.}032 \times 10^5 &= 3200\end{aligned}$$

To remove a **NEGATIVE** power of 10: move the decimal to the **left** the same number of places as the power of 10.

Examples of removing negative powers:

$$\begin{aligned}8.1E-6 &= 0.0000081 \\2.9E-3 &= 0.0029 \\500E-2 &= 5.0 \\\text{.}32 \times 10^{-5} &= 0.0000032 \\\text{.}0096 \times 10^{-1} &= 0.00096\end{aligned}$$

Practice Problems:

Writing in Scientific Notation

Part A. Writing in notation form. Write the following numbers in scientific notation (as a number between 1 and 10 times the proper power of 10. Example: $57,000 = 5.7 \times 10^4$). Also, write each in "E" notation (as a number between 1 and 10 followed by E and the power of 10. Examples: $57,000 = 5.7E4$)

- (1) 876,000
- (2) 1,030,000,000
- (3) 43,000
- (4) 25
- (5) 6.9
- (6) .003
- (7) .0000032
- (8) 0.0000450
- (9) .00000000159
- (10) .500
- (11) 12,000E5

- (12) 5320E3
- (13) .000035E3
- (14) .045E0
- (15) .000000067E9
- (16) 25,000 × 10⁻³
- (17) 35E-6
- (18) .02E-5
- (19) .000056 × 10⁻³
- (20) .950 × 10¹

Part B. Removing the Power of 10. Remove the power of 10 from the following numbers.

- (21) 4.8E5
- (22) 850E3
- (23) .003E6
- (24) .000025E1
- (25) 250E0
- (26) 100E-4
- (27) 55E-3
- (28) 68000E3
- (29) .000025 × 10⁻⁶
- (30) 1 × 10¹

ENGINEERING NOTATION

Engineering notation is a modification of scientific notation. Scientific notation is used so frequently

that names have been given to the various powers of 10. In electronics, and most scientific fields, the names are used only with the powers of 10 that are multiples of 3.

Multiplier Names

The names given to the power of 10 are called multiplier names. Table 4-2 shows the powers of 10, their respective multiplier names and E notation.

Each of the names are also given symbols which are used to further simplify the writing of numbers. The table shows the multiplier names (and symbols) but does not specify any specific unit. For example; the unit for power is watt, which can be written with the name kilo to represent 1000 watts or milliwatts to represent 1/1000th watt.

The names are all prefixes which means each of the names must be written in front of (and attached to) the unit name. This combination of prefix and unit form a new word, which essentially means the unit is multiplied by the prefix.

The student needs to memorize the various multiplier names and their multiplication values, or powers of 10. Then, as the individual units are introduced, the multiplier names can be attached to the units for the desired results.

Table 4-2. Multiplier Names.

| Multiplier Name | Symbol | Multiply By | Power of 10 | "E" Notation |
|----------------------------|------------------------|---|-------------------|--------------|
| tera | T | 1,000,000,000,000 (one trillion) | 10 ¹² | E12 |
| giga | G | 1,000,000,000 (one billion) | 10 ⁹ | E9 |
| mega (meg) | M | 1,000,000 (one million) | 10 ⁶ | E6 |
| kilo | k | 1,000 (one thousand) | 10 ³ | E3 |
| Basic unit (no multiplier) | | | 10 ⁰ | E0 |
| milli | m | 0.001 (one one-thousandth) | 10 ⁻³ | E-3 |
| micro | μ (Greek letter mu) | 0.000 001 (one one-millionth) | 10 ⁻⁶ | E-6 |
| nano | n | 0.000 000 001 (one one-billionth) | 10 ⁻⁹ | E-9 |
| pico | p | 0.000 000 000 001 (one one-trillionth) | 10 ⁻¹² | E-12 |

Writing Numbers Using Engineering Notation

Key Point. To write a number using engineering notation, the number should first be written in scientific notation. There is one modification, however; the power of 10 must be a multiple of 3. The power of 10 is then replaced with the multiplier name.

Table 4-3 shows examples of numbers that have been written in engineering notation and in exponential notation. Keep in mind, exponential notation is a way of expressing 10 raised to the power.

The multiplier names can also be replaced by their respective symbols with the symbol for the unit. For example; kilowatts can be written kW and millivolts can be mV. Notice, the symbols of multipliers larger than 1 are capital letters, except kilo and the symbols smaller than 1 are small letters. The unit symbols are usually capital letters.

Converting within Engineering Notation

Sometimes a number will be written with its multiplier and units but it is not written in the most convenient form. When this happens, it is possible, through the use of scientific notation, to convert the multiplier names to a better form. For example; 3,000 kilovolts would be better written as 3 megavolts and 0.025 millivolts would be better as 25 microvolts.

Key Point. When converting from one multiplier to another, the *actual value* of the number does not change.

Key Point. Steps to convert within engineering notation:

- (1) Replace the multiplier name with its power of 10.
- (2) To simplify the conversion, remove the power of 10 by replacing the zeros and returning to a number with no multiplier (return to basic units).
- (3) Convert to scientific notation with the desired power of 10.
- (4) Replace the power of 10 with its correct engineering notation multiplier name.

Sample Problems of Converting Engineering Notation

SP#4-1 Convert 475 kilovolts to megavolts.

- (1) 475 kV = 475E3 V
- (2) 475,000 V
- (3) .475E6 V
- (4) .475 MV (megavolts)

SP#4-2 Convert .000255 milliamps to microamps.

- (1) .000255 mA = .000255E-3 amps
- (2) .000 000 255 amps
- (3) .255E-6 amps
- (4) .255 μ A (microamps)

Table 4-3. Engineering Notation.

| Number with Unit | Written In "E" Notation | Written in Engineering Notation |
|--------------------------|-------------------------|---------------------------------|
| 86,000,000,000 hertz | 86E12 hertz | 86 terahertz |
| 2,000,000,000 hertz | 2E9 hertz | 2 gigahertz |
| 15,000,000 watts | 15E6 watts | 15 megawatts |
| 368,000 ohms | 368E3 ohms | 368 kilohms |
| 20 amps | 20E0 amps | 20 amps (no change) |
| 0.065 henry | 65E-3 henry | 65 millihenry |
| 0.000 125 volts | 125E-6 volts | 125 microvolts |
| 0.000 000 034 seconds | 34E-9 seconds | 34 nanoseconds |
| 0.000 000 000 005 farads | 5E-12 farads | 5 picofarads |

SP#4-3 Convert .000 004 microfarads to picofarads.

- (1) .000 004 μF = .000 004E-6 farads
- (2) .000 000 000 004 farads
- (3) 4E-12
- (4) 4 pF (picofarads)

SP#4-4 Convert 2.5 kilohms to ohms

- (1) 2.5 k Ω = 2.5E3 Ω
- (2) 2,500 Ω (ohms)

The following set of practice problems will provide the student with practice in converting numbers within engineering notation.

**Practice Problems:
Converting Engineering Notation**

Convert each of the given numbers to the units shown.

- (1) 5,600,000 ohms
- (2) 273,000 hertz
- (3) 2,900 watts
- (4) 15 amps
- (5) .0035 volts
- (6) .125 henry
- (7) .000 000 05 farads
- (8) .000 0087 seconds
- (9) 250 milliwatts
- (10) 1500 millivolts
- (11) .055 milliamps
- (12) .000 001 milliseconds
- (13) 630 kilohertz
- (14) 250,000 kilowatts
- (15) .000 75 kiloamps
- (16) .005 kilovolts
- (17) 25 microvolts
- (18) .75 microamps
- (19) 50 nanofarads
- (20) .05 nanoseconds
- (21) 150 picofarads
- (22) 75 megohms
- (23) .003 megahertz
- (24) 1200 gigawatts
- (25) .005 terahertz

- | | |
|-------|---------------|
| _____ | k Ω |
| _____ | kHz |
| _____ | mW |
| _____ | mA |
| _____ | mV |
| _____ | mH |
| _____ | μF |
| _____ | μs |
| _____ | W |
| _____ | kV |
| _____ | μA |
| _____ | s |
| _____ | Hz |
| _____ | MW |
| _____ | A |
| _____ | mV |
| _____ | mV |
| _____ | nA |
| _____ | μF |
| _____ | s |
| _____ | nF |
| _____ | k Ω |
| _____ | Hz |
| _____ | MW |
| _____ | MHz |

- | | |
|-------|---------------|
| _____ | M Ω |
| _____ | MHz |
| _____ | kW |
| _____ | kA |
| _____ | μV |
| _____ | μH |
| _____ | nF |
| _____ | ms |
| _____ | kW |
| _____ | V |
| _____ | A |
| _____ | μs |
| _____ | MHz |
| _____ | W |
| _____ | mA |
| _____ | V |
| _____ | nV |
| _____ | A |
| _____ | pF |
| _____ | μs |
| _____ | μF |
| _____ | G Ω |
| _____ | kHz |
| _____ | W |
| _____ | GHz |

**ARITHMETIC
OPERATIONS WITH POWERS OF 10**

One of the advantages of using scientific and engineering notations is the ease in dealing with arithmetic operations.

There are two sets of rules for handling the decimal point; addition/subtraction and multiplication/division.

Addition/Subtraction

Referring to addition and subtraction with decimal numbers, the rule is to align the decimal points in a column. By doing this, the addition/subtraction operation is performed with numbers that have the same place value. For example; the ones column, the tens column, etc.

Key Point. To add or subtract numbers containing powers of 10 (scientific notation or engineering notation); the powers of 10 **must** be the same and the operation will be performed as with any decimal numbers.

Sample Problems of Addition/Subtraction

SP#4-5 Add: 25.3 kilohms + 4.68 kilohms =

- (1) The powers of 10 need no change because they are the same.
- (2) Perform the addition as with any decimal numbers.

$$\begin{array}{r} 25.3 \text{ kilohms} \\ + 4.68 \text{ kilohms} \\ \hline 29.98 \text{ kilohms} \end{array}$$

SP#4-6 Add: 1.5 megawatts + 250 kilowatts =

- (1) The powers of 10 are different. Change megawatts to kilowatts.
- (2) Add the numbers in kilowatts.

$$\begin{array}{r} 1.5 \text{ MW} = 1500 \text{ kW} \\ + 250 \text{ kW} \\ \hline 1750 \text{ kW} \end{array}$$

SP#4-7 Add: 15 amps + 3 milliamps =

- (1) The powers of 10 are different. Change milliamps to amps.
- (2) Add the numbers in amps.

$$\begin{array}{r} 3 \text{ mA} = 0.003 \text{ A} \\ + 15 \text{ A} \\ \hline 15.003 \text{ A} \end{array}$$

SP#4-8 Subtract: .150 kilovolts - 80 volts =

- (1) The powers of 10 are different. Change kilovolts to volts.
- (2) Subtract the numbers in volts.

$$\begin{array}{r} 0.150 \text{ kV} = 150 \text{ V} \\ - 80 \text{ V} \\ \hline 70 \text{ V} \end{array}$$

Multiplication/Division

It is not necessary to align the decimal points, as it is with addition or subtraction. Instead, the arithmetic operation is performed and the decimal

point is adjusted. If the operations of multiplication and division of decimal numbers is examined, two very simple rules can be formed to deal with the powers of 10.

When performing multiplication with decimal numbers, the multiplication is performed and the decimal places are added together. When performing division with decimal numbers, the division is performed and the decimal point is adjusted to the right (in the negative direction).

Key Point. Perform the arithmetic operation as with any decimal numbers. Adjust the decimal point as follows: to multiply numbers; add the powers of 10, to divide numbers; subtract the powers of 10 (numerator minus denominator).

Sample Problems of Multiplication/Division

SP#4-9 Multiply: 2 milliamps \times 25 megohms =

- (1) Convert from engineering notation to powers of 10 (E notation) with the basic units.
- (2) Perform the multiplication.
- (3) Add the powers of 10.
- (4) Re-combine the results of the multiplication with the power of 10, then write the final answer in engineering notation.

$$\begin{aligned} 2 \text{ mA} \times 25 \text{ M}\Omega &= 2\text{E}-3 \text{ A} \times 25\text{E}6 \Omega \\ 2 \times 25 &= 50 \\ \text{E}-3 + \text{E}6 &= \text{E}3 \\ 50\text{E}3 &= 50 \text{ kilovolts} \end{aligned}$$

SP#4-10 Multiply: 15 milliamps \times 10 volts =

- (1) Perform the multiplication.
- (2) Add the powers of 10.

$$\begin{aligned} 15 \text{ mA} \times 100 \text{ V} &= 15\text{E}-3 \text{ A} \times 100\text{E}0 \text{ V} \\ 15 \times 100 &= 1500 \\ \text{E}-3 + \text{E}0 &= \text{E}-3 \\ 1500 \times \text{E}-3 &= 1500 \text{ milliwatts} \\ 1500 \text{ mW} &= 1.5 \text{ W} \end{aligned}$$

SP#4-11 Multiply: 6.28 \times 10 kilohertz \times .5 millihenry =

- (1) Perform the multiplication.

- (2) Add the powers of 10.

$$6.28 \times 10 \text{ kHz} \times .5 \text{ mH} =$$

$$6.28 \times 10E3 \text{ Hz} \times .5E-3 \text{ H}$$

$$6.28 \times 10 \times .5 = 31.4$$

$$E3 + E-3 = E0$$

$$31.4E0 = 31.4 \text{ ohms}$$

SP#4-12 Divide: 100 volts / 25 milliamps =

- (1) Perform the division.
 (2) Subtract the powers of 10. (numerator minus denominator)

$$100 \text{ V} / 25 \text{ mA} = 100E0 \text{ V} / 25E-3 \text{ A}$$

$$100 \div 25 = 4$$

$$E0 - E-3 = E3$$

$$4E3 = 4 \text{ kilohms}$$

SP#4-13 Divide: 12 milliwatts / 60 volts =

- (1) Perform the division.
 (2) Subtract the powers of 10. (numerator minus denominator)

$$12 \text{ mW} / 60 \text{ V} = 12E-3 \text{ W} / 60E0 \text{ V}$$

$$12 \div 60 = .2$$

$$E-3 - E0 = E-3$$

$$.2E-3 = .2 \text{ milliamps}$$

SP#4-14 Divide: 6 milliwatts / 3 milliamps =

- (1) Perform the division.
 (2) Subtract the powers of 10. (Use caution when subtracting signs.)

$$6 \text{ mW} / 3 \text{ mA} = 6E-3 \text{ W} / 3E-3 \text{ A}$$

$$6 \text{ divided by } 3 = 2$$

$$E-3 - E-3 = E0$$

$$2E0 = 2 \text{ volts}$$

SP#4-15 Multiply: 5 milliamps \times 10 kilohms =

- (1) Perform the multiplication.
 (2) Add the powers of 10.

$$5 \text{ mA} \times 10 \text{ k}\Omega = 5E-3 \text{ A} \times 10E3 \Omega$$

$$5 \times 10 = 50$$

$$E-3 + E3 = E0$$

$$50E0 = 50 \text{ volts}$$

Practice Problems: Arithmetic Operations

Perform the indicated operations with each of the following problems. Write the answer using the appropriate engineering notation, with three significant figures.

- (1) 2.2 kilohms + 3.3 kilohms =
 (2) 480 ohms + 620 ohms =
 (3) 48 MW + 100 kilowatts =
 (4) .250 kV - 150 volts =
 (5) 1.5 amps + 250 milliamps =
 (6) 6.8 mW - 3.5 mW =
 (7) .35 millihenries + 100 μ H =
 (8) .01 microfarads + .001 μ F =
 (9) 10 kV - 10 mV =
 (10) 5 uF + 25 picofarads =
 (11) 15 amps \times 10 ohms = (volts)
 (12) 25 mA \times 300 ohms = (volts)
 (13) 50 mA \times 1.2 kilohms = (volts)
 (14) 30 mA \times 25 volts = (watts)
 (15) 50 μ A \times 10 volts = (watts)

(16) $\frac{100 \text{ volts}}{25 \text{ kilohms}} =$ (amps)

(17) $\frac{25 \text{ volts}}{10 \text{ milliamps}} =$ (ohms)

(18) $\frac{50 \text{ kilowatts}}{100 \text{ kilovolts}} =$ (amps)

(19) $\frac{430 \text{ milliwatts}}{4.3 \text{ microamps}} =$ (volts)

(20) $\frac{200 \text{ V} \times 200 \text{ V}}{4 \text{ kilohms}} =$ (watts)

PROGRAMS FOR THIS CHAPTER

The programs for this chapter are designed to quiz the student in the various concepts involved in rounding numbers, significant figures, scientific notation and engineering notation, with special emphasis placed on exponential notation.

The programs provide excellent practice after the student has mastered the rules.

Whenever there is a wrong answer, the computer will offer a series of "helpful hints" for the

purpose of reviewing the rules. Always keep in mind, the computer programs are only a supplement to the text and they are not intended to replace proper study and practice with the practice problems.

This chapter is also a good time for the student to begin using an electronic calculator. It will be very important later to have a working knowledge of how the calculator uses exponential notation.

Figure 4-1 shows the program menu for scientific notation and a sample of the program to preview.

ENGINEERING NOTATION COMPETENCY TEST

A. Round each of the following to three significant figures.

- (1) 103,859
- (2) 555,555
- (3) 320.8
- (4) 598.3
- (5) 639.56
- (6) 231.37
- (7) 0.714285714
- (8) .09090909
- (9) .66666666
- (10) .33333333

B. Write each of the following in scientific notation (as a number between 1 and 10 times the proper power of 10. Example: 57,000 = 5.7×10^4).

- (11) 876,000
- (12) 3,200
- (13) 980,000,000
- (14) 1,200,000
- (15) 0.00000035
- (16) 0.000189
- (17) 0.0002
- (18) 1.8
- (19) 2500×10^3
- (20) $.0036 \times 10^{-5}$

C. Write each of the following in exponential "E" notation (as a number between 1 and 10 followed by "E" and the power of 10. Example: 57,000 = 5.7E4).

- (21) 250,000
- (22) 1,800
- (23) 68,000,000
- (24) 560
- (25) 0.00000000025
- (26) 0.00000357
- (27) 0.0013
- (28) 0.00098
- (29) 560,000E-2
- (30) 0.0000047E3

D. Convert each of the numbers on the left to the new units shown.

- (31) 25000 V _____ kV
- (32) 1.25 A _____ mA
- (33) 25.5 mW _____ W
- (34) 3.5 kHz _____ Hz
- (35) .015 mH _____ μ H
- (36) 680 μ H _____ mH
- (37) 1500 μ F _____ pF
- (38) 37,000 k Ω _____ M Ω
- (39) .000082 V _____ μ V
- (40) .000960 A _____ mA

E. Perform the indicated operations with each of the following problems. Write the answer using the most appropriate engineering notation, use three significant figures. The units shown in () will be the resultant unit without the engineering notation.

- (41) 5.6 kilohms + 8.2 kilohms = (ohms)
- (42) 280 ohms + 460 ohms = (ohms)
- (43) 23 MW + 3500 kW = (watts)
- (44) .250 mV - 125 μ V = (volts)
- (45) 25 amps \times 20 ohms = (volts)
- (46) 50 mA \times 300 ohms = (volts)
- (47) 20 mA \times .125 kV = (watts)

$$(48) \frac{200 \text{ volts}}{25 \text{ kilohms}} = (\text{amps})$$

$$(49) \frac{50 \text{ volts}}{10 \text{ milliamps}} = (\text{ohms})$$

$$(50) \frac{750 \text{ milliwatts}}{250 \text{ microamps}} = (\text{volts})$$

Chapter 5

Introduction to DC Circuit Components

Chapter Objective: To learn the principles of basic components used in dc circuits. The components will each be examined as to how they are manufactured, rated and used.

This chapter will also introduce schematic symbols and schematic drawings.

Chapter Outline:

- Dc Voltage Sources
- Conductors
- Switches
- Fuses and Circuit Breakers
- Resistors
- Resistor Color Code
- Introduction to Schematic Diagrams
- Programs for this Chapter
- Dc Circuit Components Competency Test

INTRODUCTION

Dc circuits are those circuits which use a dc voltage source. Dc stands for direct current. This simply means that the current flows only in one

direction, versus ac voltage which alternates or reverses direction periodically.

The various circuit components discussed in this chapter all have very important roles in forming a complete circuit. Dc circuits form the basic rules for all circuits.

DC VOLTAGE SOURCES

Dc voltages can be produced from three general categories; power supplies, batteries and voltage cells. Power supplies are electronic circuits that change ac to dc through the use of rectifier diodes. Batteries produce a voltage through a chemical process. Voltage cells produce voltage by either light or heat striking the surface.

Power Supplies

A power supply is an electronic circuit that produces a dc voltage by converting ac to dc using rectifier diodes. Power supplies are rated according to their output voltage and current handling capacity. The output voltage can be either fixed

(unchangeable) or it can be variable over a wide range. The output current is determined by the manufacturer and will have a protective device, such as a fuse, to prevent damage in the event of overloading.

Examples of power supplies around the home; a battery charger for a car, ac-dc converter for a radio. These two examples have two things in common; they both plug into the house electrical outlet and they both produce a dc voltage output.

Photo-Voltaic Cells

The most common type of photo-voltaic cell is the solar cell. When light energy strikes a solar cell, it causes the electrons inside the cell to move. More light causes more motion and current starts to flow.

The actual voltage produced and current capacity depends on the construction of the cell and how many cells are connected together. Normally, the voltage and current for any one cell is quite small, but several cells can be connected together to achieve the desired results.

Solar cells are in wide use with such items as pocket calculators, battery chargers, light-sensor switches, power for satellite stations, power for remote radios, etc.

Batteries

When a source of dc voltage is mentioned, usually the first thing to come to mind is a battery. "Storage batteries" as they are sometimes called use chemical reaction to produce electricity. There are two basic types of batteries; wet cell and dry cell, although there are variations of these. Either type of battery operates in much the same manner. There are two electrodes, made of different materials, and an electrolyte.

Dry cell batteries are the type used in flashlights, portable radios, etc. The center terminal is the positive electrode and the flat back end is the negative electrode. The electrolyte is the chemical inside the battery that causes the reaction to produce electricity. The electrolyte can be an alkaline, mercury or various chemicals. The output voltage of a typical dry cell battery is approximately 1.5

volts. It is possible to connect several of these dry cells together to produce a higher voltage. Some batteries actually connect more than one cell, with another, inside the same container, such as the common 6 volt "lantern" battery.

Wet cell batteries are the type used in an automobile or motorcycle. The electrolyte in this type is a liquid, usually a strong acid. Each wet cell has the voltage output of approximately 2 volts. Therefore, a 12 volt car battery has 6 cells connected together. The difference between a wet cell and a dry cell is their current handling ability. The wet cell can produce much more current than the dry cell.

Ampere-Hour Rating of Batteries

The ampere-hour rating of a battery is the rating of how long the battery will provide current before it is discharged. This is also known as the storage capacity of the battery. Usually this kind of rating is given to wet cells, especially car batteries.

If the ampere-hour rating of a particular battery is 60 ampere-hours; 60 amps of current can be drawn from the battery for 1 hour or 1 amp can be drawn for 60 hours.

Keep in mind, ratings of any product are stated for an item when it is new and under the most ideal of conditions. Temperature, for example, greatly affects the capacity of a battery. When it is cold, a battery loses much of its strength.

Schematic Symbols of DC Voltage Sources

Schematic symbols are used to represent different devices or components on a schematic drawing. A schematic drawing shows how an electric circuit is connected.

Figure 5-1 shows the schematic symbols for each of the three basic types of voltage sources. A dc voltage cell is represented by parallel lines with one shorter than the other. The longer of the two lines represents the positive terminal and the shorter of the two lines represents the negative terminal. It is not necessary to draw the positive sign next to the larger line, although it is a good practice.

Figure 5-1A is the symbol for a fixed voltage source. That means the voltage cannot be changed.

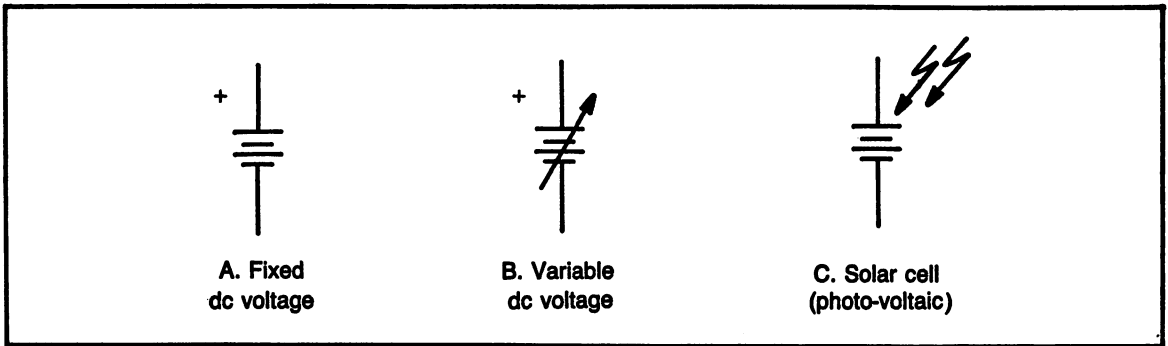


Fig. 5-1. Schematic symbols of dc voltage sources.

This symbol would be used to represent a battery or any other fixed dc voltage source. Notice, the symbol contains two cells, back to back. This is the most common method of drawing the voltage symbol. Older books use several cells in the drawings.

Figure 5-1B is the symbol for a variable voltage source. This symbol would be used to represent a dc power supply whose output voltage can be varied. Notice, the symbol is the same as the fixed except there is an arrow drawn through the cells. The arrow is used in many schematic symbols to signify "variable".

Figure 5-1C is the symbol for any photo-voltaic cell or solar cell. The basic voltage source symbol is shown with arrows pointing at the symbol. This method is used to represent light striking.

CONDUCTORS

The purpose of a conductor is to carry the electricity from one point to another. A good conductor has the least amount of resistance to the flow of electricity.

Conductor Materials

Generally speaking metals make reasonably good conductors of electricity. Metals have a large number of electrons free to travel from one atom to the next. Since electrons are the current carriers, more free electrons means electricity can flow more easily.

Insulators, such as plastic, rubber, wood, etc. have very few free electrons and resist the flow of electricity.

All materials fall somewhere between a perfect conductor, which offers no resistance, and a perfect insulator, which offers infinite resistance. Most materials can be classified as either a conductor or an insulator.

The conductor material is quite important due to the fact that so much of it is used, it will determine cost, current carrying ability, ease of assembly and several other factors. The best conductor materials are:

- Silver
- Copper
- Gold
- Aluminum

Conductor Sizes

The physical size of the conductor must also be considered since it will have a great effect on the cost, current capacity, and ease of handling. The materials mentioned as the best choices for a conductor are all expensive and heavy in large quantities.

The larger wire size will have less resistance to the flow of electricity and can carry more current. Smaller wire sizes are cheaper and easier to work with (except very small wire). Every application of a wire is a compromise of these considerations.

In addition to the size, wire is also available in both solid and stranded wire. Stranded wire has an end result of being the same size as solid except that it is made of individual strands of wire twisted together. Stranding provides flexibility and the more

strands used to make a particular wire, the more flexible it becomes.

Wire sizes are given as gauge numbers. The AWG (American Wire Gauge) number is the method by which wire is bought and sold. The following abbreviated list shows how the wires are numbered and their sizes. Note: smaller AWG numbers represent larger wires. Two examples of common uses of different size wires are; 14 gauge is common in household wiring, 22 gauge is common in electronic circuit wiring.

| AWG # | Diameter (mils) |
|-------|-----------------|
| 0000 | 460.0 |
| 2 | 258.0 |
| 6 | 162.0 |
| 10 | 102.0 |
| 14 | 64.0 |
| 18 | 40.0 |
| 20 | 32.0 |
| 22 | 25.3 |
| 36 | 5.0 |

Note: "mils" equals 1/1000 inches. 0000 AWG is approximately 1/2 inch in diameter, 18 AWG is about the thickness of the lead in a wooden pencil, 36 AWG is about the thickness of human hair.

SWITCHES

Switches are a very important part of any electrical circuit. They enable the user to control, not only off and on functions, but many other switching functions.

This section will deal with some of the more commonly used types of switches to allow the stu-

dent to become familiar with the schematic symbols and some introduction to the operation of switches in circuits. Figure 5-2 shows several switches to be discussed.

Toggle Switches

A toggle switch is the type of switch often thought of as an "on/off" switch. For example, the switches used for the lights in a house are toggle switches. Figure 5-2A shows another type of toggle switch. This type would be mounted through a panel with access to the switch lever from the front.

There are many different styles of switches that serve the same function as the toggle switch. The only difference is the style and how it looks from the outside. Two of these styles are; slide and rocker, and a drawing of these can be seen in Fig. 5-2.

Schematic Symbols

The schematic symbol of a switch shows that the switch "makes" or "breaks" the circuit. Often, the switch is drawn in an "open" position, with the switch line not making contact. When a switch is drawn in the open position, it symbolizes that the circuit is in a "break" condition and the switch must be "closed" to "make" the current operate. Examine Fig. 5-3A. This simple switch is known as an on/off switch. It is a perfect example of make-break.

Figure 5-3A represents a single pole single throw (SPST) toggle switch. The straight lines with the small circles represent the wires and switch terminals. The line drawn at an angle represents the switch contact. This switch is drawn in the open position. It could also be drawn in a closed position.

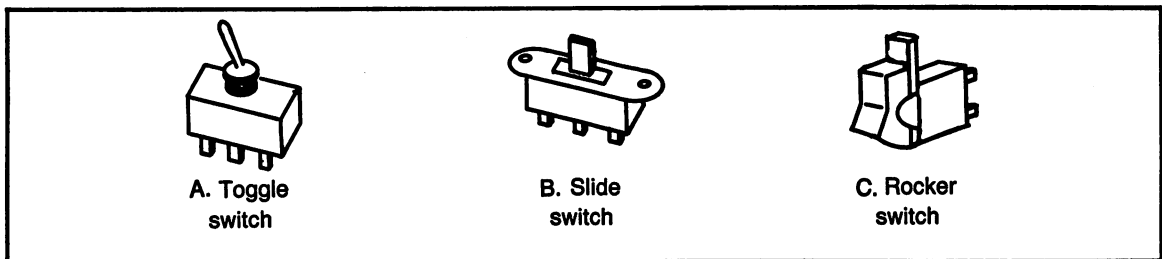


Fig. 5-2. Pictorial drawings of switches that use the same schematic symbol as the toggle switch.

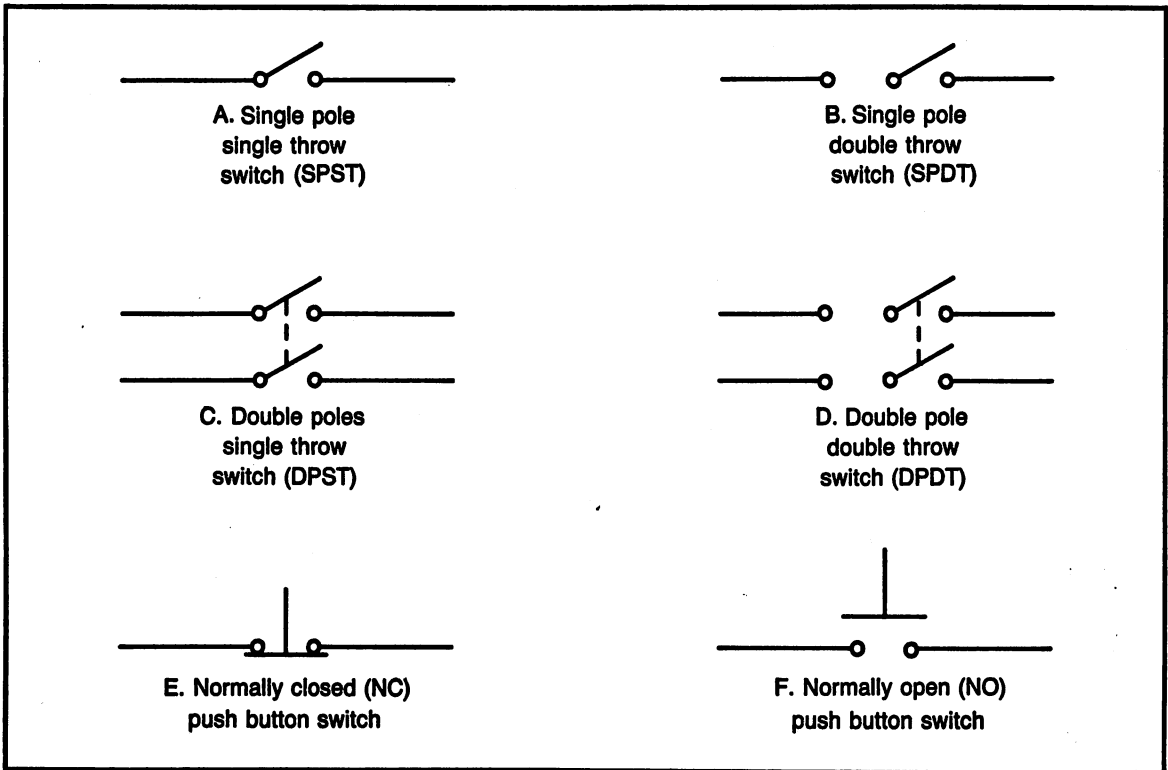


Fig. 5-3. Schematic symbols of switches.

The SPST switch can be used only to control one circuit path.

Figure 5-3B shows the schematic symbol of a single pole double throw (SPDT) switch. Notice, there are places for three wires to be connected to the terminals of this switch. The center terminal is called "common". The left and right sides are two different circuits, with the center terminal common to both circuits. The switch is used to select which circuit, right or left will be connected to the center common.

Figure 5-3C is the symbol of a double pole single throw (DPST) switch. This switch is two single pole switches operated by the same switch level. Two circuit paths, usually the two wires of the same circuit, go to the switch terminals and the switch will turn on or off both of the wires at the same time.

Figure 5-3D shows a double pole double throw (DPDT) switch symbol. This switch is two SPDT

switches connected together. Notice, there are six terminals available for wires. The three terminals on one side of the switch are completely separate from the terminals on the other side. The two commons are separate and each common is used with the circuit paths on its own side.

Figure 5-3E shows the symbol of a normally closed (N.C.) push button switch. This type of symbol means that the push button has its contacts closed until the button is pushed, at which time the contacts open.

Figure 5-3F shows the symbol of a normally open (N.O.) push button switch. This type of switch has its contacts open until the button is pushed, at which time the contacts close.

It is possible for switches to have more combinations than shown here, but once the functions of these are mastered, any other combinations will be extensions of these.

FUSES AND CIRCUIT BREAKERS

The function of fuses and circuit breakers is to protect the circuit against current that could damage circuit components. Most everyone is familiar with fuses or circuit breakers in a house circuit. In a house, the typical current overload situation results when too many appliances are connected to the same circuit. When the overload occurs, the fuse will “blow” or the breaker will “trip” and the circuit will cease to have any power available.

If a fuse or circuit breaker was not used, the excessive current would create excessive heat and could cause damage, even melt wires or start fires.

Opens and Shorts

The terms “open” and “short” are two fault conditions that can happen to a circuit.

An open circuit is a condition where there is an “open” or break in the circuit path, such as a wire becoming disconnected. In order for current to flow, there must be a complete circuit path, from power source to the load, and back to the power source. If the circuit path is interrupted, current cannot flow and the load will not operate. This condition will not blow the fuse and there may still be voltage present which could present a shock hazard.

A short circuit is the opposite of an open. In a short circuit, the circuit path is “short-cut” around the load causing an excessive amount of current to flow. A fuse or circuit breaker will respond to a short circuit and will break the circuit path, stopping the flow of current.

Resetting the Circuit

When a current overload protection device breaks the circuit, the overload or shorted condition must be resolved, before the circuit can be restored to normal.

A circuit breaker looks like a switch, and to reset the circuit, it is a simple matter of switching the breaker to the off position and then back to the on position. Note: when a breaker trips, it will usually go to a state between off and on and must first be switched to the off position.

Fuses come in a wide variety of shapes and

sizes, but they all have one thing in common; when the fuse blows, it is no longer useful. The fuse will open the circuit by melting a segment of the fuse conducting element. The fuse must then be replaced.

Ratings

Fuses and circuit breakers have two categories for the ratings; quickness of response and voltage/current.

The quickness of response is a very broad term stating if it is “quick blow” or “slow blow”. A quick blow will respond the moment an overload situation is experienced. This is the most common type of current protection. Keep in mind, if a fuse is rated for 15 amps and the circuit is drawing 14 amps for an extended period of time, the fuse may heat up enough to blow.

A slow blow device is used in situations where it is normal to have a momentary high current, then drop to a much lower value. An example of this is circuits with large motors. When the motor is first starting, there is a surge of current and quickly it drops to the lower current while the motor is running.

The voltage/current rating states the maximum voltage to safely use the device and the current which will cause the device to respond. When replacing a fuse, it is safe and acceptable to replace with a higher voltage rating. However, **Do Not** replace a fuse or breaker with a **Higher Current Rating**. The manufacturer of the circuit being protected selected the particular current rating to insure protection of the circuit.

Schematic Symbols

Figure 5-4A is the schematic symbol of a fuse. Often the fuse current rating will be shown alongside the fuse symbol.

Figure 5-4B is the symbol for a circuit breaker. This symbol may also have the current rating.

RESISTORS

Resistors come in many various sizes depending on how they will be used in the circuit. Regard-

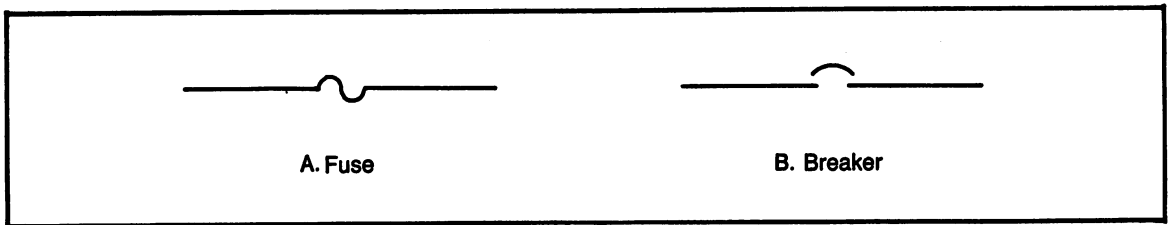


Fig. 5-4. Schematic symbols of current overload protection devices:

less of what type of electronic device, the resistor is the most commonly used individual component.

The use of resistors will fall into one of two general categories; either limit the flow of current or provide a specified voltage drop. Even though the student may not understand these concepts at the present time, it is still important to examine the various types available.

The types of resistors available come under two very broad categories; either fixed or variable. Both fixed and variable resistors have essentially two general specifications; the ohmic value and the wattage rating. Therefore, when identifying a resistor; determine if it is fixed or variable and the ohmic value and wattage rating.

Ohmic Value

The unit of measure of resistance is the ohm. The symbol for ohm is the Greek letter omega Ω . Therefore, the ohmic value is another way of stating the resistor's value in ohms.

During the manufacture of resistors, there will be a tolerance allowed between the designed ohmic value and the actual value produced. Tolerances allowed will range from 0.5% to 20%. Naturally, the lower percent tolerance will require more expense during manufacture. Generally speaking, most circuits will be designed to use resistors with a 10% tolerance, which are the most common type available.

Wattage Rating

Whenever electricity passes through a resistor, heat will be produced. Some common examples of heat produced from electricity are: incandescent light bulb, electric stove, electric heater, hair dryer, clothes dryer, etc.

The examples given produce enough heat that even a casual observer can feel the heat produced. Because electronic circuits use a number of resistors, and other components that produce heat, it is possible to feel a certain amount of heat radiating from electronic devices.

All components have a heat range in which they can safely operate. Excessive heat will destroy the component. Therefore, resistors and other components have an effective heat rating, stated in watts. Wattage is a unit of measure that can easily be calculated and is therefore very easy to work with.

When the wattage rating is stated for a resistor, it is stated with the surrounding temperature much hotter than normal room temperature. In other words, its value is for a working circuit that is producing heat.

The wattage rating affects the physical size of the resistor since the surface area dissipates the heat. The lowest standard value of wattage rating is $\frac{1}{8}$ watt. Carbon resistors are available in $\frac{1}{8}$ watt, $\frac{1}{4}$ watt, $\frac{1}{2}$ watt, 1 watt, 2 watts. Larger wattage sizes are available with wire wound resistors. A larger physical size will allow a resistor to dissipate more heat. Figure 5-5 shows some of the various sizes of carbon resistors.

Fixed Resistors

Most resistors are of the fixed type, which simply means their ohmic value is determined during manufacture and cannot be varied.

The materials used to manufacture the resistor varies. The small fixed resistors are usually made of carbon or carbon with other various compositions. Resistors needing a higher wattage rating will often be wirewound, which means they are made of wire wrapped around a core.

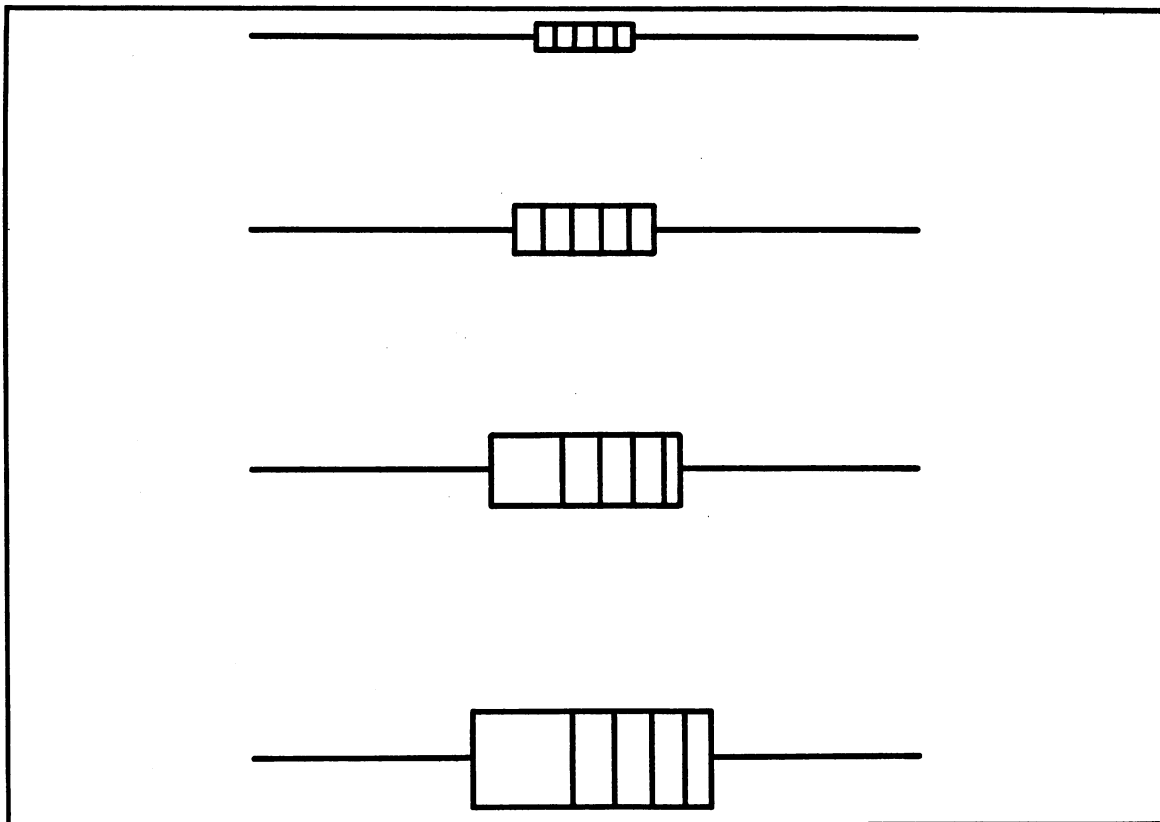


Fig. 5-5. Various sizes of resistors. Larger are higher wattage rating.

The ohmic range of fixed resistors ranges from 1 ohm to 100 megohms, it is possible to find precision resistors that have values of less than 1 ohm.

Fixed carbon resistors with a tolerance of 10 percent are the most common resistor available. The following series of numbers is used, with multiples of 10, to establish "standard values": 1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2, 10.0.

The "standard values" series expands the basic series by using multiples of 10. For example, the value 1.8 can be used as; 1.8 ohms, 18 ohms, 180 ohms, 1800 ohms, 18 kilohms, 180 kilohms, 1.8 megohms, 18 meg ohms. Each of the "standard values" has a series similar to the one shown here and will therefore produce a very wide range of fixed resistance values.

Keep in mind, the physical size of the resistor does not determine the ohmic value. The physical size is determined by the wattage rating.

Variable Resistors

A variable resistor is made in such a way that the ohmic rating can be varied. In a variable resistor, a sliding arm will slide over, and touch, the resistive element to allow the arm to select a portion of the full resistance available. The sliding arm is also called a "wiper" arm. An example of where a variable resistor is used is as a volume control. Variable resistors are also divided into two general categories; potentiometer and rheostat. The difference is in how they are wired and used.

A potentiometer is a variable resistor with three terminals. It is used in such a way that the variable arm divides the total resistance into two different, but connected resistors. Often used as a voltage divider circuit. A "pot" can be connected as a rheostat.

A rheostat is a variable resistor with two terminals. It cannot be wired to have the effect of two

connected resistors for a voltage divider effect.

Schematic Symbols

Figure 5-6 shows the three basic schematic symbols for resistors.

Figure 5-6A is the symbol for a fixed resistor. This symbol is used for any type of resistor that has a fixed value. The same symbol can also be used to show other types of circuit resistance, even if it is not a physical component. An example is the internal resistance of a power supply or the effective resistance of a long piece of wire.

Figure 5-6B is the symbol for a variable resistor. As with many other schematic symbols, the arrow is used to indicate variable. This symbol has three connections for wires, the two ends and the center contact (wiper), and is usually called a potentiometer.

Figure 5-6C is also a symbol used for a variable resistor, except this one has only two connections,

one end and the center wiper. This symbol is used to show a rheostat.

RESISTOR COLOR CODE

Carbon resistors have color bands around the body of the resistor to identify the value of the resistor. Refer to Fig. 5-7.

The Colors

There are twelve colors used to identify the value of resistors. Refer to Table 5-1. The first 10 colors represent the digits 0-9 and the last two colors, silver and gold are used to identify the percent tolerance. Silver and gold can also be used in the third band as a multiplier.

Color Bands

A resistor can have three, four or five color bands. A three band resistor is one of the older type,

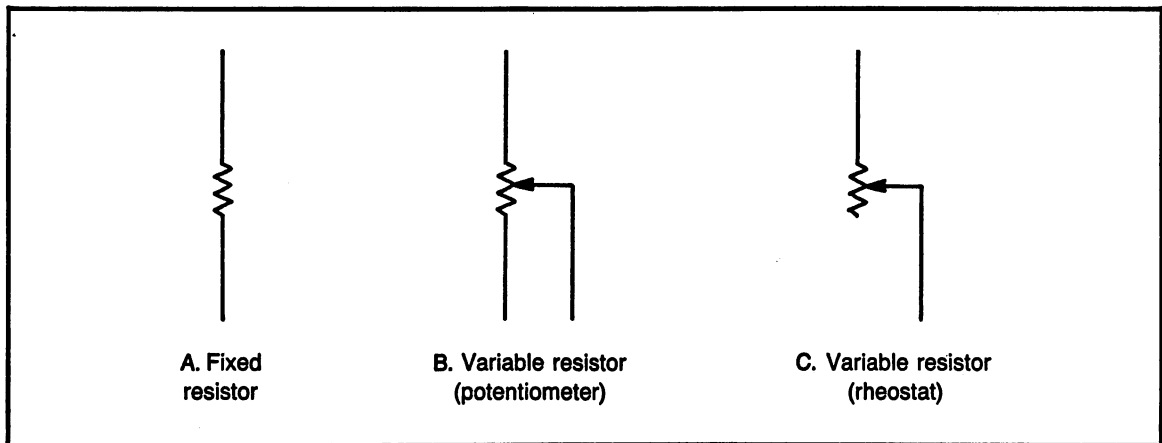


Fig. 5-6. Schematic symbols of resistors.

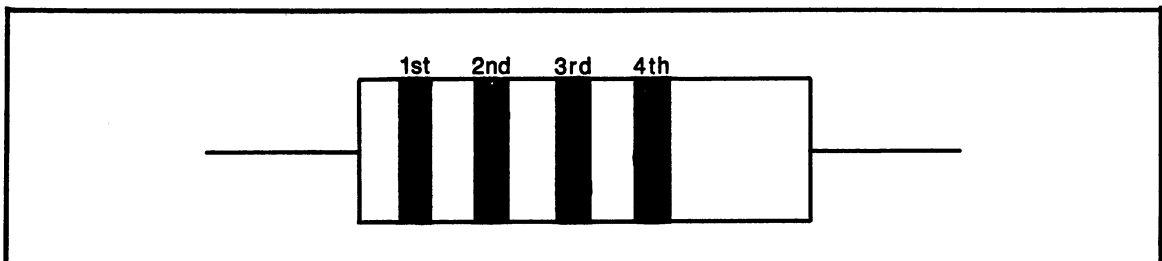


Fig. 5-7. Pictorial drawing of a carbon resistor to show the relationship of the color bands.

Table 5-1. Resistor Color Code.

| Color | Value |
|----------|--------------------|
| Black | 0 |
| Brown | 1 |
| Red | 2 |
| Orange | 3 |
| Yellow | 4 |
| Green | 5 |
| Blue | 6 |
| Violet | 7 |
| Gray | 8 |
| White | 9 |
| Gold | x0.1 (third band) |
| Silver | x0.01 (third band) |
| Gold | 5% (fourth band) |
| Silver | 10% (fourth band) |
| No color | 20% (fourth band) |

although there are some still in use. The four band resistor is the most commonly found type. The five band type is used for either precision resistors or to show a rating used for military standards. This chapter will deal with only the three and four band types because the five band types are special purpose resistors.

The first three color bands give the “nominal” value. Nominal means the “name” or ideal value. The fourth color band gives the tolerance, in percent. Keep in mind, all electronic components have a tolerance value. That is to say, the actual value can vary from the ideal value by that percent tolerance.

Bands 1 and 2 give the two significant figures. To achieve these two figures, the first two bands are directly translated into the digits they represent. For example; red-orange would give the first two significant figures of 23.

Band 3 is called the multiplier band. Each color represents the power of 10 multiplied times the significant figures. Gold is 0.1 times the significant figures and silver is 0.01 times the significant figures.

It is often easier to think of band 3 as representing the number of zeros that follow the significant figures. Gold and silver still remain multipliers.

Band 4 is the tolerance, stated in percentage. Gold is 5%, silver is 10% and if there is no fourth band, the tolerance is 20%. The tolerance is converted from percentage to a decimal and multiplied times the nominal value (found using the first three bands.) The result of multiplying the tolerance times the nominal is the ohmic value of the tolerance. The ohmic tolerance is *added* to the nominal for the *maximum* value and *subtracted* from the nominal for the *minimum* value. Note: an in-depth explanation of percent tolerance is given in chapter 3.

Examples of Resistor Color Code

With the examples shown below, the first line is the colors given on the resistor. The second line is the value of each of the colors, as read from table 5-1, the resistor color code. The third line is the nominal value of the resistor. The fourth line is the ohmic value of tolerance, based on the given percent tolerance. The fifth line is the max and min values of the resistor, based on the ohmic value of the tolerance. Note: the first few examples include only three lines; they do not show the results of tolerance calculations in order to best show examples of reading the color code.

yellow-violet-brown-gold

4 - 7 - 0 - 5%

470 ohms +/-5%

yellow-violet-orange-gold

4 - 7 - 3 - 5%

47,000 ohms = 47 kilohms +/-5%

red-red-red-silver

2 - 2 - 2 - 10%

2200 ohms = 2.2 kilohms +/-10%

red-red-yellow-silver

2 - 2 - 4 - 10%

220,000 ohms = 220 kilohms +/- 10%

blue-gray-orange-gold

6 - 8 - 3 - 5%

68,000 ohms = 68 kilohms +/-5%

blue-gray-brown-gold

6 - 8 - 1 - 5%

680 ohms \pm 5%

blue-gray-blue-silver

6 - 8 - 6 - 10%

68,000,000 ohms = 68 megohms \pm 10%

brown-black-black-gold

1 - 0 - 0 - 5%

10 ohms \pm 5%

brown-black-red-no color

1 - 0 - 2 - 20%

1,000 ohms \pm 20%

brown-black-yellow-no color

1 - 0 - 4 - 20%

100,000 ohms = 100 kilohms \pm 20%

brown-red-brown-silver

1 - 2 - 1 - 10%

120 ohms \pm 10%

\pm 12 ohms tolerance

max = 132 ohms; min = 118 ohms

red-orange-yellow-gold

2 - 3 - 4 - 5%

230,000 ohms = 230 kilohms \pm 5%

\pm 11500 ohms tolerance

max = 241500 ohms; min = 218500 ohms

orange-orange-silver-gold

3 - 3 - x.01 - 5%

0.33 ohms \pm 5%

max = 0.3465 ohms; min = 0.3135 ohms

brown-black-gold-gold

1 - 0 - x.1 - 5%

1.0 ohms \pm 5%

max = 1.05 ohms; min = 0.95 ohms

Practice Problems: Resistor Color Code

Part A. With each of the following, the first three color bands are given. Determine the nomi-

nal value of the resistor. Ignore the tolerance.

- (1) brown-black-brown
- (2) red-violet-brown
- (3) brown-green-red
- (4) red-red-red
- (5) orange-white-red
- (6) green-blue-red
- (7) brown-black-orange
- (8) brown-green-orange
- (9) yellow-violet-orange
- (10) Gray-red-orange
- (11) brown-red-yellow
- (12) blue-gray-yellow
- (13) orange-orange-green
- (14) brown-black-black
- (15) brown-black-gold

Part B. With each of the following, the ohmic value of the resistor is given. Determine the colors of the first three color bands. Ignore the tolerance.

- (16) 120 ohms
- (17) 330 ohms
- (18) 390 ohms
- (19) 1000 ohms
- (20) 1800 ohms
- (21) 2.7 kilohms
- (22) 4.7 kilohms
- (23) 6.8 kilohms
- (24) 8.2 kilohms
- (25) 10 kilohms
- (26) 12 kilohms
- (27) 1 megohm
- (28) 18 megohms
- (29) 10 ohms
- (30) 4 ohms

Part C. With each of the following, the first four color bands are given. Determine the nominal value and the maximum and minimum values.

- (31) brown-green-brown-silver
- (32) red-red-brown-gold
- (33) yellow-violet-brown-no color
- (34) green-blue-brown-silver

- (35) orange-orange-red-gold
- (36) blue-gray-red-no color
- (37) brown-red-orange-silver
- (38) brown-gray-orange-gold
- (39) brown-red-green-no color
- (40) orange-white-blue-silver

Part D. With each of the following, the ohmic value of the resistor is given, with the tolerance. Determine the first four color bands.

- (41) 18 ohms $\pm 5\%$
- (42) 180 ohms $\pm 10\%$
- (43) 270 ohms $\pm 20\%$
- (44) 680 ohms $\pm 5\%$
- (45) 3900 ohms $\pm 10\%$
- (46) 8.2 kilohms $\pm 10\%$
- (47) 22 kilohms $\pm 10\%$

- (48) 33 kilohms $\pm 5\%$
- (49) 2.7 megohms $\pm 5\%$
- (50) 15 megohms $\pm 20\%$

INTRODUCTION TO SCHEMATIC DIAGRAMS

A schematic diagram is a diagram showing the various connections in a circuit. In this section, simple schematics will be introduced to show the basic principles of drawing.

Using Schematic Symbols

Schematic symbols have been standardized in the electronics industry. There may be some slight variations from the standard symbols, but generally speaking, the symbols are the same on all drawings. Figure 5-8 shows the schematic symbols used in the

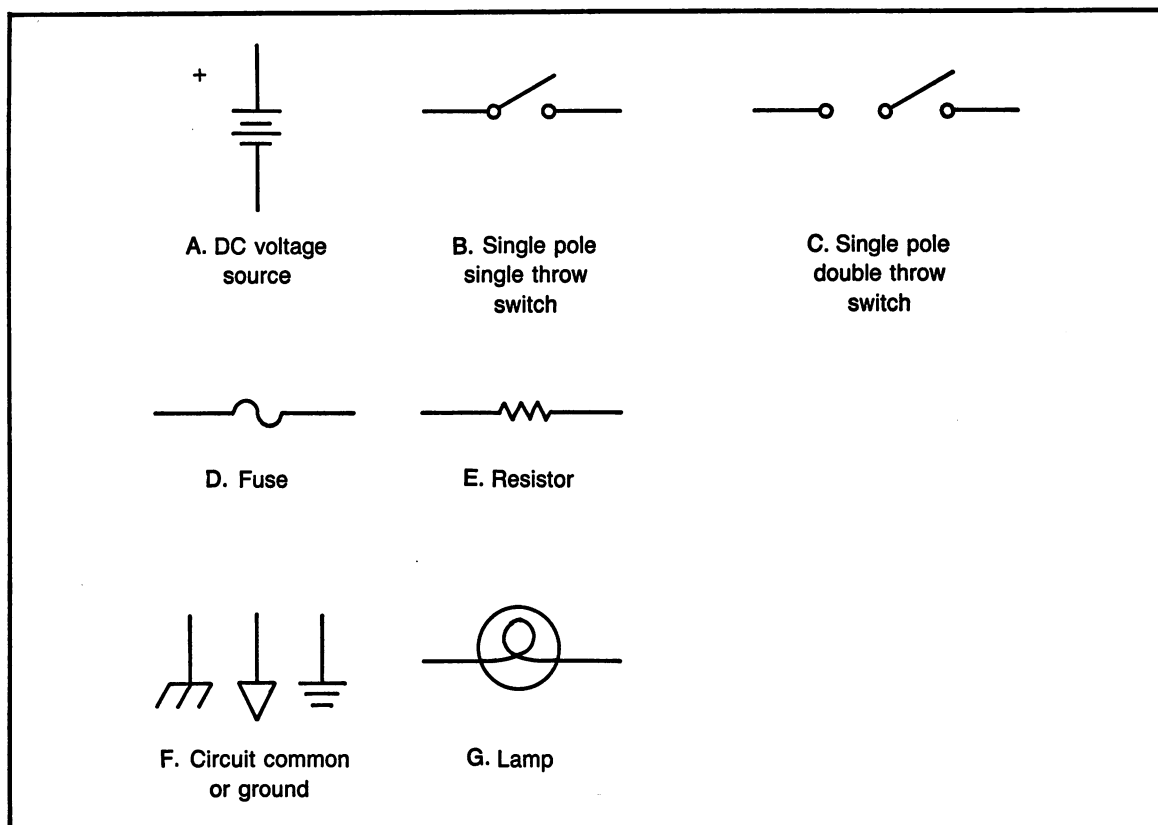


Fig. 5-8. Summary of commonly used schematic symbols.

circuits drawn for this section. Notice, there are some symbols added to this figure that were not shown previously in this chapter.

Figure 5-9 shows some examples of schematic diagrams that have been drawn correctly. Figure 5-9A is the simplest of all circuits possible, a voltage source and a load. Although a resistor is a specific electronic component, the resistor symbol can be used to represent any load. This drawing simply shows the battery is connected to something.

Figure 5-9B is a schematic diagram with the four basic parts of a circuit; a voltage source, an on/off switch, a fuse for current protection and a load to use the electricity. Notice the wiring of the switch and the fuse. They are both in the direct path of the current. This is the correct way to connect these two devices.

Figure 5-9C demonstrates one possible use of a double throw switch. When the switch is in the

right hand position, the resistor load will be connected. When the switch is in the left hand position, the lamp will be connected. Only one load can be connected to the battery at a time with the switch connected in this manner. Also, take note of the circuit common symbols. There are many types of circuit common or circuit ground symbols. They are often used to eliminate some of the lines on the schematic. Keep in mind, all commons are connected together.

The process of reading schematic diagrams and connecting wires in an actual circuit is a task that takes a lot of practice. It is as important to recognize a correct circuit drawing, as it is to recognize an incorrect drawing. Figure 5-10 shows some common mistakes.

Figures 5-10A and 5-10B are incorrect because the switch and the fuse are connected "across" the battery instead of "in series with" the battery.

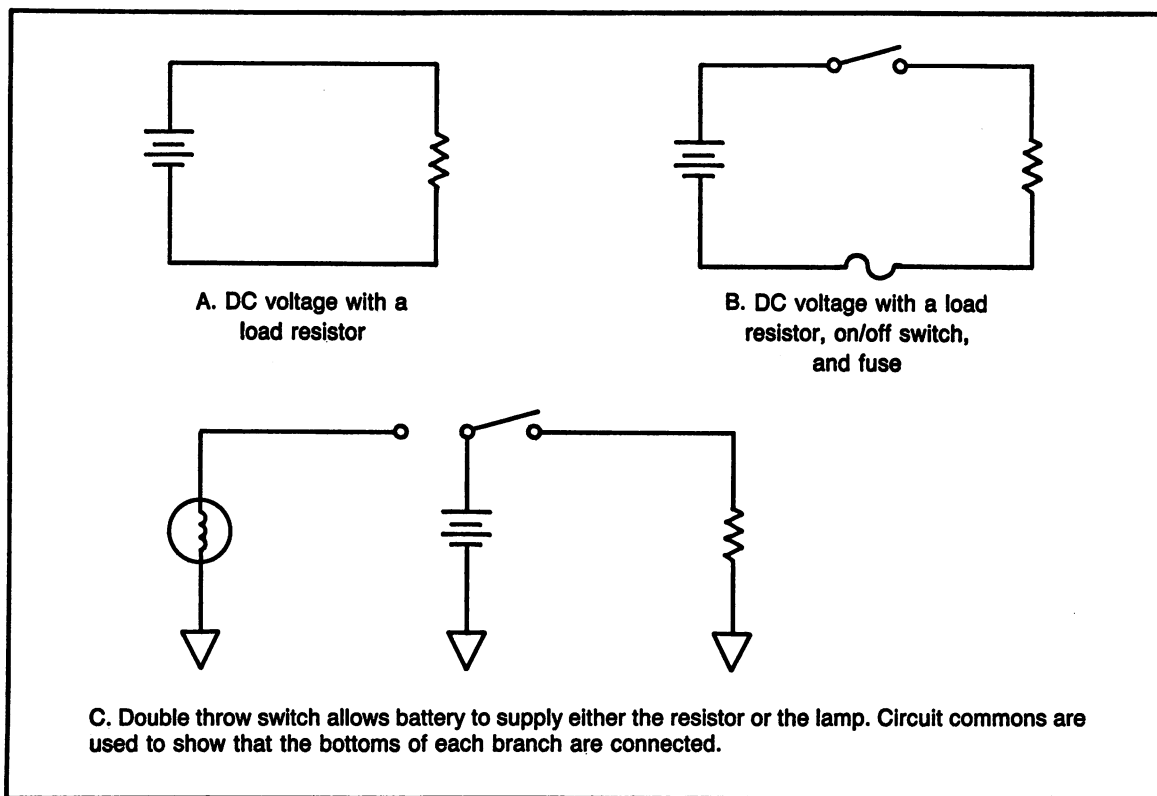


Fig. 5-9. Examples of correctly wired complete dc circuits.

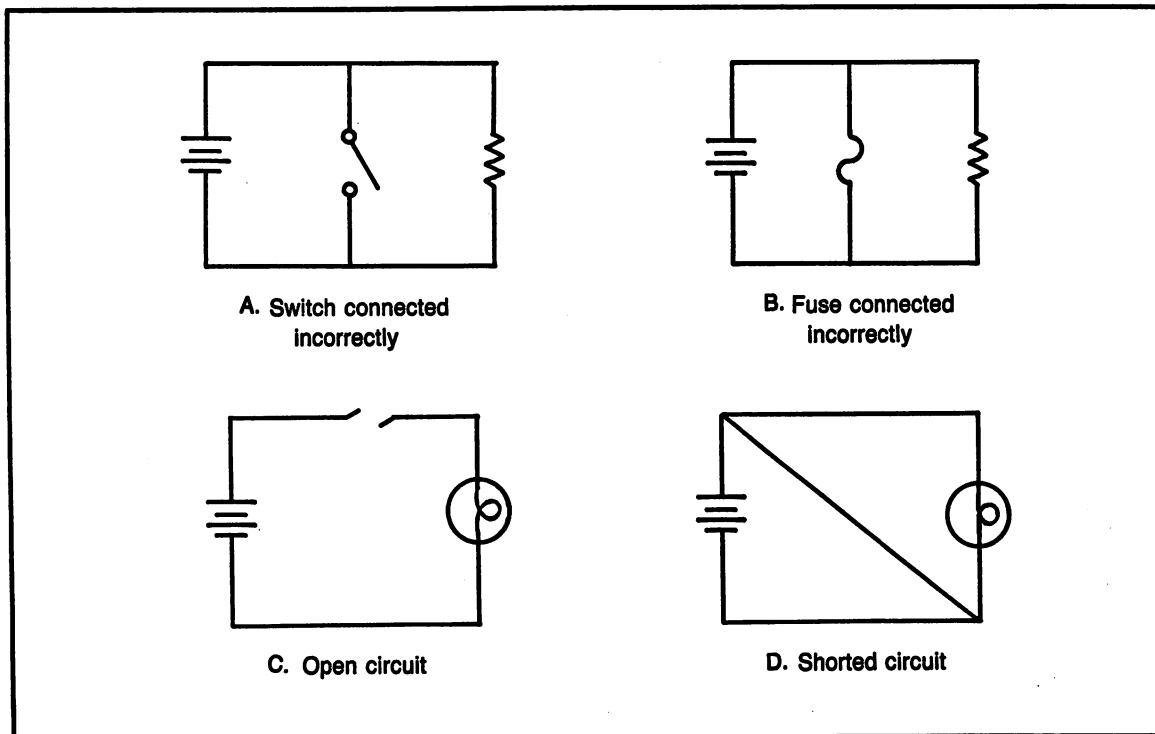


Fig. 5-10. Schematic diagrams showing some common wiring errors.

When the switch is open, the battery will supply voltage to the resistor load. However, when the switch is closed, there will be a short circuit because the current will flow through the zero resistance path of the switch. This would cause serious problems. In Fig. 5-10B, the fuse is a zero resistance path. The moment the battery is connected, the fuse is a short circuit path and the battery will try to supply a large amount of current. This will instantly “blow” the fuse.

Figure 5-10C is an open circuit. This simply represents a broken connection. The lamp will not light because there is not a complete path for the electricity. However, no other problems will result from the open circuit.

Figure 5-10D has a short circuit. The diagonal line is the short circuit. Any circuit path that allows the electricity to by-pass the load is considered a short circuit. The phrase “electricity takes the path of least resistance” applies to the short circuit.

PROGRAMS FOR THIS CHAPTER

There is one program for this chapter. It is practice with the resistor color code.

The resistor color code is something that is expected every student would memorize. The program provides practice in knowing the value of resistance when the colors are given.

Figure 5-11 is a preview sample of the color code program. This program may be used with either color or B&W monitors.

DC CIRCUIT COMPONENTS COMPETENCY TEST

1. What is the approximate output voltage of a single dry cell?
2. Draw the schematic symbol of a fixed voltage source. Label positive and negative.
3. Draw the schematic symbol of a variable voltage supply.

Color Code

Program sample:

GRN BLU ORG

What is the value
of this resistor? 56k

Correct !

Space bar to continue,
N for main menu

Fig. 5-11. Color code program sample.

4. Does a good conductor have low or high resistance?
5. Does a good insulator have low or high resistance?
6. Which wire size is larger; 18 AWG or 22 AWG?
7. Which wire size is more commonly used in house wiring; 14 AWG or 36 AWG?
8. When a switch is closed, does it have 0 resistance or infinite resistance?
9. When a switch is closed, is it an open circuit or a short circuit?
10. When a switch is open, does it have 0 resistance or infinite resistance?
11. When a switch is open, is it an open circuit or a short circuit?
12. Does electric current flow with an open or a closed switch?

With questions 13 to 18, draw the schematic symbols of these switches:

13. Single pole, single throw
14. Single pole, double throw
15. Double pole, single throw
16. Double pole, double throw
17. Normally open push button
18. Normally closed push button
19. Which over-current protection device needs to be replaced after use; fuse or circuit breaker?
20. Draw the schematic diagram of a fuse.
21. Draw the schematic diagram for a fixed resistor.
22. Draw the schematic diagram for a variable resistor.

With questions 23 to 30, convert the given value

to the units shown.

23. 470 ohms = _____ kilohms
24. 33 kilohms = _____ ohms
25. 150 kilohms = _____ megohms
26. 8.6 kilohms = _____ ohms
27. 4.7 kilohms = _____ ohms
28. 1.2 megohms = _____ kilohms
29. 18 megohms = _____ ohms
30. 220,000 ohms = _____ megohms

With questions 31 to 35, use the three colors given to determine the ohmic value of the resistor. Ignore the tolerance.

31. brown-black-brown
32. red-red-red
33. green-blue-orange
34. blue-gray-yellow
35. orange-white-green

With questions 36 to 40, use the four colors given to determine the nominal value, and maximum

and minimum values.

36. brown-green-brown-silver
37. yellow-violet-red-gold
38. orange-orange-orange-no color
39. brown-black-yellow-silver
40. gray-red-blue-silver

With questions 41 to 49, determine the first four color bands of the resistor.

41. 10 ohms $\pm 10\%$
42. 270 ohms $\pm 5\%$
43. 330 ohms $\pm 20\%$
44. 1000 ohms $\pm 10\%$
45. 1800 ohms $\pm 5\%$
46. 4.7 kilohms $\pm 10\%$
47. 6.8 kilohms $\pm 20\%$
48. 10 kilohms $\pm 5\%$
49. 1 megohm $\pm 10\%$
50. Draw a complete schematic diagram of a simple flashlight (the type that uses 2 "D" cell batteries).

Chapter 6

Use of an Ohmmeter

Chapter Objective: A hands-on lesson to learn to operate an ohmmeter, correctly read the scale, use the range switch, and make resistance measurements.

Chapter Outline:

- Construction of an ohmmeter
- Ohmmeter range switch
- Ohmmeter scale
- Hands-on experience
- Programs for this chapter
- Ohmmeter written competency test

INTRODUCTION

An ohmmeter is used to measure resistance. It is usually part of a “multimeter”, which is a combination meter containing an ohmmeter, voltmeter and ammeter. There are two general types of meters; analog, which uses a meter needle sweeping across the scale and digital, which uses electronic circuitry to convert the measurement to a digital readout.

Figures 6-1, 6-2, and 6-3 are models of multimeters. Figures 6-1 and 6-2 are analog type meters and 6-3 is a digital type meter.

CONSTRUCTION OF AN OHMMETER

All ohmmeters have their own internal power source. The internal power can come from being plugged into the wall socket or it can be from batteries. The purpose of the internal power source is to allow the meter to make measurements without voltage from the circuit.

The voltage from the meter is applied to the resistance to be measured. Current will flow from the meter, through the “circuit” being measured and allow the meter to measure the amount of current flowing. It is the amount of current flow that allows the meter to make the actual resistance measurement.

Simplified Schematic Drawing

Figure 6-4 shows a simplified schematic drawing of an ohmmeter. The three parts of this figure

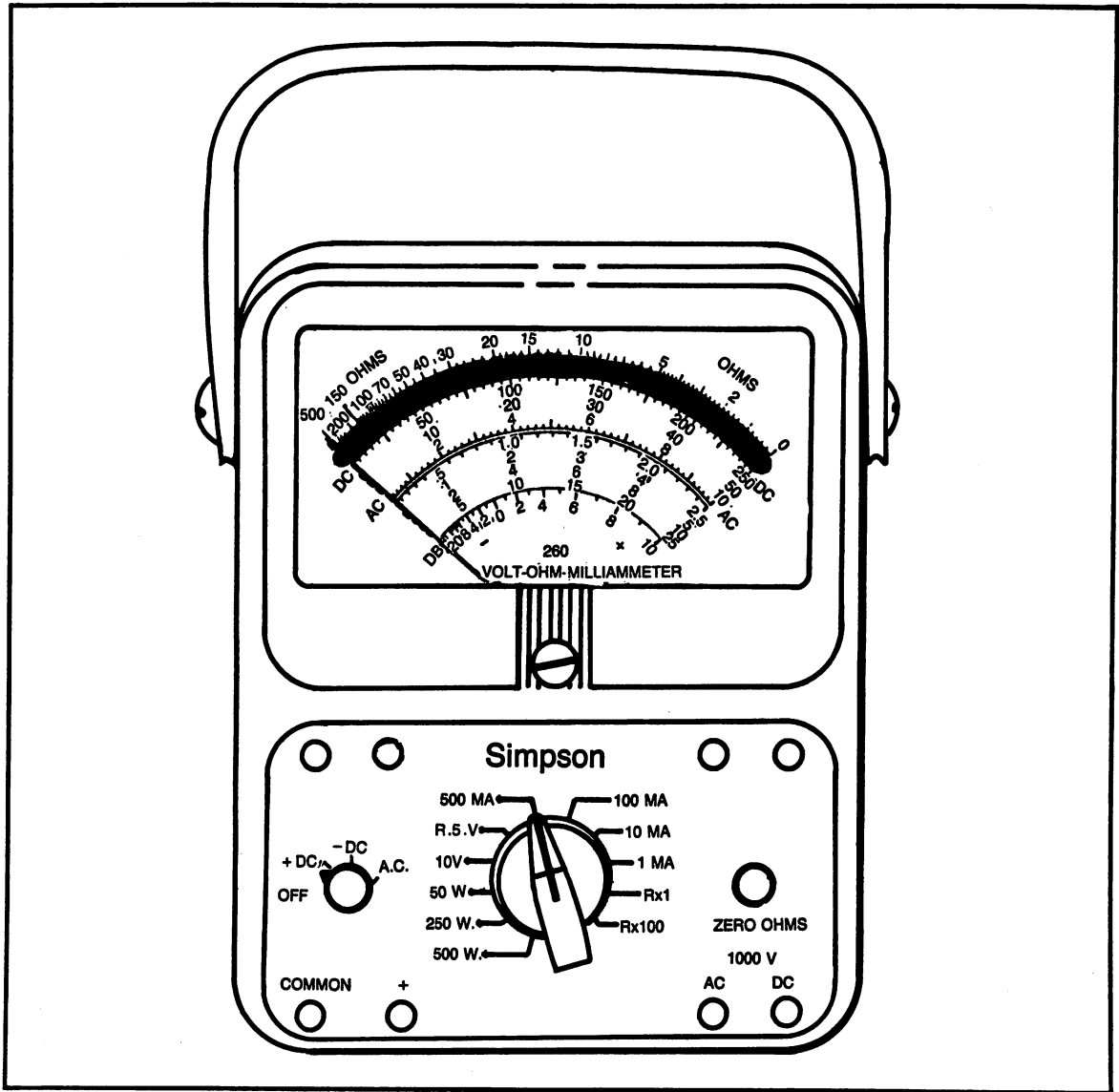


Fig. 6-1. Analog type multimeter.

show how the meter responds under different conditions.

Notice that each figure contains; a meter movement, a battery, a variable resistor and a fixed resistor. The meter movement is represented as a 100 microammeter, which is typical. The battery is shown as 1.5 volts, since most meters use one flashlight battery to power the ohmmeter. The variable resistor is used to adjust the ohmmeter to zero. The

fixed resistor is used to limit the current to the meter movement.

Figure 6-4A shows the meter terminals open. When the meter terminals of an ohmmeter are open, there will be no current flow because there is not a complete circuit. In this condition, the meter will read infinity, which for most meters, is the left side of the scale. Note: some ohmmeters have the zero on the left and the infinity on the right.

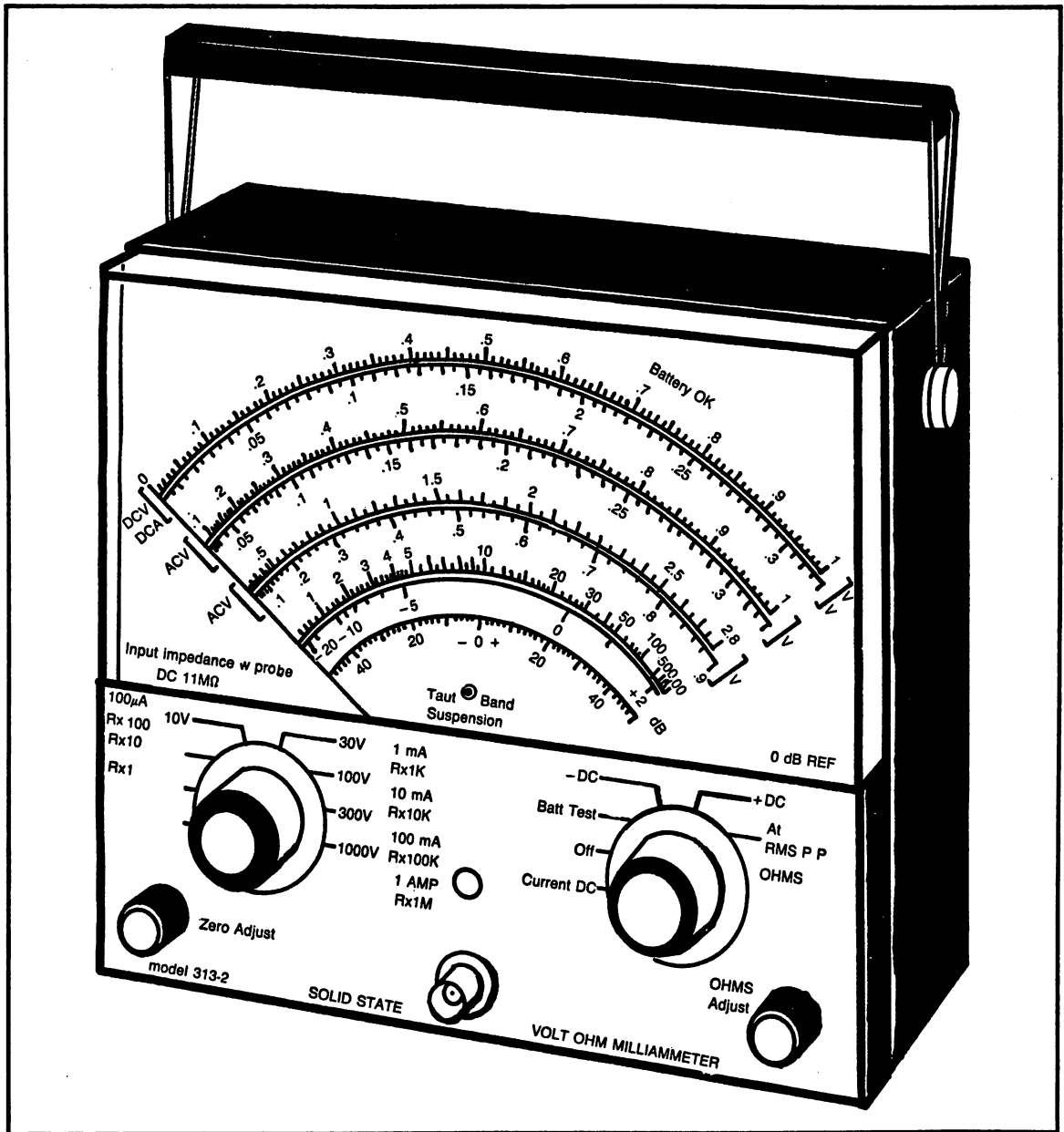


Fig. 6-2. Analog type multimeter.

Figure 6-4B shows the test leads shorted together. This connection makes a complete circuit. Current will flow from the battery, through the meter, R2 and R1. R1 can be adjusted to allow an amount of current to flow in the circuit to make the meter have full scale deflection. The test leads are considered

to have zero ohms resistance and when the meter is adjusted for full scale, it will read zero ohms.

Figure 6-4C has the ohmmeter test leads connected to a resistor to measure its ohmic value. In this particular case, the test resistor is almost the same as the internal resistance of the meter. When

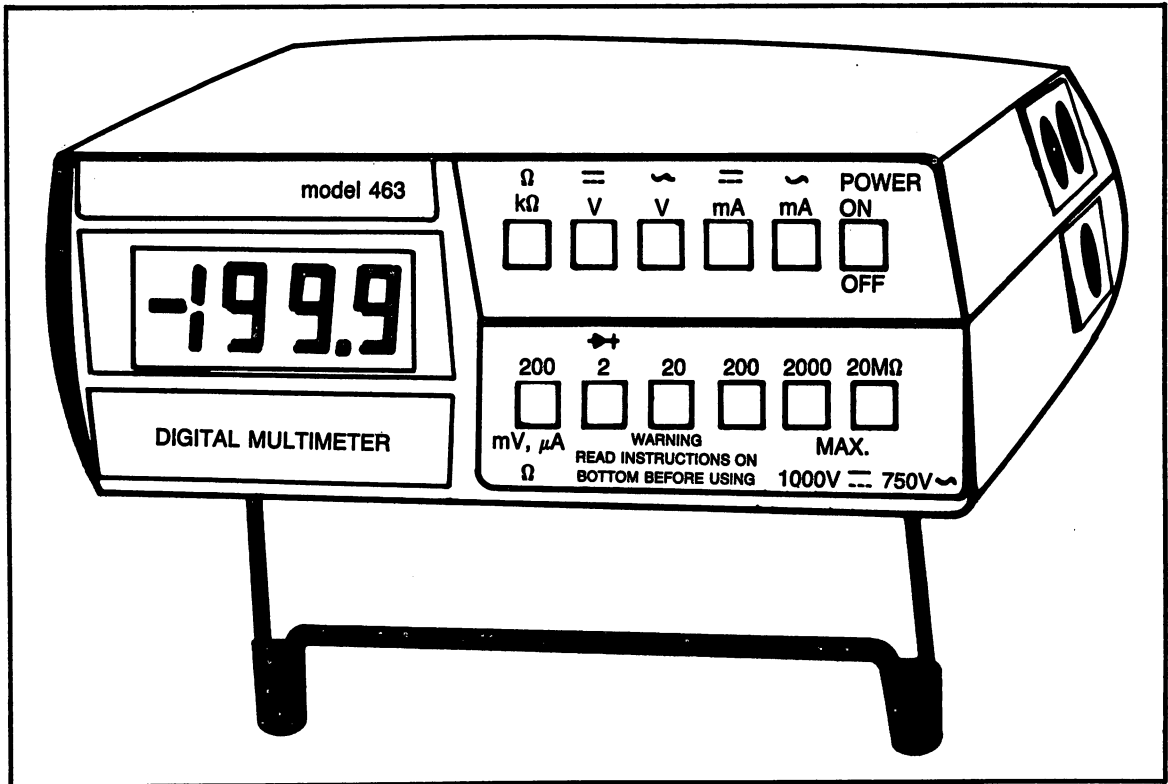


Fig. 6-3. Digital type multimeter.

this occurs, the meter will read center scale. A center scale reading is the most accurate reading with an ohmmeter.

Typical Schematic with Range Switch

Figure 6-5 is a "typical" schematic diagram of an ohmmeter, including the connections for the range switch. It is termed "typical" because, even if other meters are not exactly the same, the basic concept is the same.

This particular meter has a three position range switch. The two rotary switches shown are connected together on the same shaft. When the knob on the meter front is turned, both rotary switches will turn at the same time.

Comparing the typical schematic of Fig. 6-5 to the simplified schematic of 6-4, compare the many similarities. Both drawings have the meter movement, both have R1, ohms adjust, and both have an-

other resistor in series with R1 (in the same path) to limit current flow to the meter.

The meter movement can accept only a certain amount of current. In the case of the one in this example, 100 microamps is maximum. The maximum amount of current flows through the meter when the test leads are shorted together. When the range switch is in the highest range, in this case 10,000 ohms, R2 must limit the current to the maximum value.

When the range switch is moved to the next lower position, a much smaller resistor is connected. A smaller resistor is used because when the test resistor is equal to the ohmmeter's internal resistance, there will be a mid scale reading. A smaller value of internal resistance means a larger amount of current flowing. The meter movement can still have only the maximum of 100 microamps. Therefore, some of the current is by-passed around the meter movement. The purpose of S2 is to select a

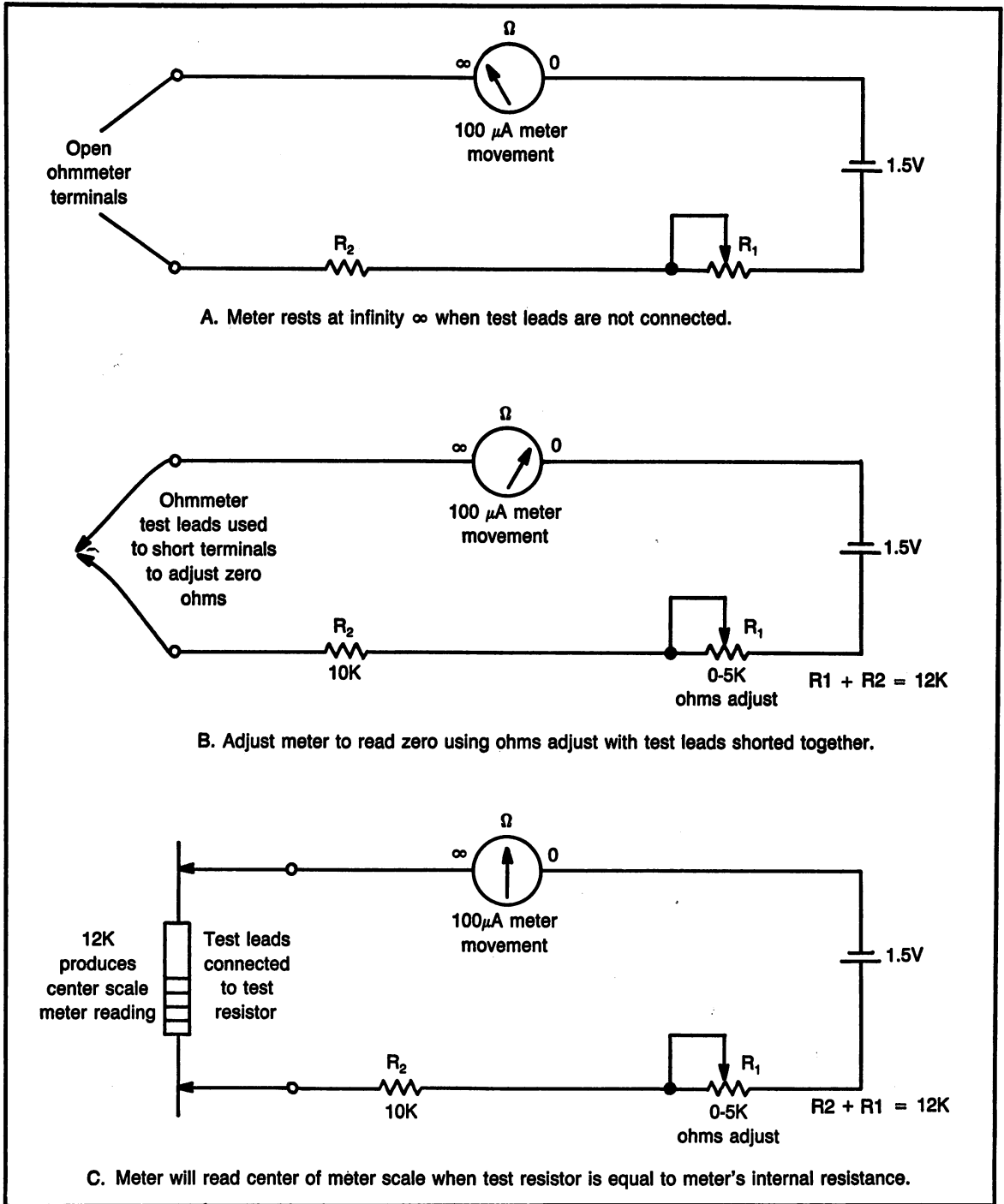


Fig. 6-4. Simplified schematic drawing of an ohmmeter. R1 and R2 are the internal resistance of the meter: A. Meter rests at infinity (∞) when the test leads are not connected; B. Adjust meter to read zero using the ohms adjust with the test leads shorted together. C. Meter will read center of meter scale when test resistor is equal to meter's internal resistance.

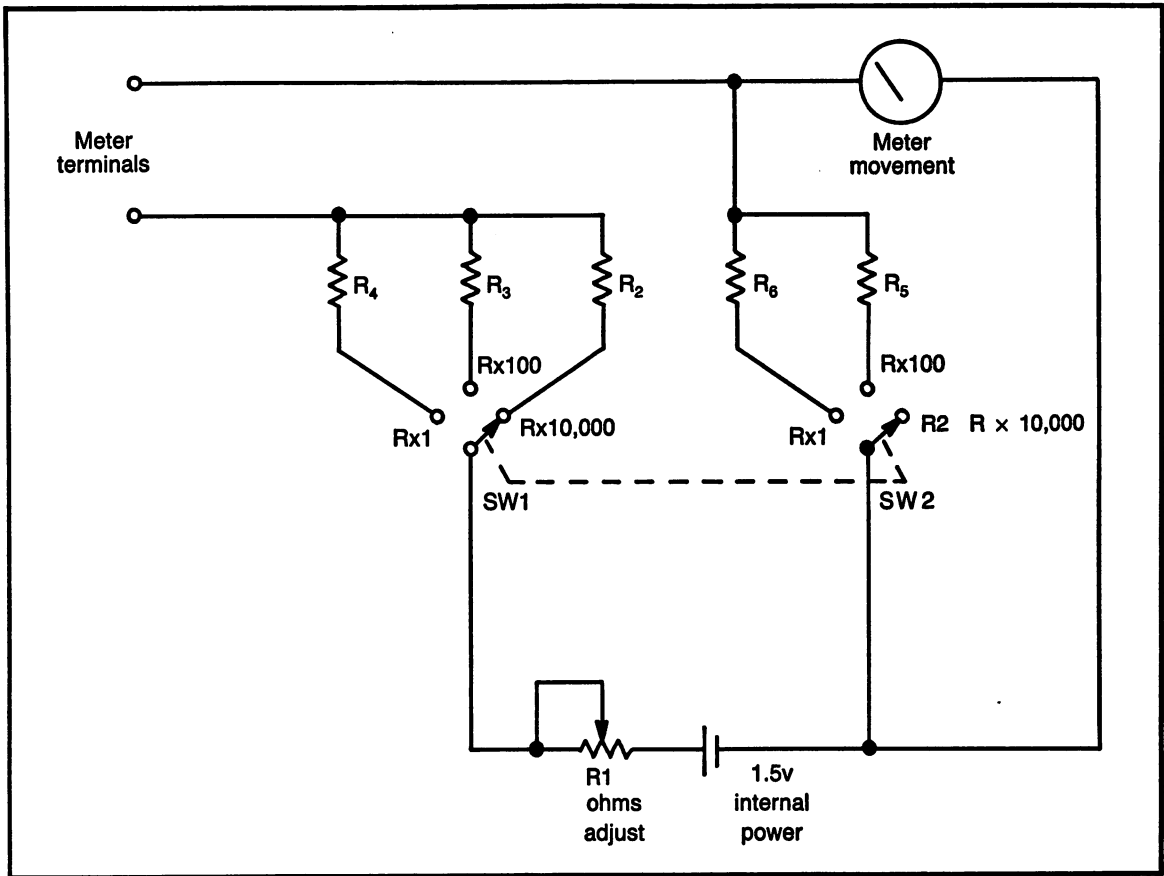


Fig. 6-5. Typical schematic of an ohmmeter, showing the range switch.

resistor to provide a path to by pass some of the current.

It is necessary to readjust the zero setting every time the range is changed. This is done by shorting the test leads together and turning the ohms adjust control.

Digital Ohmmeters

The discussion concerning the construction of an ohmmeter, above, is primarily intended for an analog meter. The digital meter uses electronic circuitry to perform the same operation.

The basic principles of operation of the analog meter can be applied to the digital type. The digital meter uses an internal resistance and compares it to the resistance being tested, which is similar to the analog type.

OHMMETER RANGE SWITCH

The range switch of the ohmmeter is actually a multiplier. In other words, whatever reading is obtained from the scale is multiplied by the switch setting.

The range switch on the ohmmeter is used to select a range that will allow taking measurements in the most accurate part of the scale. Keep in mind, the best accuracy is obtained between zero and center scale.

Example: A 1000 ohm resistor is being measured. On the ($R \times 1$) scale, the reading will be 1k, on the far left. On the ($R \times 100$) scale, the reading will be 10, in the center. On the ($R \times 10,000$) scale, the reading will be very close to zero. The best choice for the range switch setting in this example would be the ($R \times 100$) scale.

OHMMETER SCALE

On a multimeter, the ohmmeter scale is quite different from the other scales. Even though it is different, it is no more difficult to read than a thermometer.

Each of the multimeters shown in Figs. 6-1, 2 and 3 have an ohmmeter scale. These three meters are different in how they look, but they accomplish the same function.

The multimeter shown in Fig. 6-1 was used as a model to explain the functions of the ohmmeter and how to read the scale. Figure 6-6 shows only the ohmmeter portion of the multimeter scales and the range switch. Note: the four needles shown are used as examples in reading the meter.

Nonlinear Scale

The ohmmeter scale is termed "nonlinear" because it is not the same size between the different divisions. The nonlinear scale is caused by the fact that the ohmmeter has an internal resistance to limit current flow. Keep in mind, the most accurate reading is found at exactly the center. Between the center and zero, upper half of the scale, is the best place to make all resistance measurements. Adjust the range switch to make the reading fall into this range. The lower half of the scale is not very accurate because the divisions are squashed together.

Some ohmmeters have the zero on the left side, such as the one in Fig. 6-2. The most accurate part of the scale is still between zero and the center.

Reading the Ohmmeter Scale

For the purposes of learning to read the ohmmeter scale, Fig. 6-6 will be used. Note: the four needles shown are used as examples in reading the meter.

The scale has zero on the right and infinity on the left. Therefore, keep in mind, if the needle is between two divisions, a lower number is on the right and a higher number on the left.

When reading the ohmmeter scale, it is necessary to evaluate each place the needle lands individually because the distance between the different scale markings is different.

Examples of Reading an Analog Ohmmeter

Table 6-1 shows the results of reading the four example needles of the ohmmeter in Fig. 6-6.

An analog ohmmeter reading *must be multiplied by the range switch setting*. The range switch setting for this example is ($R \times 100$). The "resistance measurement" column of Table 6-1 has been multiplied by the range setting and is the final results of reading the analog example meter.

HANDS-ON EXPERIENCE

This section is designed to give the student hands-on experience using an ohmmeter. Any multimeter available will be adequate. Make sure the battery inside the meter is a fresh battery. Note: some meters that plug into the wall socket still have a battery inside.

Part A. Meter Adjustments

An ohmmeter has two adjustments to be made; they are adjustments for both ends of the scale. For the purposes of this lesson, it will be assumed that the meter in use has the ohms scale reading right to left. Zero on the right and infinity on the left.

Step 1. Meter resting position (left side of the scale).

Refer to Fig. 6-4A.

- (a) Meter leads must not be shorted together.
- (b) Turn the meter range switch to select any ohms scale.
- (c) The meter should read exactly on the left side of the scale, infinity. If not, there is an adjustment screw at the point where the needle is attached. (This adjustment screw is usually plastic and not marked.) This screw is the "meter zero" and is used to adjust the meter in the resting position. Turn the screw to place the needle exactly over the left hand side of the scale.
- (d) Turn the range switch to check the meter resting position on all scales; it should not change.

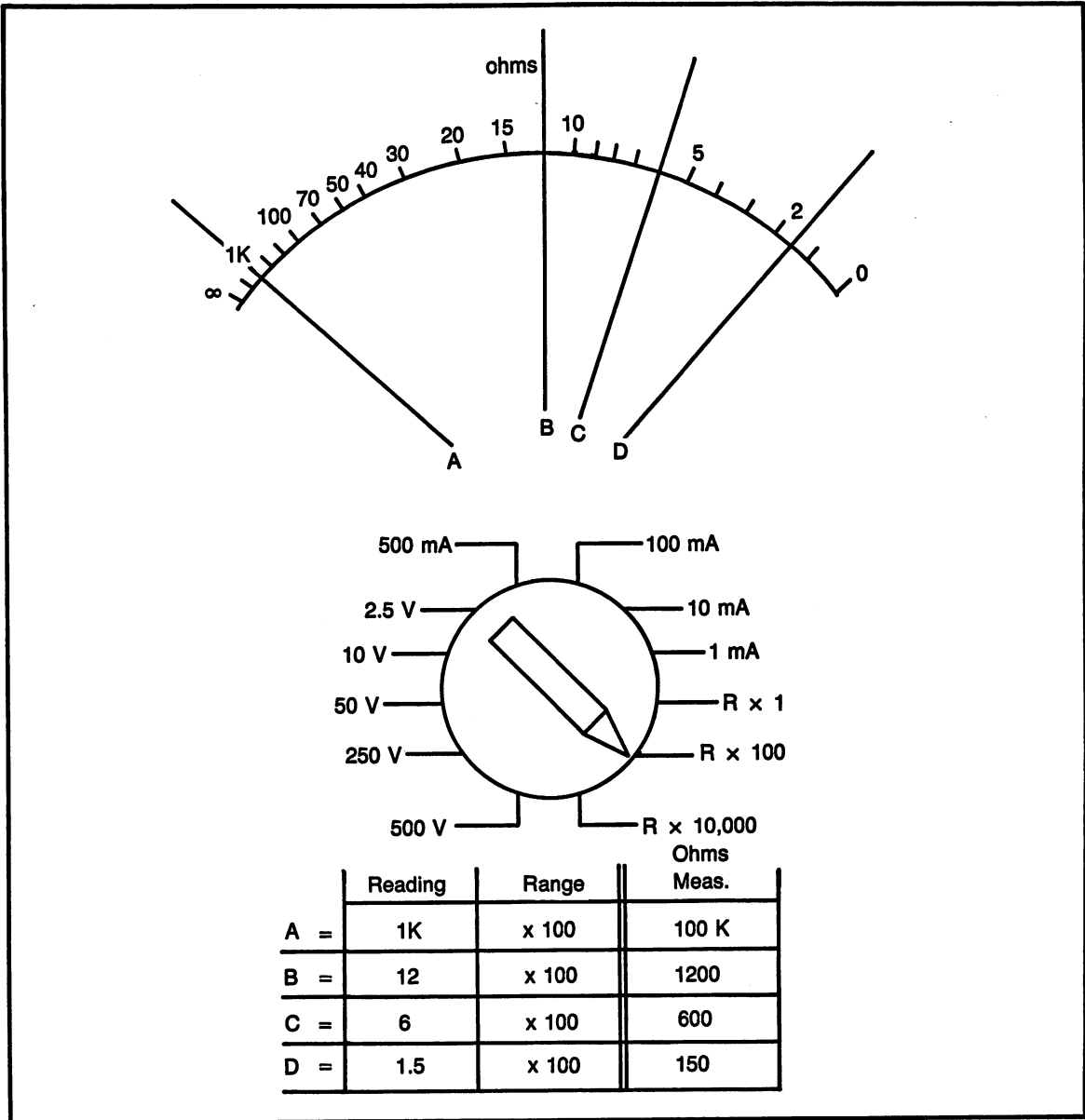


Fig. 6-6. Ohmmeter scale with examples.

Table 6-1. Ohmmeter Readings.

| Needle | Reading | Resistance Measurement |
|--------|---------|------------------------|
| A | 1k | 100 kilohms |
| B | 12 | 1200 ohms |
| C | 6 | 600 ohms |
| D | 1.5 | 150 ohms |

Step 2. Ohms Zero Adjustment.

Refer to Fig. 6-4B.

- Short the test leads together.
- With the range switch on any ohms scale, the needle should swing to the far right side, 0 ohms.
- Adjust the ohms adjust knob so the needle

falls exactly over zero. If this adjustment does not bring the needle to zero, it is probably because the battery is weak.

- (d) The zero adjust must be checked every time a new range is selected.

Part B. Measuring Resistance

Select at least 10 different resistors to make measurements in this part of the hands-on experience. Use Table 6-2 to record the results of this exercise.

Step 1. Making the Measurement.

Refer to Fig. 6-4C.

- (a) Connect the test leads to the test resistor. With the range switch on any ohms scale, there should be a reading.
- (b) Turn the range switch and make a mental note of the reading on each range. This can be done quickly without having to adjust the zero each time.
- (c) Select the range that provides the best reading for accuracy; between zero and center scale.

- (d) Adjust the zero for the range selected.
- (e) Read the meter as accurately as possible. Record this reading in Table 6-2 under the heading "scale reading".
- (f) Record the setting of the range switch in Table 6-2 under the heading "range switch".
- (g) Multiply the scale reading by the range switch setting. Record the result of this multiplication in Table 6-2 under the heading "resist measure".

Step 2. Considering Tolerance.

- (a) Determine the nominal value of the resistor under test, by reading the resistor color code. Record this in Table 6-2 under the heading "nominal value".
- (b) Calculate the maximum and minimum values, based on the resistor's tolerance. Record these values in Table 6-2 under the proper headings.
- (c) Compare the resistance measurement to the calculated maximum and minimum values and determine if the test resistor is within acceptable tolerance and mark the "accept" column yes or no.

Table 6-2. Measuring Resistance.

| | Measured Values | | | Calculated Values | | | |
|------|-----------------|--------------|----------------|-------------------|-----------|-----------|----------------|
| | Scale Reading | Range Switch | Resist Measure | Nominal Value | Max Value | Min Value | Accept? yes/no |
| (1) | | | | | | | |
| (2) | | | | | | | |
| (3) | | | | | | | |
| (4) | | | | | | | |
| (5) | | | | | | | |
| (6) | | | | | | | |
| (7) | | | | | | | |
| (8) | | | | | | | |
| (9) | | | | | | | |
| (10) | | | | | | | |

Part C. Measuring a Potentiometer

Measuring the resistance of a variable resistor (potentiometer) is a good demonstration in the proper use of an ohmmeter. Figure 6-7 shows a potentiometer schematic symbol and a pictorial drawing. Figure 6-8 shows an ohmmeter connected to the potentiometer for testing.

Step 1. Measure Total Resistance.

Connect the ohmmeter test leads to the two ends of the potentiometer, as shown in Fig. 6-8A. If the potentiometer has a resistance value marked on it, it should be equal to this measured value, within an acceptable tolerance. Turning the adjustment screw will have no effect on the measurement of total resistance. Record this measurement in Fig. 6-9, on the appropriate line.

Step 2. Wiper to Either End.

Connect the ohmmeter to the wiper and either end "a" or "b", as shown in Fig. 6-8B and 6-8C. Turning the adjustment screw will cause the resistance measurement to go up and down.

Step 3. Adding Resistor "a" and "b".

With the ohmmeter connected to point "a", adjust the potentiometer to have a reading of approximately $\frac{1}{3}$ of the total resistance. Record the actual measurement, on the appropriate line in Fig. 6-9, and label it "resistor a". **Do not make further adjustments.**

Move the ohmmeter lead to point "b". **Do not adjust the potentiometer.** Record the reading, on the appropriate line in Fig. 6-9, taken from the wiper to point "b", and label it "resistor b".

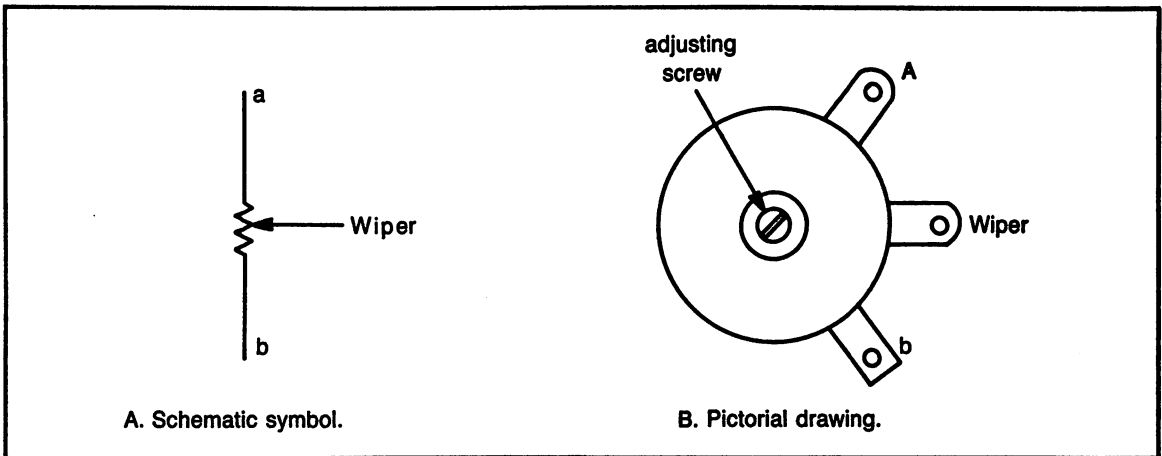


Fig. 6-7. Schematic symbol and pictorial drawing of a potentiometer.

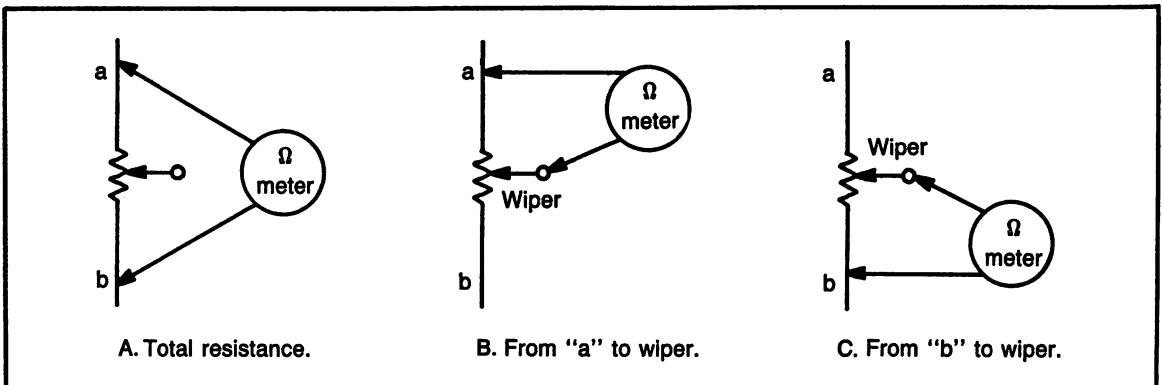
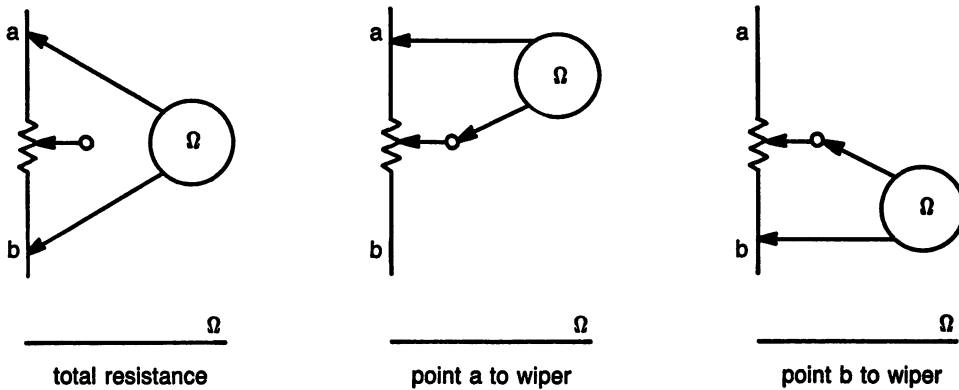
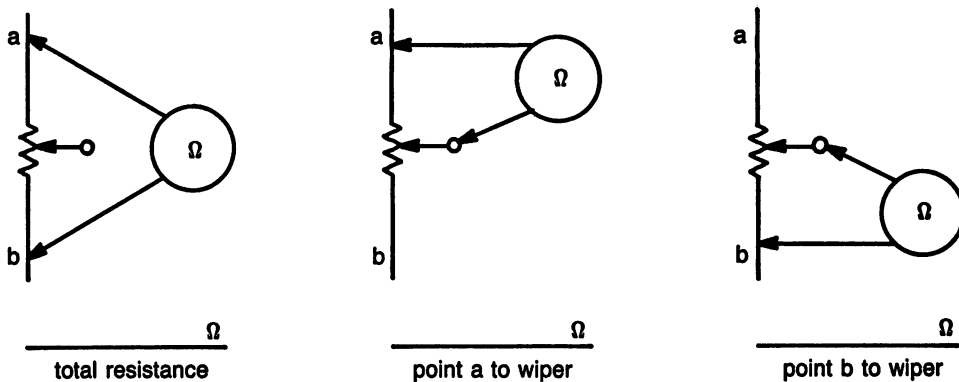


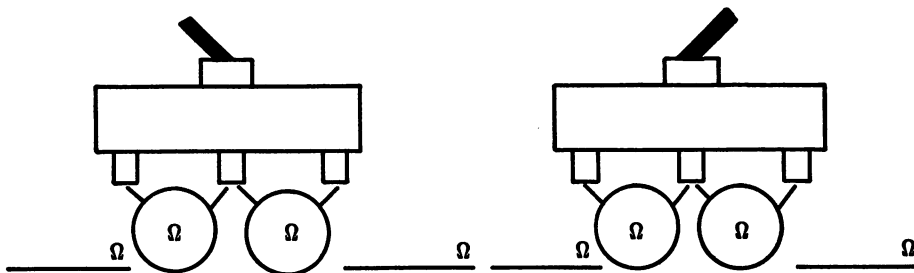
Fig. 6-8. Using the ohmmeter to measure a potentiometer.



A. Measure the resistance of the potentiometer.



B. Measure the resistance of a second potentiometer.



C. Measure from common to each side. Switch to other position, repeat.

Fig. 6-9. Ohmmeter experience.

Add "resistor a" to "resistor b". Their sum should be equal to the measured value of total resistance.

Repeat this exercise for a second, different value potentiometer.

Part D. Measuring Continuity

The ohmmeter is a very useful instrument for measuring continuity. Continuity is considered a continuous path for the flow of electricity. Examples of checking continuity are:

- Checking for breaks in a wire.
- Determine if a fuse is good or bad.
- Locating which terminals of a switch go together.

Measurements for continuity can be made on any range setting. The readings will be either in-

finity, if the circuit is open, or zero, if the circuit is closed. Tests for this section will be made on switches.

The best type of switch for making this test is a single-pole double-throw toggle switch. Figure 6-10 shows the schematic symbol and a pictorial drawing of a SPDT toggle switch.

Figure 6-11 shows the readings at each terminal with the switch in either position.

Step 1. Locating Switch Terminals.

Connect the ohmmeter test leads to the center terminal (common) and either outside terminal.

Note the reading at this outside terminal. Move the ohmmeter lead to the other outside terminal (the lead connected to common stays).

The reading from common to one terminal should be zero, and from common to the other terminal should be infinity.

The side with the zero reading is the closed con-

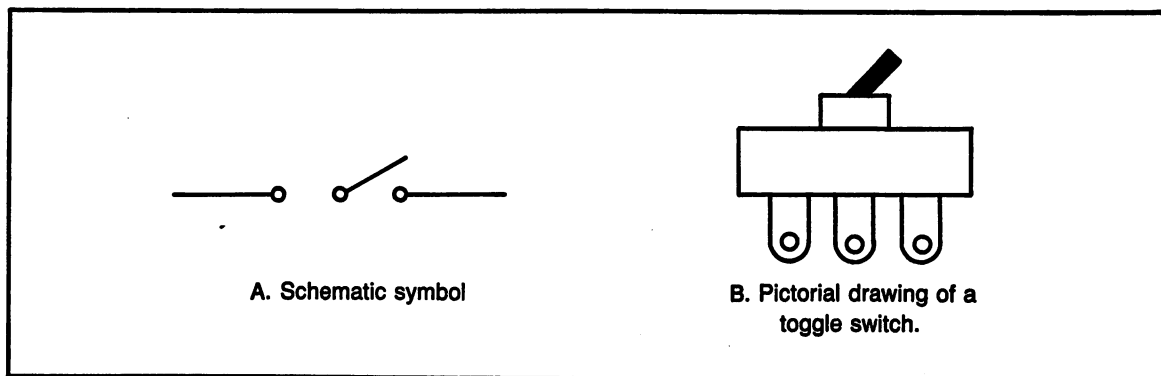


Fig. 6-10. Single pole double throw (SPDT) switch.

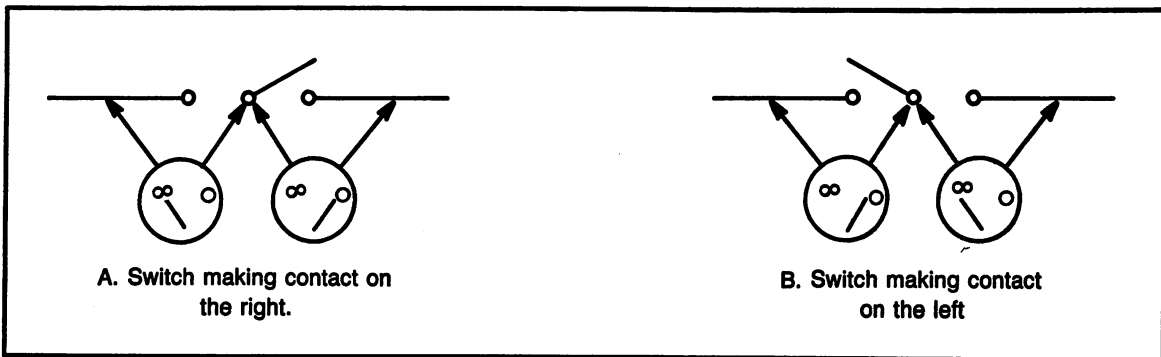


Fig. 6-11. Ohmmeter showing the readings with the switch in both positions.

tact and the side with the infinity reading is the open contact.

Step 2. Relating Terminals to Switch Position.

With the ohmmeter connected to common and either terminal, record the reading on the appropriate line in Fig. 6-9. Move the ohmmeter to the other terminal and record this reading. Move the switch lever to the other position and note the effect on the ohmmeter reading. Record the readings.

PROGRAMS FOR THIS CHAPTER

The program for this chapter will provide experience with a digital ohmmeter.

There are 20 questions; each shows the face of a digital ohmmeter with 6 ranges. One of the ranges is selected for each question. The question is to state the meter reading, in ohms, without use

of engineering notation in the answer.

If the range selected is 2 or 200, the measured value is read directly from the meter, with the decimal as shown.

If the range selected is 20k or 200k, the reading displayed on the meter is multiplied by 1000. Move the decimal 3 places to the right.

If the range selected is 2M or 20M, the reading displayed on the meter is multiplied by 1,000,000. Move the decimal 6 places to the right.

Each range setting is the maximum for that particular range. Digital meters use this method to improve accuracy.

Figure 6-12 shows a preview sample of the ohmmeter program.

OHMMETER WRITTEN COMPETENCY TEST

The 50 answers on this test are 2 points each.

Ohmmeter

Sample program:

| | |
|-------|---|
| 1.500 | 2 2 2 2 2 2 |
| | 0 0 0 M 0 |
| | 0 K 0 M |
| | K |
| | 0 0 <input checked="" type="checkbox"/> 0 0 0 |
| | Ohms |

1. What is the resistance being measured in ohms? 1500

Correct!

Space bar for next
N for new selection

Fig. 6-12. Ohmmeter program sample.

Part A. Reading an Ohmmeter

With the 5 ohmmeters (scale/range switch) shown, determine the measurement with each needle.

(1) Figure 6-13

- A _____ ohms
- B _____ ohms
- C _____ ohms
- D _____ ohms
- E _____ ohms

(2) Figure 6-14

- A _____ ohms
- B _____ ohms

- C _____ ohms
- D _____ ohms
- E _____ ohms

(3) Figure 6-15

- A _____ ohms
- B _____ ohms
- C _____ ohms
- D _____ ohms
- E _____ ohms

(4) Figure 6-16

- A _____ ohms
- B _____ ohms
- C _____ ohms

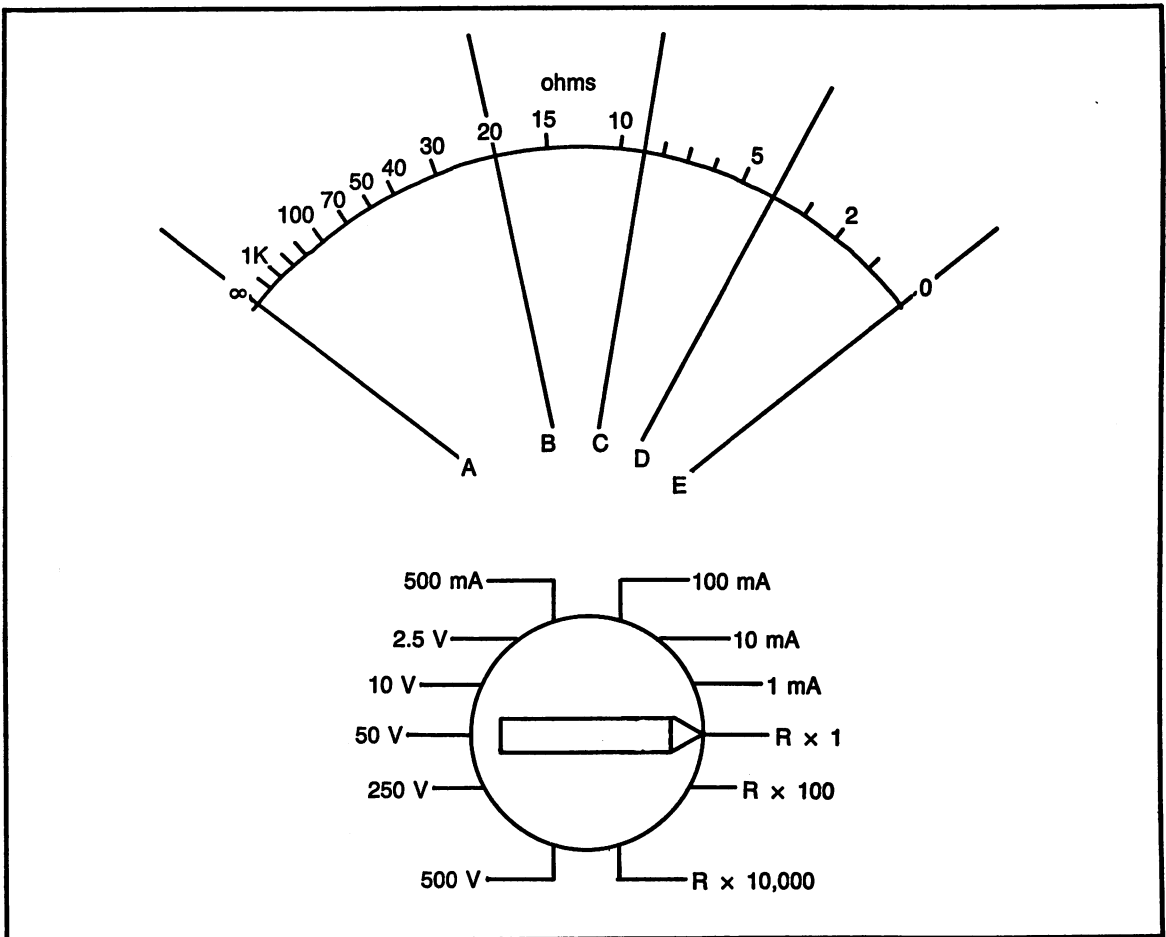


Fig. 6-13. Ohmmeter scale for question 1.

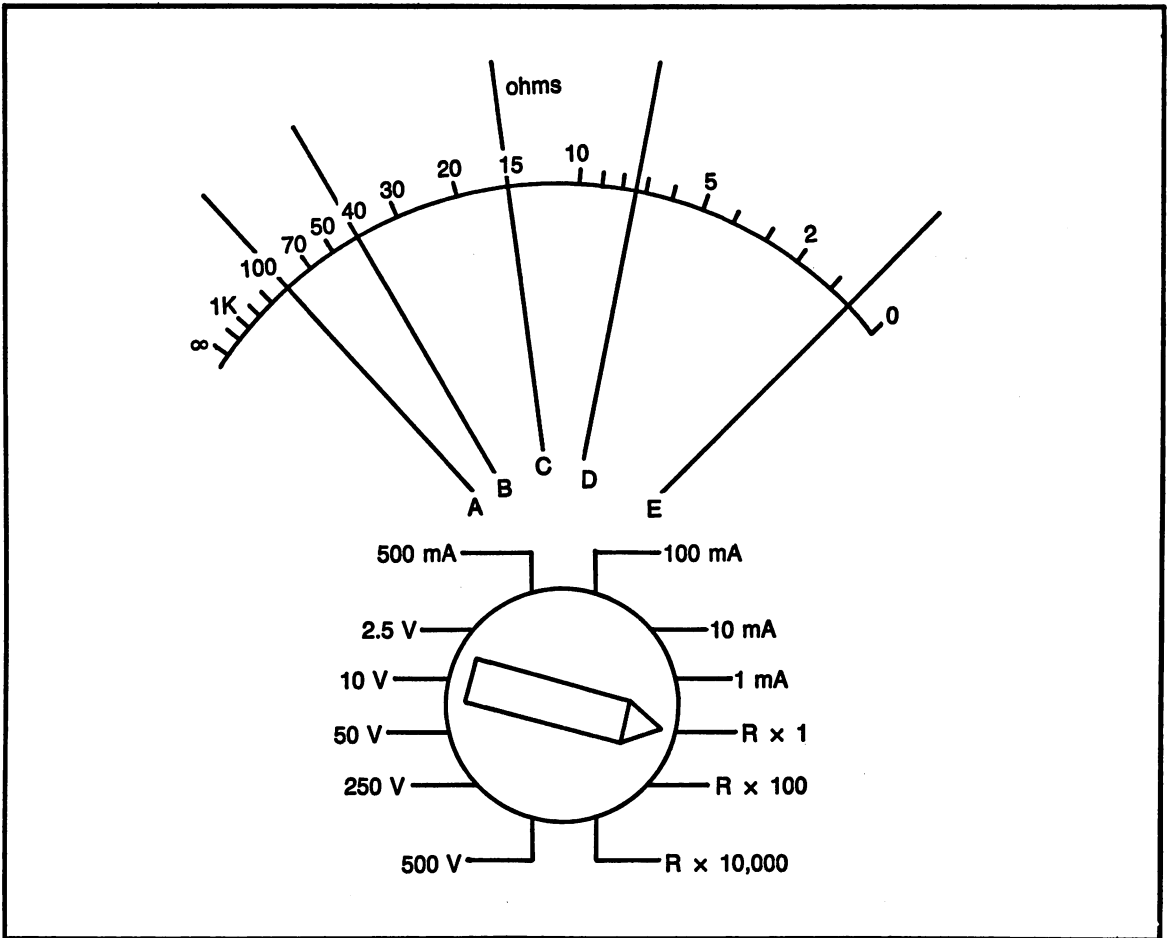


Fig. 6-14. Ohmmeter scale for question 2.

- D _____ ohms
 E _____ ohms
- (5) Figure 6-17
 A _____ ohms
 B _____ ohms
 C _____ ohms
 D _____ ohms
 E _____ ohms

Part B. Ohmmeters; General Questions

- (6) An ohmmeter is connected to both ends of a long piece of wire. The meter reads infinity. What is the condition on the wire? (good or bad)
- (7) An ohmmeter is connected to both ends of a long piece of wire. The meter reads zero. What is the condition of the wire? (good or bad)
- (8) When an ohmmeter is used to test a fuse, what should the reading be if the fuse is good?
- (9) When an ohmmeter is used to test a fuse, what should the reading be if the fuse is bad?
- (10) An ohmmeter is connected to a 200 ohm potentiometer, to one end and to the wiper. If the reading is 50 ohms, what would the reading be if it was connected from the wiper to the other terminal?
- (11) An ohmmeter is connected to a 500 kilohm potentiometer, to the wiper and one end. If the reading is 50 on the (R x 100), what would

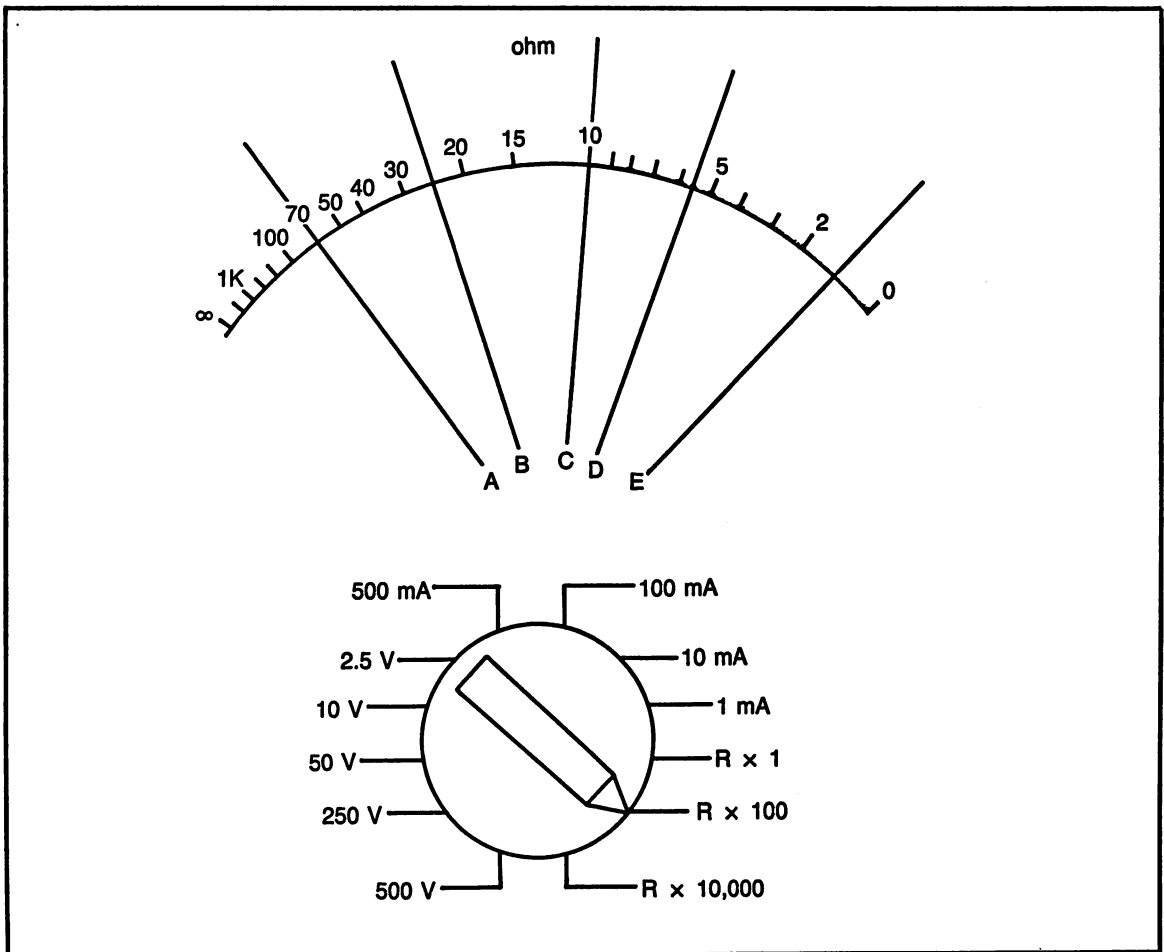


Fig. 6-15. Ohmmeter scale for question 3.

- be the reading if connected to the other end terminal?
- (12) An ohmmeter is connected to a 100 kilohm potentiometer, to the wiper and one end. If the reading is 3 on the ($R \times 10,000$) scale, what would be the reading if connected to the other end terminal?
- (13) What would the ohmmeter reading be if it were connected to the opposite terminals of a 1 kilohm potentiometer?
- (14) If an ohmmeter is connected to the center terminal of a switch and to one end, what reading would be expected when there is continuity through the switch contacts?

- (15) Describe the procedure for making the adjustment with the "ohms adjust" control.

Part C. Resistor Tolerance

Determine if the following resistors are within acceptable tolerance, based on the ohmmeter reading and color code. Answer yes or no.

| | <u>Reading</u> | <u>Scale</u> | <u>Colors</u> |
|------|----------------|-------------------|-----------------|
| (16) | 11 | $R \times 10$ | brn-red-brn-gld |
| (17) | 40 | $R \times 100$ | org-whi-red-sil |
| (18) | 3.5 | $R \times 10,000$ | yel-vio-org-sil |
| (19) | 9 | $R \times 1$ | brn-blk-blk-gld |
| (20) | 2.5 | $R \times 100$ | red-red-brn-sil |

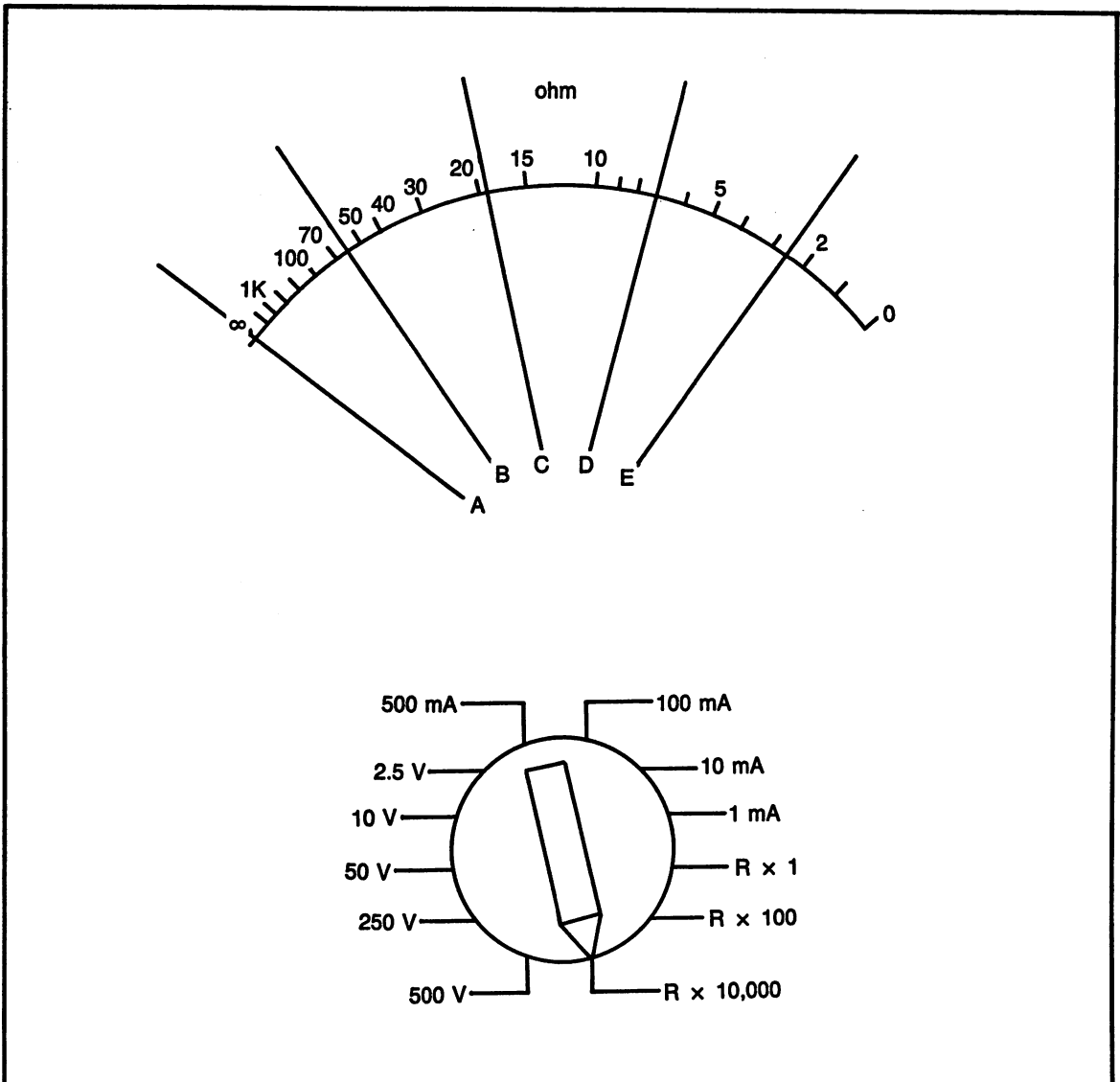


Fig. 6-16. Ohmmeter scale for question 4.

Part D. Converting in Engineering Notation

Convert the number on the left to the unit on the right.

- (21) $1.2 \text{ M}\Omega =$ _____ kilohms
- (22) $33 \text{ k}\Omega =$ _____ ohms
- (23) $1500 \text{ mV} =$ _____ volts
- (24) $0.5 \text{ W} =$ _____ milliwatts
- (25) $0.25 \text{ mA} =$ _____ microamps

Part E. Draw the Schematic Symbols of the Following:

- (26) single-pole double-throw switch
- (27) double-pole double-throw switch
- (28) potentiometer
- (29) fuse
- (30) a complete simplified schematic diagram of an ohmmeter (not including the range switch).

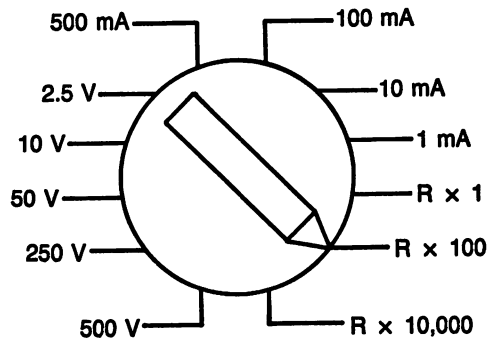
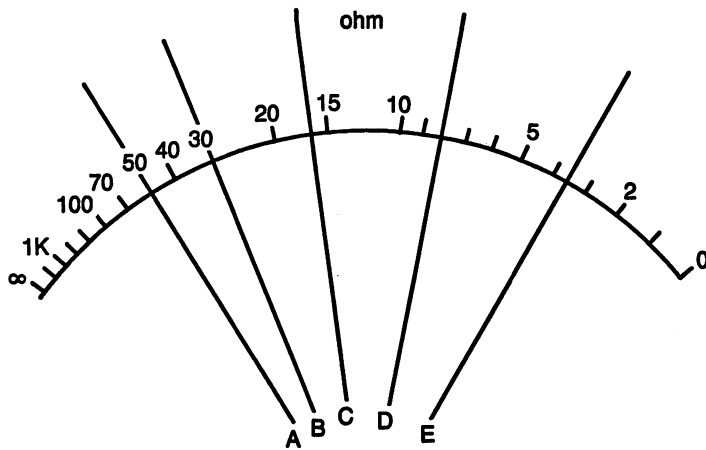


Fig. 6-17. Ohmmeter scale for question 5.

Chapter 7

DC Circuits: Relationships, Formulas and Measurements

Chapter Objectives: To define the relationships of voltage, current, resistance and power and to learn the mathematical formulas that apply to these relationships. Also, to learn to use a voltmeter and ammeter to measure circuit parameters.

Chapter outline:

- Electrical relationships
- Ohm's law
- Power formulas
- Connecting single-load circuits
- Using a voltmeter
- Using an ammeter
- Meter construction
- Programs for this chapter
- DC circuits, relationships, formulas and measurements competency test

INTRODUCTION

The terms; voltage, current, resistance, power, amps, watts and some others, are terms that many people use to describe electricity. Although these

terms are frequently used, they are often misunderstood. This chapter will not only define these terms and their relationships to each other, this chapter will also use mathematical formulas to calculate the relationships.

ELECTRICAL RELATIONSHIPS

There are four types of measure of electrical energy and its effects and relationships. These four are; voltage, current, resistance and power. Each of these have a particular unit of measure and a mathematical relationship.

Resistance

Resistance is a characteristic of a material in which electricity will, or will not flow. Resistance can range from almost zero to an infinite amount. Resistance has a characteristic similar to friction.

In Chapter 5, the subjects of resistance and voltage were discussed, and in Chapter 6 resistance was measured using an ohmmeter.

Key Point. The definition of resistance is; the opposition to the flow of electrical energy. It is the friction in an electrical circuit. The symbol for resistance is R.

Key Point. The unit of measure of resistance is ohms, symbol Ω , the Greek letter omega.

A good conductor should have as close to zero ohms resistance as possible. A closed switch allows current to flow and it should have zero resistance. An insulator does not allow the flow of electricity. Therefore, it should have resistance that is so high as to be considered infinity. An open switch should have infinite resistance, to stop the flow of electricity.

Those examples are the opposite ends of the resistance scale. Here are some examples of resistance not at the ends of the scale; a filament light bulb allows the flow of electricity, but offers a sufficient amount of resistance to cause the filament wire to heat to white hot and glow. The volume control knob on a radio or TV is a variable resistor, more resistance means less volume and less resistance gives more volume.

Resistors are used for many purposes in controlling the flow of electricity or to provide work through the use of electricity.

Voltage

Voltage is the driving force behind electricity. It can range from a very small amount to a very large amount. In Chapter 5, batteries were discussed as a source of voltage. It was also stated that voltage sources can be added together to achieve a much larger voltage supply. Power companies send voltage along the long-distance lines in amounts in the millions of volts.

The larger the voltage, the harder the driving force and the more electrical energy that can flow.

Key Point. The definition of voltage is; force or pressure of electrical energy. Symbol of voltage is V. An older symbol is E (stands for electro-motive force).

Key Point. The unit of measure of voltage is volt, symbol V.

A battery is a good example of a voltage source. If the battery is disconnected or if there is an open

switch, to not allow electricity to flow, the battery will still have its voltage. When the battery is allowed to supply energy, it will “push” electrons through the conductor. Another example is an electrical outlet. Even though there is nothing connected to the outlet, voltage is still present. This voltage can be measured with a voltmeter.

Current

Current is the flow of electricity. It is actually electrons flowing in the conductor, being pushed by the voltage. If there is no voltage to push the electrons, there will be no current flow. If the voltage applied is not strong enough to overcome the circuit resistance, such as an open switch, current cannot flow.

It is the electrons flowing through the load device that performs the electrical work.

Key Point. The definition of current is; the flow of electrical energy. Symbol for current is I.

Key Point. The unit of measure of current is amperage (amp), symbol is A.

Key Point. Current flows from negative to positive.

Most people are familiar with the term amperage from the fact that fuses are rated in amperage. The purpose of a fuse is to prevent too much current from flowing in a circuit. Resistance is similar to friction. Heat is produced due to the opposition to electron flow. Even wires will produce some heat. Too much heat in a wire can cause problems. Fuses “blow” because the heat from too much current melts the fuse.

Power

Power is the measure of work. An example is the term “horsepower”. Horsepower is a standard measure of the amount of work a horse can produce in a specific amount of time. In terms of electrical work, the end result of the use of electricity is considered power. Regardless of how electricity is used, there will be power whenever there is both voltage and current.

Key Point. The definition of power is; the measure of electrical work. Symbol of power is P.

Key Point. The unit of measure of power is wattage (watt), symbol W.

The power company that supplies electricity measures the electricity used and sells it to the customer in terms of the amount of work performed, for a period of time. They charge by the “kilowatt-hour”. In other words, one thousand watts used in one hour. The electric service meter measures in kilowatt hours.

In order for electricity to serve any useful purpose, it must perform some form of work. This work can be giving off light, heating a stove, or even oper-

ating a computer. The device that performs the work is considered the “electrical load”. In direct current (dc) circuits, the load is often considered some form of resistance.

Relationships

The four units of electricity are all related together. An analogy that is often used to show the electrical relationships is water in a pipe. Figure 7-1 shows the relationships in a circuit and in a water pipe.

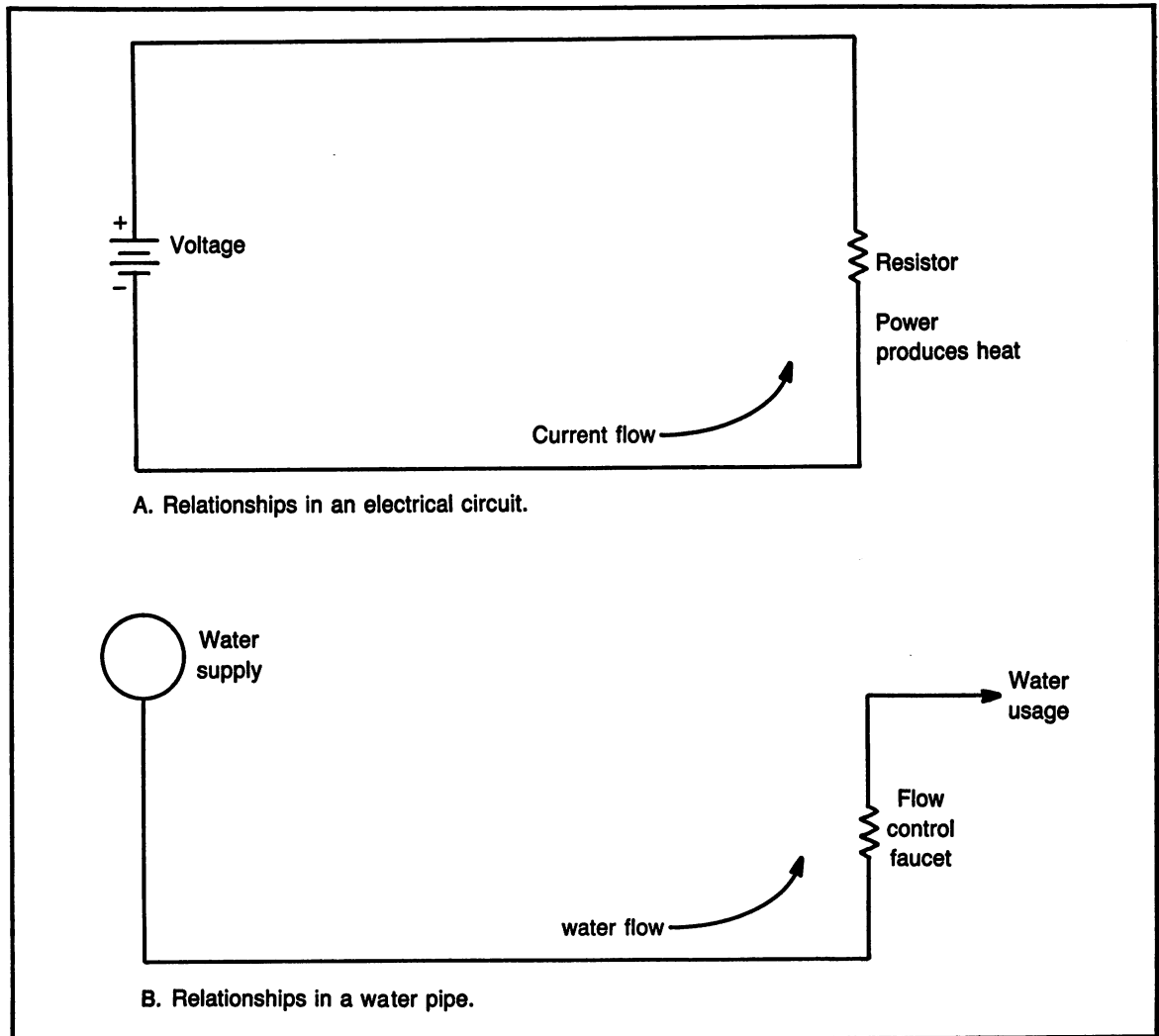


Fig. 7-1. Comparison between an electric circuit and a water pipe.

Voltage can be compared to water pressure. Even when there is no water flowing, the pressure is still there. Current is the water flowing in the pipe. In order to have flow, there must be pressure. Resistance can be compared to the friction in the pipes and a faucet that is partly open, so that it restricts the flow. Power can be compared to the result of the water flowing, such as spraying water on the grass.

Summary of Units

| <u>Quantity</u> | <u>Symbol</u> | <u>Unit</u> | <u>Symbol</u> |
|-----------------|---------------|-------------|---------------|
| Resistance | R | ohm | Ω |
| Voltage | V (or E) | volt | V |
| Current | I | amp | A |
| Power | P | watt | W |

Direct Current/Alternating Current

Dc stands for direct current and ac stands for alternating current. The definitions of the basic electrical relationships are the same regardless if it is dc or ac. Up to this point, only dc has been discussed. Later in this book, ac will be discussed in detail.

Key Point. With direct current (dc), the voltage, and current, will remain either always positive or always negative.

Key Point. With alternating current (ac), the voltage, and current, will periodically alternate from positive to negative and negative to positive.

OHM'S LAW

A German scientist named Georg Ohm stated the electrical relationship between voltage, current and resistance as a mathematical formula. The formula is now called *Ohm's law*.

Ohm's Law Formulas

There are three formulas in Ohm's law, each solves for one of the three electrical quantities of voltage, current and resistance. Power is solved for using a different formula, discussed later in this chapter.

When using formulas, the symbols representing the terms are used in place of the terms. Therefore, it is necessary to memorize the symbols:

- R — resistance; measured in ohms (Ω)
- I — current; measured in amps (A)
- V — voltage; measured in volts (V)

Formula #1. Ohm's Law to Solve for Voltage.

$$V = I \times R$$

voltage = current \times resistance
volts (V) = amps (A) \times ohms (Ω)

Example of Solving for Voltage:

How much voltage is applied to a circuit if there is 2 amps of current flowing through 50 ohms of resistance?

Formula: $V = I \times R$
Substituting: $V = 2 \text{ amps} \times 50 \text{ ohms}$
Solving: $V = 100 \text{ volts}$

Notice: when solving these formulas, always use the unit of measure for the value being solved for.

Formula # 2. Ohm's Law to Solve for Current.

$$I = \frac{V}{R}$$

current = $\frac{\text{voltage}}{\text{resistance}}$
amps (A) = $\frac{\text{volts (V)}}{\text{ohms } (\Omega)}$

Example of Solving for Current:

Calculate the amount of current flowing in a circuit containing 80 volts and 20 ohms.

Formula: $I = \frac{V}{R}$
Substituting: $I = \frac{80 \text{ V (volts)}}{20 \Omega \text{ (ohms)}}$
Solving: $I = 4 \text{ amps}$

Notice: the answer is in the units for the value being found.

Formula #3. Ohm's Law to Solve for Resistance.

$$R = \frac{V}{I}$$

$$\text{resistance} = \frac{\text{voltage}}{\text{current}}$$

$$\text{ohms } (\Omega) = \frac{\text{volts (V)}}{\text{amps (A)}}$$

Example of Solving for Resistance:

Calculate the circuit resistance when there is 0.3 amps of current flowing with an applied voltage of 6.0 volts.

$$\text{Formula: } R = \frac{V}{I}$$

$$\text{Substituting: } R = \frac{6.0 \text{ V (volts)}}{0.3 \text{ A (amps)}}$$

$$\text{Solving: } R = 20 \text{ ohms}$$

Notice: the answer is in the units for resistance.

Mathematical Relationships

When using a mathematical formula, it is very important to understand the relationships between all members of the formula. In other words, if one of the values is changed, how are the other values affected?

First, examine formula #1; $V = I \times R$ to see how each member relates. As with every formula, we are particularly concerned about the value that will be solved for, in this case, V. It is important to visualize how V will be affected if R or I were to go up or down.

If R is as a constant value (the circuit is built with a fixed value of resistance) and the current through the resistor changes, how does the voltage

change? If I increases, voltage will also increase. If I decreases, V will also decrease. This is known as a "direct relationship".

If the current is held at a fixed value, and the resistance is changed, how does the voltage change? If the circuit resistance is increased, it will require more voltage to maintain the constant current. If R is decreased, V will also decrease. This is known as a "direct relationship".

Key Point. A direct relationship is; when one value on one side of the equation changes, the value on the other side of the equation will change in the same direction. This will always occur when the operation side of the equation is multiplication, or a numerator of a fraction.

Examine formula #2; $I = V/R$ and determine how the values relate. In this formula, current is the value being solved for and voltage and resistance are allowed to vary to determine the circuit conditions.

If the circuit contains a fixed resistor and the voltage changes, how will the current change? If V increases, I will increase. If V decreases, I will decrease. Since they both change in the same direction, this is a "direct relationship". This occurs because V is the numerator of the fractional formula.

If the circuit voltage is maintained at a constant value and R is changed, how will the circuit current change? It should make sense that if the resistance is increased, the current will decrease. If the resistance is decreased, the current will increase. Since these values go in opposite directions, this is called an "inverse (or indirect) relationship".

Key Point. an inverse (or indirect) relationship occurs when the value on one side of the equation is changed and the value on the other side is changed in the opposite direction. This occurs with division or with the denominator of a fraction.

Finally, examine formula #3; $R = V/I$ to determine the relationships of the terms. V and I are related to R in this formula.

Since V is in the numerator of the fraction, it is a direct relationship. If V increases, R must also increase to maintain a constant I. If V decreases, R decreases to maintain I.

Since I is in the denominator of the fraction, it is an inverse relationship. If I increases, R will de-

crease to maintain a constant V and if I decreases, R will increase.

Practice Problems: Ohm's Law

With each of the following; use the given values to solve for the unknown value. The proper units must be included with each answer.

- | | | |
|------------------------|--------------------|---------|
| (1) R = 100 ohms | I = 0.2 amps | Find: V |
| (2) I = 500 mA | R = 250 ohms | Find: V |
| (3) R = 1 kilohm | I = .03 amps | Find: V |
| (4) I = 10 mA | R = 2.2 k Ω | Find: V |
| (5) V = 100 volts | R = 25 ohms | Find: I |
| (6) R = 0.5 k Ω | V = 50 volts | Find: I |
| (7) V = 0.3 kV | R = 1 k Ω | Find: I |
| (8) R = 30 ohms | V = 60 mV | Find: I |
| (9) V = 60 volts | I = 3 amps | Find: R |
| (10) I = 50 mA | V = 10 volts | Find: R |
| (11) V = 25 mV | I = 5 μ A | Find: R |
| (12) I = 300 μ A | V = 60 mV | Find: R |
| (13) I = 25 μ A | R = 2 M Ω | Find: V |
| (14) R = 15 M Ω | I = 3 μ A | Find: V |
| (15) V = 3 mV | R = 10 ohms | Find: I |

POWER FORMULAS

Power is considered one of the four basic circuit relationships. Calculations for power can be made using any two of the other three circuit values.

An important point to make is the fact that power is the measure of electrical work performed. It is a measure of electrical energy.

Voltage-Current Relationship

The power formulas start with the basic relationship of voltage and current. The unit of measure of power is watt, with the symbol of W. The symbol for power is P.

Formula #4. Power Formula Using the V \times I Relationship.

$$P = V \times I$$

power = voltage \times current
watts = volts \times amps

Example of Solving for Power:

Determine the amount of power dissipated in a circuit with 0.5 amps of current and an applied voltage of 120 volts.

$$\text{Formula: } P = V \times I$$
$$\text{Substituting: } P = 120 \text{ volts} \times 0.5 \text{ amps}$$
$$\text{Solving: } P = 60 \text{ watts}$$

This same formula can be rearranged to solve for either voltage or current, similar to the manner in which Ohm's law was used.

Example of Solving for Voltage:

What is the applied voltage in a circuit that uses 20 milliwatts of power and has a current flow of 10 milliamps?

$$\text{Formula: } V = \frac{P}{I}$$
$$\text{Substituting: } V = \frac{20 \text{ mA}}{10 \text{ mA}}$$

$$\text{Solving: } V: 2 \text{ volts}$$

Example of Solving for Current:

How much current flows in a circuit if 5 watts of power is dissipated, with an applied voltage of 20 volts?

$$\text{Formula: } I = \frac{P}{V}$$
$$\text{Substituting: } I = \frac{5 \text{ W}}{20 \text{ V}}$$

$$\text{Solving: } I = 0.25 \text{ amps}$$

Combining the Power Formula with Ohm's Law

With the use of simple algebra, the three variations of Ohm's law can be combined with the three variations of the basic power formula. This is performed with algebra by substituting formulas in place of the different variables.

As a result of the combining of formulas, one of the four circuit values can be found, provided any two of the other values are known.

Solving for Power when R and I are Known:

Formulas needed: $P = V \times I$ and $V = I \times R$

Use the power formula and substitute Ohm's law in place of V.

Combining formulas: $P = (I \times R) \times I$

Formula #5. Power Formula Using I and R.

$$P = I^2 \times R$$

Example of Solving for Power When R and I are Known:

Find the power in circuit with 100 ohms resistance and 20 mA current flow.

Formula: $P = I^2 \times R$

Substituting: $P = (20 \text{ mA})^2 \times 100 \text{ ohms}$

Solving: $P = 40 \text{ mW}$

Note: $(20 \text{ mA})^2 = 20\text{E}-3 \times 20\text{E}-3 = 400\text{E}-6 = 0.0004$

Substituting: $P = .0004 \times 100 = .04 \text{ W} = 40 \text{ mW}$

Solving for Power when V and R are Known:

Formulas needed: $P = V \times I$ and $I = V/R$

Use the power formula and substitute Ohm's law in place of I.

$$\text{Combining formulas: } P = V \times \left(\frac{V}{R}\right)$$

Formula #6. Power Formula Using V and R.

$$P = \frac{V^2}{R}$$

Example of Solving for Power with V and R Known:

A circuit contains 2 kilohms resistance; what is the power dissipated with an applied voltage of 10 volts?

$$\text{Formula: } P = \frac{V^2}{R}$$

$$\text{Substituting: } P = \frac{(10 \text{ V})^2}{2 \text{ kilohms}}$$

$$\text{Solving: } P = 50 \text{ mW}$$

Table 7-1 shows all of the combined Ohm's law and power formulas. Keep in mind, it is much better to learn how to re-arrange the formulas than to try and memorize each of the 12 different versions.

Table 7-1. Combined Ohm's Law and Power Formulas.

| Values Given | Unknown to Find | Formula to use |
|--------------|-----------------|--------------------------|
| I, R | Voltage | • $V = I \times R$ |
| I, R | Power | • $P = I^2 R$ |
| V, R | Current | $I = \frac{V}{R}$ |
| V, R | Power | • $P = \frac{V^2}{R}$ |
| I, V | Resistance | $R = \frac{V}{I}$ |
| I, V | Power | • $P = I \times V$ |
| P, V | Current | $I = \frac{P}{V}$ |
| P, V | Resistance | $R = \frac{V^2}{P}$ |
| P, I | Voltage | $V = \frac{P}{I}$ |
| P, I | Resistance | $R = \frac{P}{I^2}$ |
| P, R | Current | $I = \sqrt{\frac{P}{R}}$ |
| P, R | Voltage | $V = \sqrt{P \times R}$ |

* Note: these four formulas are the basic formulas. The others are re-arranged versions, to allow solving for any desired unknown.

**Practice Problems:
Ohm's Law and Power Formulas**

Part A. With the table below, use the two given values to find the two unknown values. All answers must have the proper units.

| | Voltage | Current | Resistance | Power |
|------|-----------|-----------|------------|---------|
| (1) | _____ | 15 amps | 2 ohms | _____ |
| (2) | _____ | 2 amps | _____ | 5 watts |
| (3) | 100 volts | 0.01 amps | _____ | _____ |
| (4) | 250 volts | _____ | 5 ohms | _____ |
| (5) | 15 volts | _____ | _____ | 100 mW |
| (6) | _____ | _____ | 1 kilohm | 10 mW |
| (7) | _____ | 25 mA | 10 kilohms | _____ |
| (8) | _____ | 2 mA | _____ | 25 mW |
| (9) | 50 volts | 5 mA | _____ | _____ |
| (10) | 5 volts | _____ | 2500 ohms | _____ |

Part B. Use the information given in each of the following word problems to find the unknown values.

- A resistor with the color code brown-black-red-silver is connected to a 6 volt battery. Determine the current flowing from the battery and the power dissipated by the resistor.
- A particular light bulb in a car is rated at 36 watts. What is the resistance of the light and the current drain? (Assume a 12 volt battery.)
- A zener diode has a voltage dropped across it of 6 volts. The current through the diode is 2 amps. Determine the power-dissipation requirements and what value resistor could be used in its place.
- What is the resistance of a 60 watt/120 volt light bulb. Also determine the current requirement.
- A load resistor with the color code yellow-violet-orange-gold is connected to 2 "D-size" dry cell batteries. Determine the current flow and the power dissipated.

CONNECTING SINGLE-LOAD CIRCUITS

Whenever possible, all of the circuit parameters (voltage, current, resistance, power) should be calculated before making an attempt at measurements. This will insure the meters are used properly.

Wiring a Circuit

On paper, schematic diagrams are neatly drawn and a student quickly learns to read the schematics. However, when connecting a circuit with wires and components, things are not so neat and easy.

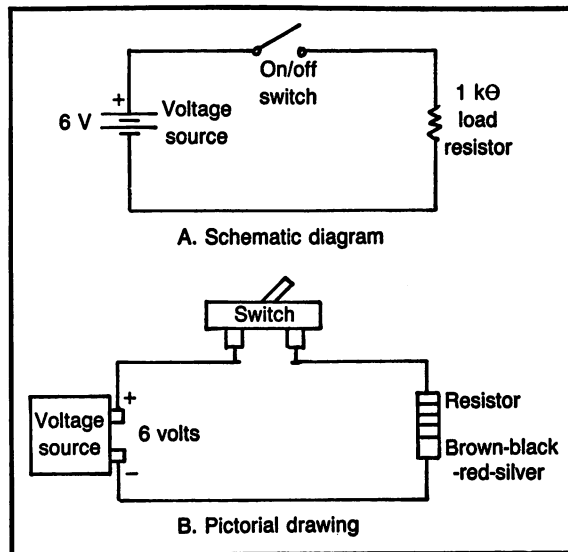


Fig. 7-2. A schematic diagram and pictorial drawing of the same dc circuit.

Figure 7-2 shows a schematic diagram and a pictorial drawing. The symbol for a battery is shown as a box in the pictorial. It is most common to use a variable power supply in a laboratory situation. If a variable power supply is not available, a 6 volt "lantern" battery will be adequate for the circuits presented here. Notice, the voltage source is labeled with + and -. This is the polarity of the voltage and is very important when working with dc.

All of the lines in a schematic diagram represent wires in an actual circuit. In Fig. 7-2, a wire runs from the + side of the voltage source to a switch. It is shown here as a two terminal on/off switch. Keep in mind, a double-throw switch works as well as a single-throw switch when it is used as on/off. A wire runs from the switch to the resistor. Resistors do not have a specific polarity, therefore, they can be connected in any direction. A wire then runs from the resistor back to the voltage source to complete the circuit.

It is best when connecting circuits to trace each wire as if it were a line on the schematic diagram.

Calculating the Circuit Parameters

It is very important to calculate the parameters of a circuit, whenever possible. By doing this, it will

be seen immediately on the meters if all connections have been made correctly.

The circuit of Fig. 7-2 shows a 6 volt battery connected to a 1 kilohm resistor, through a switch. When the switch is closed, current will flow in the circuit and the voltage will be applied to the resistor. Using Ohm's law, if the voltage is known and the resistance is known, current and power can be calculated.

Calculating Current:

$$\text{formula: } I = \frac{V}{R}$$

$$\text{substituting: } I = \frac{6 \text{ volts}}{1 \text{ kilohm}}$$

$$\text{solving: } I = 6 \text{ milliamps}$$

Calculating Power:

$$\text{formula: } P = I \times V$$

$$\text{substituting: } P = 6 \text{ mA} \times 6 \text{ volts}$$

$$\text{solving: } P = 36 \text{ milliwatts}$$

Due to the nature of measuring instruments, meters to measure power are seldom used. The calculation for power is necessary only to insure that the resistor connected will be a large enough wattage rating for the circuit. The calculation for current is much more important since a current meter (ammeter) will be used.

USING A VOLTMETER

The voltmeter most technicians use, and therefore most students, is the multimeter type. In other words, the same meter used as an ohmmeter will now change the range switch and become a voltmeter. Figure 7-3 shows two different multimeters, with quite different voltmeter scales.

Reading the Meter Scales

Always keep in mind that the range switch determines which scale is to be read.

Generally speaking, all meters will use the same

scales for both voltage and current, and most meters will use a different scale for dc and ac, but usually they are marked with exactly the same numbers.

The meter on the left, in Fig. 7-3 has four scales. Ohms at the top, dc, ac and dB. The meter on the right has five scales, dc on the top, ac (RMS), ac (P-P), R and dB.

Using just the dc scale as a model, examine both meters. The scales are quite different, but consider the function of the range switch. The range switch determines the maximum or "full-scale" reading for each scale.

The meter on the left has scales for the ranges of 10, 50 and 250. The range switch for that same meter has those three positions, plus 2.5 and 500. That means the range switch also acts like a multiplier. The 50 scale is used for 500 and the 250 scale is used for the 2.5 range.

The meter on the right has its dc scale marked 1 and .3 and the range switch goes from .3 V to 1000 V. Notice, however, each step on the range switch is a multiple of the scales.

Key Point. The range switch of a voltmeter or ammeter selects the maximum for that range.

Connecting a Voltmeter

When connecting a voltmeter in a circuit, it is very important to remember that voltage will be applied to the meter. The meter must be properly connected and adjusted to insure no damage will result from the applied voltage.

Polarity must be observed when using dc voltages. That means; connect the negative side of the meter to negative and the positive side of the meter to positive.

When first connecting a meter, it is best to use a range higher than expected and then switch down to a lower range. In this manner, the meter is protected from over-voltage in the event that the voltage is higher than expected.

Voltmeters have a very high "input resistance". Although current flowing through the meter is required, voltmeters require a very small amount of current. Therefore, voltmeters are connected across (in parallel with) the voltage to be measured.

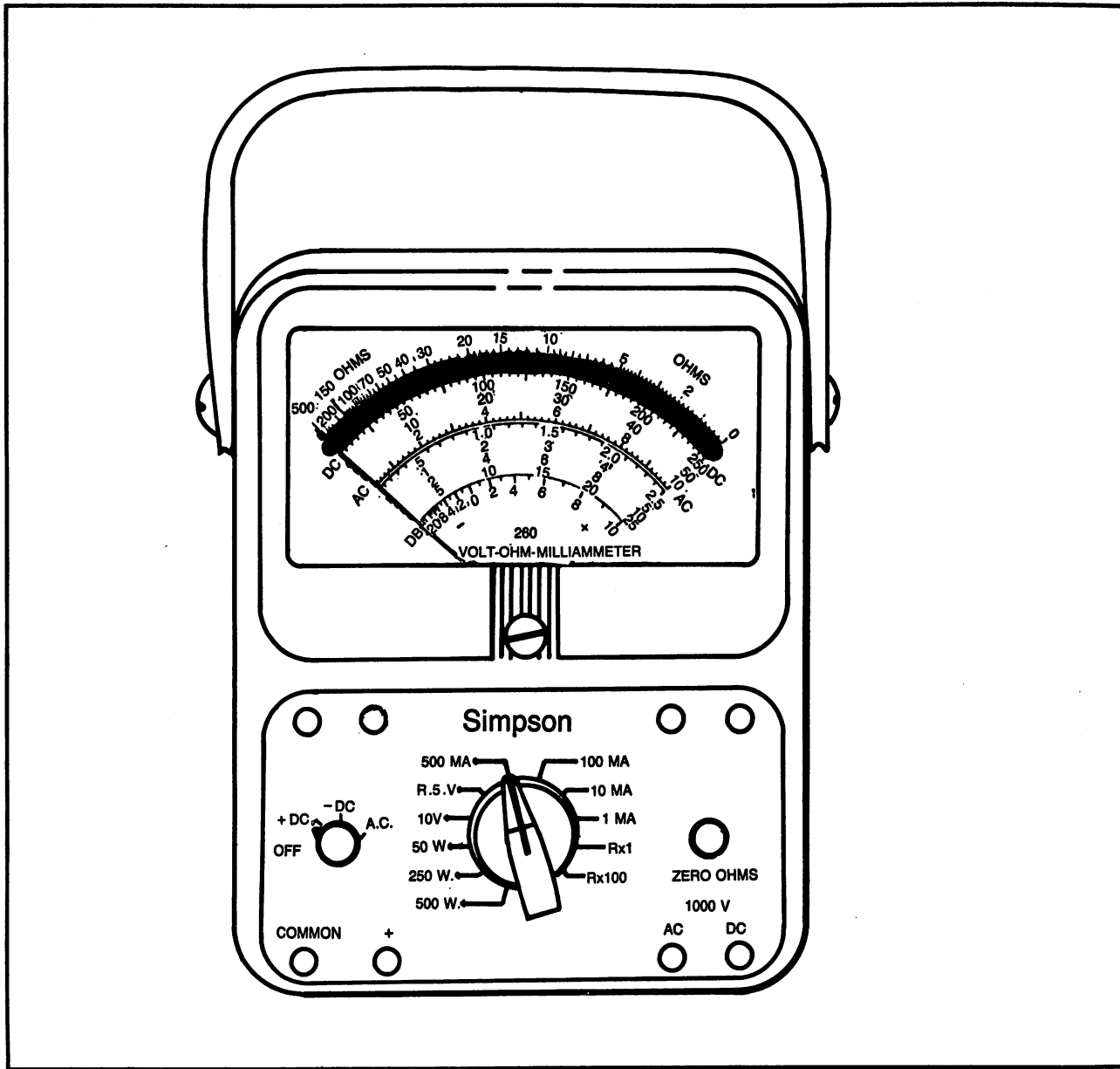


Fig. 7-3. Sample multimeters. (Photos supplied by Simpson Electric Co.)

Key Point. Voltmeters are connected across (in parallel with) the voltage being tested.

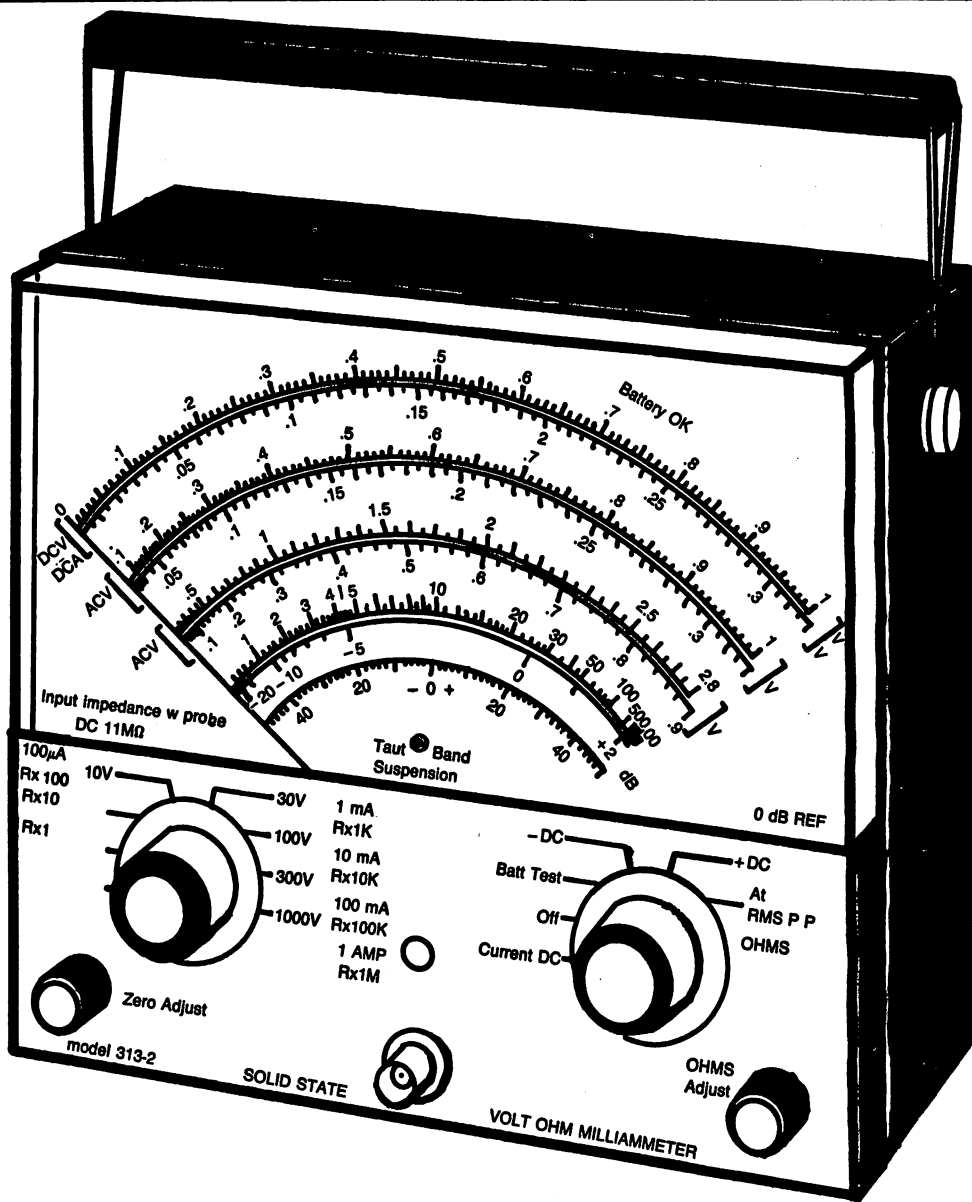
Practice Voltmeter Measurements

In order to obtain practice with a voltmeter be-

fore making actual circuit measurements, dry cell batteries will be used.

Find several dry cell batteries. The type used in flashlights is good for a start. It is best if some of the batteries are old and some new.

Figure 7-4 shows a schematic diagram of con-



necting the voltmeter to the battery. Be sure to observe meter polarity.

A dry cell battery should measure approximately 1.5 volts. For a new battery, slightly higher is normal and for a weak battery, much lower. This test will indicate the relative strength of the battery.

For a better test of a battery's quality, connect a load to the terminals. Figure 7-5 is a schematic diagram of a voltmeter connected to test a battery under load. The load used here is a 1 kilohm resistor. When drawing current from the battery, if the battery is weak, the voltage will drop.

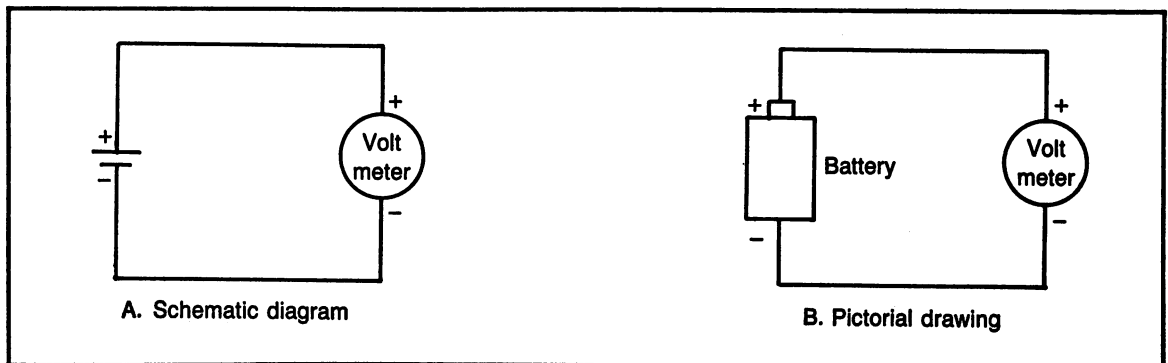


Fig. 7-4. Connecting a voltmeter to a battery.

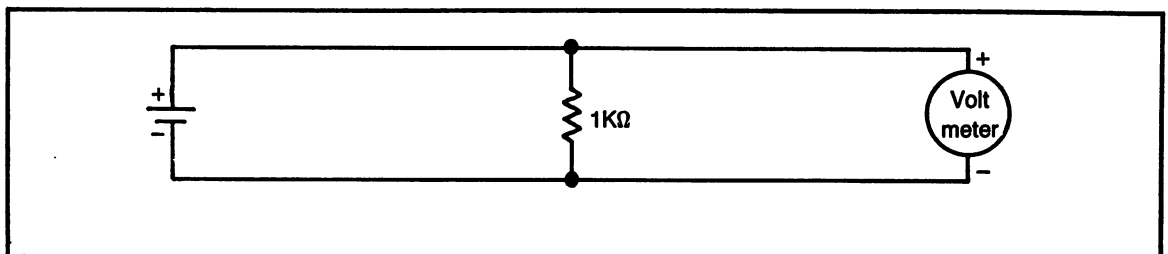


Fig. 7-5. Measuring the voltage of a battery with a 1 kilohm load resistor.

The test demonstrated here can be performed on any battery to test the quality of the battery.

USING AN AMMETER

An ammeter is used to measure the current flow in a circuit. Like a voltmeter and ohmmeter, the ammeter is part of the one meter called a “multimeter”. Figure 7-3 shows two examples of multimeters. Both of these meters have a scale to measure current (amps or milliamps).

Reading the ammeter scales is exactly the same as reading the voltmeter scale, since they both use the same scale. The only difference is the position of the range switch.

Connecting an Ammeter

When connecting an ammeter in a circuit, it is important to remember that the current must flow through the meter. The meter must be connected in series with (in the path of) the current flow. An ammeter has no built-in current protection, therefore, the circuit being tested is relied upon to limit the current flow, which the load resistor will do. The

ammeter must not be connected directly to a voltage source without a load resistor. Figure 7-6 shows the wrong and right ways to connect an ammeter. Always be sure to observe polarity.

Key Point. An ammeter must be connected in series with the current path.

Key Point. An ammeter must not be connected directly to a voltage source without a load resistor.

Practice Ammeter Measurements

Using Fig. 7-6C as an example, connect a circuit with which to measure current. Any battery can be used, such as a 6 volt lantern battery. Any resistor can be used. A good size to start with is 1 kilohm.

Whenever connecting a circuit for practice, be sure and calculate the circuit parameters. Knowing the circuit parameters beforehand will insure proper use of the meters. Notice that if the circuit is already built, it is necessary to disconnect one of the current paths to insert the meter. Make certain the negative side of the meter is connected toward the

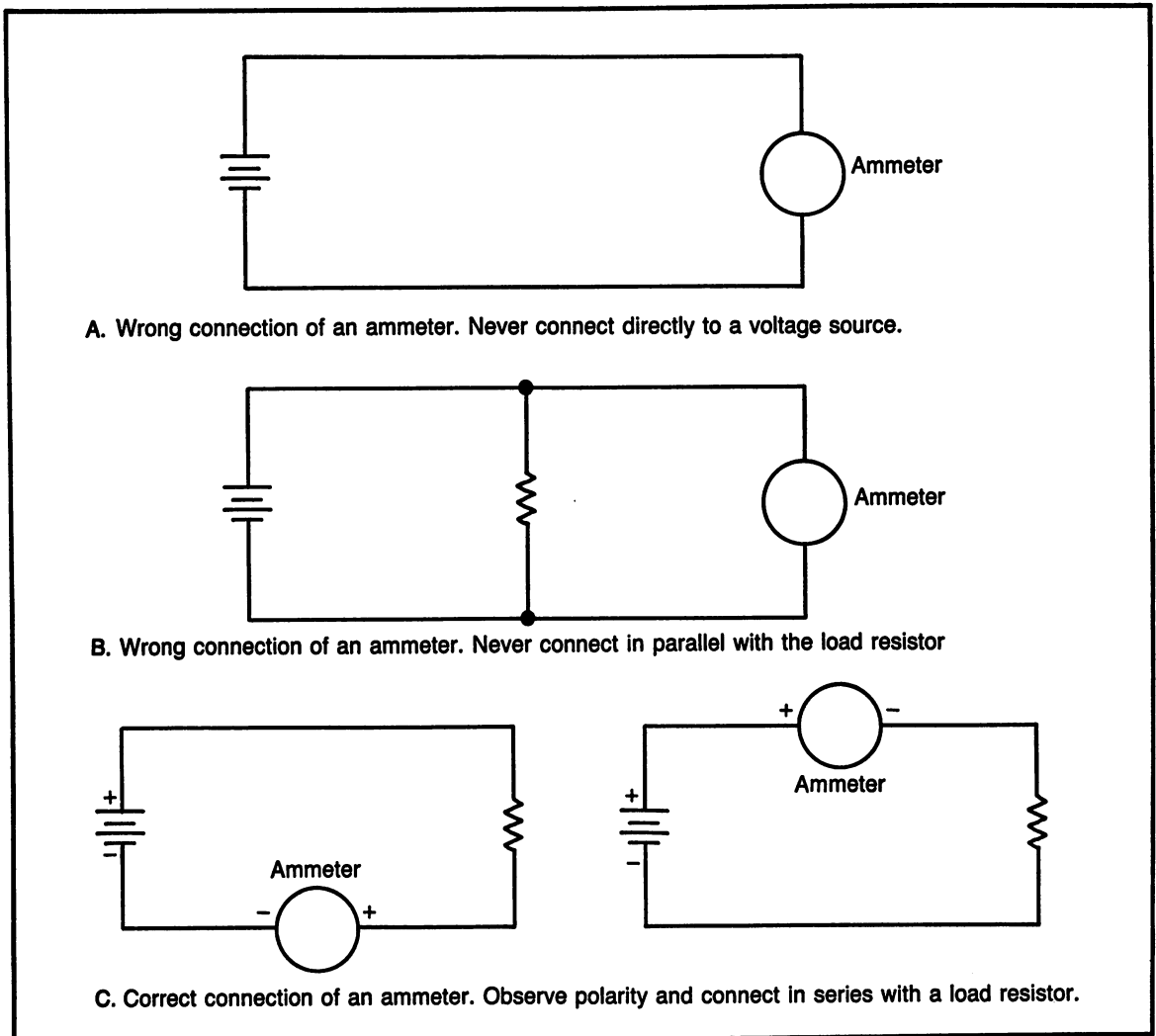


Fig. 7-6. Wrong and right ways to connect an ammeter.

negative side of the battery and the positive side of the meter is connected toward the positive side. Always observe the needle to make certain it does not go backwards or off the scale.

After making current measurements, reconnect the circuit and make voltage measurements to verify calculations.

METER CONSTRUCTION

The meter construction discussed here is of the analog-type meter. In other words, the type of me-

ter that uses a needle.

Moving Coil

The most popular type of analog meter is the type with a moving coil. Figure 7-7 is a drawing of a meter movement using the moving coil. The moving coil is fixed on a pivot and is allowed to rotate inside the field of a permanent magnet.

When current flows through the coil, a magnetic field is developed which interacts with the permanent magnet and the coil rotates.

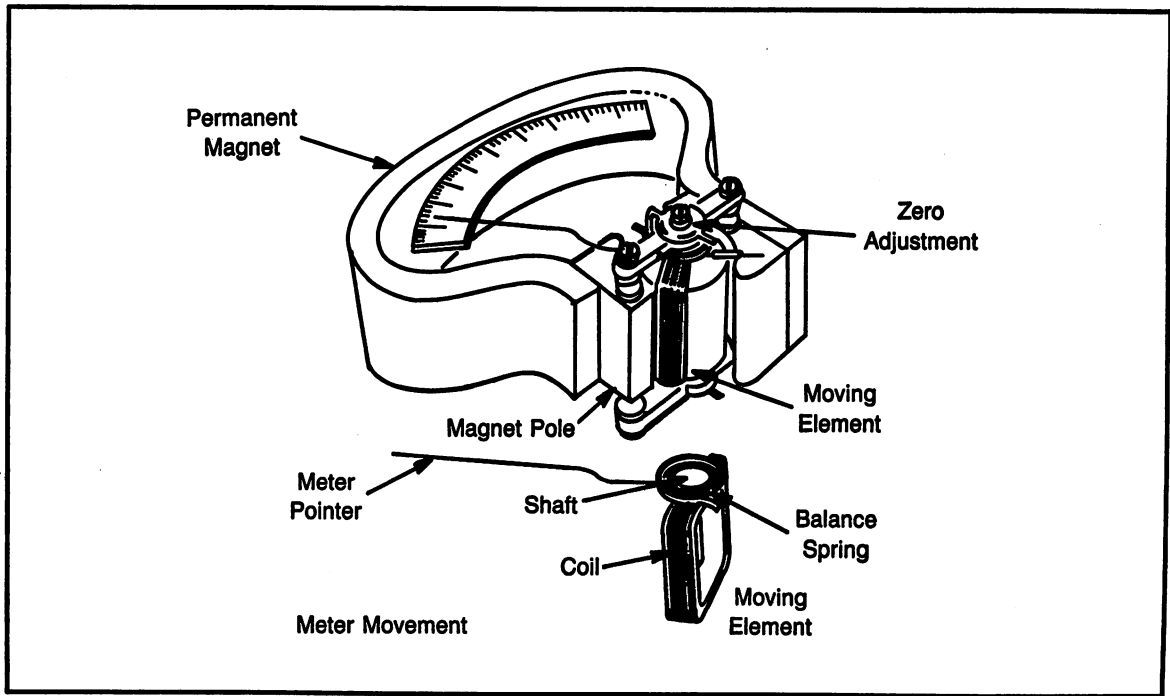


Fig. 7-7. Drawing of a meter movement showing the individual parts and the moving coil.

Meter Schematic Diagrams

Examination of the meter schematics helps to better understand how the meter will perform its functions.

When the ohmmeter was discussed in Chapter 6, its schematic diagram showed an internal battery was necessary for operation. That is because resistance is never measured when a circuit has voltage applied. The meter must supply its own voltage.

The voltmeter and ammeter use the electricity in the circuit to operate. In all three types of meters, it is current flowing through the coil that rotates the needle.

Voltmeter Schematic Diagram

A voltmeter allows only a very small amount of current to flow through the meter. Only the amount necessary to move the needle. In this way, it has almost no effect on the circuit being measured. A voltmeter should have a very large internal resistance, as close to infinity as possible and still allow current to the meter coil.

Figure 7-8 shows a simplified schematic diagram of a voltmeter. Notice the internal resistance of the meter is connected in series with the meter movement. This internal resistance is called a "multiplier" and is a very high value. The multiplier resistor is

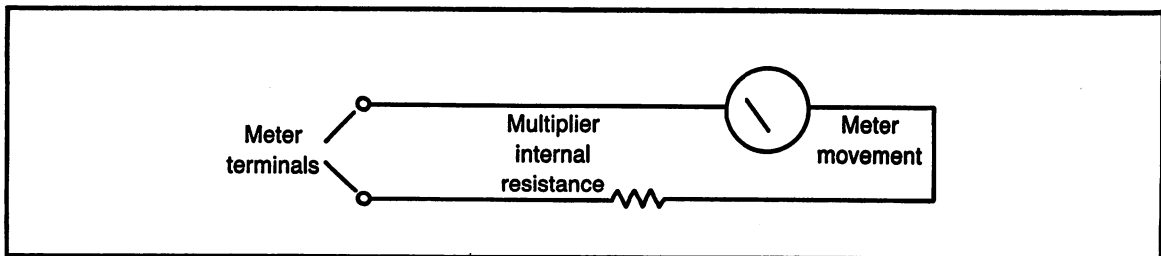


Fig. 7-8. Simplified schematic diagram of a voltmeter.

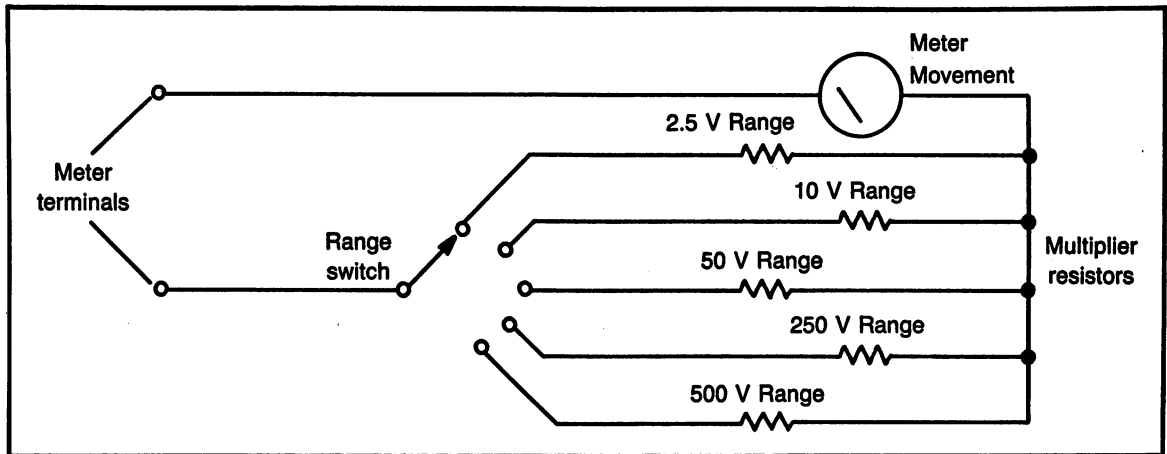


Fig. 7-9. Complete schematic diagram of a voltmeter, showing the range switch.

used to limit the current flow to the meter.

Figure 7-9 shows a complete schematic diagram of a voltmeter. The range switch is used to select different values of multiplier resistors. It takes a certain amount of current, typically 100 microamps, through the meter movement to make the needle go to "full scale". With each higher range, there will be more voltage, therefore, the multiplier resistor must be a higher value for each higher range. The lowest range will have the lowest multiplier and the highest range will have the highest value of multiplier resistor.

Ohm's Per Volt Rating

Voltmeters have an "ohms per volt" rating. The "ohms per volt" rating states the input resistance of the voltmeter, which is based on the current through the meter. The "ohms per volt" rating is always stated for a full scale reading. For example: if a voltmeter has a rating of 1000 "ohms per volt", it will have an input resistance of 2500 ohms on the 2.5 volt scale, 10000 ohms on the 10 volt

range, etc. This means that when the voltmeter is connected to a circuit, its resistance (which may affect the circuit) can be calculated, depending on the range. Voltmeters with a high input resistance, therefore, a high "ohms per volt" rating will have less adverse effect on a circuit than a voltmeter with a lower rating.

Voltmeter Accuracy

The accuracy of a voltmeter is usually stated in percentage of full scale. If the voltmeter has a percent accuracy of 2% and the range is 10 volts, when the meter reads 10 volts, the tolerance is from 9.8 volts to 10.2 volts ($10 \times .02 = .2$). If this same meter is used on the same 10 volt range, but measures 2 volts, the tolerance is from 1.8 volts to 2.2 volts. It is obvious then, readings that are closer to full scale are less affected by the percent accuracy than lower readings on the same range.

Ammeter Schematic Diagram

Figure 7-10 shows a simplified schematic diagram of an ammeter. The meter terminals, that con-

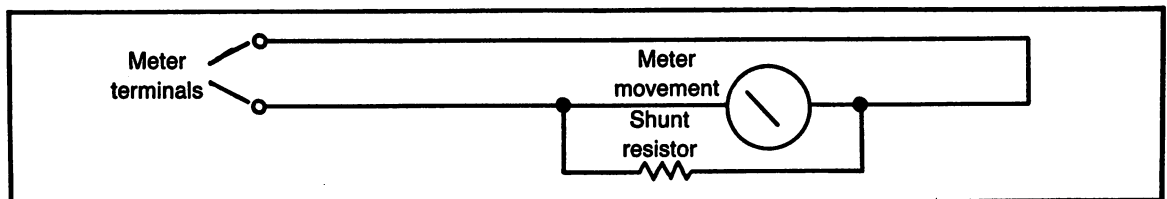


Fig. 7-10. Simplified schematic diagram of an ammeter.

nect to the circuit being measured, go directly to the meter movement. There is no resistor in series to limit current flow. The shunt resistor is connected in parallel with the meter. The word "shunt" means parallel. The shunt resistor is in parallel with the meter movement to allow a percentage of the applied current to bypass the meter.

Figure 7-11 shows a complete schematic diagram of an ammeter. The range switch selects a shunt resistor. Therefore, each range has a percentage of current that bypasses the meter. Let's say for example, the meter movement is rated for 100 microamps (.1 milliamps) and the range selected is 1 milliamp. When the meter reads full scale, 1 milliamp flows through the meter terminals, but only $\frac{1}{10}$ of that amount flows through the meter movement and the other $\frac{9}{10}$ is bypassed through the shunt resistor.

Ammeters have very low resistance because they are connected in series in a circuit. The ideal situation is for the meter to have no more effect on the circuit than a piece of wire.

Ammeter Accuracy

The accuracy of an ammeter is based on a percentage of full scale, in the same manner as a voltmeter. If the meter is rated as 1% of full scale accuracy, the tolerance on the 100 mA range (100

$\times .01 = 1$), with a current of 100 mA is 99 mA to 101 mA. The same meter on the same 100 mA range, but measuring a current of 10 mA will have a range of 9.9 mA to 11 mA.

It is obvious then, meter readings are the most accurate when closest to full scale.

PROGRAMS FOR THIS CHAPTER

There are two programs for this chapter. The first is practice with Ohm's law and the power formulas and the second is practice with a voltmeter.

Figure 7-12 is a preview of the Ohm's law program. In this program two values are given and it is necessary for the student to calculate a third value. The student should make every effort to make the actual calculations rather than just guessing at the answers.

Figure 7-13 is a preview of the V&A meter program. This program displays an analog-type meter scale. The student selects the meter range; either 30, 300, or 3000, then with the use of the computer keys, moves the needle. Once the meter is set, the student then has the opportunity to give the value of the meter reading. This program is unique in that it is a never-ending program, that is to say that the computer will continue to display the meter and allow for student response until the student ends the routine.

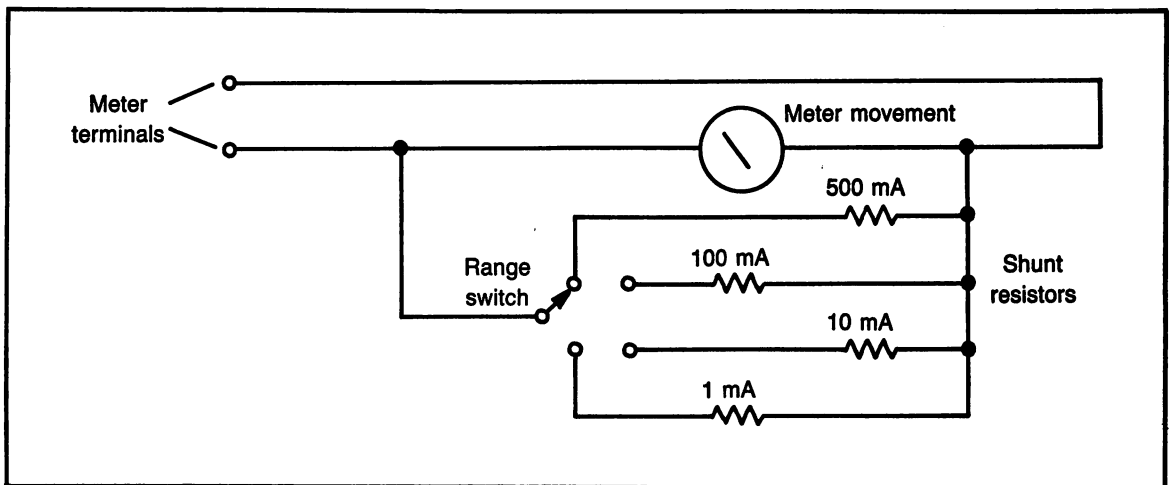


Fig. 7-11. Complete schematic diagram of an ammeter, including the range switch.

Ohm's law

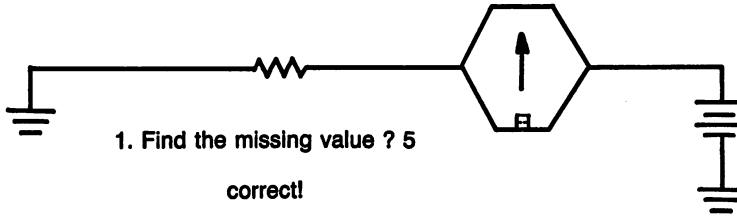
Sample Program:

Given:

Voltage = ? Volts

Current = .25 amps

Resistance = 20 ohms



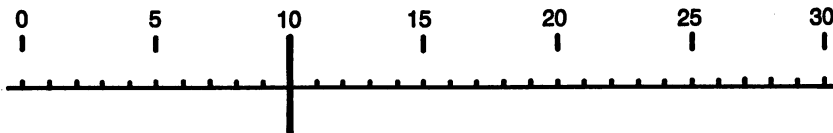
space bar for next
N for new selection

Fig. 7-12. Ohm's law program sample.

V&A Meter

Program Sample:

Enter (86) At meter setting to exit.



Set meter range (30, 300, or 3000) ?30

Present scale is 30 volts

To set meter needle Use function keys (F5) = left, or (F7) = right

Press space bar for question.

What is the value in volts? 10

Correct!

Press space bar for next.

Fig. 7-13. V&A meter program sample.

DC CIRCUITS: RELATIONSHIPS, FORMULAS AND MEASUREMENTS COMPETENCY TEST

A calculator is required for this test.

Part A. Definitions

Define the following terms. Whenever possible, give examples.

- (1) resistance
- (2) voltage
- (3) current
- (4) power
- (5) direction of current flow
- (6) dc
- (7) ac
- (8) direct relationship in a formula
- (9) indirect relationship in a formula
- (10) polarity
- (11) analog-type meter
- (12) multiplier resistor
- (13) shunt resistor
- (14) ohms per volt rating (give example)
- (15) meter accuracy rating (give example)

Part B. Calculations

With each of the following, use the information given to solve for the unknown quantity.

- | | | |
|------------------------|-------------------|-----------|
| (16) $R = 200$ ohms | $I = 3$ amps | Find: V |
| (17) $I = 5$ mA | $R = 4$ kilohms | Find: P |
| (18) $I = 25$ mA | $V = 15$ volts | Find: R |
| (19) $V = 30$ volts | $I = 2$ microamps | Find: P |
| (20) $R = 2.2$ kilohms | $V = 44$ volts | Find: I |
| (21) $V = 60$ volts | $R = 250$ ohms | Find: P |
| (22) $P = 2$ mW | $R = 15$ kilohms | Find: I |
| (23) $R = 500$ ohms | $P = 20$ mW | Find: V |

- | | | |
|---------------------------|---------------------|-----------|
| (24) $P = 4$ watts | $I = 2$ amps | Find: V |
| (25) $I = 50$ mA | $P = 1$ watt | Find: R |
| (26) $P = 100$ milliwatts | $V = 25$ millivolts | Find: I |
| (27) $V = 3$ volts | $P = 60$ mW | Find: R |
| (28) $R = 2$ megohms | $I = 5$ microamps | Find: P |
| (29) $I = 30$ microamps | $R = 4$ megohms | Find: V |
| (30) $P = 10$ milliwatts | $R = 25$ megohms | Find: I |

Part C. Schematic Diagrams

- (31) Draw a simplified schematic diagram of an ohmmeter.
- (32) Draw a simplified schematic diagram of a voltmeter.
- (33) Draw a simplified schematic diagram of an ammeter.
- (34) Draw a schematic diagram of a resistor connected to a battery. Show a voltmeter connected to measure the voltage applied to the resistor.
- (35) Draw a schematic diagram of a resistor connected to a battery. Show an ammeter connected to measure the current in the circuit.

Part D. Reading Meters

Use the sample meter scales in Figs. 7-14, 7-15, 7-16, 7-17, 7-18 state the reading of each needle. Read the scale as accurately as possible.

All Answers Must Have Proper Units.

- | | | |
|------------|------------|------------|
| (36) _____ | (37) _____ | (38) _____ |
| (39) _____ | (40) _____ | (41) _____ |
| (42) _____ | (43) _____ | (44) _____ |
| (45) _____ | (46) _____ | (47) _____ |
| (48) _____ | (49) _____ | (50) _____ |

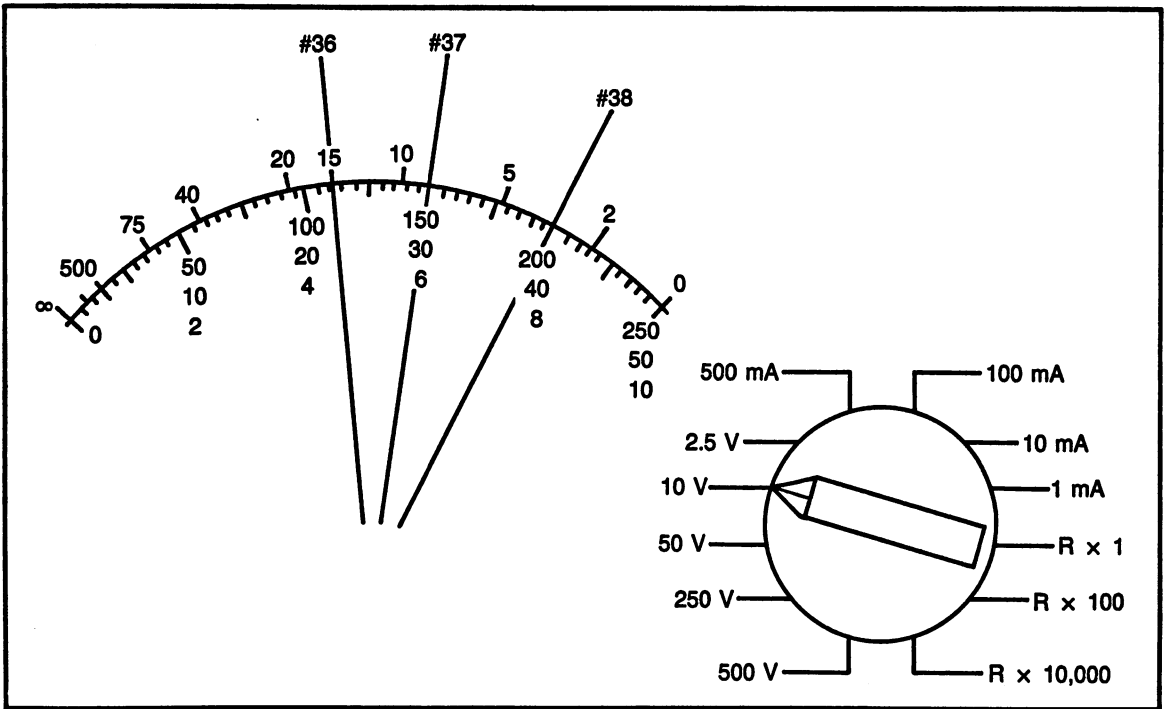


Fig. 7-14. Meter scale for test questions 36, 37, 38.

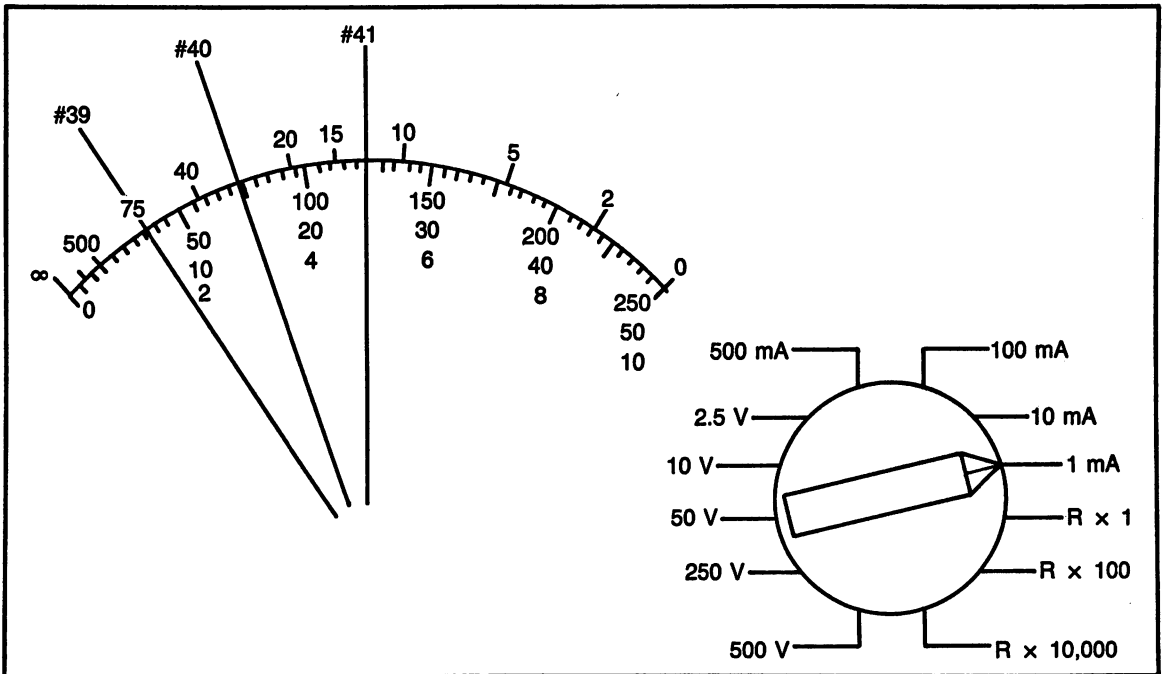


Fig. 7-15. Meter scale for test questions 39, 40, 41.

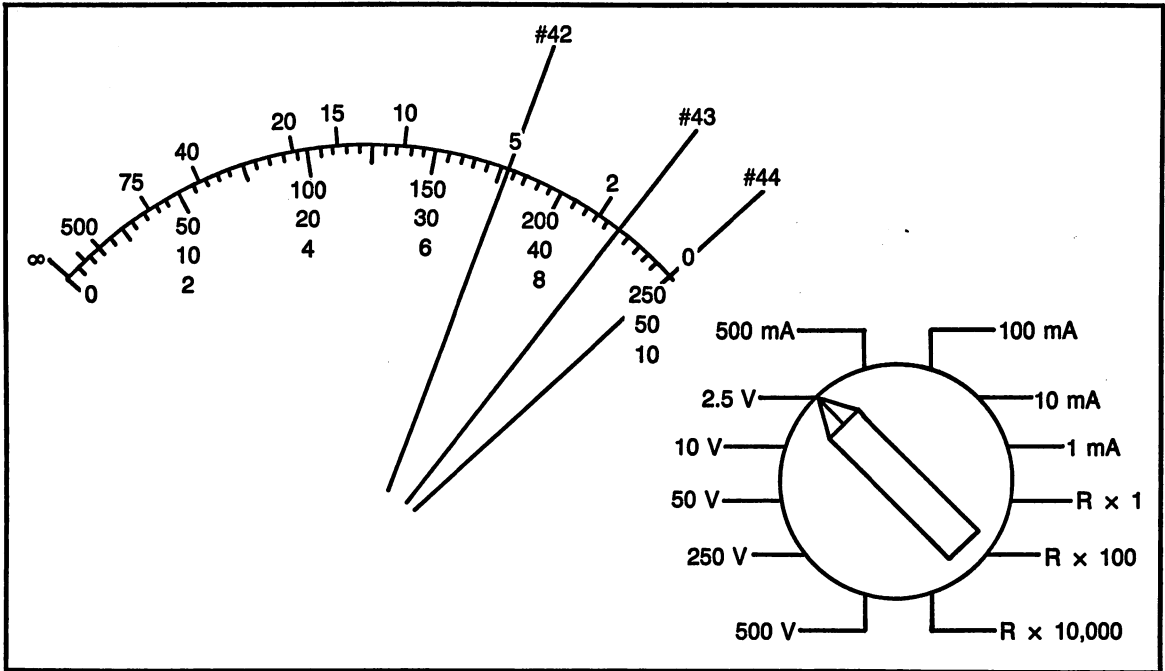


Fig. 7-16. Meter scale for test questions 42, 43, 44.

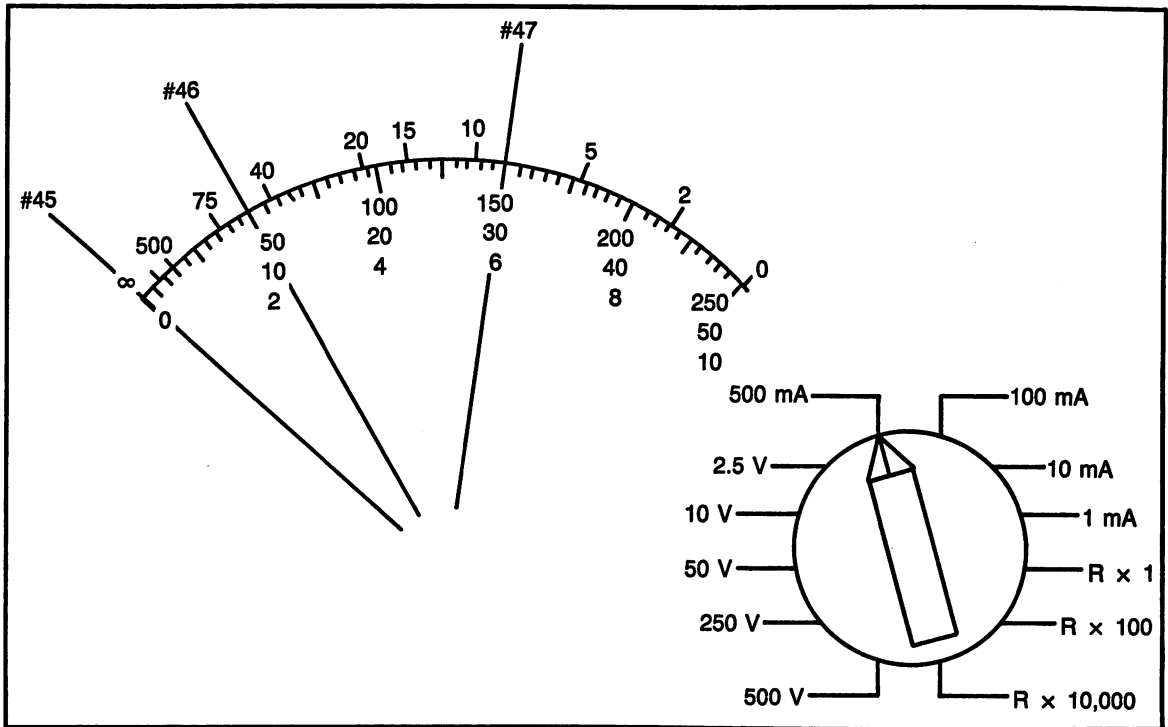


Fig. 7-17. Meter scale for test questions 45, 46, 47.

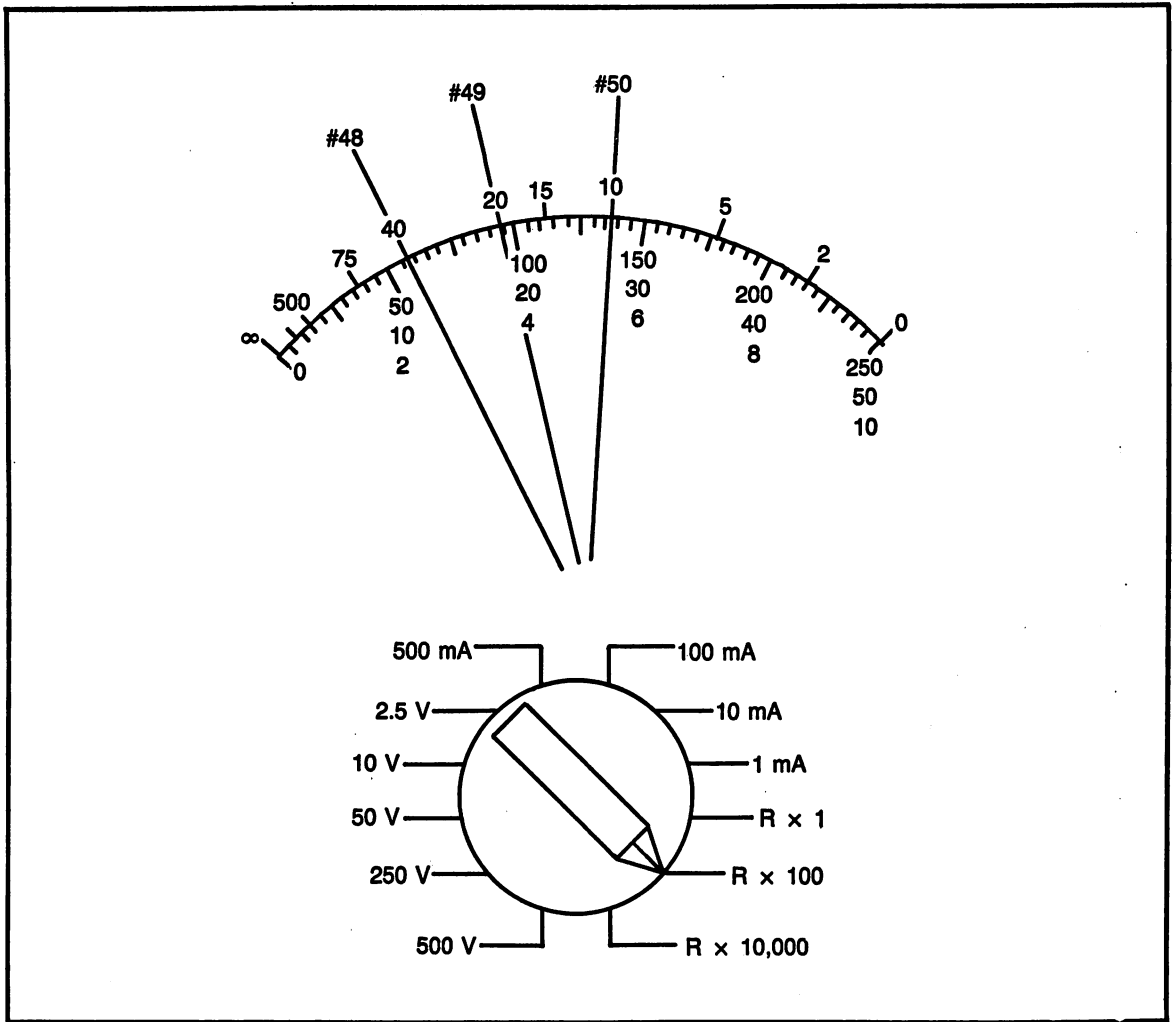


Fig. 7-18. Meter scale for test questions 48, 49, 50.

Chapter 8

Oscilloscope Familiarization

Chapter Objective: A hands-on lesson to become familiar with the operation of the oscilloscope and use it to measure dc voltages.

Chapter outline:

- What an oscilloscope does
- Oscilloscope screen
- Understanding oscilloscope controls
- Measuring dc voltages
- Hands-on practice with dc voltages
- Programs for this chapter

INTRODUCTION

An oscilloscope, “scope” for short, is an electronic instrument used for making various voltage and waveform measurements. It is one of the most popular, and useful tools for troubleshooting a circuit.

Scopes have a cathode-Ray-Tube (CRT) screen similar to that of a TV for viewing the voltages being measured. It is this “picture” that makes the scope such a useful tool.

Scopes range in size from very small, a few inches across, with a screen area of only two inches, to quite large cabinets, with screens several inches across.

WHAT THE OSCILLOSCOPE DOES

In some ways, an oscilloscope is a voltmeter with a “picture” of the voltage as it varies over time.

In the field of electronics, there are many different types of waveforms that need to be measured and analyzed to determine if the electronic signal is correct for what is expected.

Therefore, it is very important for the student technician to gain experience with the oscilloscope as early as possible in the electronics training program.

The oscilloscope replaces a voltmeter in certain applications because of its capability to display a picture. However, it does not simply give an instant number reading of the measurement. In this way, the scope is harder to read and most technicians pre-

fer using a voltmeter when all that is necessary is a number measurement.

One thing an oscilloscope cannot do is measure current or resistance. The voltage waveform can be thought of as a result of a current flowing and therefore, the current waveform can be observed.

Voltage Measurements

The scope measures voltage by showing the relative size and shape of the waveform. The accuracy of the measurement can be seen on the screen. Voltage sizes are measured in comparison to a reference line, established with each measurement.

It is possible to display on the oscilloscope more than one voltage waveform at a time. Most scopes have "dual trace capability" and some have four or more traces. Each trace is a voltage measurement. A "dual trace" scope can measure two voltages at the same time.

The dual trace capability allows two voltages to

be measured and observed at the same time. This means the voltages can be compared for both size (actual voltage measurement) and shape (what type of waveform it is). The dual trace capability is sometimes the only way to determine if a circuit is working correctly.

OSCILLOSCOPE SCREEN

The oscilloscope screen is usually rectangular and is divided into small squares. The squares are used to measure the size of the waveform measurements, both vertically and horizontally. Figure 8-1 is a drawing of a dual trace oscilloscope.

The scope screen is actually a cathode ray tube, like a TV screen. A beam of electrons strikes the back of the screen to form the trace.

Vertical Divisions

The lines going across the screen, forming the tops and bottoms of the squares, measure the wave-

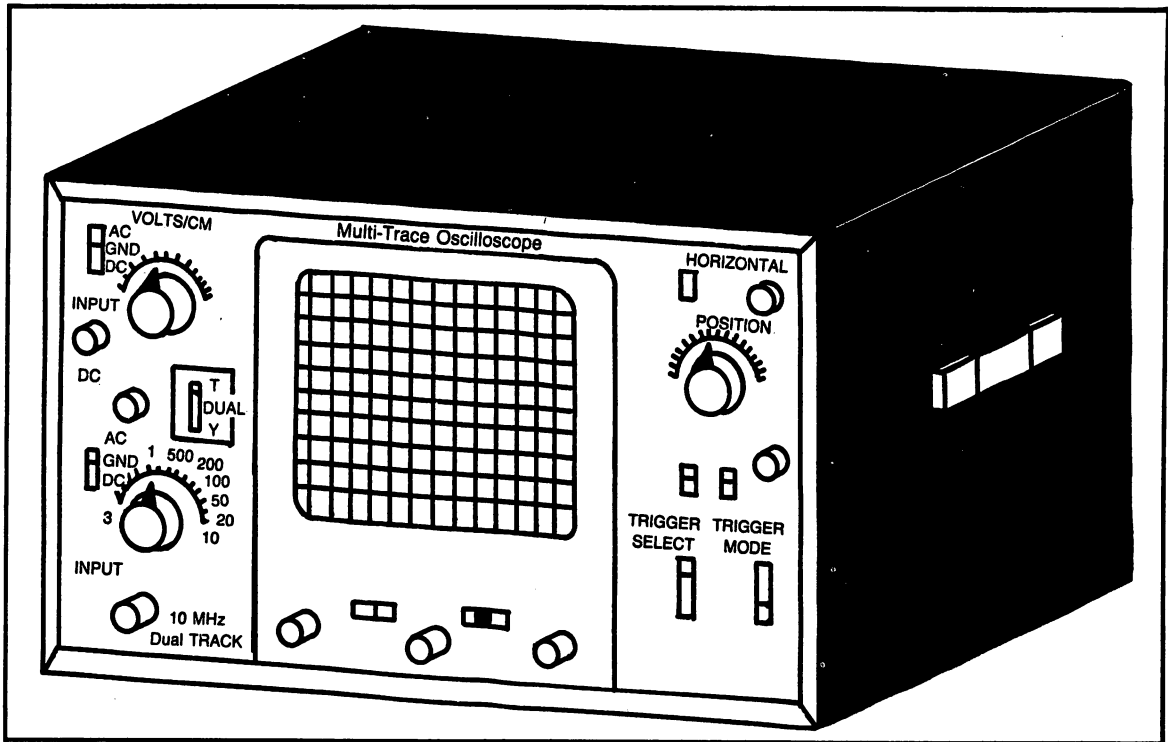


Fig. 8-1. Dual trace oscilloscope.

form in the vertical direction. Each of these lines are referred to as divisions. A voltage is measured by counting the number of divisions from the reference line.

Horizontal Divisions

The lines that run up and down on the screen, forming the sides of the squares are the divisions used to make measurements in the horizontal direction. These measurements are actually time measurements and can be used to determine frequency of the waveform.

This chapter will be mostly concerned with learning the controls and making measurements with a dc voltage. A dc voltage appears as a straight line on the screen. The horizontal divisions will not be of any major importance with dc voltages. In a later chapter, the horizontal, time per division, will be used for making measurements with ac voltages.

UNDERSTANDING OSCILLOSCOPE CONTROLS

The controls on the front of the oscilloscope come in the form of slide switches, rotary switches, potentiometers, connectors, etc. Although each scope will have the controls in different places and some will have a few extra controls, all scopes will have the same basics.

Figure 8-1, a dual trace scope, will be used as a model for explaining the function of the controls. If the student has an oscilloscope available, it is recommended to follow the explanation here, using the scope available as a model.

Trace Adjustments

Each of the following adjustments is used to adjust the trace for proper operation.

On/Off Switch. The on/off switch controls the power to the scope. It can be located by itself but usually is part of the intensity control, as it is in the model shown.

Intensity Control. The intensity control is a potentiometer, and therefore, a control that turns. It is used to make the trace brighter and dimmer.
Caution: Do not adjust the intensity of the trace

too high; damage to the CRT can result. The correct and best adjustment is to have the intensity just high enough to comfortably see the trace.

Focus. The focus control is used to adjust the focus of the trace. When the intensity is low, it will be easiest to focus. A high intensity will be difficult to focus.

Astigmatism. This control is used in conjunction with the focus control. Most scopes have the astigmatism on the back and it is accessible only to a screwdriver. This control is used only when the regular focus does not make a clear trace.

VERTICAL CONTROLS AND ADJUSTMENTS

Vertical deflection is the up and down movement of the oscilloscope trace. It is these controls and adjustments that affect the voltage measurements. Voltage is measured by its relative size or position to a reference and how the controls are set. When a scope is referred to as "dual trace", there is a separate vertical channel for each trace.

A division on an oscilloscope screen is each line running across the face of the screen. A division is sometimes referred to as a centimeter, CM, because on some screens, each division is one CM apart.

Volts/Division. The volts per division control is a rotary switch which is used in a manner similar to the range switch on a multimeter. The volts/division control selects the amount of voltage from one division to the next (in the vertical direction). For example; if the volts/division control is set for 500 mV, each division going up (or down) is 500 mV or ½ volt. If the trace is 4 divisions high, the waveform would be 2 volts.

Variable. The variable control is a potentiometer, usually mounted to look like part of the volts/division control. When the knob is rotated all the way in one direction, an on/off click will be observed. That is the "calibrate" (or cal) position and is the normal position for this control. When in the cal position, the volts/division switch will be calibrated as labeled. Under certain test conditions, the variable control can be used to reduce the size of the waveform display.

AC/GND/DC. This slide switch is used to control how the input voltage is being measured.

GND blocks the input voltage waveform. In the GND position, the scope trace will be a straight line at the "ground reference level". The reference level is usually placed at a convenient line on the screen. (The position is adjusted using the position control.) The ground reference line must be adjusted each time the volts/division control is changed.

AC allows the scope to respond to only the ac content of a waveform. Any voltage waveform viewed in the AC position will center itself around the reference line. Most AC waveforms are symmetrical; that is, they have an equal amount of voltage above the reference as they have below. It is possible, however, for a voltage waveform not to be symmetrical and it would appear distorted if viewed in the AC position.

DC allows the scope to respond to both the dc and ac components of the waveform. It is very important to use dc with voltages that are unsymmetrical. When a dc voltage is measured, it must be performed in dc. Failure to do so will cause only a straight line at the zero reference. Ac voltages that are symmetrical will appear exactly the same on either ac or dc. If a voltage has both a dc component and an ac component, it may be desired to measure only the ac portion, at which case ac must be used. Experience teaches the technician which setting to use for any given test.

Vertical Position. The position control is used to position the trace up and down on the screen. It is usually best to make this adjustment using the ground reference line, with the switch in GND.

HORIZONTAL CONTROLS

Regardless of how many voltage inputs a scope may have, there will only be one set of horizontal controls. These controls affect two functions; movement of the trace in the horizontal direction, and time measurements. All input channels are affected by these controls at the same time.

Horizontal Position. A potentiometer is used to adjust the horizontal position of the trace. When making time measurements, the waveform can be

moved sideways to line it up exactly on a line to allow for each in making the measurements.

Time Per Division. The time per division control is a rotary switch used to adjust the speed of the beam across the screen. Time measurements are used to determine the frequency of a voltage waveform. Switching to a higher time setting will spread the width of a waveform and switching to a lower time setting will narrow the waveform. Most oscilloscopes have an added feature on the time per division control, a setting marked X-Y. When X-Y is selected, one voltage input controls the horizontal deflection and the other voltage input controls the vertical deflection. Although this is seldom used, its display can be useful for certain measurements.

Variable. The variable control is used to vary the time per division setting. Under normal conditions, the variable control is set to calibrate, cal. When an exact time measurement is not necessary, the variable control can be used to reduce the time/division. Sometimes a slight adjustment with the variable control will help in making a voltage measurement.

Normal x5. Many scopes have a switch associated with the time/division control to allow an instant multiplication by 5 of the time/division setting. Under normal conditions, this switch would be left in normal. Under certain conditions, it is necessary to expand the size of the waveform for a closer look at a portion of it. This has the effect of using a zoom lens on a camera.

TRIGGER

The trigger on an oscilloscope is used to allow for a stable trace. Since most waveforms that will be displayed have a continuously varying shape, it is necessary to have the same "starting point" each time the trace sweeps across the screen. The trace sweeps from left to right on the screen, therefore, the "starting point" is on the left and is adjustable by selecting the trigger point, a voltage level. If the trigger point is not correctly set, the waveform display will appear to move across the screen.

Trigger Select (Trigger Source). The trigger select or trigger source is a switch that selects

which voltage will be used to trigger the display. There are usually four sources to choose from; channel 1, channel 2, external, line. For most applications, select the channel where the input voltage is connected. If both channels are used, the channel selected for trigger becomes a reference voltage. Under certain test conditions, a third voltage can be applied to the external trigger connector. This external voltage will be used as a reference. The fourth source, line is used whenever the waveform displayed is 60 cycle (line frequency), in which case, the trigger is internal to the scope.

Trigger Mode. The trigger mode selects the type of voltage to be used as the trigger. When dc is selected, it is a voltage level that triggers the scope. When ac is selected, it is a change in voltage that triggers the scope. Another choice available is TV which allows selecting a type of waveform, such as would be found in a TV receiver. For most test conditions, dc or ac is used.

Slope +/-. The slope switch is used to select whether the signal will trigger on a positive (+) or a negative (-) voltage. For most test conditions, select whichever provides the stable trace.

Auto/Normal. In the auto (automatic) mode, the scope will trigger on any voltage available. For many test conditions, auto is satisfactory, as long as the trace is stable. The auto mode bypasses the other trigger controls. Normal is used when it is desired to have control of the other trigger functions.

Level. The level control is a potentiometer that is turned to select the amount of voltage necessary to trigger the scope. Many level controls are labeled with - on the left and + on the right, which would be used in place of the slope control.

MEASURING DC VOLTAGES

Although the oscilloscope is primarily thought of as displaying waveforms, it is also very useful for measuring dc voltages. If a dc voltage is a pure dc voltage, it will appear as a straight line on the scope, at a height above (or below for negative voltages) the reference line. If it is a perfect straight line, that means it is a constant voltage. Remember, voltage is up and down on the screen, therefore a constant

voltage does not change in height.

Scope Test Leads

The test leads connecting to an oscilloscope are made of coaxial wire. It has a center conductor, which is surrounded by an insulator. Wrapped around the insulator is a braided jacket and a final insulation is on the outside. One end of the test lead has a "BNC" connector which is connected to the BNC connector on the scope. The other end of the test lead has either alligator clips or a probe.

Connect the test lead BNC connector to the scope BNC connector to the channel 1 input. On the model, Fig. 8-1, it is labeled Y1 input. Notice, the center conductor of the test lead has a pin to fit into the connector on the scope. The braided jacket is connected to the metal portion of the connector, which clips onto the metal portion of the BNC connector on the scope. The connector on the scope is connected directly to the chassis of the scope, which means the electrical ground, from the three prong plug, is connected to the braided jacket of the test lead. The other end of the test lead is a black wire with an alligator clip. That is the ground wire.

Connecting a Scope to a Circuit

When connecting a scope to a circuit, it is very important to consider where the ground wire is connected. Where the ground is connected becomes zero volts reference in the circuit.

For example; if a flashlight battery is measured with the ground on negative and the probe to positive, the measurement will be positive 1.5 volts. However, if the leads are reversed and the ground is connected to the positive and the probe to negative, the measurement will be negative 1.5 volts.

Figure 8-2 shows the scope connected to a bat-

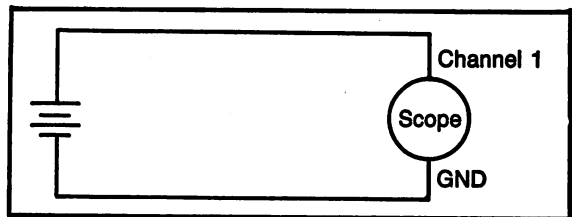


Fig. 8-2. Oscilloscope connected to a battery.

tery. The schematic diagram looks like a voltmeter connected to a battery. The reason a scope and voltmeter have the same schematic diagram is because they both make the same measurement.

Preliminary Scope Adjustments

When a technician becomes familiar with the scope, it is not necessary to make preliminary adjustments. However, preliminary adjustments can be a great help to a student.

Scope adjustments come in four groups; beam (intensity and focus), time per division, trigger, volts per division. Preliminary adjustments are used with the trigger and time controls.

Trigger. When there is no voltage input signal, the scope must trigger on automatic. Select auto as a preliminary setting.

Beam. Once there is a trace on the screen, a straight line, adjust the intensity and focus to a normal level.

Time per division. The time per division makes very little difference when a dc voltage is being measured. However, if the time is too slow, such as 100 ms, the trace will be a dot going across the screen. If it is too fast, such as 1 μ s, the trace may appear dim and hard to trigger. The best preliminary setting before measuring dc voltages is a setting of approximately 1 ms. This setting should give a stable straight line.

Volts Per Division. This control will be the primary control when making dc measurements. If the setting is too low, such as 10 mV, the line may jump off the screen when taking a measurement. If the setting is too high, such as 20 V, the line may appear not to move and make it impossible to take an accurate reading. Only experience and practice will dictate the setting of this control.

HANDS-ON PRACTICE WITH DC VOLTAGES

It is best with these practice dc measurements, to use both a scope and a dc voltmeter. In this way, the student gains more experience with the voltmeter and has more confidence in the measurements taken with the scope.

The hands-on practice for using a scope to measure dc voltages is designed in a step-by-step

procedure to gain the most from the experience.

Step 1. Select a dc voltage source: a variable power supply or a 6 volts dry cell battery.

Step 2. Connect the ground lead from the scope and the negative voltmeter lead to the negative side of the battery.

Step 3. Connect the scope lead and the positive voltmeter lead to the positive side of the battery.

Step 4. Preadjust the scope settings as described in this chapter.

Step 5. Select the 1 volt per division setting. Make certain the variable adjustment is set to cal. Use the GND switch and adjust the ground reference line to the bottom line on the screen. (Use the position control to adjust the trace to the desired position.)

Step 6. Move the AC/GND/DC switch to DC. The trace should jump up 6 divisions (1 volt per division). See Fig. 8-3. If the voltage of the battery is not exactly 6 volts, the trace will not fall exactly on the major division line. At the center of the oscilloscope screen, the divisions are divided with small lines to enable a more accurate reading. Use these minor divisions to read the screen as accurately as a voltmeter. The reading obtained in this step should be equal to the voltmeter connected.

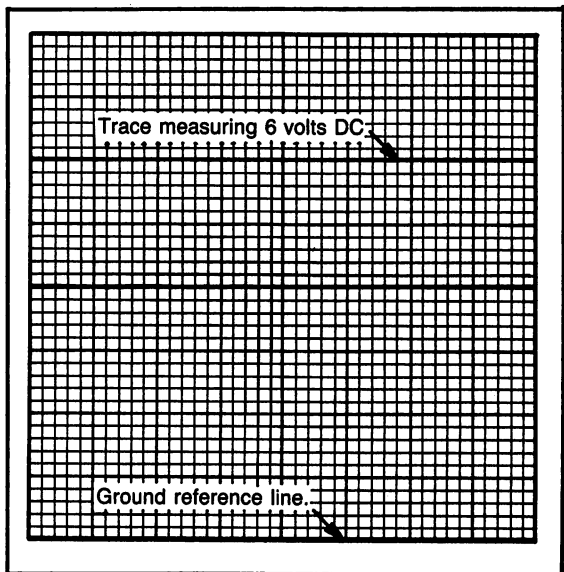


Fig. 8-3. Oscilloscope display measuring 6 volts DC. Scope setting: 1 volt/div.

Step 7. Change the volts/div setting to 2 volts/div. Make certain the variable control is set to cal. Use the GND switch and adjust the ground reference line to the bottom line on the screen.

Step 8. Move the AC/GND/DC switch to DC. The trace should now appear 3 divisions above the ground reference line (2 volts per division). See Fig. 8-4.

Step 9. Change the volts per division to 5 volts/div. Make certain variable is set at cal. Adjust the ground reference line.

Step 10. Move the AC/GND/DC switch to DC. The trace should now appear a little over 1 division above ground (5 volts/div).

Step 11. Change the volts/div to 500 mV/div. Make certain the variable control is set to cal. Use the GND switch and adjust the ground reference line to the bottom line on the screen.

Step 12. Move the AC/GND/DC switch to DC. The trace should disappear from the screen. The reason for this is the fact that if each division is 500 mV ($\frac{1}{2}$ volt), there are not enough divisions on the screen to measure 6 volts.

Step 13. Select 1 volt per division, check the variable and adjust the ground reference line. Se-

lect DC to verify the measurement is the same as step 6, above. In the next steps, the volts/div will remain on 1 volt/div.

Step 14. Move the AC/GND/DC switch to AC. The trace may jump up momentarily, but it will quickly go to the ground level and stay there. The scope does not recognize dc voltages when ac is selected.

Step 15. Return the AC/GND/DC switch to DC. (The trace should again appear at 6 volts). Turn the variable control. As the variable control is turned further from the cal position, the trace should move closer to the ground level. This control is valuable under certain conditions, but when measuring voltage, it must be set in the cal position.

Proper Selection of Volts/Div

It is very important to select the proper setting for the volts/div control. Too sensitive and the trace jumps off the screen; not sensitive enough and the voltage measurement is quite inaccurate. As a general rule, the best setting for the volts/div control is the setting that allows the maximum deflection of the trace, and still remain on the oscilloscope screen.

PROGRAMS FOR THIS CHAPTER

The program for this chapter is an opportunity for the student to learn and practice operation of the oscilloscope. The name is "Oscilloscope DC".

The screen is very similar to an actual oscilloscope screen. Refer to Fig. 8-5 for a sample of the oscilloscope dc program. The ground reference line has been placed at the center of the screen. Whenever counting divisions up or down, always begin counting from the center line.

On the right hand side of the computer, notice there are three information blocks. The top info block is the setting for "time/division". Since all of the measurements in this program are dc, the time/division has no effect. The middle info block is the setting for "volts/division" for channel #1. This is the channel setting that will be in use throughout

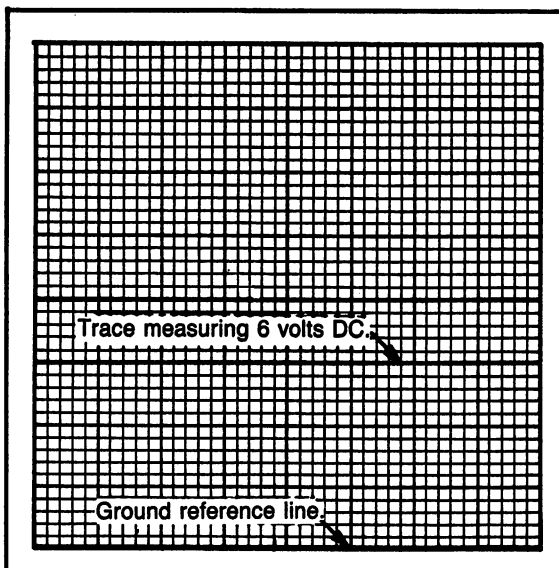
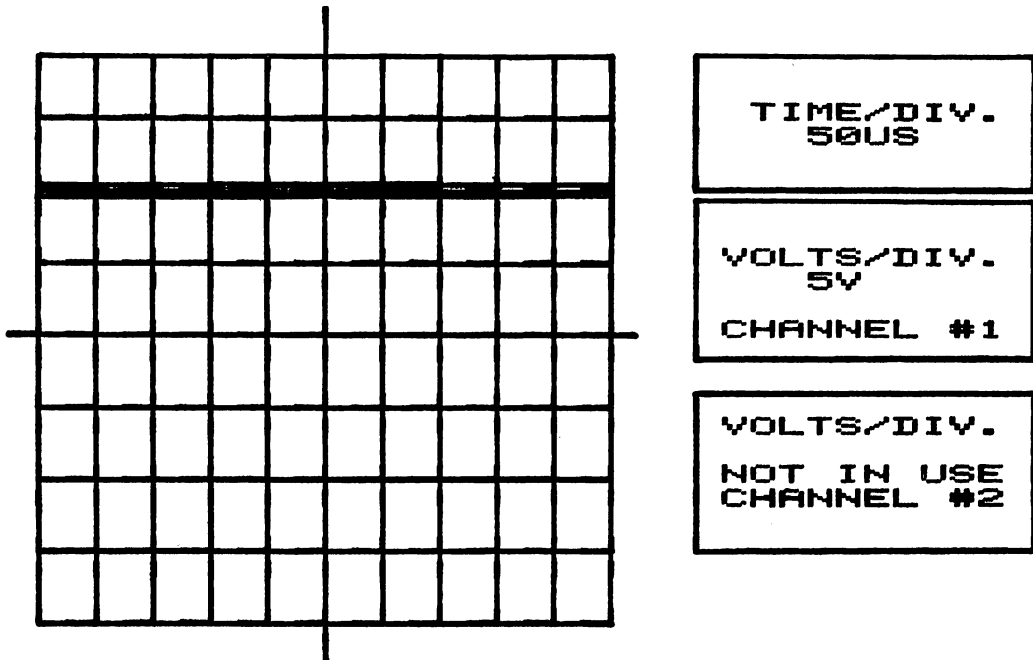


Fig. 8-4. Oscilloscope display measuring 6 volts DC. Scope setting: 2 volts/div.

OSCILLOSCOPE DC
PROGRAM SAMPLE :



1 .WHAT IS THE VOLTAGE ? 10

XXXXXXXXXX

XXXXXXXXXX = NEXT, ■■■■ = NEW SELECTION.

Fig. 8-5. Sample of oscilloscope DC program.

the program. The third info block is the setting for "volts/division" for channel #2. Channel #2 is not used at this time.

The middle information block with volts/div for

channel #1 must be observed for each reading. This will change each time. Multiply the volts/div by the number of divisions away from the ground reference line, which is the center line in this program.

Chapter 9

Dc Circuit Analysis

Chapter Objectives: To learn to calculate the circuit parameters of series and parallel dc circuits. To use a multimeter and an oscilloscope to measure the circuit parameters and compare measurements to calculated values.

Chapter Outline:

- Series Circuits
- Hands-On Practice: Series Circuit Measurements
- Parallel Circuits
- Hands-on Practice: Parallel Circuit Measurements
- Series-Parallel Combinations
- Programs for this Chapter
- Dc Circuit Analysis Competency Test

INTRODUCTION

This chapter will discuss dc circuits with more than one load resistor. The resistors can be con-

nected in one of two manners, either series or parallel. They each have a set of rules to follow, including new formulas. The formulas learned in the past, Ohm's law and the power formulas will be used again. The formulas and theory learned in this chapter will be used to calculate the four basic circuit parameters; voltage, current, resistance and power.

The three meters of the multimeter; ohmmeter, voltmeter, and ammeter, will be used to measure the circuit parameters. The oscilloscope will also be used for practice.

SERIES CIRCUITS

A series circuit is defined as having only one path for current to flow. Using this definition as a guideline, the following rules are established. Each rule will be explained in detail.

- (1) Current is the same throughout a series circuit.
- (2) Total resistance in a series circuit is the sum of the individual resistors.

- (3) The sum of the voltage drops in series circuit equals the applied voltage.
- (4) The sum of the individual powers equals the total applied power.

Current is the Same in Series

A series circuit has only one path for the flow of current; therefore, the current must be the same at all points in the circuit. The current through one resistor is the same as the current in all resistors, of the same circuit, and is equal to the total current flow.

In order for current to flow in a circuit, there must be a complete path for the electrons to leave the negative side of the voltage source, flow through the circuit, and an equal number of electrons return to the positive side of the power supply.

Figure 9-1 shows a circuit with three resistors connected in series. Notice, the arrow indicates the direction of current flow, from negative to positive. This arrow can be drawn at any location in this circuit, because current flow is the same throughout the circuit. The mathematics of calculating current will be demonstrated later.

Total Resistance is the Sum of Series Resistors

In a series circuit, the current flows through each resistor, therefore, the total resistance imposed upon the current is equal to adding the individual resistors. This statement can be expressed as a formula.

Formula #7. Total Resistance in a Series Circuit.

$$R_T = R_1 + R_2 + R_3 + \dots$$

Resistance total = resistor 1 + resistor 2 + resistor 3 + all other series resistors.

Sample Circuit Calculation of Total Resistance

The total resistance can be calculated for the sample circuit of Fig. 9-1.

Formula:

$$R_T = R_1 + R_2 + R_3 + \dots$$

Substituting:

$$R_T = 50 \text{ ohms} + 30 \text{ ohms} + 20 \text{ ohms}$$

Solving:

$$R_T = 100 \text{ ohms}$$

Calculating Total Current Using Total Resistance

Total current is calculated using the basic Ohm's law formulas with the applied voltage and the total resistance. The sample circuit, Fig. 9-1, is used to show the calculation of total current.

Applied voltage = 100 volts

Total resistance = 100 ohms

Formula:

$$I = \frac{V}{R}$$

Substituting:

$$I = \frac{100 \text{ volts}}{100 \text{ ohms}}$$

Solving:

$$I = 1 \text{ amp}$$

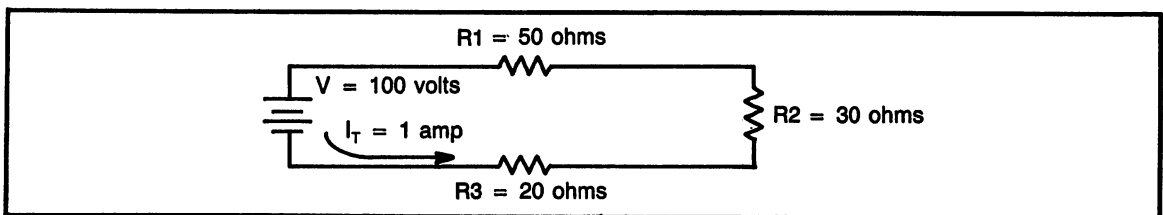


Fig. 9-1. A series circuit with three resistors.

The Sum of the Voltage Drops Equals the Applied Voltage

As current flows through a resistor, some of the voltage is dropped across the resistor. A portion of the voltage available from the voltage source will be “dropped” at each of the circuit resistors. The larger resistor will require more “voltage drop” and the smaller resistor will require a smaller “voltage drop”. All of the voltage available will be distributed among the circuit resistors. This statement can be made with a mathematical formula.

Formula #8. Voltage Drops in a Series Circuit

$$V_T = V_{R1} + V_{R2} + V_{R3} + \dots$$

Voltage total equals the sum of the voltage drops across each resistor.

In order to calculate the voltage drop across each resistor in a series circuit, it is necessary to use Ohm’s law to solve for voltage.

$$V = I \times R \text{ or } V = IR$$

It is very common, therefore, to rename the term “voltage drop” as the “IR drop”. To reflect the “IR drop” phrase, the formula for voltage drops in a series circuit can be re-written.

Formula #9. IR Drops in a Series Circuit

$$V_T = IR_1 + IR_2 + IR_3 + \dots$$

Voltage total equals the sum of the IR drops of the individual resistors.

Comment: Both formulas for voltage drops have the same end result. The important point to remember is the fact that the voltage drops of the individual resistors must add up to equal the total applied voltage. Always use this as a check to insure calculations have been made correctly.

Sample Voltage Drops Calculations

Figure 9-1 will be used again here to demonstrate how to calculate voltage drops. In this sample, the voltage drop across each individual resistor will be calculated separately.

Current = 1 amp (same at all points in the circuit)

Voltage Across R_1

Formula: $V_{R1} = I \times R_1$

Substituting: $V_{R1} = (1 \text{ amp}) \times (50 \text{ ohms})$

Solving: $V_{R1} = 50 \text{ volts}$

Voltage Across R_2

Formula: $V_{R2} = I \times R_2$

Substituting: $V_{R2} = (1 \text{ amp}) \times (30 \text{ ohms})$

Solving: $V_{R2} = 30 \text{ volts}$

Voltage Across R_3

Formula: $V_{R3} = I \times R_3$

Substituting: $V_{R3} = (1 \text{ amp}) \times (20 \text{ ohms})$

Solving: $V_{R3} = 20 \text{ volts}$

Adding the Voltage Drops

Formula: $V_T = IR_1 + IR_2 + IR_3 + \dots$

Substituting: $V_T = (50 \text{ volts}) + (30 \text{ volts}) + (20 \text{ volts})$

Solving: $V_T = 100 \text{ volts}$

Sum of the Powers Equals the Applied Power

Since the voltage source supplies both voltage and current to all parts of the circuit, it can also be said that the voltage source also supplies power. All of the power supplied from the source is dissipated at the individual resistors, therefore, the sum of the individual powers equals the total power. This can be expressed as a formula.

Formula #10. Total Power

$$P_T = P_{R1} + P_{R2} + P_{R3} + \dots$$

Total power equals the sum of the individual powers.

Sample Power Calculations

Figure 9-1 is again used to solve for the individual power dissipation of each resistor and the total power. Total power can be calculated in two ways; first, the sum of the powers and second, total current and applied voltage.

It is best to first calculate the power of the individual resistors.

Power of R_1

Formula: $P_{R1} = I \times V_{R1}$

Substituting: $P_{R1} = (1 \text{ amp}) \times (50 \text{ volts})$

Solving: $P_{R1} = 50 \text{ watts}$

Power of R_2

Formula: $P_{R2} = I \times V_{R2}$

Substituting: $P_{R2} = (1 \text{ amp}) \times (30 \text{ volts})$

Solving: $P_{R2} = 30 \text{ watts}$

Power of R_3

Formula: $P_{R3} = I \times V_{R3}$

Substituting: $P_{R3} = (1 \text{ amp}) \times (20 \text{ volts})$

Solving: $P_{R3} = 20 \text{ watts}$

Sum of the Powers Equals Power Total

Formula: $P_T = P_{R1} + P_{R2} + P_{R3} + \dots$

Substituting: $P_T = (50 \text{ watts}) + (30 \text{ watts}) + (20 \text{ watts})$

Solving: $P_T = 100 \text{ watts}$

Power Total Using Power Formula

Formula: $P_T = I \times V$

Substituting: $P_T = (1 \text{ amp}) \times (100 \text{ volts})$

Solving: $P_T = 100 \text{ watts}$

Summary of Solving a Series Circuit

The following procedure is intended to be a

general guideline for solving a series circuit. Some series circuit problems offer a different set of unknowns, however, an understanding of this guideline will help to solve any circuit.

- (1) Find R_T . Finding the total resistance is the first step in solving a series circuit. Total resistance is the sum of the individual resistors.
- (2) Find I_T . Remember, the current is the same throughout a series circuit. In order to calculate current, it is necessary to know the voltage and the resistance. Always use either total voltage and total resistance or the voltage drop across a resistor and its resistance.
- (3) Find individual voltage drops. Voltage is calculated using Ohm's law with resistance and current. Make certain to add the individual voltage drops to check that they equal the applied voltage.
- (4) Find power. Individual power of each resistor can be calculated by using the current and the individual voltage drops. Total power is the sum of the individual powers or use the power formula and total current with the applied voltage.

Practice Problems: Series Circuit

Part A. Use the information given in the schematic diagrams and in the problems to find the unknowns.

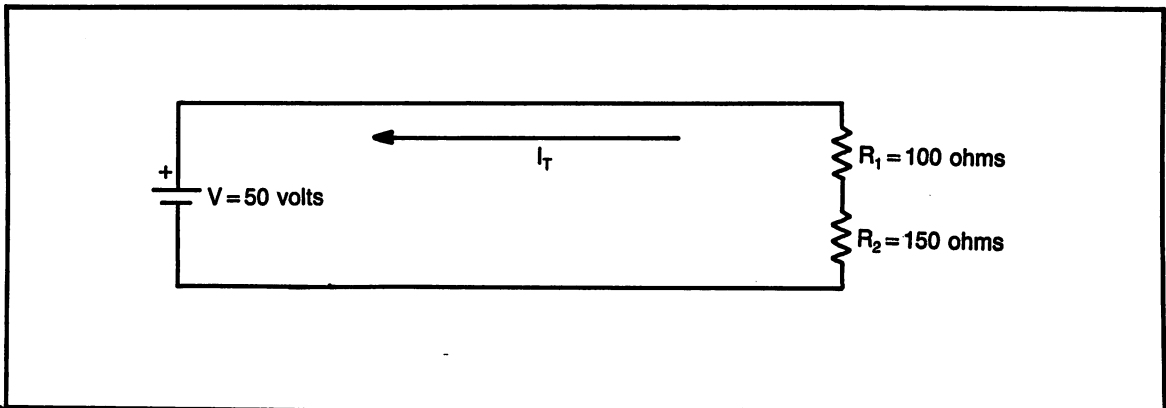


Fig. 9-2. Problem 1. Find: I_T , R_T , V_{R1} , V_{R2} , P_{R1} , P_{R2} .

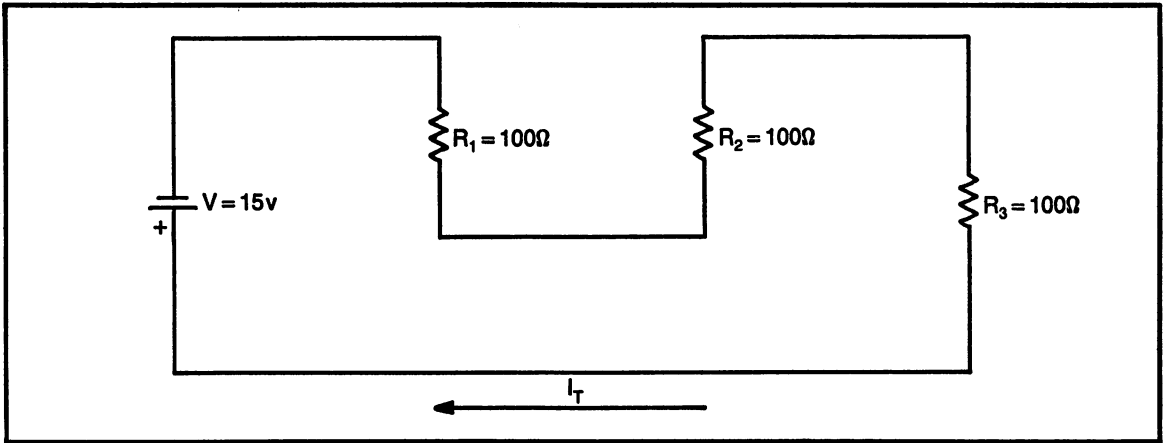


Fig. 9-3. Problem 2. Find: I_T , R_T , V_{R1} , V_{R2} , V_{R3} , P_{R1} , P_{R2} , P_{R3} .

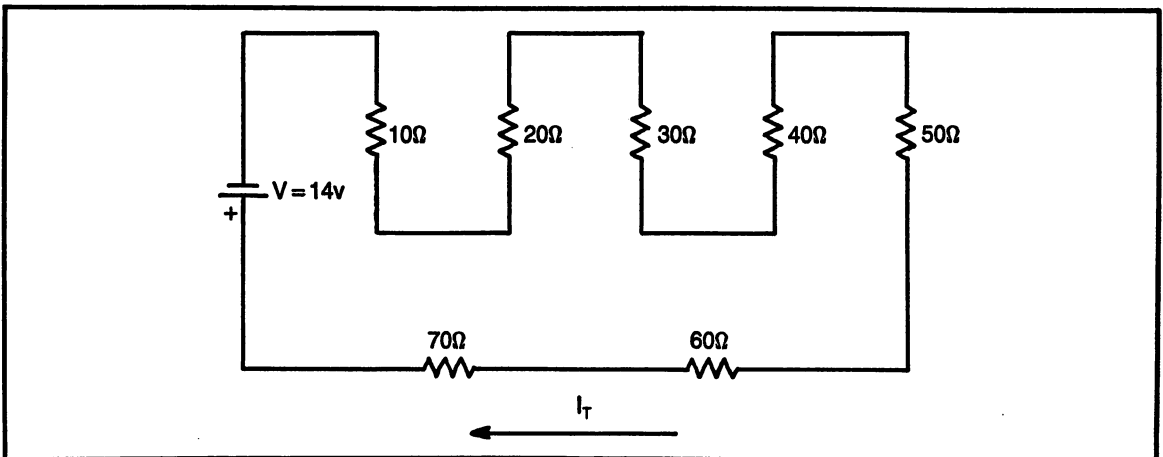


Fig. 9-4. Problem 3. Find: I_T , R_T .

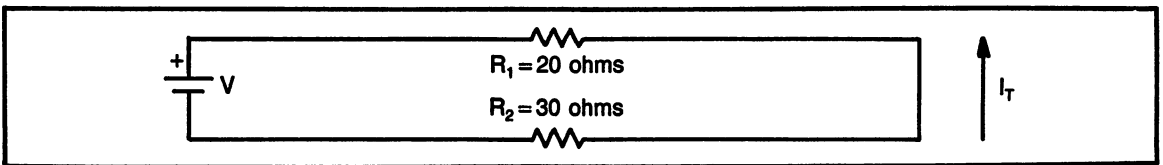


Fig. 9-5. Problem 4. Find: I_T , V .

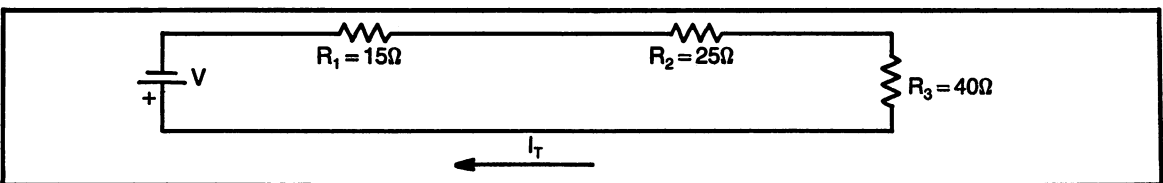


Fig. 9-6. Problem 5. Find: I_T , R_T , V .

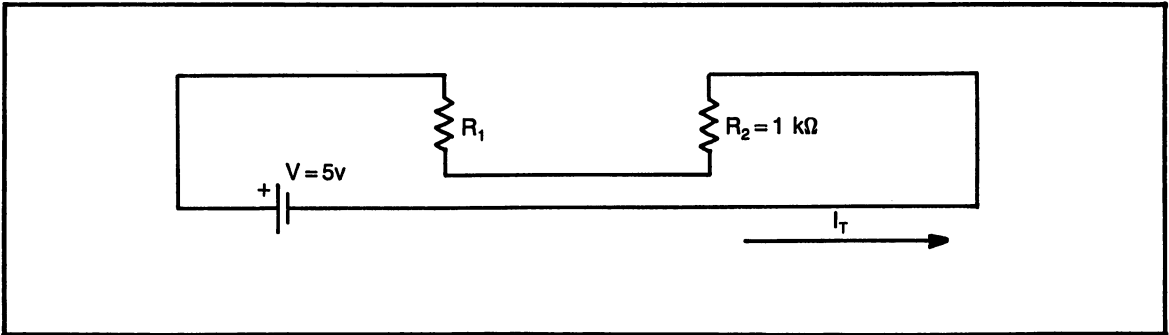


Fig. 9-7. Problem 6. Find: R_T , R_1 .

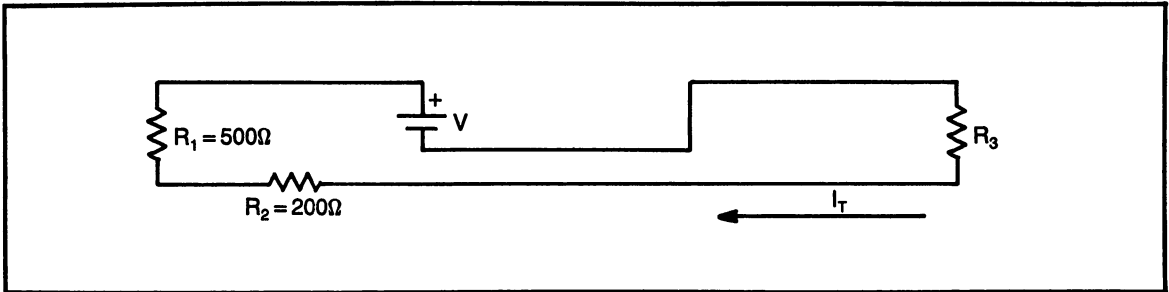


Fig. 9-8. Problem 7. Find: R_T , R_3 , V .

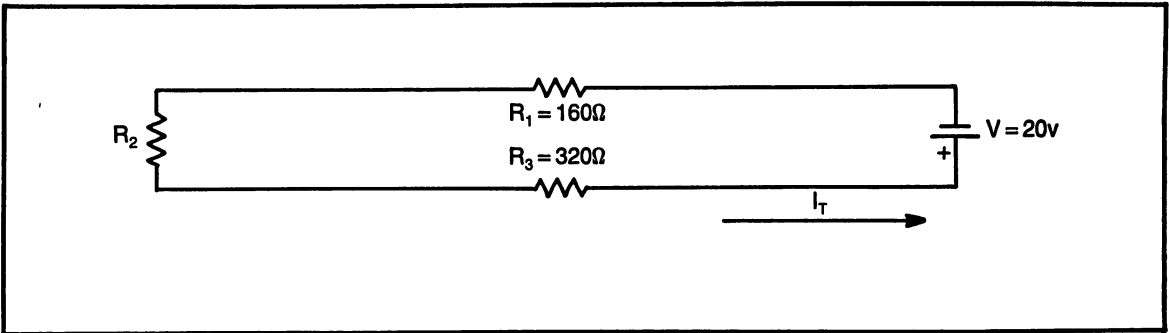


Fig. 9-9. Problem 8. Find: I_T , R_2 , V_{R1} .

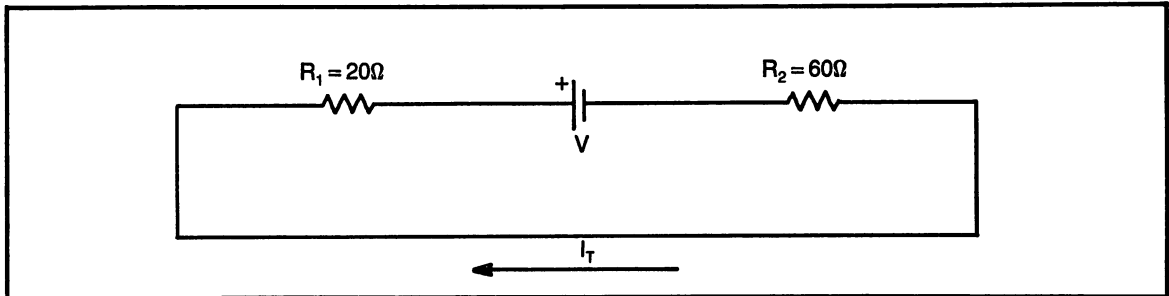


Fig. 9-10. Problem 9. V , I_T , R_2 .

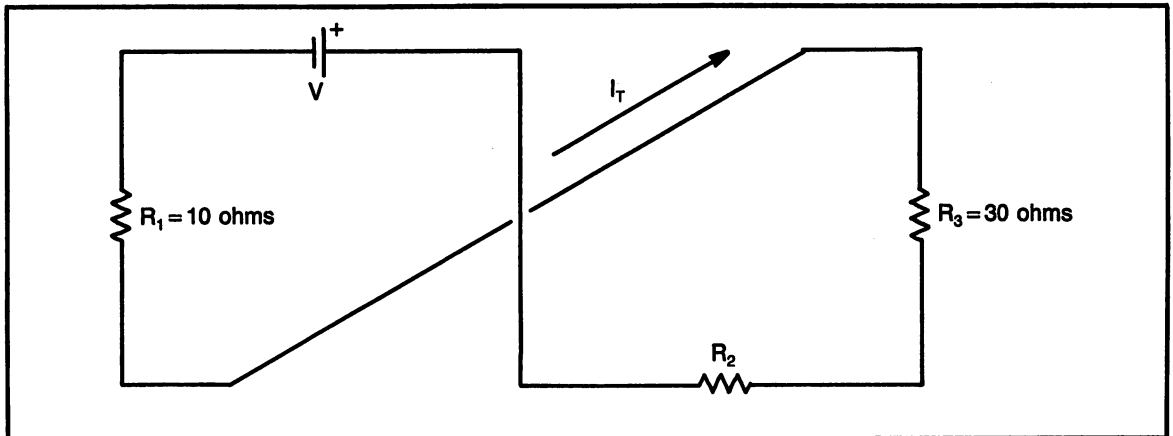


Fig. 9-11. Problem 10. V , I_T , R_2 .

HANDS-ON PRACTICE: SERIES CIRCUIT MEASUREMENTS

This section will contain both measurements and calculations of dc circuits. The objective is to achieve complete learning of the theory of series circuits. When the student completes this section he/she should feel comfortable making measurements in a series dc circuit.

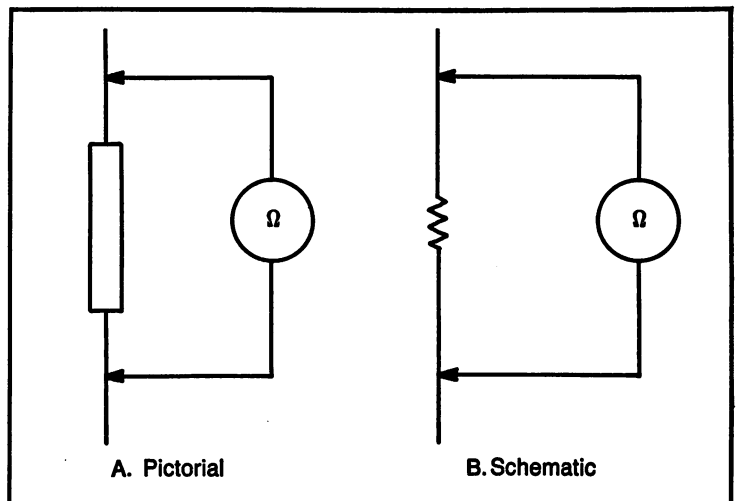
Even though specific resistance values are used in this procedure, the values are not critical. If the specific values cannot be found, substitutes may be used.

$$R_1 = 330 \text{ ohms}, R_2 = 220 \text{ ohms}$$

Measuring Two Resistors in Series

- (1) Use the color codes of the resistors to determine the tolerance range.
 R1 Color Code: _____
 R1 Maximum value = _____
 R1 Minimum value = _____
 R2 Color Code: _____
 R2 Maximum value = _____
 R2 Minimum value = _____
- (2) Figure 9-12 shows an ohmmeter connected to a resistor. Figure 9-12A is a pictorial drawing to help "picture" the connection and Fig. 9-12B is a schematic. Use Fig. 9-12 as a refer-

Fig. 9-12. Using an ohmmeter to check the resistor's value.



ence and measure the actual values of the resistors.

R1 (measured) = _____

R2 (measured) = _____

Verify if the resistors are within tolerance. (y/n)

- (3) Figure 9-13 shows the two resistors connected in series. First calculate the total resistance, showing the formula used, then measure the

total resistance with the ohmmeter. (Use nominal values of the resistors for the calculations.)

Total resistance formula: _____

Calculated total resistance = _____

Measured total resistance = _____

- (4) Figure 9-14 shows the two resistors connected to a power supply and a voltmeter. (A six volt battery can be used in place of the power supply)

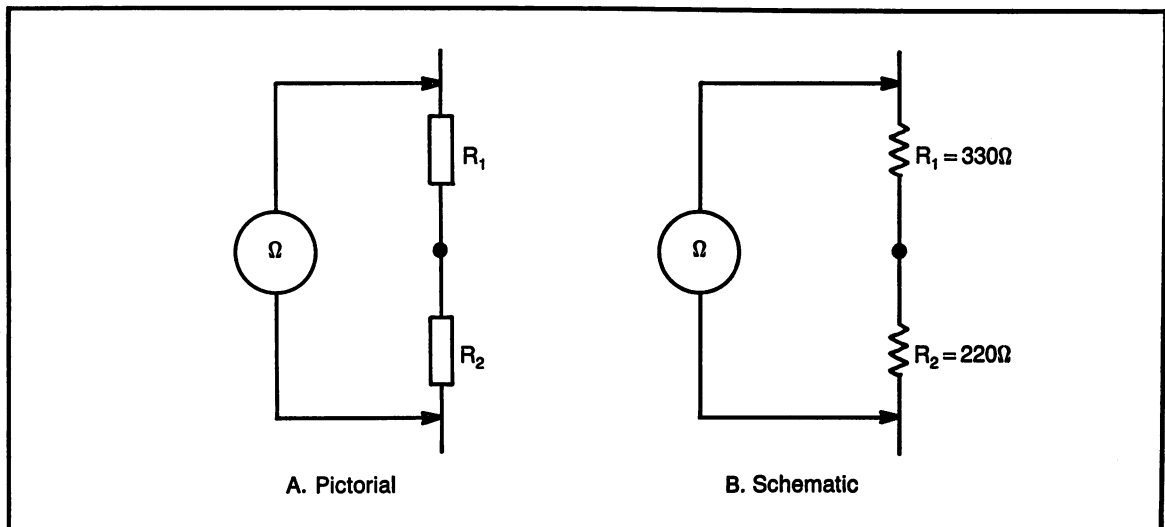


Fig. 9-13. Using an ohmmeter to check total circuit resistance.

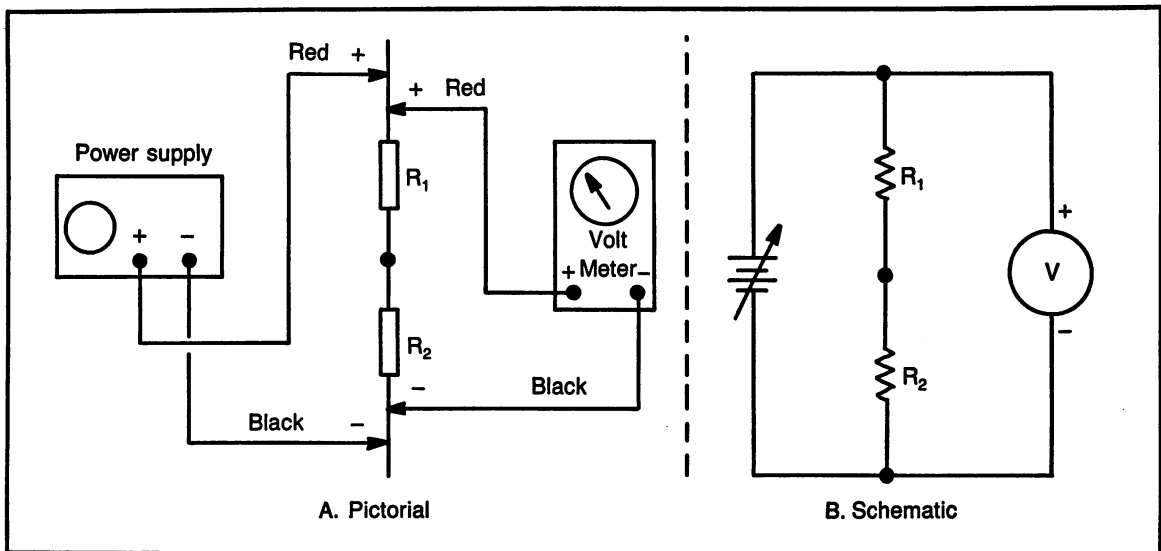


Fig. 9-14. Voltage measured across the entire circuit.

ply.) Notice the voltmeter is connected not only across the resistors, but also connected directly across the power supply. Use this arrangement to set the power supply voltage to 6 volts. **Be sure to observe meter polarity.**

(5) Using the nominal values of the resistors and an applied voltage of 6 volts; calculate total cur-

rent and voltage drop across each resistor.

Formula for $I_T =$ _____

I_T (calculated) = _____

Formula for voltage drop = _____

V_{R1} (calculated) = _____

V_{R2} (calculated) = _____

(6) Use Fig. 9-15 and 9-16 as samples to measure

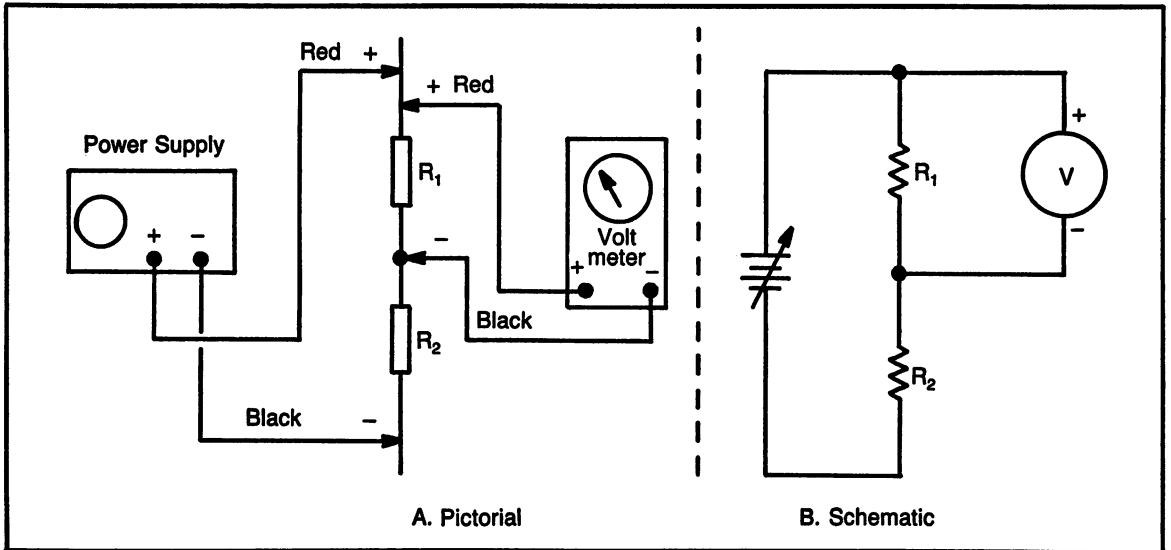


Fig. 9-15. Voltage measured across R1.

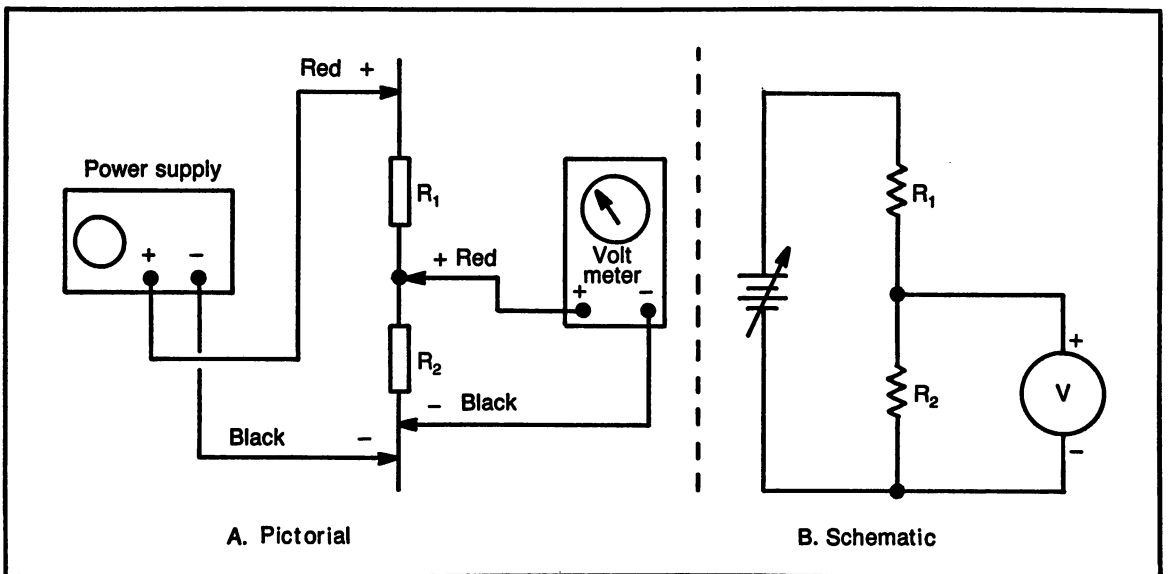


Fig. 9-16. Voltage measured across R2.

the voltage drop across each resistor.

V_{R1} (measured) = _____

V_{R2} (measured) = _____

- (7) Compare the voltage readings of steps 5 and 6. It is normal for there to be a slight difference. Explain what causes this difference and how much is considered within acceptable tolerance.
- (8) Use Fig. 9-17 as a sample to measure current flow in the circuit. An ammeter is connected in series, therefore, it is necessary to place the meter directly in the path of current flow. Disconnect the wire from the negative side of the power supply to the resistor. Attach the negative side of the meter to the power supply and the positive side of the meter to the resistor. Remember to change the multi-meter to the current range.

I_T (measured) = _____

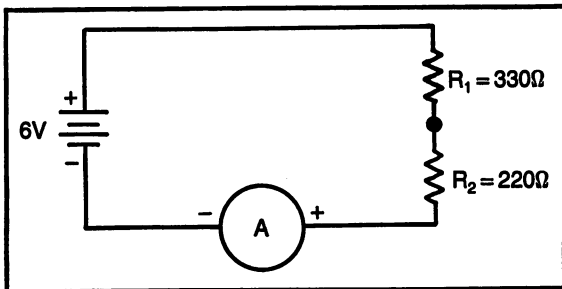


Fig. 9-17. Ammeter to measure total current.

- (9) Compare the measured value of current with the calculated value of step 5. Explain the difference and how to determine what is an acceptable tolerance range.
- (10) In this step, the oscilloscope will be used to measure the total voltage in the circuit. Connect the oscilloscope probe to the top of R_1 , as shown in Fig. 9-18, and the ground lead connected to the negative side of the battery. Note: be sure the AC/GND/DC switch is in the DC position.

V_{applied} (measured) = _____

- (11) Connect the scope probe to the connection between the two resistors, as shown in Fig. 9-19, and the ground to the negative side of the battery. This connection will measure the voltage

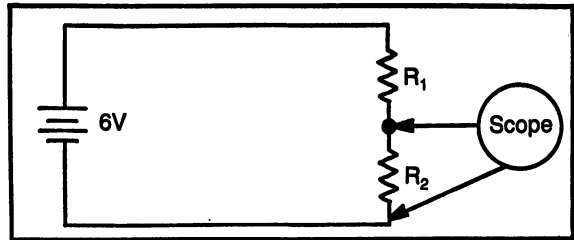


Fig. 9-18. Oscilloscope is used to measure total voltage.

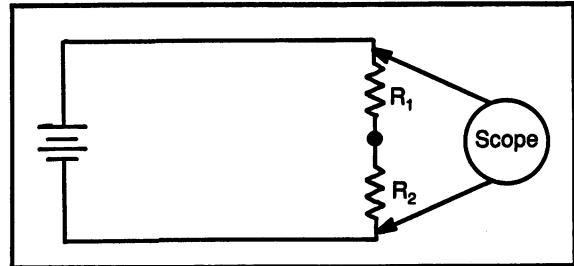


Fig. 9-19. Oscilloscope is used to measure voltage drop across R_2 .

across R_2 . The voltage across R_1 cannot be measured directly with the scope because the scope ground lead cannot be connected between two resistors in the circuit. Therefore, the voltage across R_1 is found by subtracting the voltage across R_2 from the applied voltage (this is still considered a measured value).

V_{R1} (measured) = _____

V_{R2} (measured) = _____

- (12) The circuit that was used for steps 1 - 11 will now be expanded to have a third resistor. Refer to Fig. 9-20. Add the 270 ohm resistor in

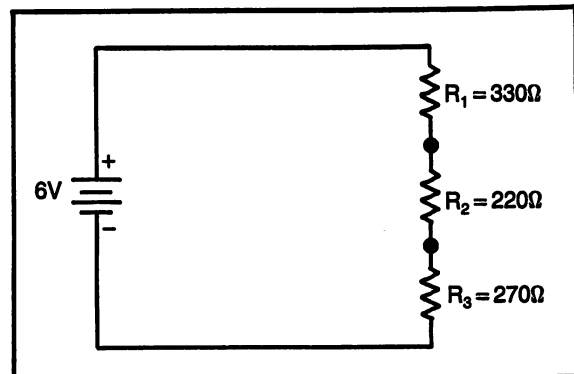


Fig. 9-20. Three resistors connected in series.

series with the other two resistors. Before connecting the power supply, calculate and measure the total resistance of the circuit.

Formula for $R_T =$ _____

R_T (calculated) = _____

R_T (measured) = _____

- (13) Connect 6 volts dc to the circuit of Fig. 9-20. Calculate the circuit current, then properly connect an ammeter and measure the current flow. (Use Fig. 9-17 as a sample.)

Formula for $I_T =$ _____

I_T (calculated) = _____

I_T (measured) = _____

- (14) Use the nominal value of the resistors, the calculated value of total current and the applied voltage to calculate the voltage across each resistor. Using Fig. 9-21 as a reference, move the voltmeter to measure the voltage across each resistor.

Formula for voltage drop = _____

V_{R1} (calculated) = _____

V_{R1} (measured) = _____

V_{R2} (calculated) = _____

V_{R2} (measured) = _____

V_{R3} (calculated) = _____

V_{R3} (measured) = _____

- (15) In Fig. 9-21, the voltage measurements across the resistors can all be made with reference to negative. When voltages are measured in reference to negative, the negative lead of the voltmeter remains attached to the negative of the power supply and the positive lead is moved to place the meter across the resistors.

$V_{R3} =$ _____

$V_{R3} + V_{R2} =$ _____

$V_{R2} =$ _____

$V_{Total} =$ _____

$V_{R1} =$ _____

- (16) Repeat the measurements of step 15, this time using an oscilloscope.

$V_{R3} =$ _____

$V_{R3} + V_{R2} =$ _____

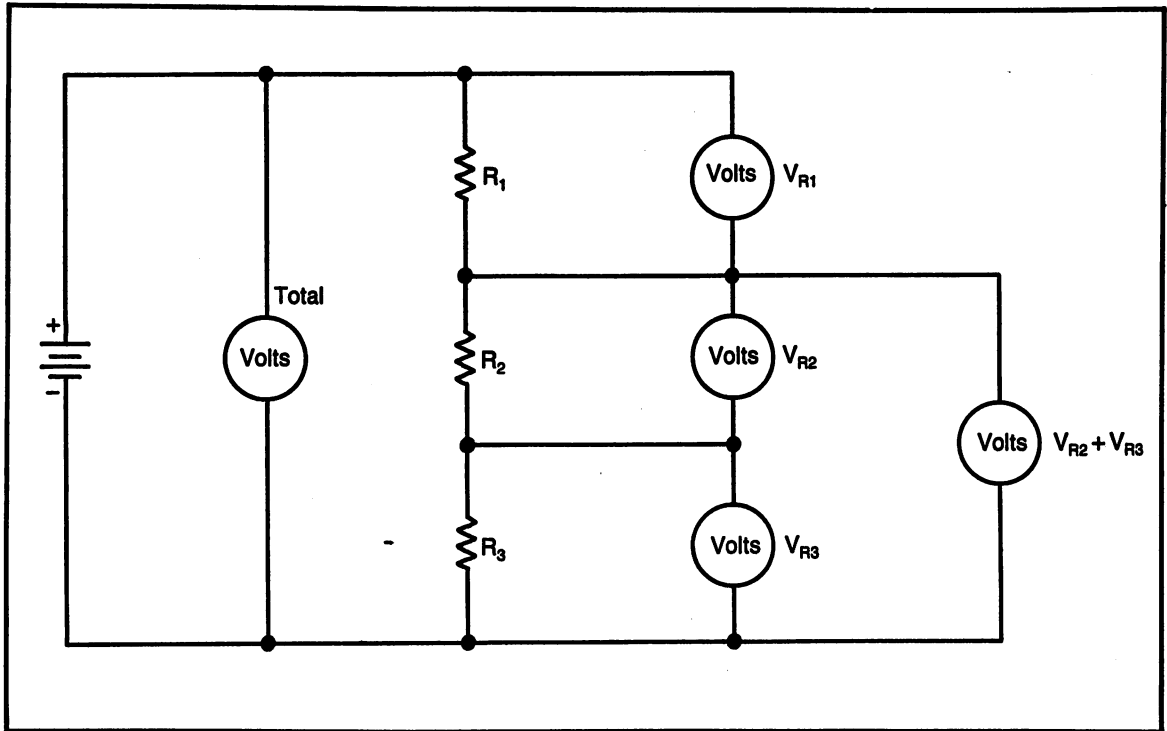


Fig. 9-21. A series circuit showing the voltmeter connections for the various voltage measurements.

$$V_{R2} = \underline{\hspace{2cm}}$$

$$V_{Total} = \underline{\hspace{2cm}}$$

$$V_{R1} = \underline{\hspace{2cm}}$$

PARALLEL CIRCUITS

A parallel circuit is defined as having more than one path for current to flow. With this definition, the following rules can be formed. Each of these rules will be discussed in detail.

- (1) Voltage is the same throughout a parallel circuit.
- (2) In a parallel circuit, current divides to the individual branches, indirectly proportional to the size of the branch resistance.
- (3) Total current in a parallel circuit is the sum of the individual branch currents.
- (4) Total resistance in a parallel circuit is found using the "reciprocal formula". Total resistance is always less than the smallest resistance connected in parallel.
- (5) The sum of the individual powers in a parallel circuit is equal to the total power.

Voltage is the Same in a Parallel Circuit

Figure 9-22 shows a parallel circuit with three resistors. Notice, the wires from the power supply connect to each of the resistors. This means that each resistor will receive the same voltage.

Another example of a parallel circuit is the electrical outlets in a home. Each outlet supplies 120 volts. It doesn't matter which outlet is used or how many loads are connected, each receives the same voltage.

Current Divides to the Individual Branches

Figure 9-23 is a parallel circuit that shows how the current divides to the individual branches. The total current is supplied from the negative side of the power supply. The applied voltage supplies current to the individual parallel branches according to the amount needed for each branch. A smaller resistor will have more current than a larger resistor. The current flows through each branch and combines together to form the total current, to return to the positive side of the power supply.

Figure 9-24 has the branch currents labeled with the values of the branch currents. The branch currents are calculated as follows:

$$I = \frac{V}{R} \text{ (Ohm's law)}$$

Current in Branch #1:

$$\text{Formula: } I_1 = \frac{V}{R_1}$$

$$\text{Substituting: } I_1 = \frac{12 \text{ volts}}{470 \text{ ohms}}$$

$$\text{Solving: } I_1 = 25.5 \text{ mA}$$

Current in Branch # 2:

$$\text{Formula: } I_2 = \frac{V}{R_2}$$

$$\text{Substituting: } I_2 = \frac{12 \text{ volts}}{680 \text{ ohms}}$$

$$\text{Solving: } I_2 = 17.6 \text{ mA}$$

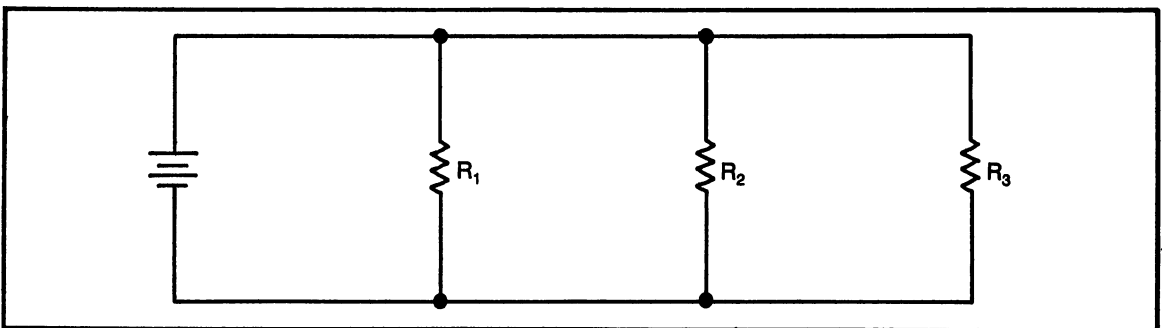


Fig. 9-22. A parallel circuit with three resistors.

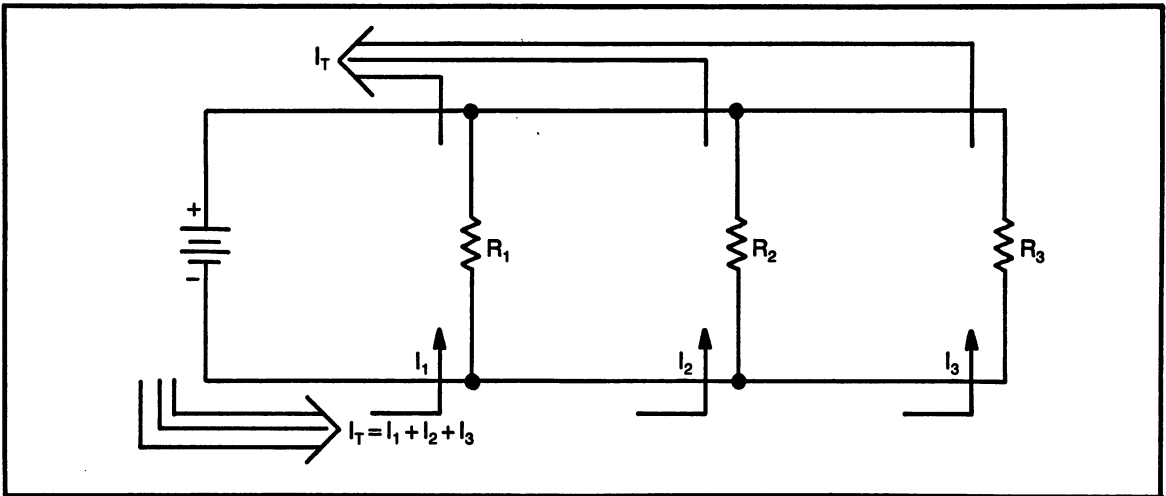


Fig. 9-23. A parallel circuit showing how the current divides.

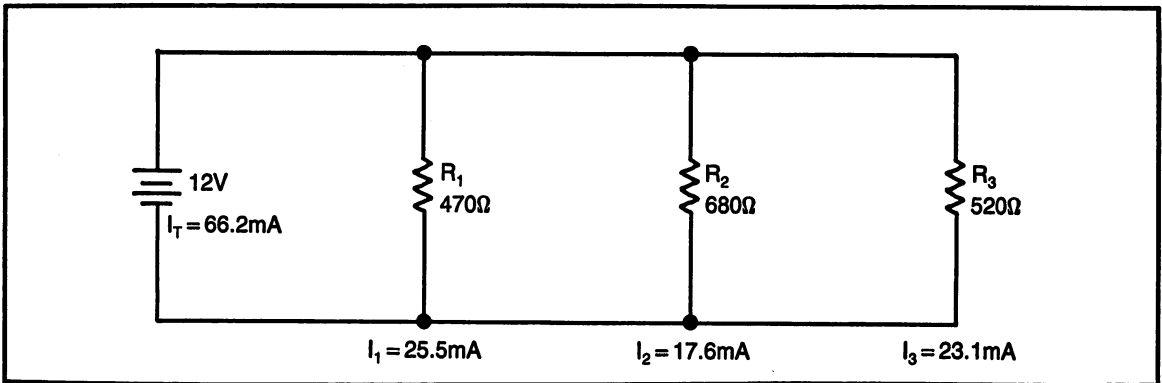


Fig. 9-24. Parallel circuit with branch currents. See text for complete calculations.

Current in Branch #3:

Formula: $I_3 = \frac{V}{R_3}$

Substituting: $I_3 = \frac{12 \text{ volts}}{520 \text{ ohms}}$

Solving: $I_3 = 23.1 \text{ mA}$

Total Current Is Sum of Branch Currents

In any circuit, the same amount of current that leaves the negative side of the battery must return to the positive side. In a parallel circuit, this means that the current supplied to the individual branches must add together to equal the total current.

Formula #11. Total Current in a Parallel Circuit

$$I_T = I_1 + I_2 + I_3 + \dots$$

Total circuit current (for Fig. 9-14).

Formula: $I_T = I_1 + I_2 + I_3$

Substituting: $I_T = 25.5 \text{ mA} + 17.6 \text{ mA} + 23.1 \text{ mA}$

Solving: $I_T = 66.2 \text{ mA}$

Total Resistance in a Parallel Circuit

The total resistance in any circuit is a value of resistance "seen" by the power supply. The power supply must supply current to the circuit. The

amount of current supplied to the circuit is determined by the applied voltage and the circuit resistance.

Total resistance in a parallel circuit can be found using either of two methods; total current or the reciprocal formula.

The total resistance in a parallel circuit must always be lower than the smallest branch resistance. This should make sense because the power supply must supply current to all branches. More current supplied appears to the power supply as lower resistance.

Formula #12. Total Resistance in a Parallel Circuit, Using Total Current

$$R = \frac{V}{I_T} \text{ (Ohm's law)}$$

Formula #13. Total Resistance in a Parallel Circuit, Reciprocal Formula

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

Total Resistance for Fig. 9-24. Total Current Method.

Formula: $R = \frac{V}{I}$

Substituting: $R_T = \frac{12 \text{ volts}}{66.2 \text{ mA}}$

Solving: $R_T = 181 \text{ ohms}$

Using the Reciprocal Formula

To use the reciprocal formula follow these steps:

- (1) Write down the formula.
- (2) Substitute the known values into the formula in place of the variables.
- (3) Take the reciprocal of each of the resistance values. Most calculators have a reciprocal key. Use this key rather than dividing into 1 each time. It is not necessary to write down the decimal equivalents, simply press the + (addition) key after each reciprocal. After adding the dec-

imal values of the reciprocals, the decimal total will be very small.

- (4) Take the reciprocal of the sum of the reciprocals and this value will be the total resistance of the circuit. The total resistance will be lower than the lowest value of parallel resistor. Notice, only for extremely rare conditions, the value of total resistance should not be less than 1. Use this as a check to be sure all steps have been followed.

Total Resistance for

Fig. 9-24. Reciprocal Formula Method.

Formula: $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Substituting: $\frac{1}{R_T} = \frac{1}{470} + \frac{1}{680} + \frac{1}{520}$

Decimal equivalents of reciprocals:

$$\frac{1}{R_T} = .00213 + .00147 + .00192$$

Adding decimals: $\frac{1}{R_T} = .00552$

Final answer: $R_T = 181 \text{ ohms}$

Short Cut Formulas

There are two short cut formulas available to calculate total resistance in a parallel circuit.

Formula #14. Short Cut Formula for Total Resistance With Two Resistors in Parallel

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

This formula can be used only when there are two resistors in parallel. Notice the numerator is a multiplication and the denominator is an addition. Many students find that the calculators now available are so easy to use that it is not worth the effort to learn this so called "short cut" formula. It is presented here to be sure the student has been exposed to all of the different formulas.

Formula #15. Short Cut Formula for Total Resistance with Equal Values of Resistors in Parallel

$$R_T = \frac{R}{n} \quad \begin{array}{l} \text{(resistance value)} \\ \text{(number of resistors)} \end{array}$$

This short cut formula is rather handy. The total resistance of a parallel circuit when the resistors are equal value is found by dividing the value of branch resistance by the number of equal resistors.

Example: Two 100 ohm resistors are connected in parallel, total resistance is 50 ohms (100 divided by 2).

Example: Three 600 ohm resistors are connected in parallel, total resistance is 200 ohms (600 divided by 3).

Total Power in a Parallel Circuit is the Sum of the Individual Powers

In all circuits, the total power is the sum of the individual powers dissipated by the individual loads. Power can also be calculated using the applied voltage and the total circuit current.

Practice Problems: Parallel Circuits

Use the information given in the schematic diagrams and the problems to find the unknown quantities.

**HANDS-ON PRACTICE:
PARALLEL CIRCUIT MEASUREMENTS**

This section will contain both calculations and measurements of parallel circuits. When the student completes this section he/she should feel confident in making measurements in a parallel dc circuit.

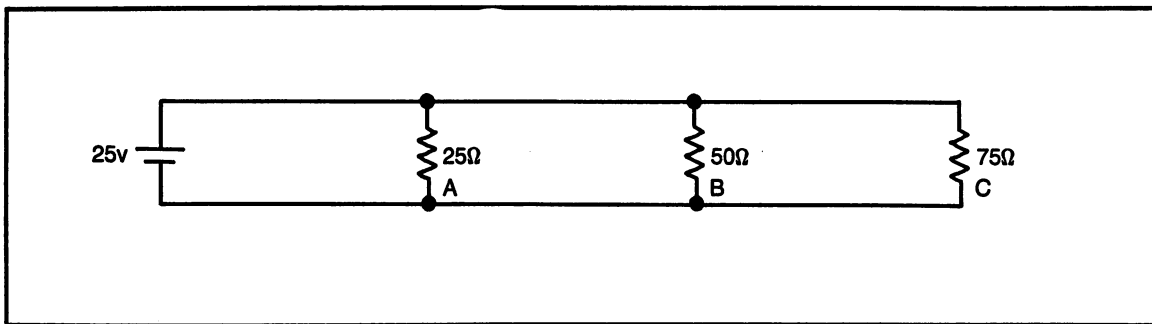


Fig. 9-25. Problem 1. Find: R_T , I_T , I_A , I_B , I_C (branch currents).

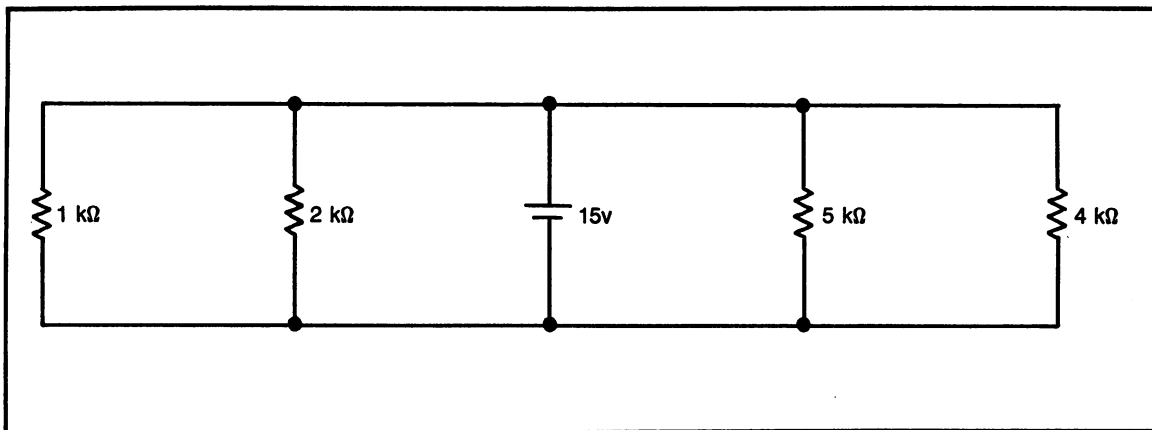


Fig. 9-26. Problem 2. Find: R_T , I_T .

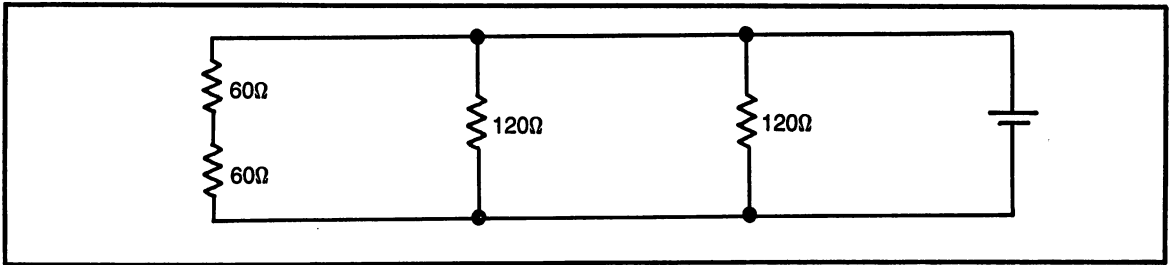


Fig. 9-27. Problem 3. Find: R_T .

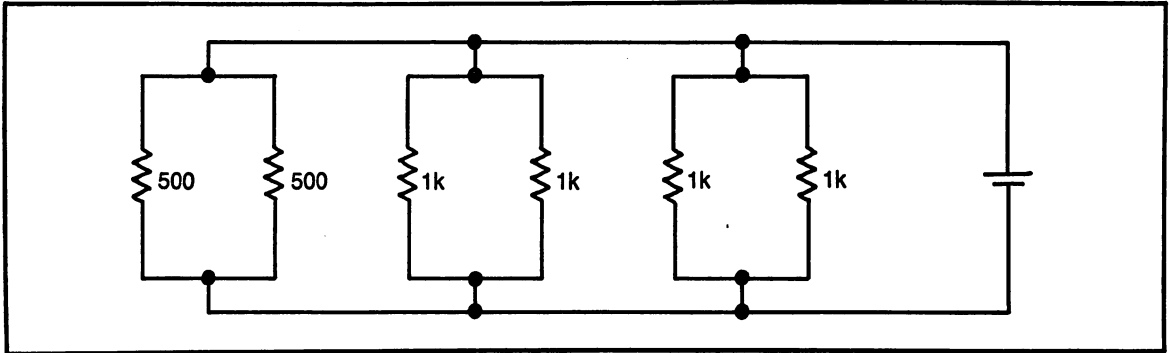


Fig. 9-28. Problem 4. Find: R_T .

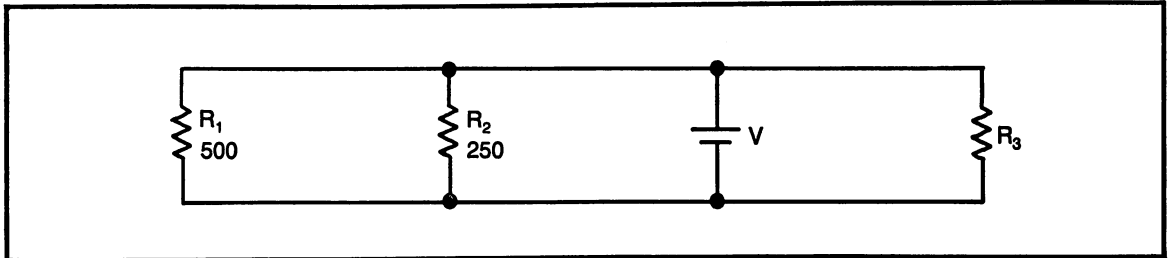


Fig. 9-29. Problem 5. Find: R_3 .

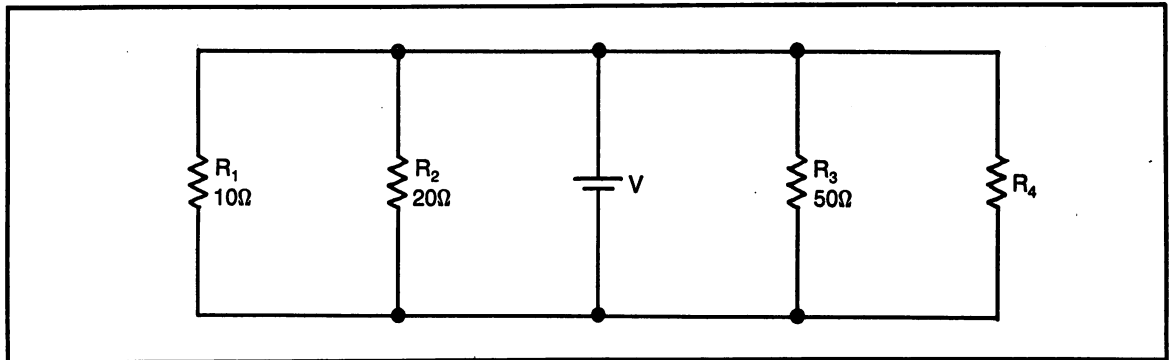


Fig. 9-30. Problem 6. Find: R_4 .

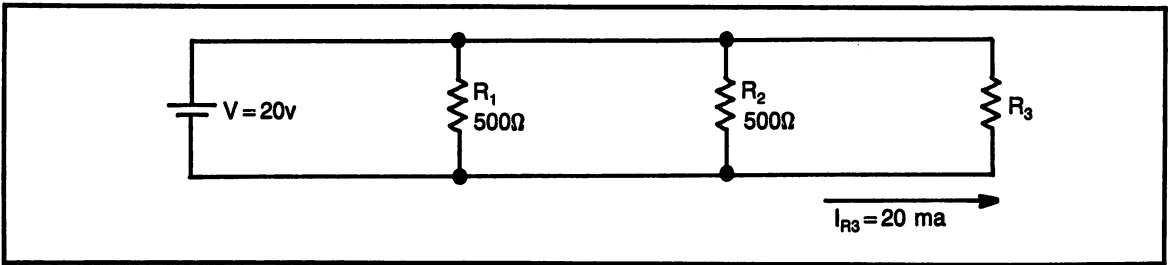


Fig. 9-31. Problem 7. Find: R_T , I_T , R_3 .

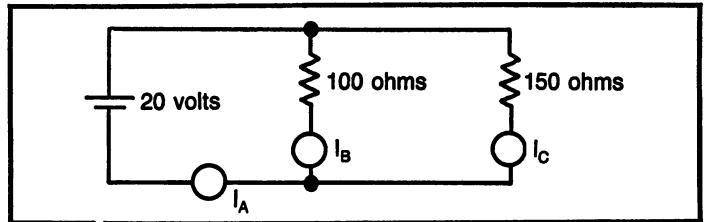


Fig. 9-32. Problem 8. Find: R_T , I_A , I_B , I_C .

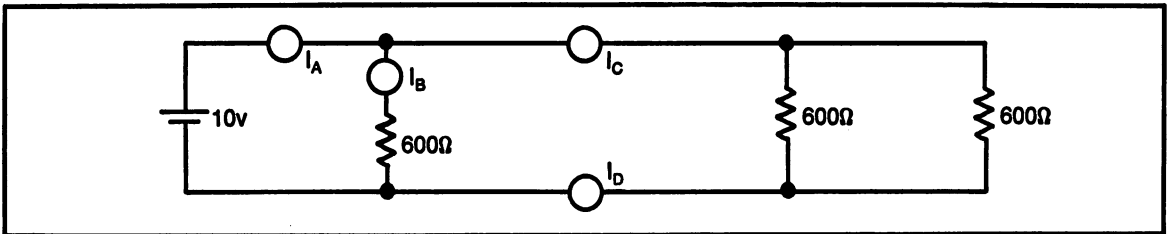


Fig. 9-33. Problem 9. Find: R_T , I_A , I_B , I_C , I_D .

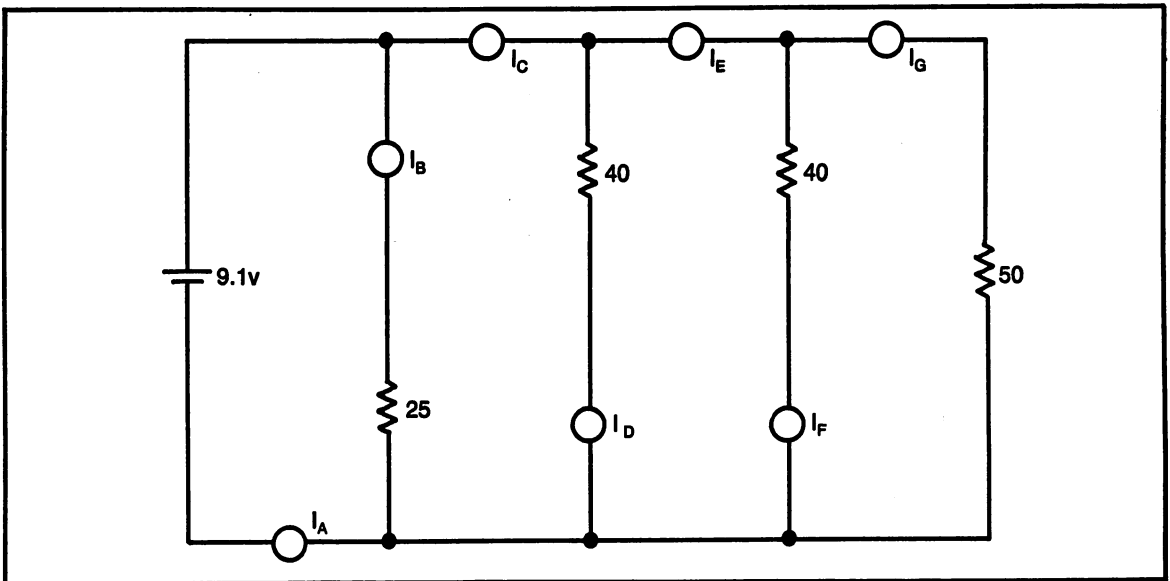


Fig. 9-34. Problem 10. Find: R_T , I_A , I_B , I_C , I_D , I_E , I_F , I_G .

Even though specific resistance values are given for these exercises, the actual values are not critical. Substitutes may be used.

Total Resistance of a Parallel Circuit

(1) Figure 9-35 shows three resistors connected in parallel. An ohmmeter is connected in place of the voltage source. Note: whenever using an ohmmeter, there must not be any other voltage connected to the circuit. First, calculate

the total resistance of this circuit, then use the ohmmeter to measure the circuit resistance.

Total resistance formula: _____

R_T (calculated) = _____

R_T (measured) = _____

(2) Remove the ohmmeter and connect a dc power supply, as shown in Fig. 9-36. Connect a voltmeter across the power supply (with the circuit also connected) and set the power supply for 6 volts. Move the voltmeter to measure the voltage across each of the resistors.

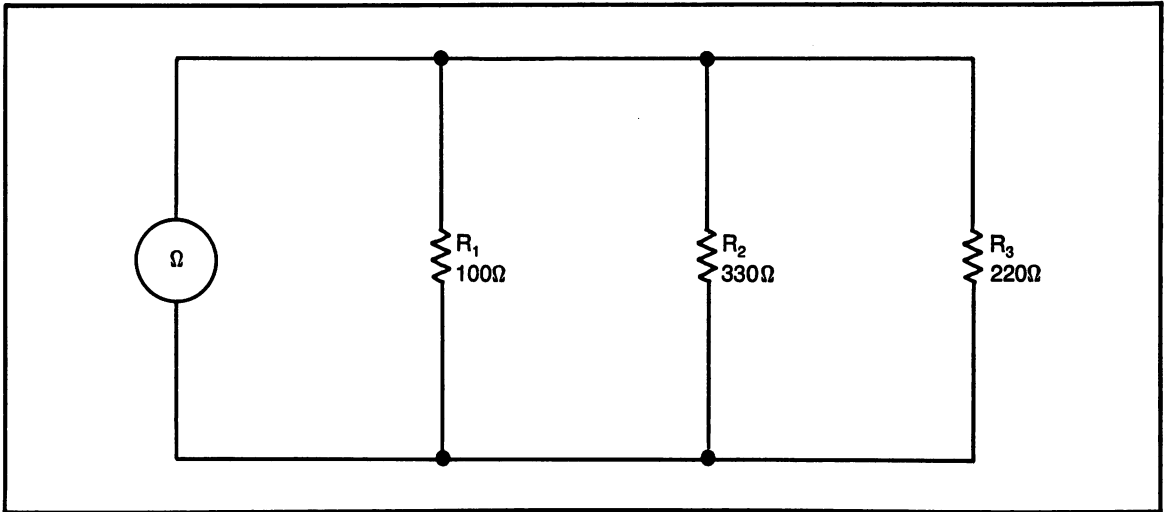


Fig. 9-35. An ohmmeter connected to a parallel circuit.

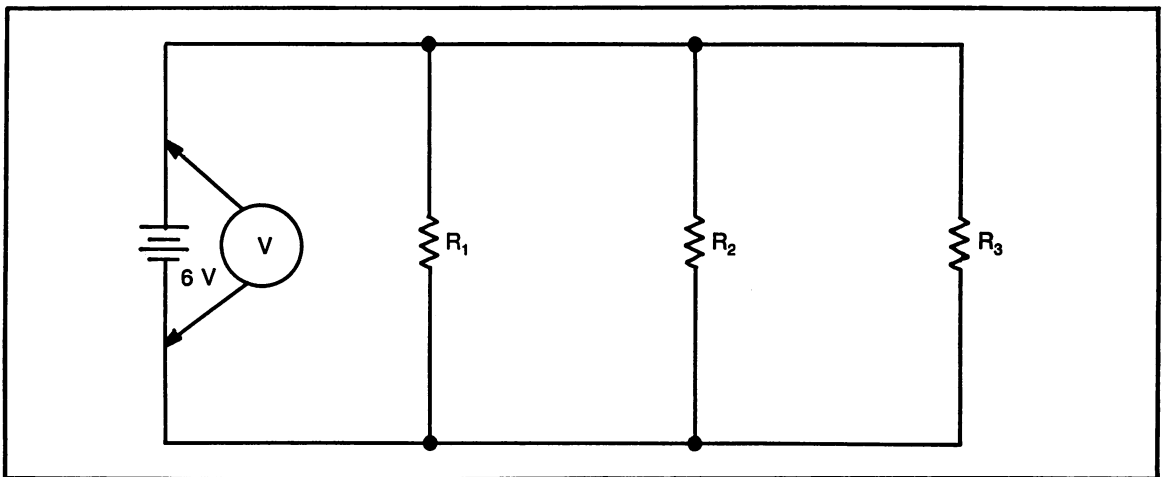


Fig. 9-36. Voltmeter connected to measure supply voltage.

$$V_{R1} = \underline{\hspace{2cm}}$$

$$V_{R2} = \underline{\hspace{2cm}}$$

$$V_{R3} = \underline{\hspace{2cm}}$$

- (3) Remove the voltmeter and connect an oscilloscope in its place. Make the same voltage measurements with the oscilloscope that were made with the voltmeter.

$$V_{Total} = \underline{\hspace{2cm}}$$

$$V_{R1} = \underline{\hspace{2cm}}$$

$$V_{R2} = \underline{\hspace{2cm}}$$

$$V_{R3} = \underline{\hspace{2cm}}$$

- (4) First, calculate total current and branch currents. Then, use Fig. 9-37 as a guide to connect an ammeter to measure circuit currents. Disconnect the wire from the positive side of the power supply to the circuit. Connect an ammeter in place of the wire. Remember: ammeters are connected in series with the current flow. Measure each branch current using the same technique; disconnect a wire and connect the meter in its place. Be sure to observe meter polarity.

$$I_T \text{ (calculated)} = \underline{\hspace{2cm}}$$

$$I_1 \text{ (calculated)} = \underline{\hspace{2cm}}$$

$$I_2 \text{ (calculated)} = \underline{\hspace{2cm}}$$

$$I_3 \text{ (calculated)} = \underline{\hspace{2cm}}$$

$$I_T \text{ (measured)} = \underline{\hspace{2cm}}$$

$$I_1 \text{ (measured)} = \underline{\hspace{2cm}}$$

$$I_2 \text{ (measured)} = \underline{\hspace{2cm}}$$

$$I_3 \text{ (measured)} = \underline{\hspace{2cm}}$$

SERIES-PARALLEL COMBINATIONS

A series-parallel combination circuit, also called a complex circuit, is a circuit that contains both series resistors and parallel resistors.

To begin to analyze a complex circuit, it is necessary to separate the series from the parallel, because they different rules and formulas.

Review of Series and Parallel

Series:

- (1) Current is the same throughout a series circuit.
- (2) Total resistance in a series circuit is the sum of the individual resistors.
- (3) The sum of the voltage drops in a series circuit equals the applied voltage.

Parallel:

- (1) Voltage is the same throughout a parallel circuit.
- (2) Total resistance in a parallel circuit is found using the "reciprocal formula".
- (3) Total current in a parallel circuit is the sum of the individual branch currents.

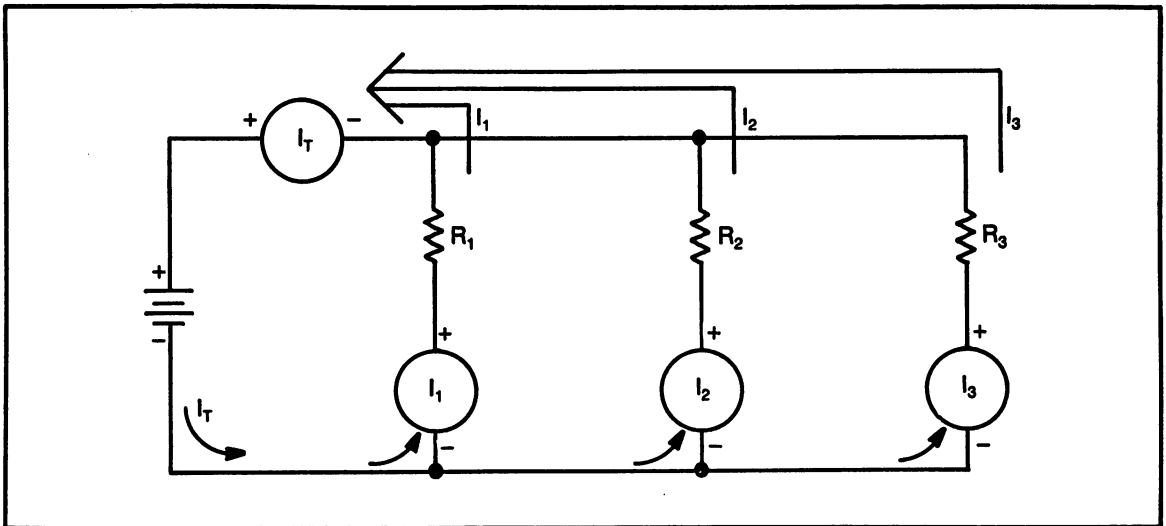


Fig. 9-37. Parallel circuit with ammeters to measure branch current.

Solving a Complex Circuit

Figure 9-38 shows the three steps in solving a complex circuit. Figure 9-38A is the complete circuit.

Tracing the current flow, starting from the negative side of the battery, all of the current flowing from the battery, I_T , goes through R_4 . Therefore, R_4 is a series resistor. The current flow then reaches point "b", where it divides to flow through the parallel branches of R_2 and R_3 . The current flow from these two branches recombines at point "a" and becomes I_T , and flows through R_1 back to the positive side of the battery.

The following procedure is a suggested guideline for solving any complex circuit.

- (1) Solve for total resistance, R_T . It is best to start from a point farthest from the power supply.
 - a. Combine parallel branches into an equivalent series resistance.
 - b. Combine the equivalent resistance with the series resistors.
 - c. Continue this combination process until the entire circuit can be represented as one equivalent resistance.
- (2) Use total resistance, R_T , to find I_T . $I = V/R$ (Ohm's law).
- (3) Use I_T to find the voltage drop across resistors that are in series with I_T .
 - a. Add the series voltage drops together.
 - b. Subtract the total series voltage drops from the applied voltage.
 - c. The result of the subtraction is the voltage remaining for the entire rest of the circuit (the parallel circuits).
- (4) Use the voltage drop for the parallel circuits to determine what the current flow is in each branch.

Steps In Solving Figure 9-38

- (1) Find total resistance, R_T
 - a. Determine which resistors are in series and which are in parallel. Combine the parallel resistors farthest from the power supply first.
 - b. Combine resistors R_2 and R_3 . This will be

labeled R_{par} , short for parallel, as shown in Fig. 9-38B.

$$\text{Formula: } \frac{1}{R_{par}} = \frac{1}{R_2} + \frac{1}{R_3}$$

$$\text{Substituting: } \frac{1}{R_{par}} = \frac{1}{100} + \frac{1}{100}$$

Decimal equivalent of reciprocals:

$$\frac{1}{R_{par}} = 0.01 + 0.01$$

$$\text{Adding decimals: } \frac{1}{R_{par}} = 0.02$$

$$\text{Final answer: } R_{par} = 50 \text{ ohms}$$

Note: since the two parallel resistors are exactly the same value, the short cut formula can be used.

$$\text{Formula: } R_{par} = \frac{R}{n}$$

$$\text{Substituting: } R_{par} = \frac{100 \text{ ohms}}{2}$$

$$\text{Solving: } R_{par} = 50 \text{ ohms}$$

Re-draw the circuit diagram to show the parallel resistors replaced by the equivalent resistance, as shown in Fig. 9-38B.

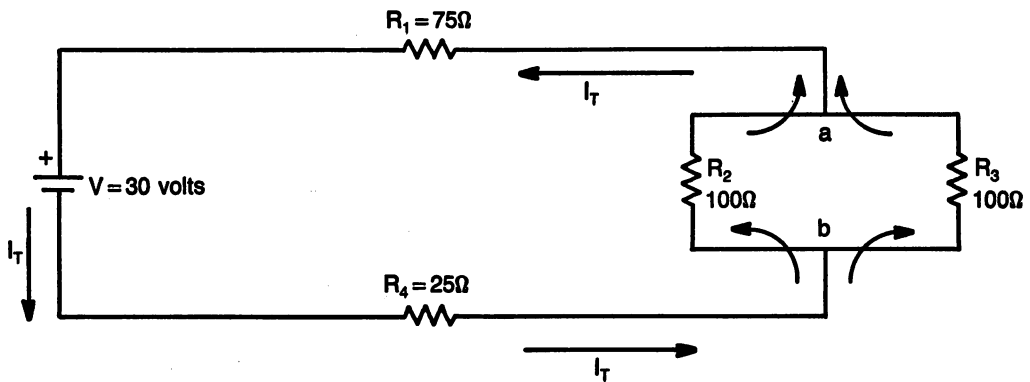
- c. The circuit of Fig. 9-38B shows three resistors connected in series. Combine these resistors to find one equivalent resistance, R_T .

$$\text{Formula: } R_T = R_1 + R_{par} + R_4$$

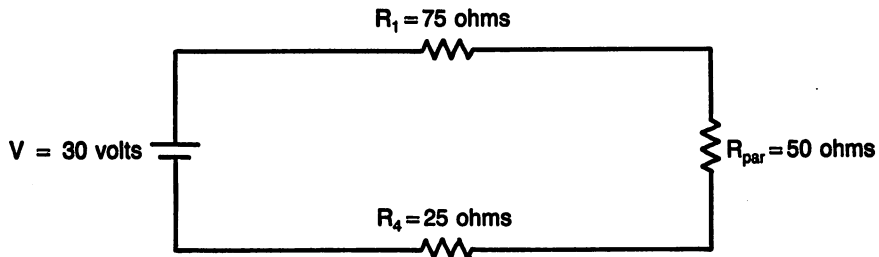
$$\text{Substituting: } R_T = 75 \text{ ohms} + 50 \text{ ohms} + 25 \text{ ohms}$$

$$\text{Solving: } R_T = 150 \text{ ohms}$$

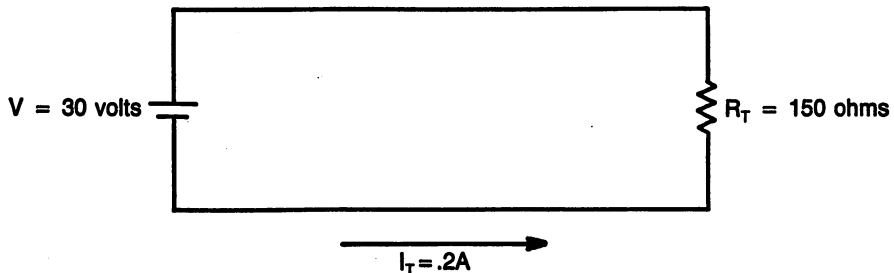
Re-draw the circuit to show the one final equivalent



A. Complex D.C. circuit.



B. One step in solving a complex circuit.



C. Equivalent circuit showing R_T and I_T .

Fig. 9-38. Steps in finding total resistance and total current in a complex circuit. See text for calculations.

lent resistance, R_T , as shown in Fig. 9-38C.

(2) Use the total resistance to find the total current.

Formula: $I = \frac{V}{R}$ (Ohm's law)

Substituting: $I = \frac{30 \text{ volts}}{150 \text{ ohms}}$

Solving: $I = 0.2 \text{ amps}$

(3) Use I_T to find voltage drops across the series resistors.

Voltage Drop Across R_1

Formula: $V_{R1} = I_T \times R_1$

Substituting: $V_{R1} = 0.2 \text{ amps} \times 75 \text{ ohms}$

Solving: $V_{R1} = 15 \text{ volts}$

Voltage Drop Across R_4

Formula: $V_{R4} = I_T \times R_4$

Substituting: $V_{R4} = 0.2 \text{ amps} \times 25 \text{ ohms}$

Solving: $V_{R4} = 5 \text{ volts}$

Voltage drop across the parallel combination of R_2 and R_3 , V_{par} is found by either of two methods. Either by finding the voltage drop across the equivalent resistance or by subtracting the other voltage drops from the applied voltage. The method used here will be the subtraction method.

Add the voltage drops of the series resistors.

Formula: $V_{series} = V_{R1} + V_{R4}$

Substituting: $V_{series} = 15 \text{ volts} + 5 \text{ volts}$

Solving: $V_{series} = 20 \text{ volts}$

Subtract the series voltage drops from the ap-

plied voltage to find the voltage across the parallel branches.

Formula: $V_{par} = V_{applied} - V_{series}$

Substituting: $V_{par} = 30 \text{ volts} - 20 \text{ volts}$

Solving: $V_{par} = 10 \text{ volts}$

- (4) Use the voltage across the parallel branches, V_{par} to find the current flow in each branch. Note: in this particular example, the branches have equal resistance, therefore they will have an equal current flow. Since there are only two branches, each branch will have $\frac{1}{2}$ of the total current. The method used as an example here will be to calculate the current flow. $I_{R2} = I_{R3}$ because they are equal value resistance.

Formula: $I = \frac{V}{R}$

Substituting: $I = \frac{10 \text{ volts}}{100 \text{ ohms}}$

Solving: $I = 0.1 \text{ amps}$

This completes the analysis of the circuit shown in Fig. 9-38. Figure 9-39 is the schematic with all

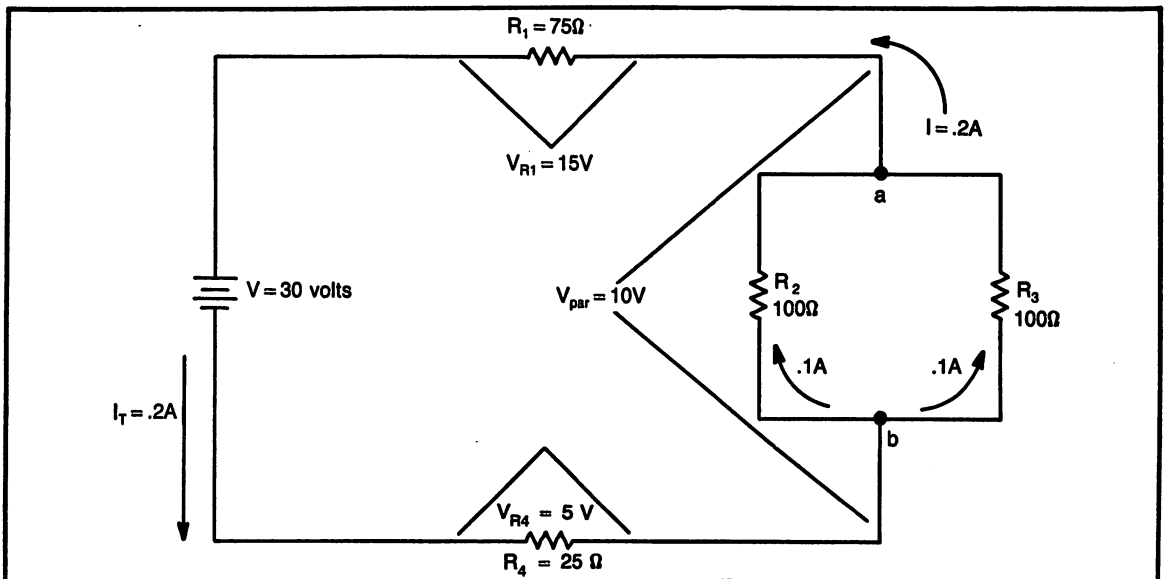


Fig. 9-39. Complex circuit showing voltage drops and current flow.

of the necessary information shown. It is also possible to continue the analysis by finding the power dissipated by each resistor. Power would be found by using the current through a resistor and the voltage across the resistor.

Solving for Total Resistance and Total Current of Figure 9-40

Figure 9-40 is a rather complicated looking circuit. The steps in solving this circuit are basically the same as any other complex circuit. Start from a point farthest from the power supply, combining series and parallel circuits individually. Remember, series circuits and parallel circuits cannot be combined together in one step.

- (1) Combine the series resistors R8, R9 and R10 together. This will be labeled R_a.

Formula: $R_a = R_8 + R_9 + R_{10}$

Substituting: $R_a = 5 + 20 + 15$

Solving: $R_a = 40$ ohms

- a. Re-draw the circuit diagram, shown in Fig. 9-40B, to show R_a as a single equivalent resistor to replace the combined resistors.
- (2) Combine the series resistors R6 and R7. Note: this is not shown in the figure as a separate step. Combine the equivalent of these two resistors (40 ohms) in parallel with R_a. The result of this combination will be labeled R_b. Since the two branches are equal, the equivalent is the resistance value divided by 2.

Formula: $R_{par} = \frac{R}{n}$

Substituting: $R_b = 40/2$

Solving: $R_b = 20$ ohms

- a. Re-draw the circuit diagram, as shown in Fig. 9-40C, to show R_b as a single equivalent resistor to replace the combined resistors.
- (3) Combine the series resistors R4, R5 and R6. Label this combination as R_c.

Formula: $R_c = R_4 + R_5 + R_6$

Substituting: $R_c = 20 + 10 + 20$

Solving: $R_c = 50$ ohms

- a. Re-draw the circuit diagram, as shown in Fig. 9-40D, to show R_c as a single equivalent resistor to replace the combined resistors.
- (4) Combine the parallel resistors R3 and R_c. Label this combination as R_d.

Formula: $\frac{1}{R_d} = \frac{1}{R_3} + \frac{1}{R_c}$

Substituting: $\frac{1}{R_d} = \frac{1}{15} + \frac{1}{50}$

Decimal equivalents of reciprocals:

$$\frac{1}{R_d} = .0667 + .02$$

Adding decimals: $\frac{1}{R_d} = .0867$

Final answer: $R_d = 11.5$ ohms

- a. Re-draw the circuit diagram, as shown in Fig. 9-40E, to show R_d as a single equivalent resistor to replace the combined resistors.
- (5) Combine the series resistors R1, R2 and R_d. This is the final combination and will be labeled R_T, to show it is the equivalent total circuit resistance.

Formula: $R_T = R_1 + R_2 + R_d$

Substituting: $R_T = 10 + 10 + 11.5$

Solving: $R_T = 31.5$ ohms

- a. Re-draw the circuit diagram, as shown in Fig. 9-40F, to show R_T as a single equivalent resistor to replace the entire circuit.
- b. Use the equivalent total resistance, R_T, and the applied voltage to calculate the total current.

Formula: $I = \frac{V}{R}$ (Ohm's law)

Substituting: $I = \frac{20 \text{ volts}}{31.5 \text{ ohms}}$

Solving: $I = 0.635$ amps

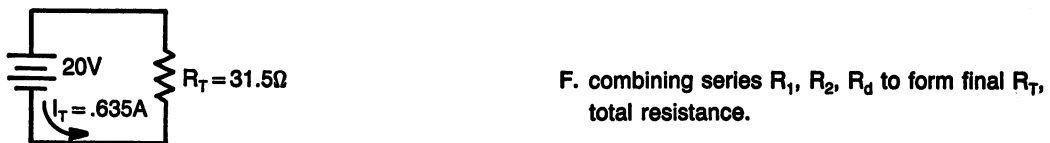
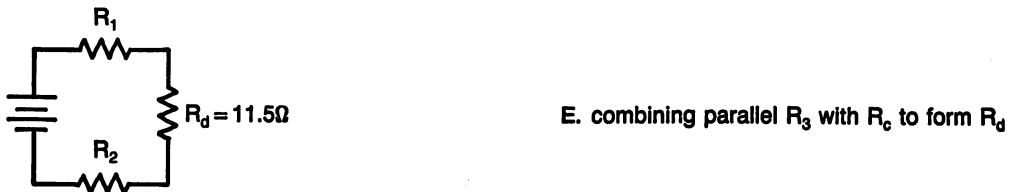
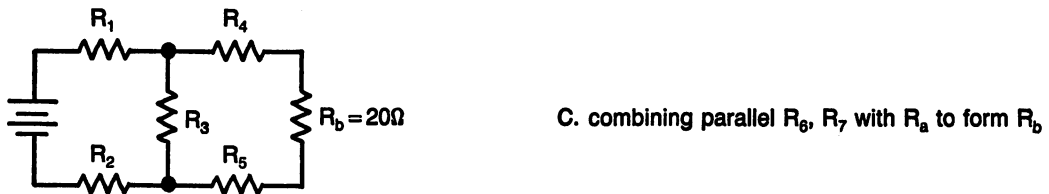
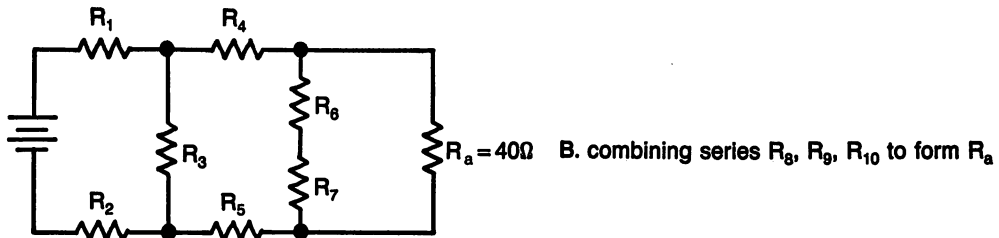
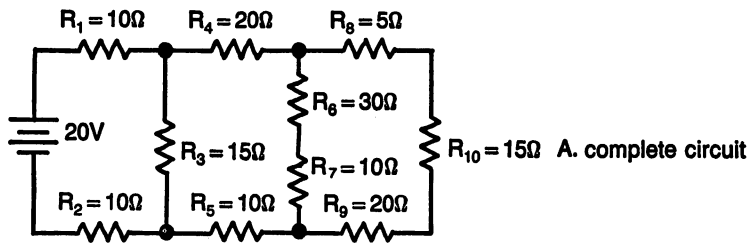


Fig. 9-40. Steps in solving for total resistance of a complex circuit.

c. Voltage drops for each resistor can be found by working backwards with the equivalent circuit diagrams. Use the current and the resistance value to determine the voltage drops. Where a parallel circuit is concerned, keep in mind; current divides, voltage is constant. Where a series circuit is concerned,

keep in mind; voltage drops, current is constant.

Practice Problems: Complex Circuits

Use the schematic diagrams shown to find the unknown circuit parameters.

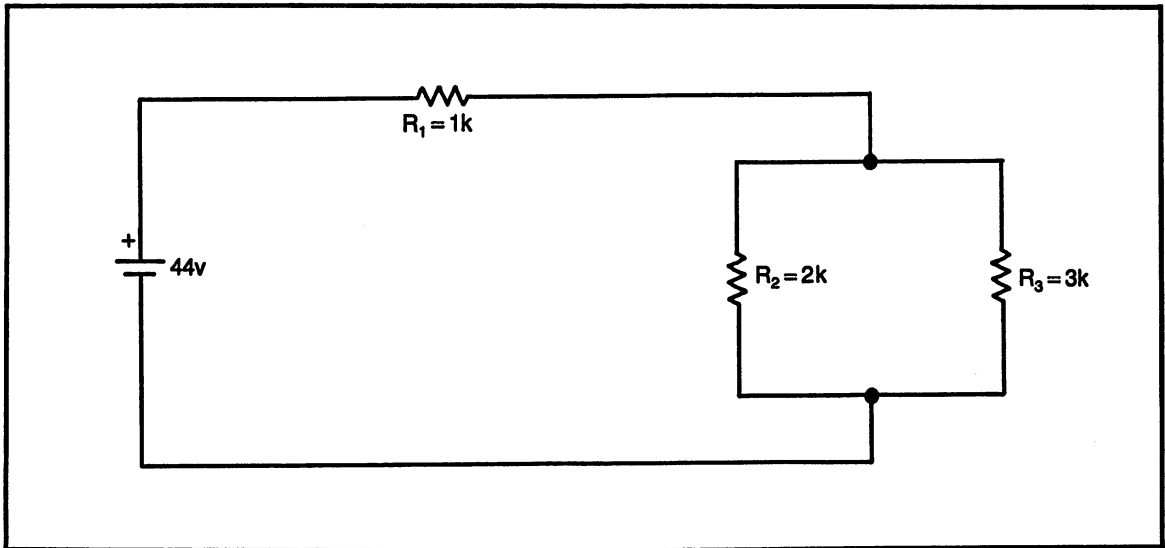


Fig. 9-41. Problem 1. Find: R_T , I_T , V_{R1} , V_{R2} , V_{R3} , I_{R2} , I_{R3} .

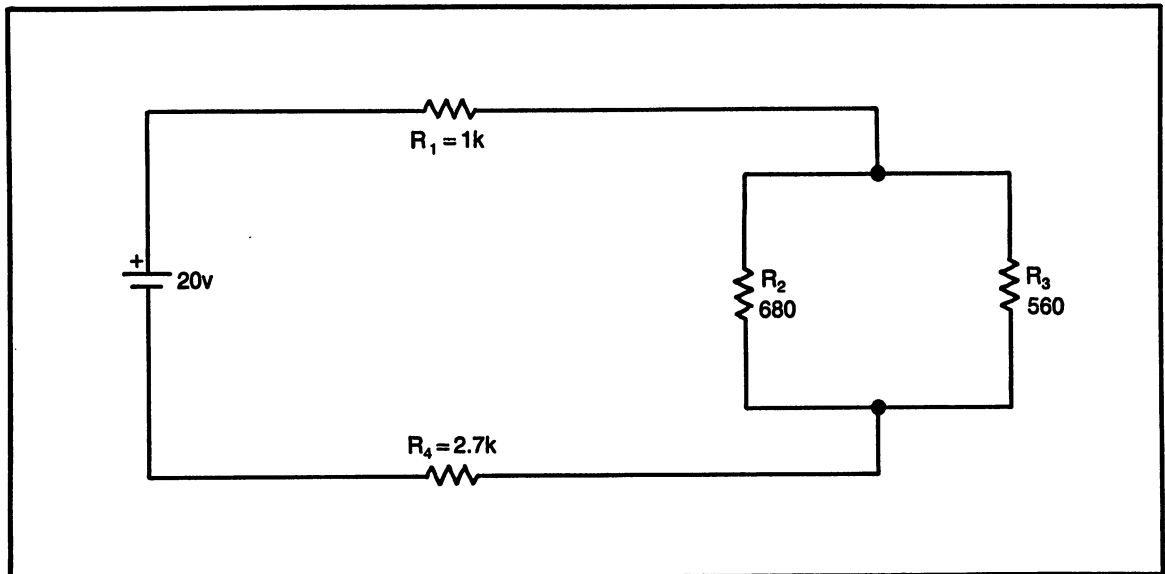


Fig. 9-42. Problem 2. Find: R_T , I_T , V_{R1} , V_{R2} , V_{R3} , V_{R4} , I_{R2} , I_{R3} .

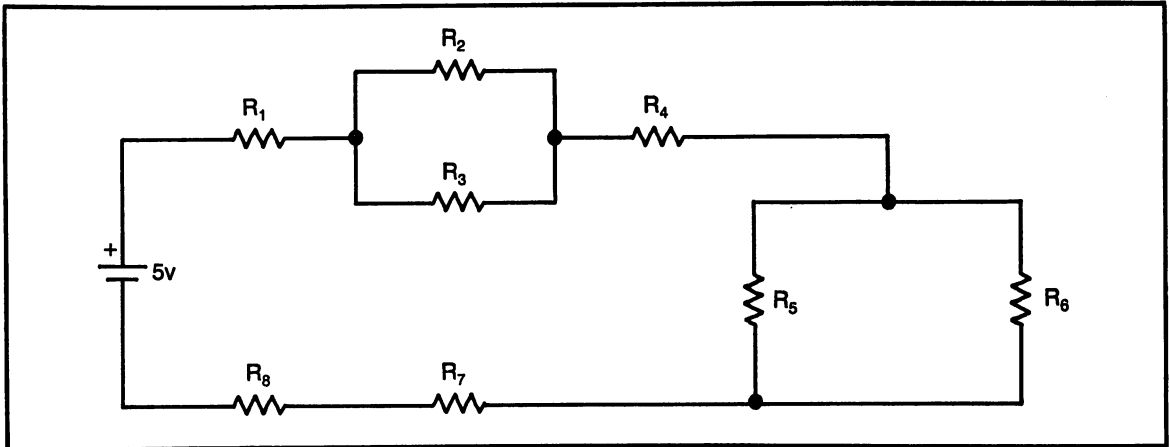


Fig. 9-43. Problem 3. Find: R_T , I_T , I_{R2} , I_{R5} , voltage drops for all resistors

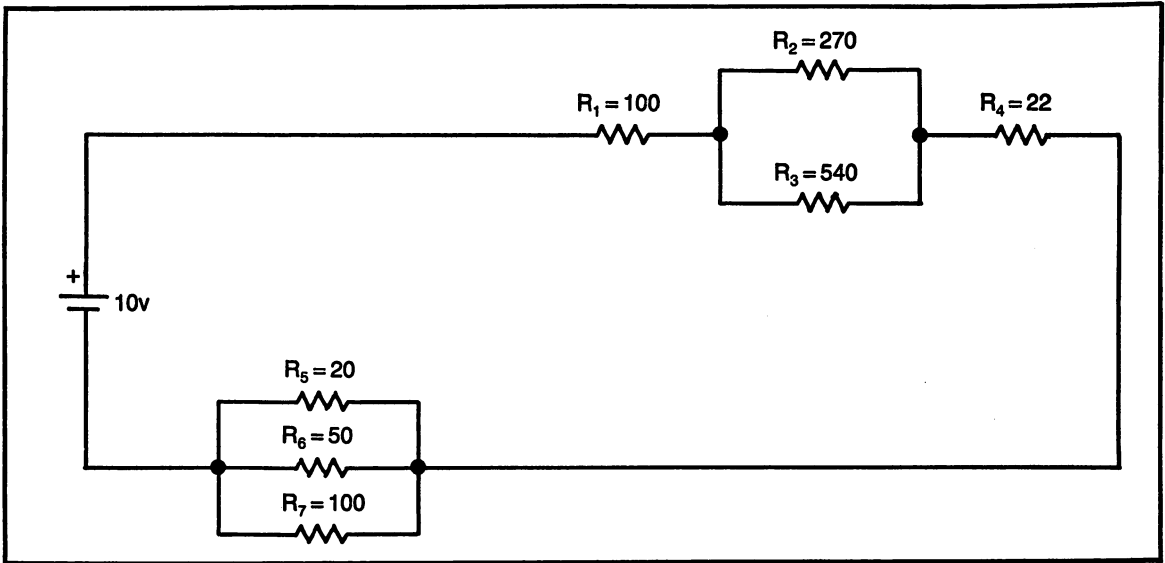


Fig. 9-44. Problem 4. Find: R_T , I_T , current in all resistors and voltage drops across all resistors.

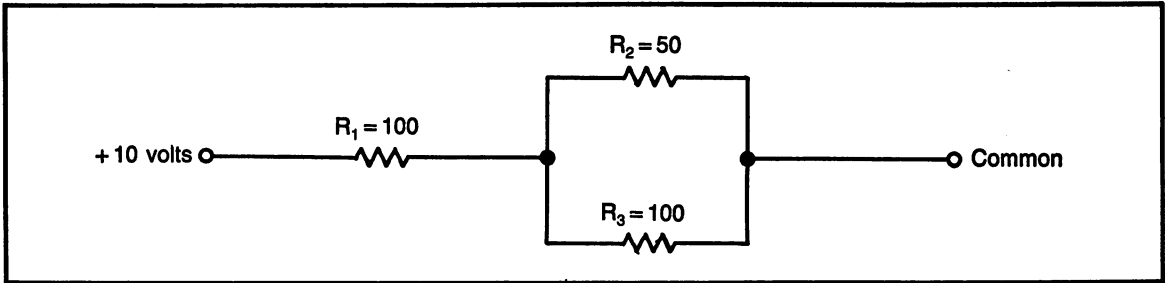


Fig. 9-45. Problem 5. Find: R_T , I_T , V_{R1} , V_{R3} , I_{R1} , I_{R2} , I_{R3}

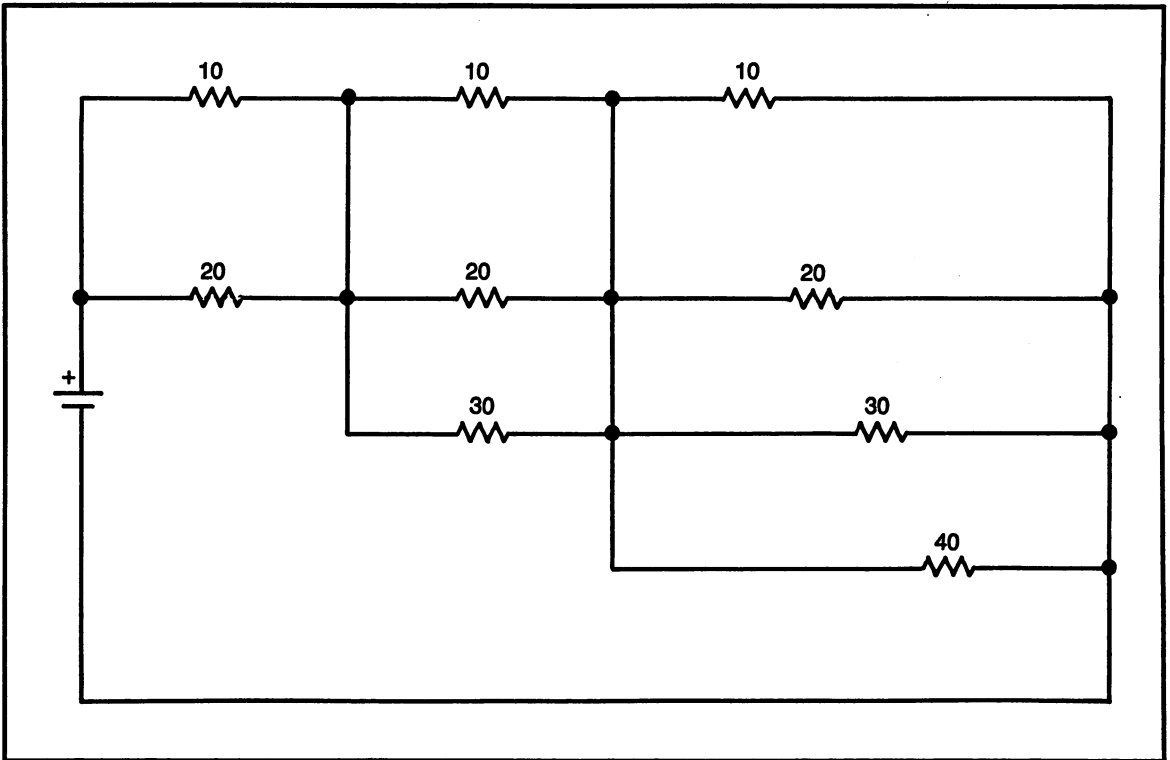


Fig. 9-46. Problem 6. Find: R_T .

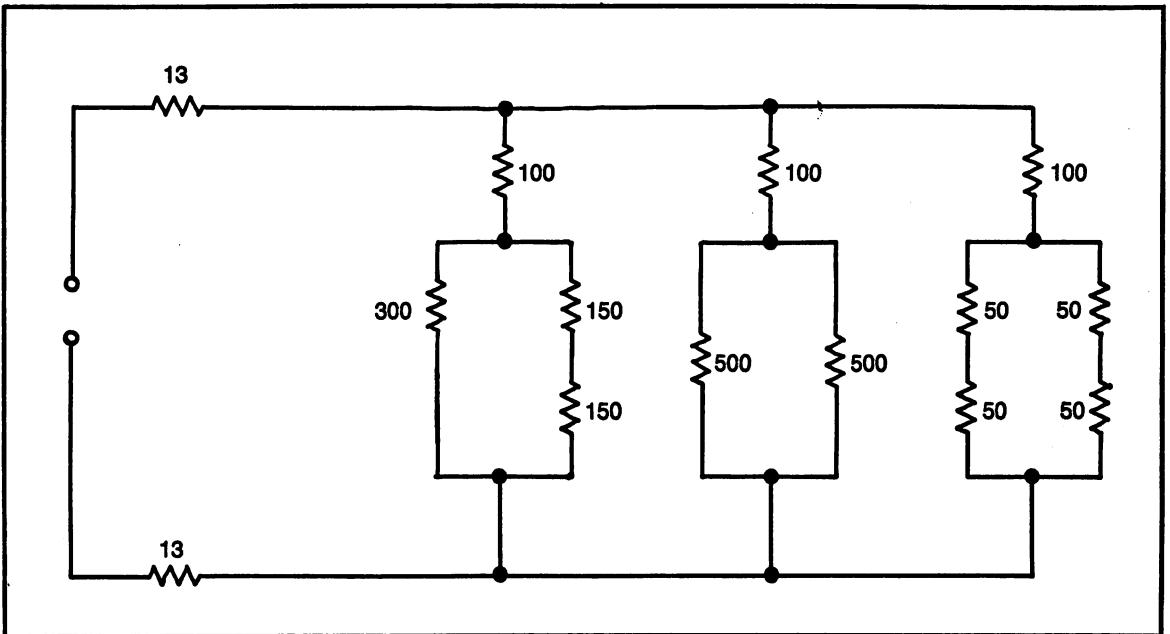


Fig. 9-47. Problem 7. Find: R_T .

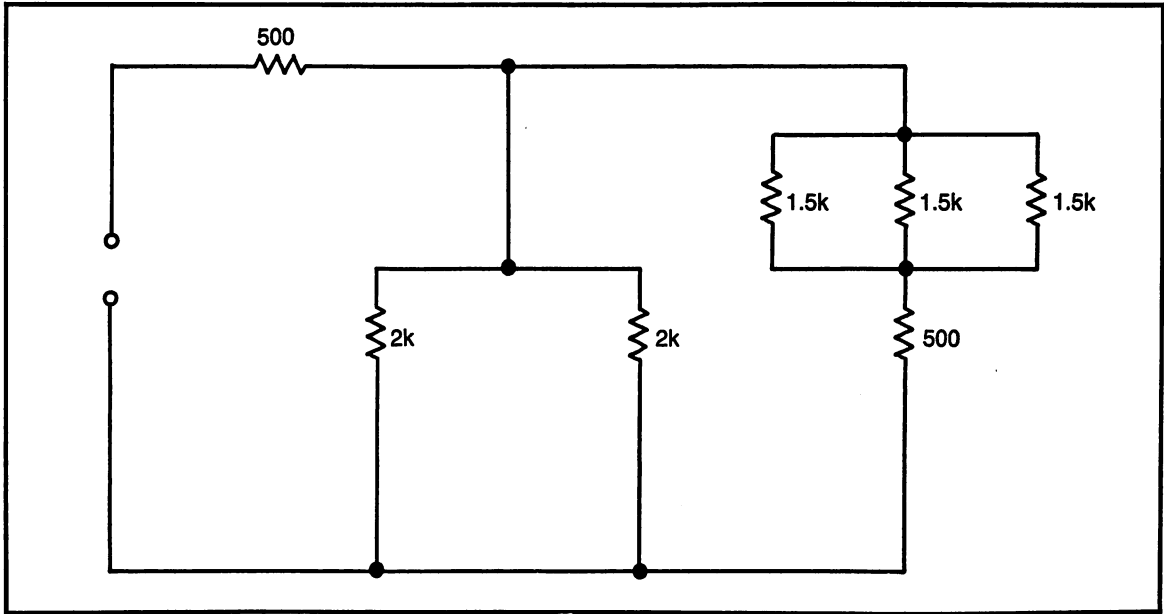


Fig. 9-48. Problem 8. Find: R_T .

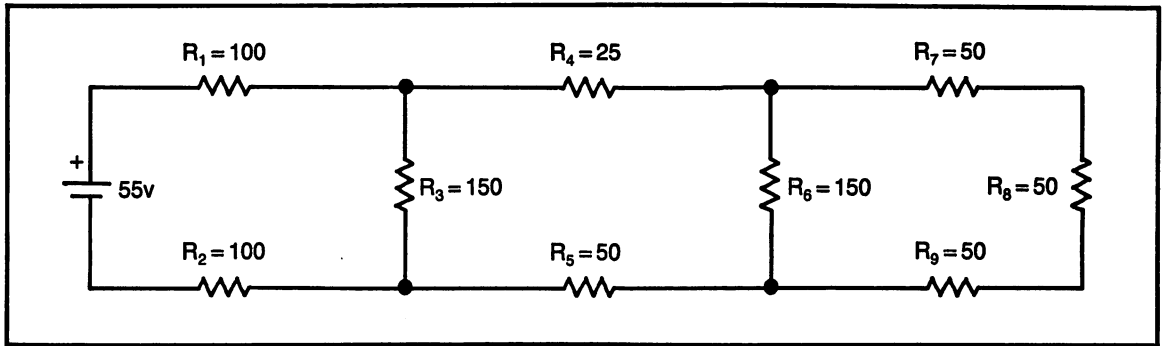


Fig. 9-49. Problem 9. Find: R_T , I_T .

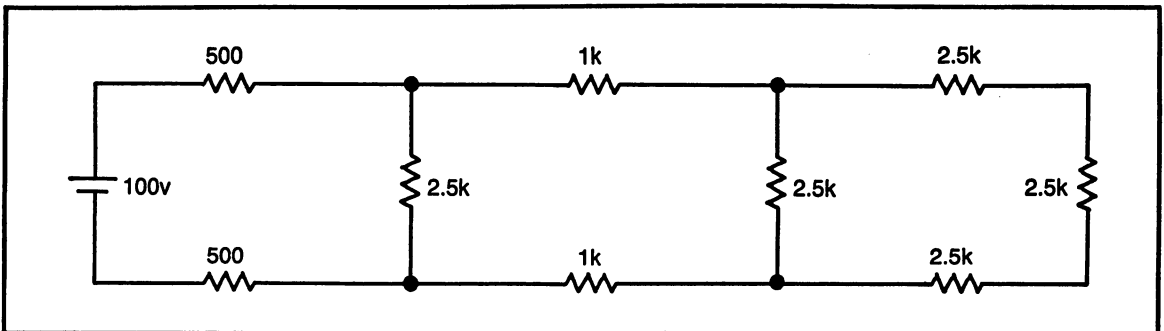


Fig. 9-50. Problem 10. Find: R_T , I_T .

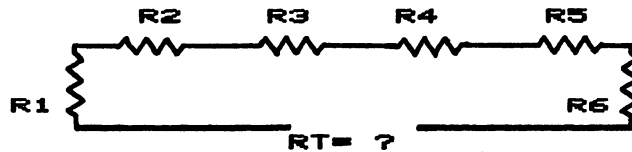
DC ANALYSIS

PROGRAM SAMPLE:

GIVEN:

EVEN # RESISTORS = 1K OHMS

ODD # RESISTORS = 200 OHMS



- 1 . WHAT IS THE VALUE OF RT ? 3600
CORRECT !

~~RETURN TO MAIN~~ FOR NEXT
FOR NEW SELECTION

Fig. 9-51. DC analysis program sample.

PROGRAMS FOR THIS CHAPTER

The program for this chapter is a set of dc circuits to allow the student to further practice the rules of series and parallel circuits.

It would be best for the student to use a calculator when solving these circuits. By using the calculator, two very important concepts will be practiced: solving with the calculator and review of the circuit rules.

Use the help hints when you have a wrong answer. It is also a good idea to review the book when any concept is not fully understood. Keep in mind, the computer programs provide valuable practice, when used properly.

Figure 9-51 shows a sample of the dc analysis program.

DC CIRCUIT ANALYSIS TEST

Part A. Circuit Analysis Theory

(1) In a series circuit; which circuit parameter is

common at all points in the circuit?

- a. voltage
- b. current
- c. resistance
- d. power

(2) Which value of resistor will have the largest voltage drop?

- a. small ohmic value
- b. large ohmic value
- c. size makes no difference
- d. not enough information given

(3) In a parallel circuit; which circuit parameter is common throughout the circuit?

- a. voltage
- b. current

- c. resistance
- d. power

(4) Which value of resistor will have the largest current flow?

- a. small ohmic value
- b. large ohmic value
- c. value makes no difference
- d. not enough information given

(5) In a parallel circuit; the total resistance is:

- a. larger than the largest value resistor
- b. smaller than the smallest value resistor
- c. one-half the value of the two resistors
- d. the sum of all resistors

(6) In a series circuit; the total resistance is:

- a. larger than the largest value resistor
- b. smaller than the smallest value resistor
- c. one-half the value of the two resistors
- d. the average of the resistor values

(7) The formula for total resistance in a parallel circuit is:

- a. $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$
- b. $R_T = \frac{R_1 \times R_2}{R_1 + R_2}$

- c. $R_T = R_1 + R_2 + R_3 + \dots$
- d. none of the above

(8) The formula for total resistance in a series circuit is:

- a. $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$
- b. $R_T = \frac{R_1 \times R_2}{R_1 + R_2}$
- c. $R_T = R_1 + R_2 + R_3 + \dots$
- d. none of the above

(9) A voltmeter is connected in:

- a. series
- b. parallel
- c. series-parallel

(10) An ammeter is connected in:

- a. series
- b. parallel
- c. series-parallel

Part B. Circuit Calculations

Questions 11 through 15 use the series circuit, Fig. 9-52.

(11) Find total resistance

(12) Find total current

(13) What does meter "a" read?

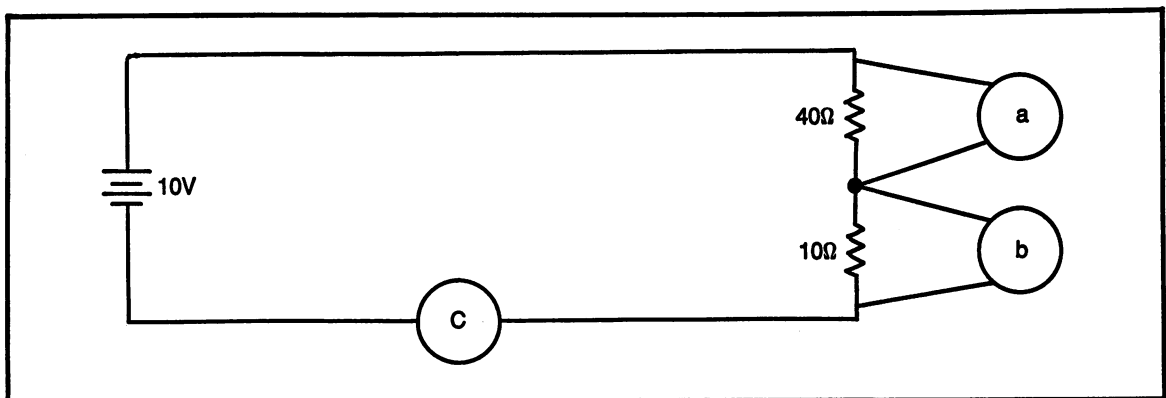


Fig. 9-52. Circuit for questions 11-15.

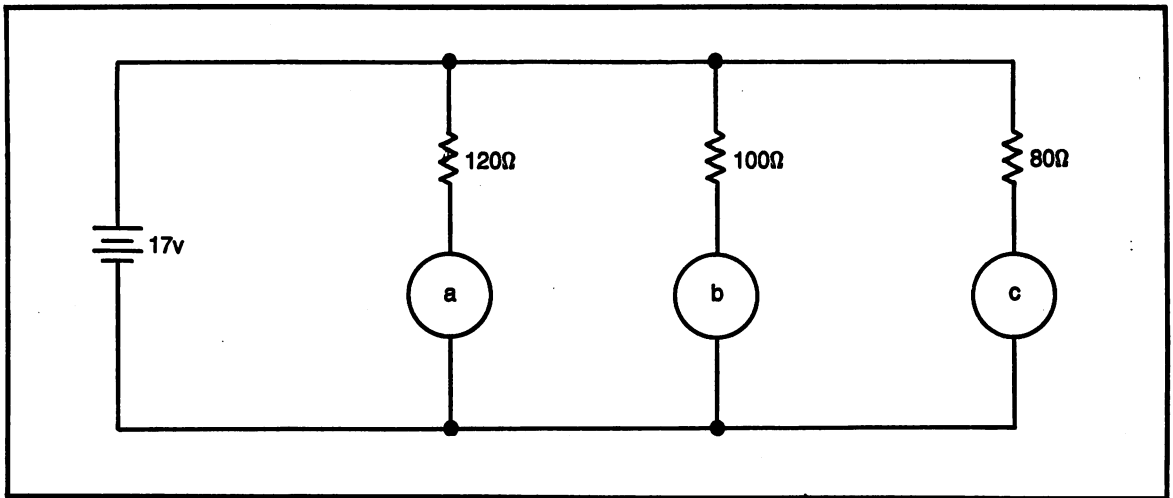


Fig. 9-53. Circuit for questions 16-20.

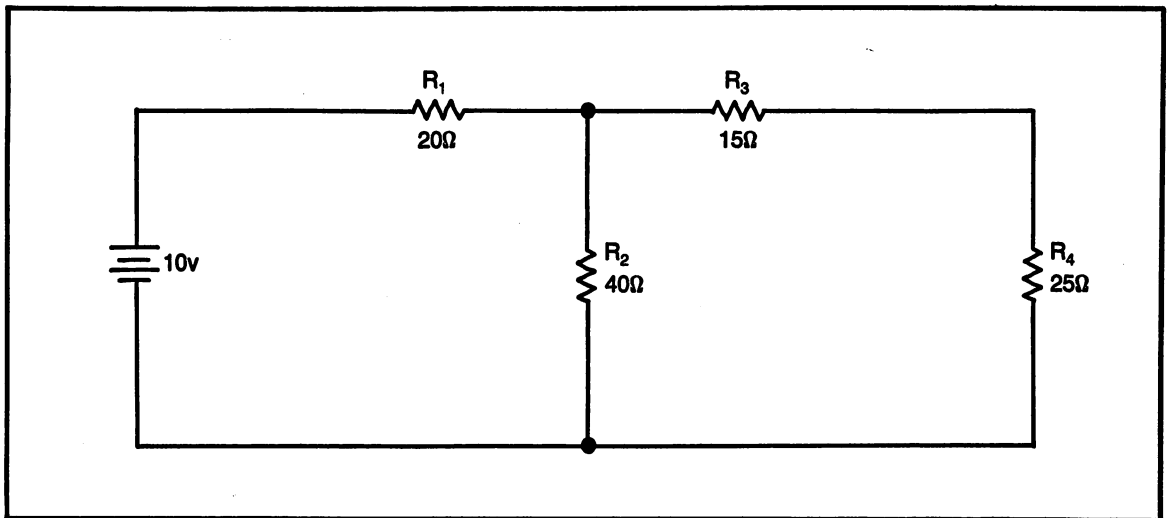


Fig. 9-54. Circuit for questions 21-25.

- (14) What does meter "b" read?
 (15) What does meter "c" read?

- (20) What does meter "c" read?

Questions 16 through 20 use the parallel circuit, Fig. 9-53.

Questions 21 through 25 use the combination circuit, Fig. 9-54.

- (16) Find total resistance
 (17) Find total current
 (18) What does meter "a" read?
 (19) What does meter "b" read?

- (21) Find total resistance
 (22) Find total current
 (23) Find the voltage drop across R_1
 (24) Find the voltage drop across R_2
 (25) Find the voltage drop across R_4

Exam #1. DC Building Blocks

- Safety
- Engineering Notation
- Resistor color code
- Schematic symbols
- Use of an ohmmeter
- Ohm's law
- Power formulas
- Use of a multimeter and an oscilloscope
- DC circuits

SAFETY

- (1) Shop safety is the responsibility of:
 - a. the teacher
 - b. the school principal
 - c. the student
 - d. all of the above
- (2) In order to determine if a soldering iron is hot enough to use for soldering:
 - a. sprinkle water on the tip
 - b. melt a piece of solder on the tip to see if it flows freely
 - c. touch tip with your fingers
- (3) In the event of an injury, you should:
 - a. allow another student to administer first aid
 - b. inform the instructor
 - c. disregard a small injury
- (4) If you witness a person being electrocuted, the best action is:
 - a. pull the person from the source of electricity
 - b. turn off the source of electricity before touching the person
 - c. call for the instructor
- (5) Severe electrical shock results from:
 - a. only large voltages
 - b. only large currents
 - c. small amounts of current passing through the body

ENGINEERING NOTATION

Convert the given numbers to the units shown.

- (6) 5,600,000 hertz _____ kHz
- (7) 15 amps _____ mA
- (8) 0.0035 volts _____ mV
- (9) 250 milliwatts _____ W
- (10) 25 microvolts _____ mV

RESISTOR COLOR CODE

Use the colors given to determine the resistance value.

- (11) brown - black - black
- (12) red - violet - brown
- (13) green - blue - red
- (14) yellow - violet - orange
- (15) blue - gray - yellow

SCHEMATIC SYMBOLS

Draw the following schematic symbols:

- (16) Dc power supply (show + and -)
- (17) Single pole, single throw switch in the closed position
- (18) fuse
- (19) potentiometer
- (20) fixed value resistor

USE OF AN OHMMETER

- (21) What will the ohmmeter reading be with a good fuse?
- (22) What will the ohmmeter reading be with an open wire?
- (23) Read the meter in Fig. Ex1-1, needle #23
- (24) Read the meter in Fig. Ex1-1, needle #24
- (25) Read the meter in Fig. Ex1-1, needle #25

OHM'S LAW

Use Ohm's law to find the unknown value. The proper unit **must** be included with each answer. If the answer is over 1000 or less than $\frac{1}{1000}$, answer **must** be written in the proper form of engineering notation.

- (26) $R = 100$ ohms $I = 0.2$ amps Find: V
- (27) $V = 100$ volts $R = 25$ ohms Find: I
- (28) $V = 60$ volts $I = 3$ amps Find: R

- (29) $I = 500$ mA $R = 250$ ohms Find: V
- (30) $R = 30$ ohms $V = 60$ mV Find: I

POWER FORMULAS

Use the power formulas to find the unknown value. The proper unit **must** be included with each answer. If the answer is over 1000 or under $\frac{1}{1000}$, answer **must** be written in the proper form of engineering notation.

- (31) $V = 100$ volts $I = 0.02$ amps Find: P
- (32) $I = 15$ amps $R = 2$ ohms Find: P
- (33) $I = 2$ amps $P = 5$ watts Find: V
- (34) $V = 15$ volts $P = 100$ mW Find: I
- (35) $P = 5$ watts $I = 2$ amps Find: R

USE OF A MULTIMETER AND AN OSCILLOSCOPE

- (36) Draw a schematic diagram of a voltmeter connected to measure voltage across a resistor.
- (37) Draw the schematic diagram of an ammeter connected to measure current flow in a circuit with one resistor.
- (38) Draw the schematic diagram of an oscilloscope connected to measure the voltage of a dc voltage source.
- (39) An oscilloscope is adjusted to measure dc voltages and the volts/division is set at 2 v/d. How many divisions will the trace "jump" for a voltage of 7 volts?

For questions 40 - 45, read the multimeter scales in the appropriate figures.

Figure Ex1-2

- (40) _____
- (41) _____
- (42) _____

Figure Ex1-3

- (43) _____
- (44) _____
- (45) _____

DC CIRCUITS

In the questions below, the term "parameters" refers to: resistance, current, voltage, power.

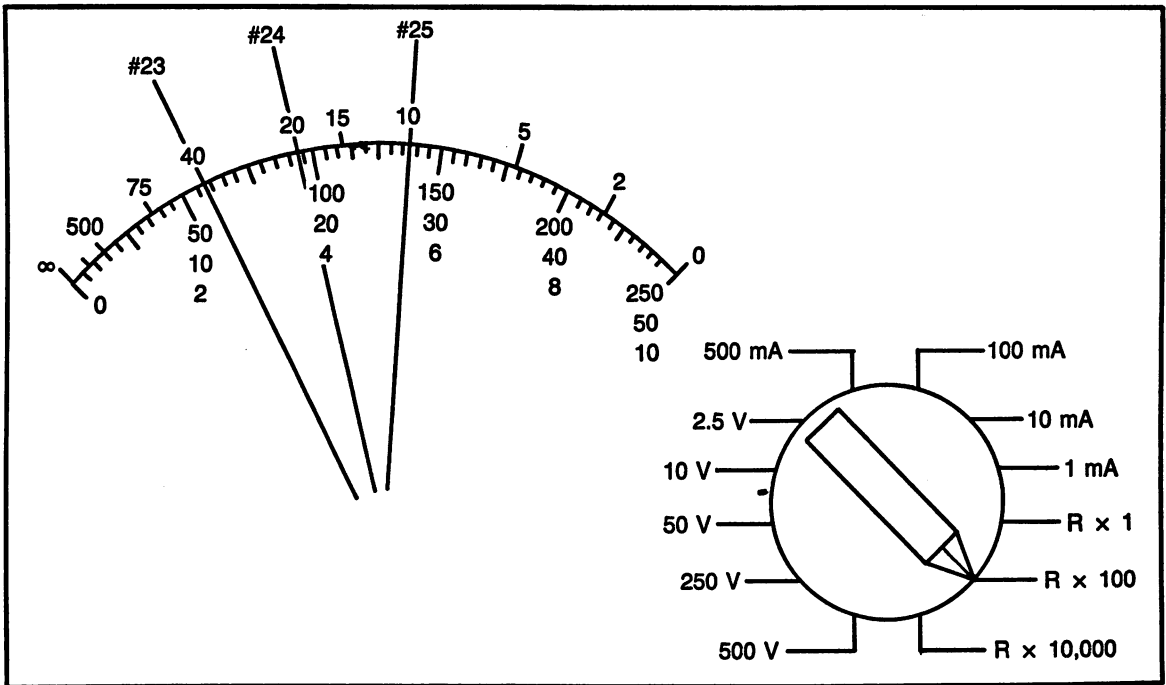


Fig. Ex1-1. Ohmmeter scale for questions 23-25.

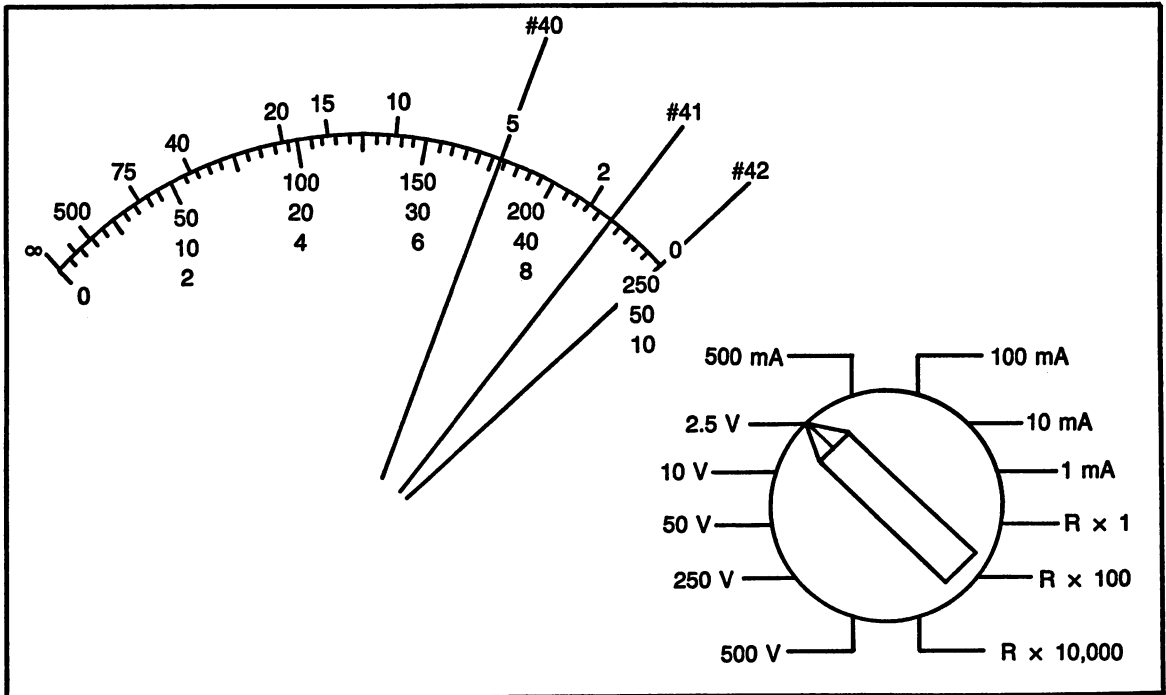


Fig. Ex1-2. Multimeter scale for questions 40-42.

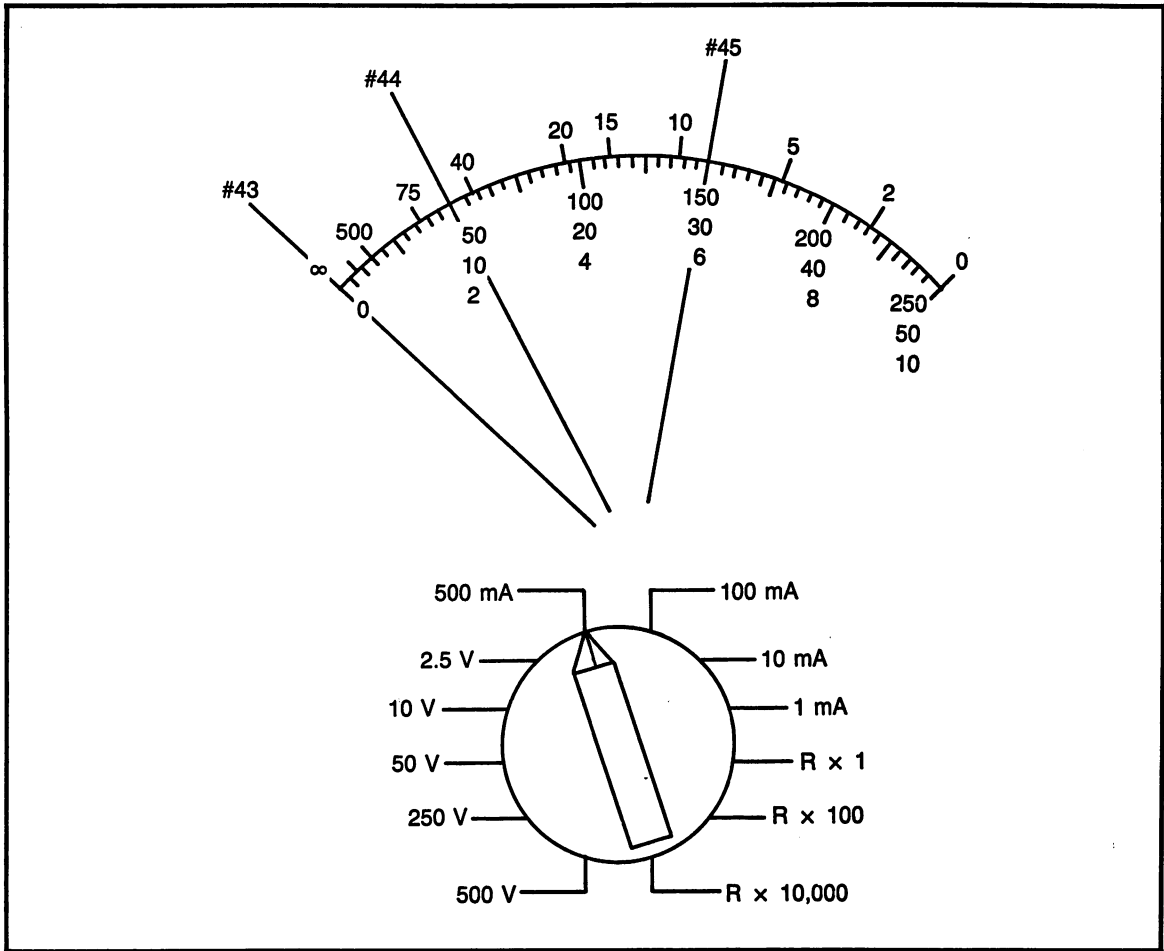


Fig. Ex1-3. Multimeter scale for questions 43-45.

- (46) Which parameter is the same at all points in a series circuit?
- (47) Which parameter is the same throughout a parallel circuit?
- (48) Use the circuit in Fig. Ex1-4 to find total resistance.
- (49) Use the circuit in Fig. Ex1-5 to find total current.
- (50) Use the circuit in Fig. Ex1-6 to find total resistance.

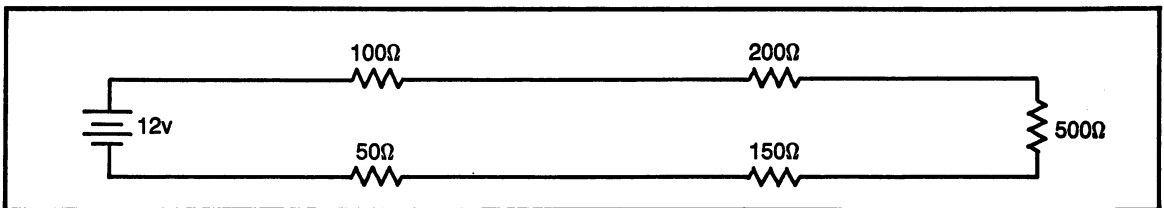


Fig. Ex1-4. Problem 48.

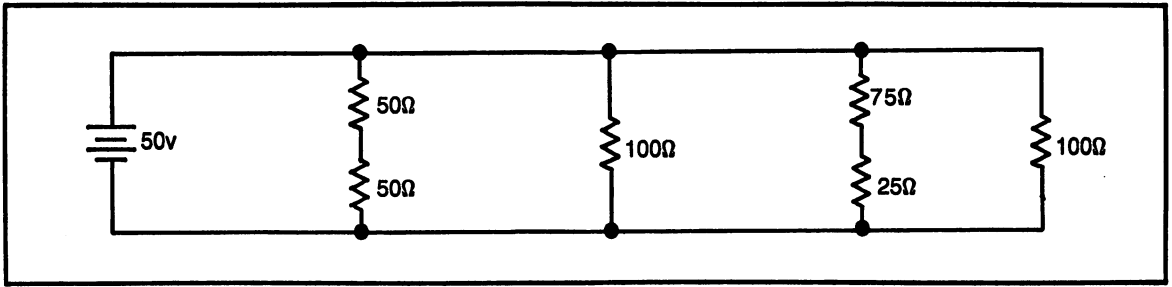


Fig. Ex1-5. Problem 49.

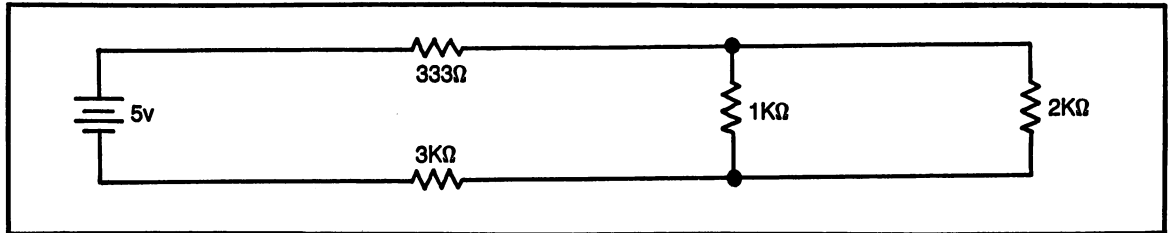


Fig. Ex1-6. Problem 50.

Chapter 10

Magnetism and Inductance

Chapter Objectives: to become familiar with the characteristics of magnetic fields and magnets. To learn how voltage is induced in a wire within a magnetic field and how electric current flow produces magnetism. To examine inductance, as a property, and as a circuit component.

Chapter Outline:

- Magnetism
- Inducing Voltage
- Electro-Magnets
- Applications of Electro-Magnets
- Properties of Inductance
- Inductors in Series
- Inductors in Parallel
- Programs for This Chapter
- Magnetism and Inductance Competency Test

INTRODUCTION

Magnetism is a subject that almost everyone is familiar with. Magnetism and magnetic fields have

a very important place in the field of electricity and electronics. When a wire is moved through a magnetic field, voltage will be induced in the wire. When electric current flows through a wire, a magnetic field is developed around the wire. An electro-magnet has a very wide range of applications, some of which will be examined in this chapter and others in later chapters.

MAGNETISM

Magnetism, as defined in general terms is; a force of attraction to itself.

Magnetic Fields

A magnetic field is an invisible force surrounding a magnet. The magnetic field is produced from the ends of the magnet, called poles. A magnet has a north and a south pole. Figure 10-1 shows how the magnetic field goes from the north to the south pole, with no lines of force in the center. If a small magnet, such as a compass, were placed within the

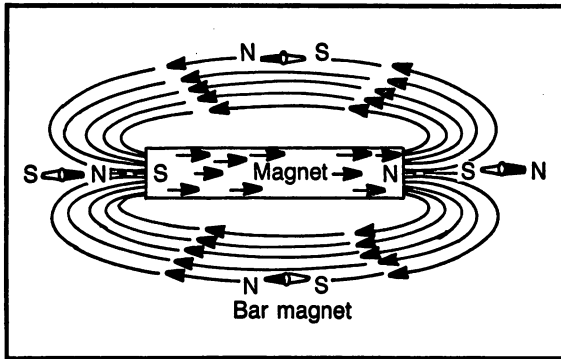


Fig. 10-1. Magnetic lines of force.

magnetic field, the lines of force would align it so the opposite poles would face each other.

Magnetic Terms and Definitions

The list of terms and definitions shown here is to familiarize the student with the terminology. In the study of electronics, a familiarization with the terminology of magnetism is satisfactory since an in-depth study isn't required.

Magnetic Field. the area around a magnet that has the effects of magnetism.

Magnetic Lines of Force. the force of the magnetic forms lines from the north to the south pole.

Flux. another term used to describe the magnetic lines of force. A stronger flux means a stronger magnetic field.

Retentivity. the ability of a material to retain magnetism.

Residual Magnetism. magnetism that remains in a material.

Temporary Magnet. a material with poor retentivity and low residual magnetism, an example is soft iron. This type of material loses its magnetic properties soon after the magnetizing force is removed. Used for electro-magnets.

Permanent Magnet. a material with good retentivity and high residual magnetism, examples are hard steel and alloys containing nickel. This type of material will hold its magnetic properties for long periods of time.

Permeability. the ease with which magnetic lines pass through a material. Materials with high

permeability are classified as magnetic materials. This is the type of material that will be attracted to a magnet.

Reluctance. the opposition to the passage of magnetic lines of force.

Magnetic Shield. stops the magnetic field from affecting an object by absorbing the magnetic field and allowing it to pass around the object being protected.

Law of Attraction. unlike magnetic poles are attracted to each other, see Fig. 10-2A.

Law of Repulsion. like magnetic poles repel, see Fig. 10-2B.

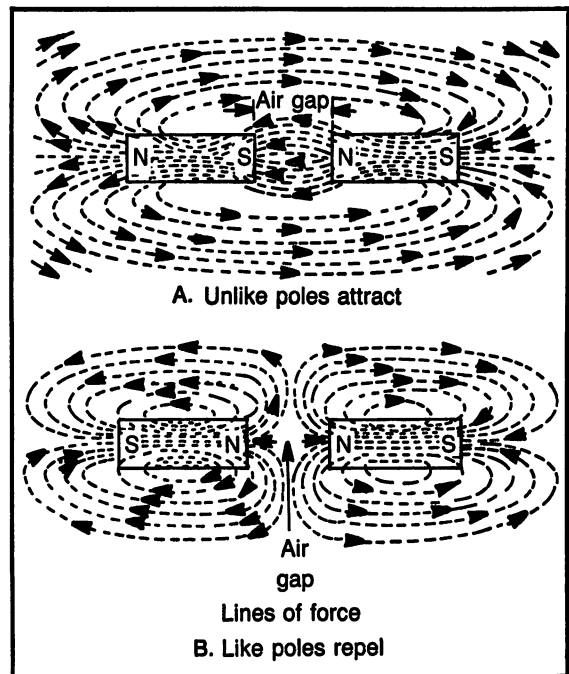


Fig. 10-2. Lines of force between unlike and like poles.

INDUCING VOLTAGE

The purposes of magnets in the field of electricity or electronics comes into two categories; using a magnet to produce voltage or using voltage to produce magnetism.

A Conductor in a Magnetic Field

When a conductor is moved through a magnetic field, electrons will move in the conductor and pro-

duce a voltage. The voltage is referred to as an induced voltage. The amount of induced voltage is determined by:

1. Speed of cutting the magnetic lines of force. Faster movement will increase the induced voltage.
2. Strength of the magnetic field. A stronger field will induce a stronger voltage.
3. Angle of cutting the magnetic lines. When the magnetic lines of force are cut by the conductor at right angles, maximum voltage will be induced in the conductor. When the conductor is moving in the same direction as the magnetic lines, no voltage will be induced.

This chapter will also discuss in further detail the effects of inducing voltage in a conductor, when it is passed through a magnetic field.

ELECTRO-MAGNETS

When electric current flows through a conductor, a magnetic field is developed around the conductor, and an electro-magnet is formed. The strength of the magnetic field depends on the amount of current flow and the concentration of the lines of

force. A coil of wire will concentrate the lines of force and produce a stronger magnet.

Magnetic Cores

An iron bar can be used as a magnetic core by wrapping the coil around it. The purpose of the core is to concentrate the lines of force and produce a stronger magnet than can be achieved with the coil with no core.

An example of a large electro-magnet is the magnets used in a commercial application (such as auto-parts salvage) where it is necessary to lift or move very heavy metallic objects.

Solenoids

A solenoid is an application of an electro-magnet where the core has a moveable portion, called a plunger, see Fig. 10-3A. When electrical current flows through the coil, it generates a magnetic field. The iron core acts as both a support frame and as a core to strengthen the magnetic field. The magnetic field will draw the plunger in to fill the hollow portion of the core. When the magnetic field is released, the return spring will pull the plunger back to its resting position.

Figure 10-3B shows the schematic diagram of a solenoid. The symbol represents a coil of wire.

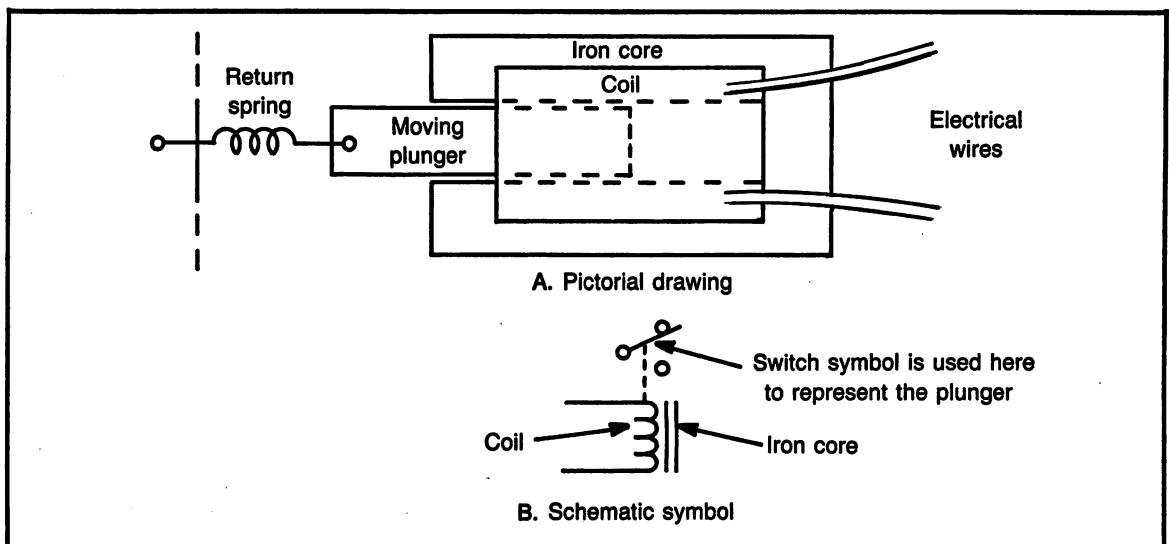


Fig. 10-3. Solenoid.

The two straight lines next to the coil represent an iron core. It is not always necessary for a solenoid to have an iron core. The dotted line indicates a magnetic connection to the plunger. In this particular drawing, a switch is used to show the plunger, for lack of a better symbol.

A solenoid is used to perform work by the fact that the plunger can move. For example, the plunger could be attached to a door latch. The solenoid would be used to electrically open the door latch. Another example is in a washing machine. Solenoids are used to turn the water on and off, change speeds of the motor and go from wash cycle to spin cycle.

To test a solenoid, usually checking the continuity of the coil is enough. An ohmmeter applied

to the coil wires should indicate low resistance if the coil is electrically good.

Relays

A relay is a form of solenoid. Instead of a plunger, an armature is used, which is a moveable plate that is attracted by the magnetic field. The spring returns the armature to its resting position. Refer to Fig. 10-4A. Also notice, attached to the moveable armature is a set of electrical switch contacts. These are also referred to as relay contacts. The switch contacts are separated from the metal plate with an insulator.

Figure 10-4B is a sample circuit to show a possible application for a relay. The relay coil is con-

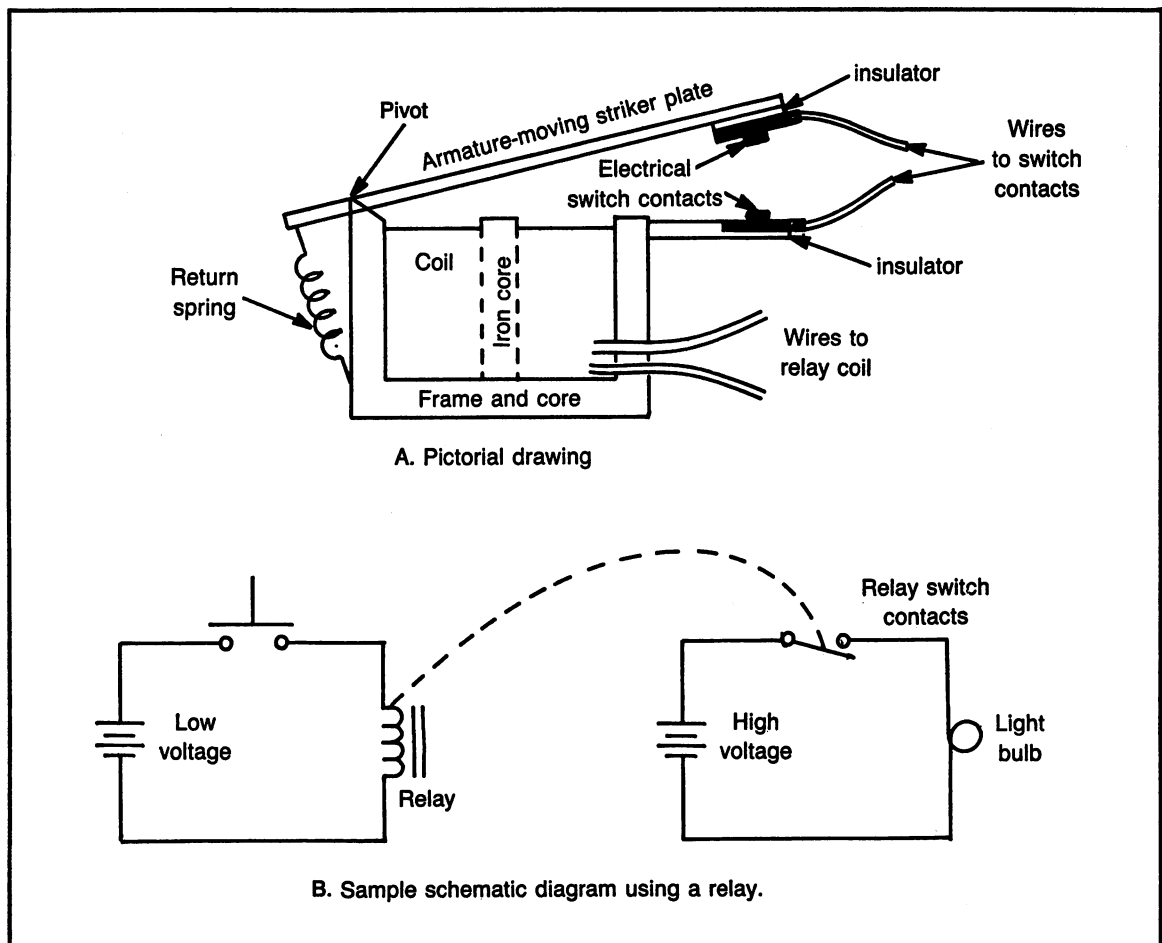


Fig. 10-4. Relay: A. Pictorial drawing.

nected to a voltage source, through a push button switch. When the switch is pressed, the relay will develop a magnetic field. The magnetic field will operate the switch contacts attached to the moveable armature.

Notice in particular, in Fig. 10-4B, the dotted line indicates that only the magnetic field is used to operate the second circuit. When the relay is energized, the relay switch contacts will close, which allows the high voltage battery to supply electricity to the light bulb.

Like toggle switches, a relay can have many different sets of switch contacts. Each set of contacts can be used to operate different circuits. Therefore, one relay can control many different circuits, with only the magnetic field common to the relay and the switch contacts.

PROPERTIES OF INDUCTANCE

Along with resistors, inductors and capacitors are the basic components of electricity and electronics. Inductors and capacitors have the unique capability of storing electrical energy. Also, both can be used with ac and dc.

Inductance is the principle by which a transformer works. Another example of an inductor is the ignition coil for an engine, which stores energy and uses it to fire the spark plug. Capacitors can be used for filter circuits in a power supply, also for timing circuits and energy stored can be used in the electronic flash unit on a camera.

Self-Induced Voltage and Back-EMF

Whenever electrical current is flowing in a piece of wire, there is a magnetic field developed around the wire. The strength of the magnetic field depends on the amount of current flowing. Inductance is the ability of a conductor to use the magnetic field to induce a voltage within itself.

It is important to note that even though there is a magnetic field developed whenever there is current flow, the only time there can be "self-induced" voltage is when there is a changing current. This changing current does not need to be ac. Dc can also have a changing current. This self-induced voltage

is known as "back EMF". The term EMF stands for "Electro-Motive-Force", which is a term used to describe voltage. The strength or amount of self-induced voltage, back EMF, is determined by the amount of current flow and the size of inductance.

The size of inductance is determined by several factors, the most important being; number of turns in the coil and the core material. An inductor can be thought of as an electro-magnet, and the factors that produce more magnetism will also produce more inductance.

An inductor, as a component, is a coil of wire that is essentially an electro-magnet. The main "property" of inductance is the back-EMF, which opposes any change in current flow.

Let's examine the effects of current flowing in a coil of wire:

1. When current first starts to flow, it will start developing the magnetic field.
2. The developing magnetic field causes a back-EMF, which opposes the changing current. This opposition to current flow is the property of inductance.
3. When the current reaches a point where it is no longer changing, the magnetic field will be steady, and there will no longer be any back-EMF. In other words, when current is not changing, there is no back-EMF and no opposition to the current flow.
4. When the current starts to decrease, the magnetic field will start to collapse, which will induce a back-EMF that will actually aid the current, therefore, opposing any further change in current.

Unit of Inductance

The unit of inductance is the Henry. An inductor can be rated from very small to very large. The unit Henry, symbol H, is the base unit for inductance. The symbol for an inductor, as a component, is L.

The size of inductors range from less than 1 mH (milli-Henry), for a tuning coil in a radio, to several Henrys for a strong solenoid. An electro-magnet, such as the one in a junk yard, might be several hundred Henrys.

Key Points of Inductance

A magnetic field is produced whenever current flows in a wire.

Self-induced voltage is produced in an inductor when there is changing current.

Back-EMF is another term for self-induced voltage.

Inductance is the characteristic that opposes any change in current.

Henry is the base unit for inductance, symbol for Henry is H and symbol for inductor is L.

INDUCTORS IN SERIES

Like resistors, inductors (and capacitors) can be connected in series or parallel. There are different reasons for doing this, such as, two solenoids connected together, two electro-magnets connected, etc. Another reason might be to simply use two, or more component values to form a new value.

Mutual Inductance

Mutual inductance is a term used to describe two coils that are physically close enough together for their magnetic fields to interact.

In the case of a transformer, it is desired to have a maximum amount of mutual inductance. In fact, the ideal situation is mutual coupling of 1:1, which means every magnetic line of force from one coil interacts with the other coil.

Two completely separate inductors could have their coils close enough together so some of the magnetic lines of force interact. The interaction between coils could result in an aiding condition or an opposing condition.

Normally, mutual inductance is considered only when the inductors are connected in series. It is possible with the inductors in parallel but the calculations would be very difficult. Since mutual inductance is only considered in series and since it can be aiding or opposing, there are four formulas possible for calculating series inductance.

Formula #16. Series Inductors, No Mutual Inductance

$$L_T = L_1 + L_2 + L_3 + \dots$$

Total inductance equals the sum of the individual inductors in series. The same type of formula is used for series resistors.

Formula #17. Series Inductors, Aiding Mutual Inductance

$$L_T = L_1 + L_2 + 2L_M$$

Total inductance equals the sum of the inductors plus 2 times the amount of mutual inductance.

Formula #18. Series Inductors, Opposing Mutual Inductance

$$L_T = L_1 + L_2 - 2L_M$$

Total inductance equals the sum of the inductors minus 2 times the amount of mutual inductance.

Formula #19. Series Inductors, with Aiding or Opposing Mutual Inductance

$$L_T = L_1 + L_2 + / - 2L_M$$

Total inductance equals the sum of the inductors plus (for aiding) or minus (for opposing) 2 times mutual inductance.

Schematic Diagrams

Figure 10-5 shows the three possible conditions for two inductors in series.

Figure 10-5A shows the schematic diagram for two inductors in series, with no mutual inductance. Notice the schematic symbol for an inductor represents a coil.

Figure 10-5B shows the schematic diagram of two inductors in series, with their "phasing dots" in the same direction. The phasing dots are schematic symbols that are added to the inductor symbol to show the direction of the turns, or magnetic field. When the phasing dots are drawn in the same direction, they represent an aiding mutual inductance.

Figure 10-5C shows the schematic diagram for two inductors in series, with their phasing dots in opposite directions. This represents opposing mutual inductance.

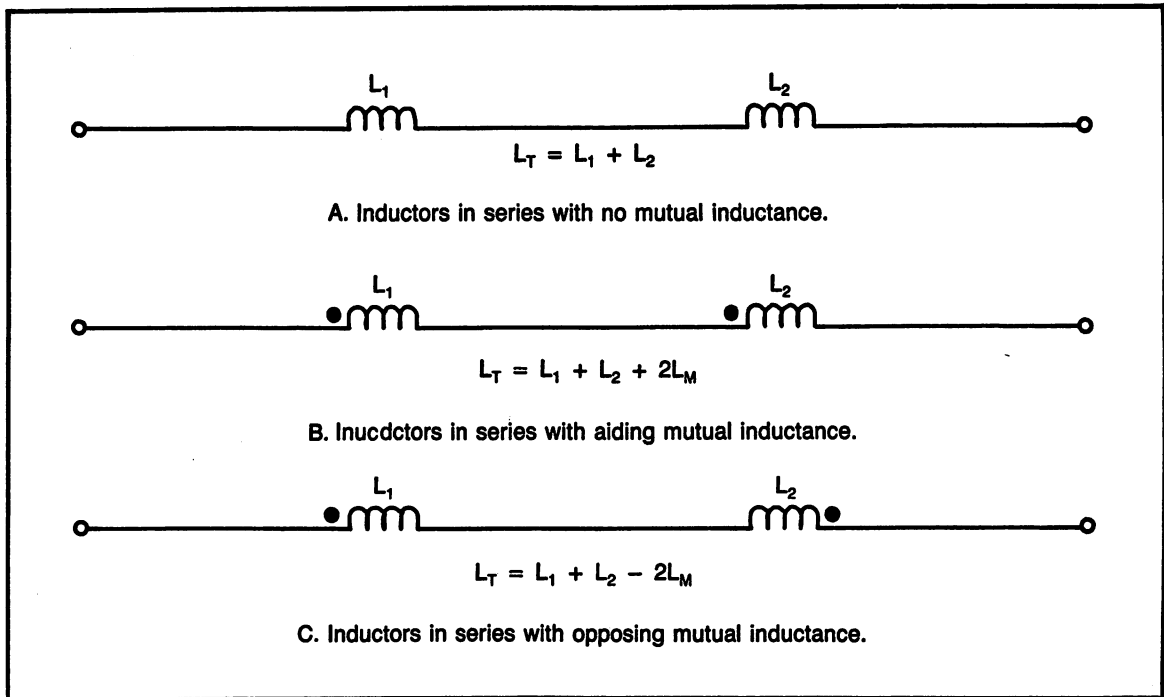


Fig. 10-5. Series inductors showing the possible combinations of mutual inductance.

Key Points of Mutual Inductance

Mutual inductance is the result of the magnetic fields of inductors interacting.

Phasing dots show the polarity of magnetic fields.

Sample Problems: Inductors in Series

SP#10-1 Determine the equivalent inductance of three inductors connected in series, no mutual inductance and their values are; 25 mH, 50 mH, 75 mH.

Formula: $L_T = L_1 + L_2 + L_3$

Substituting: $L_T = 25 \text{ mH} + 50 \text{ mH} + 75 \text{ mH}$

Solving: $L_T = 150 \text{ mH}$

SP#10-2 Two 100 mH coils are connected in series. What is the total inductance with 10 mH aiding mutual inductance.

Formula: $L_T = L_1 + L_2 + 2 L_M$

Substituting: $L_T = 100 \text{ mH} + 100 \text{ mH} + (2 \times 10 \text{ mH})$

Solving: $L_T = 220 \text{ mH}$

SP#10-3 A 5 H inductor is connected in series with a 4 H inductor, with 0.5 H opposing mutual induc-

tance. What is the effective inductance?

Formula: $L_T = L_1 + L_2 - 2 L_M$

Substituting: $L_T = 5 \text{ H} + 4 \text{ H} - (2 \times .5 \text{ H})$

Solving: $L_T = 8 \text{ H}$

INDUCTORS IN PARALLEL

Inductors are connected in parallel for different reasons, such as; the value of circuit inductance needed is not available, but by connecting them in parallel, the value can be achieved. This is similar to connecting resistors in parallel when a different value is needed. Another example of inductors in parallel is when several electric motors are connected across the same power line.

It can be seen then, that there are times when it is desirable to have inductors connected in parallel and it might be required to know the value of total circuit inductance.

Reciprocal Formula

To calculate the total inductance of inductors connected in parallel, use the reciprocal formula.

This is essentially the same formula used to calculate resistors in parallel. Any of the "short-cut" formulas used with resistance can be used for calculating inductance in parallel.

Formula #20. Inductors in Parallel, Reciprocal Formula

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \dots$$

Mutual Inductance in Parallel

Mutual inductance occurs anytime the magnetic field from one inductor interacts with the magnetic field of another inductor.

Even though mutual inductance is quite possible in parallel circuits, the necessary mathematics to calculate it would be extremely difficult due to the reciprocal formula. Because of this, mutual inductance in parallel is not used.

Sample Problem: Inductors in Parallel

SP#10-4 Two 250 mH inductors are connected in parallel. Determine the total circuit inductance.

Formula: $\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2}$

Substituting: $\frac{1}{L_T} = \frac{1}{250 \text{ mH}} + \frac{1}{250 \text{ mH}}$

Solving: $L_T = 125 \text{ mH}$

PROGRAMS FOR THIS CHAPTER

This chapter has one multiple-choice quiz. This is an excellent method of reviewing the theory associated with magnetism and inductance.

Figure 10-11 shows a sample of the program. There are no help hints with this program because there is no mathematics.

Practice Problems: Inductance

Determine the total inductance of each of the following combinations. Assume no mutual inductance when no value is given.

- (1) Series circuit; 500 μH , 700 μH
- (2) Series circuit; 10 mH, 50 mH, 30 mH
- (3) Series circuit; 100 mH, 0.2 H, 0.15 H, $L_M = 10 \text{ mH}$ aiding
- (4) Series circuit; 1 H, 1.5 H, 1200 mH, $L_M = 25 \text{ mH}$ opposing
- (5) Parallel circuit; 100 mH, 200 mH
- (6) Figure 10-6
- (7) Figure 10-7
- (8) Figure 10-8
- (9) Figure 10-9
- (10) Figure 10-10

MAGNETISM AND INDUCTANCE COMPETENCY TEST

Part A. Definitions

Questions 1-20, define the following terms.

- (1) magnetic lines of force
- (2) magnetic field

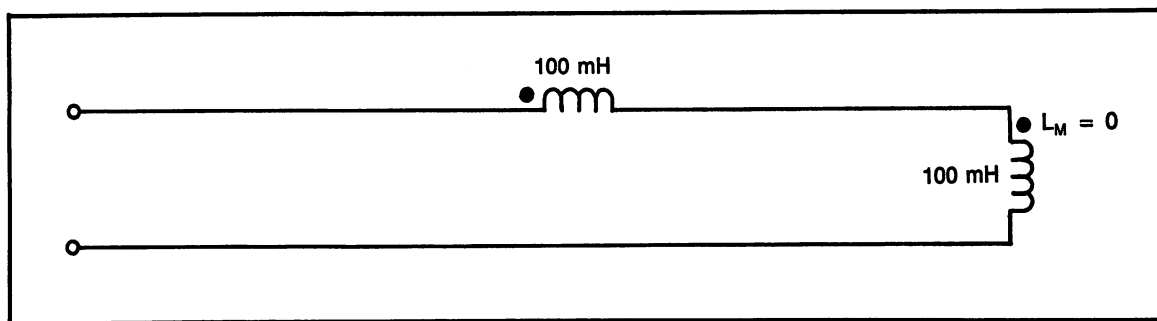


Fig. 10-6. Problem 6.

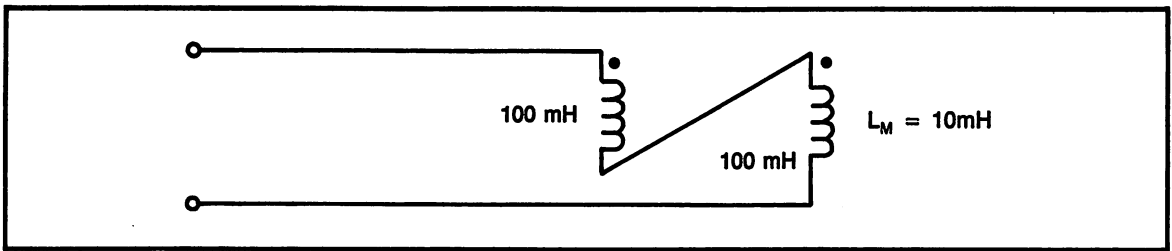


Fig. 10-7. Problem 7.

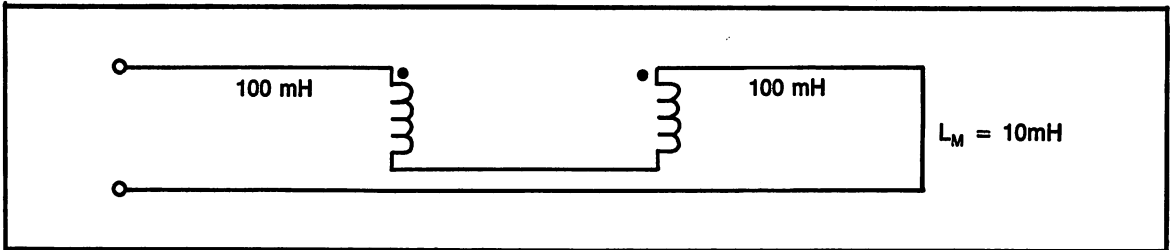


Fig. 10-8. Problem 8.

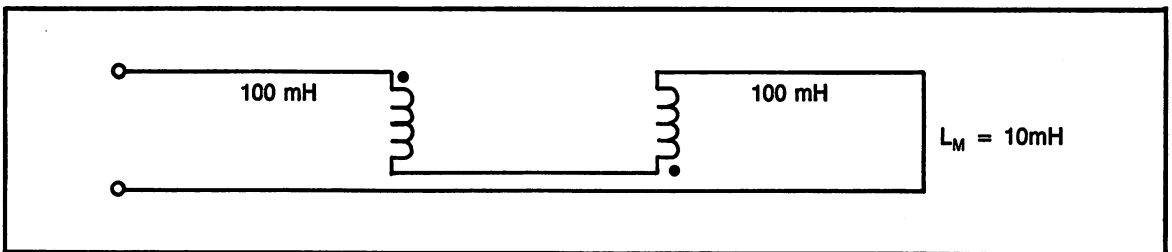


Fig. 10-9. Problem 9.

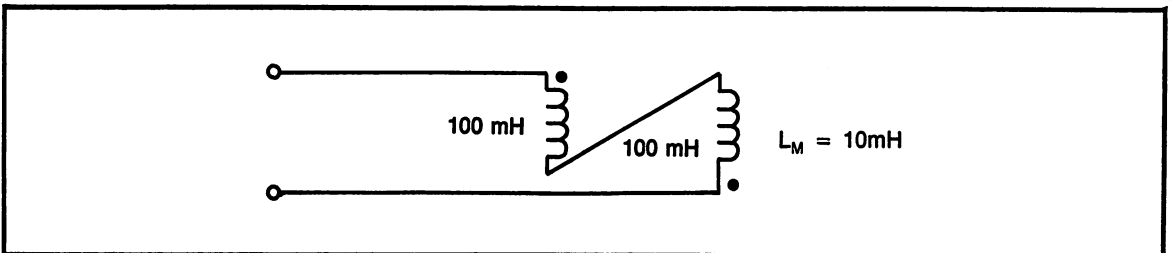


Fig. 10-10. Problem 10.

- | | |
|---------------------------------------|--------------------------------------|
| (3) residual magnetism | (11) self-induced voltage |
| (4) temporary magnet | (12) back EMF |
| (5) permanent magnet | (13) opposes a change in current |
| (6) reluctance | (14) basic unit for inductance |
| (7) electro-magnet | (15) inductance |
| (8) magnetic core (state its purpose) | (16) mutual inductance |
| (9) solenoid | (17) phasing dots |
| (10) relay | (18) formula for inductors in series |

MAGNETISM
PROGRAM SAMPLE :

CHOOSE THE MOST CORRECT ANSWER.

- A) REPEL
- B) ATTRACT
- C) MELT
- D) DESTROY THE MAGNETS

1 . MAGNETS DO THIS WHEN LIKE POLES ARE
PLACED CLOSE TOGETHER.

THE LETTER OF YOUR CHOICE IS ?A

XXXXXXXXXX

XXXXXXXXXX FOR NEXT
XXXX FOR NEW SELECTION

Fig. 10-11. Magnetism program sample.

- (19) formula for inductors in parallel
- (20) Henry

Part B. Calculations

- (21) Determine the total inductance of two inductors (50 mH and 80,000 μ H) connected in series, with no mutual inductance.
- (22) Determine the total inductance of two inductors (.350 H and 250 mH) connected in series with 100 mH aiding mutual inductance.
- (23) Determine the total inductance of two inductors (10 H and 5 H) connected in series with 2 H opposing mutual inductance.
- (24) Determine the total inductance of two inductors (75 mH and 100 mH) connected in parallel.
- (25) Determine the total inductance of three inductors (each 150 mH) connected in parallel.

Chapter 11

Sine Wave Analysis

Chapter Objectives:

To learn how a sine wave is produced and plot its waveform. Also, to learn to calculate, measure and analyze the parameters of sine waves and other waveforms. This chapter included hands-on practice with an oscilloscope and ac voltmeter.

Chapter Outline:

- Alternating current (ac)
- AC Line Voltage
- Producing a Sine Wave
- Plotting a Sine Wave
- Units of Amplitude
- Units of Time
- Using an Oscilloscope to Measure a Sine Wave
- Hands-On Practice with Sine Waves
- Programs for This Chapter
- Sine Wave Analysis Competency Test

INTRODUCTION

The sine wave is a naturally occurring waveform that can be found in many aspects of science. The

sine wave is the type of electricity that is produced by the electric companies and becomes a very important subject in the study of electricity and electronics, it is also referred to as ac.

ALTERNATING CURRENT (AC)

Alternating current, abbreviated ac, is electricity that periodically changes direction. Although it uses the term “current”, it also refers to voltage and power. Ac produces a waveform that has a definite pattern that repeats itself periodically. The sine wave is an example of ac. An example of a similar concept is the waves in an ocean. The waves in an ocean go from high to low, back to high and the pattern is repeated.

DC Compared to AC

Previous chapters of this book have dealt with dc, direct current. The formulas and circuit theory are almost identical for both dc and ac. The major difference is the fact that dc has a voltage that is

fairly constant at all times (although there are certain exceptions) and ac has the voltage constantly changing.

Dc is necessary to operate almost all electronic circuitry, such as radios, TV's, computers, etc. In cases where an electronic device is plugged into the wall socket, which supplies ac, the electronic circuitry will convert the ac to dc.

Dc is not practical for long distances on wire because it produces a large voltage drop on the wire. Ac is much better for travel over long wires because it does not cause an excessive voltage drop.

Dc is the type of voltage stored in batteries. When it is used to power a motor, the speed of the motor will be determined by the amount of voltage applied. Therefore, dc is used quite extensively with motor speed controls.

Ac is the electricity supplied from the household wall socket. It is easy for the power companies to produce and distribute. Many types of motors operated in a house are operated directly from the ac line. For example, a refrigerator, furnace, electric clock, fan, air conditioner, etc. All of these motors are called "synchronous" because the speed of the motor is determined by the frequency of the ac supply voltage. Under normal conditions, the speed of the motor cannot be changed.

Ac cannot be stored for future use, dc can be stored in a battery, although ac is easy to produce for use at that moment.

Waveforms

Figure 11-1 shows four different types of waveforms. Figure 11-1A shows a dc voltage waveform. There are two dc voltages shown in the same drawing, positive and negative.

Figure 11-1B is a sine wave. This is the most commonly found waveform. Figure 11-1C is a sawtooth and 11-1D is a square wave. These are also a form of alternating current, ac.

AC LINE VOLTAGE

The electricity available from the wall socket is referred to in this book as the ac line voltage. It can also be called household electricity, for lack of a bet-

ter term. Regardless of what it is called, a student of electronics must become familiar with the characteristics of the electricity in use.

Nominal Voltage

The nominal voltage of household electricity is 120 volts at 60 cycles per second. Each of these terms will be explained as the chapter is further developed.

The actual voltage can range from about 110 volts to about 120 volts. The exact value of voltage is of little concern, normally, because most equipment that an electronics technician will deal with changes the ac line voltage to dc.

The 60 cycles per second frequency is exact and the power companies constantly monitor it to ensure it remains exact.

3 Wire System

The ac line voltage is supplied with a 3 wire system. The wires are: hot, neutral and ground. Refer to Fig. 11-2.

The ground wire in a standard system is a green wire and is the semi-round hole/prong. This wire is not intended to be a current carrying wire. Instead, it is used to provide protection in the event that the hot wire was to become disconnected or faulty in some way. It is becoming increasingly more popular to have a "ground fault indicator" (GFI) connected to certain types of circuits. These sense extremely small amounts of current in the ground wire and disconnect the circuit. In this manner, electric shock is avoided.

The neutral wire is white and is the larger flat blade/hole. The neutral wire is intended to be a current carrying wire, however, by itself it has no voltage potential. In many cases, it is actually connected to ground. Its function is to be the "return" wire to the voltage supply. In a household fuse panel, all of the white wires in the house are connected to a center "buss-bar", which is then connected to the in-coming supply wires. The white wire should not be used for switching. In other words, it should not be the one connected to turn on/off an electric circuit. The electricity in the circuit will stop flowing,

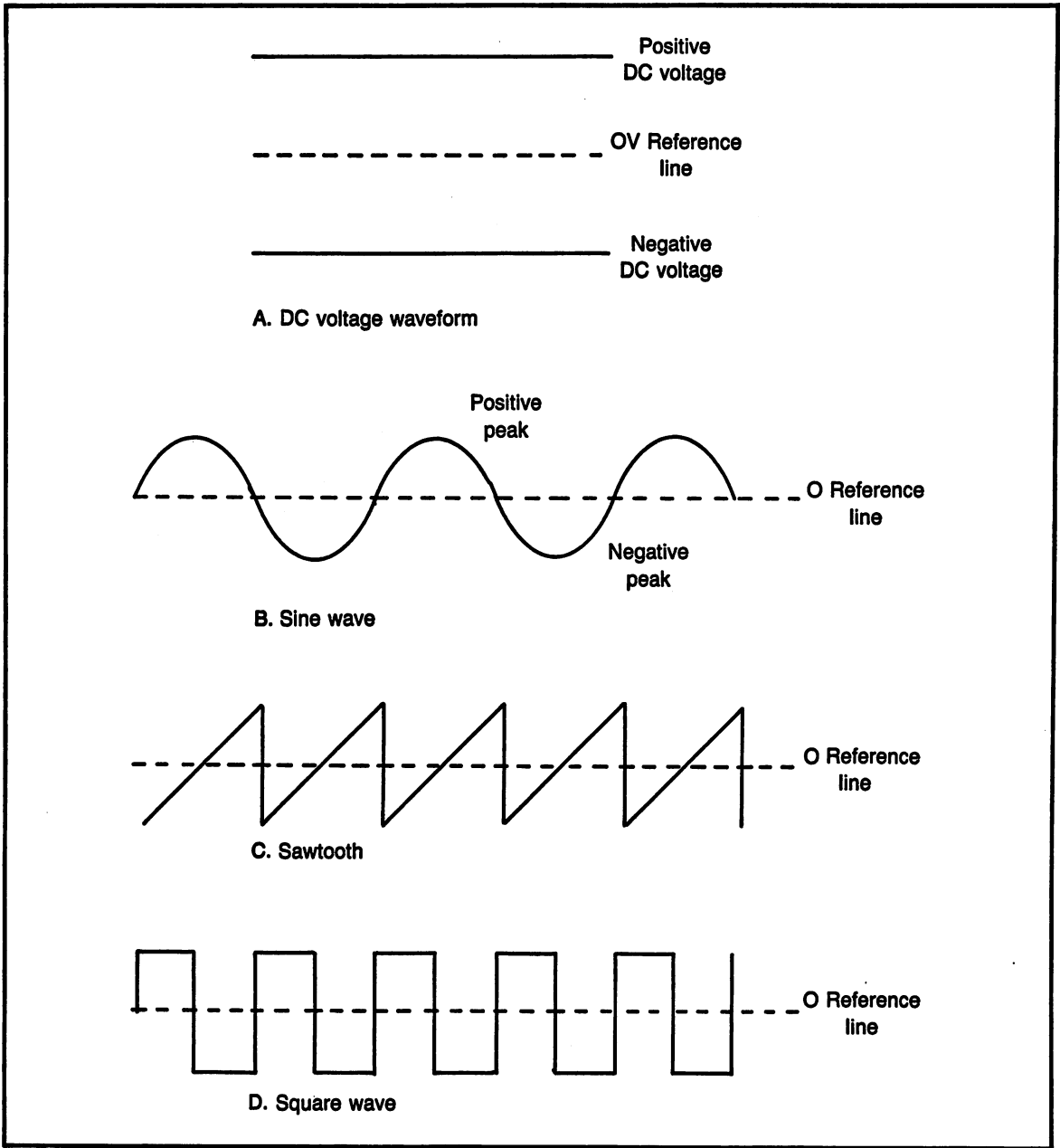


Fig. 11-1. Various waveform displays.

and the light will go out, but there will still be voltage available. In this case, the circuit is still considered "live" and can cause a shock. With proper electrical connections, the white wire itself cannot cause shock.

The hot wire is the smaller flat blade/hole and is the black wire. This is the wire that supplies voltage to the circuit, It is the hot wire that should be used to switch the circuit on/off. At the fuse panel, the black wires individually go to separate

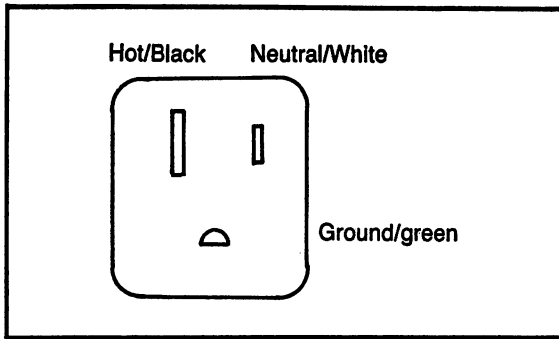


Fig. 11-2. Pictorial drawing of a wall socket.

fuses/circuit breakers. Each fuse is a separate circuit rated to carry a certain amount of current. If a person touches the black wire and is in any way grounded (by touching something metal, bare feet, wet surfaces, etc.) there will be potential for an electric shock. If the hot wire becomes loose in an electric appliance and touches the side of the box, the appliance could become a shock hazard. The green ground wire is usually attached to the box to prevent this.

If an appliance or electric device is wired for three wire operation, the green, ground wire, will be attached to the outside case. Often the neutral wire is also attached to the outside metal case. A very dangerous thing that some people will do is interrupt the three wire system. Sometimes the round ground prong is cut off because the outlet to be used has only two holes. Sometimes an extension cord with only two wires is used. Whatever the fault, if the third wire is not connected, the device will still operate, but it is possible (50% chance) to reverse the two wires. In other words, the hot wire may be connected to the outside metal case and the neutral wire may be connected to the machine. The machine will still operate, but there will be an extreme danger of electric shock. Therefore, it is very important to be sure that the three wire system in use remains as intended.

PRODUCING A SINE WAVE

A sine wave can be produced by different methods. This chapter will discuss the method of generating a sine wave through the use of a gener-

ator. Examining how the generator produces a sine wave will tie together the concepts of magnetic fields and inducing a voltage and how and why the sine wave is shaped the way it is.

The Sine Wave Generator

A sine wave generator is made with magnetic poles, producing a magnetic field and wire rotating through the magnetic field to induce voltage in the wire.

As a wire is moved through a magnetic field, voltage will be induced. The strongest voltage will be induced when the wire is moving perpendicular (at right angles) to the magnetic lines of force. This will occur when the wire moves past the pole of the magnet.

Zero voltage will occur when the wire is moving in the same direction as the lines of force. This will occur when the wire is between the magnetic north and south poles.

A reference of positive and negative voltage is established when the wire is first started to rotate. If north is said to produce a positive voltage, then south must produce a negative voltage. When the wire passes a north pole, a positive voltage will be induced in the wire and when it passes a south pole, a negative voltage is induced.

Rotating a Wire in the Generator

Figure 11-3 shows a loop of wire rotating in the magnetic field of a two pole generator. Note: actual generators have many more than one pole and many turns of wire, but the principle is the same.

The loop of wire in this drawing will make a complete revolution of 360 degrees, with check points every 90 degrees.

Point "a" is the start of the rotation. This point marks 0 degrees. At this point, the wire is exactly in line with the magnetic lines of force, therefore, no voltage is induced in the wire. The graph shows a point of zero volts, marked at 0 degrees.

Point "b" shows the wire has moved counterclockwise to a position directly perpendicular to the magnetic lines of force. The wire is marked with a + at north and a - at south to indicate the polarity

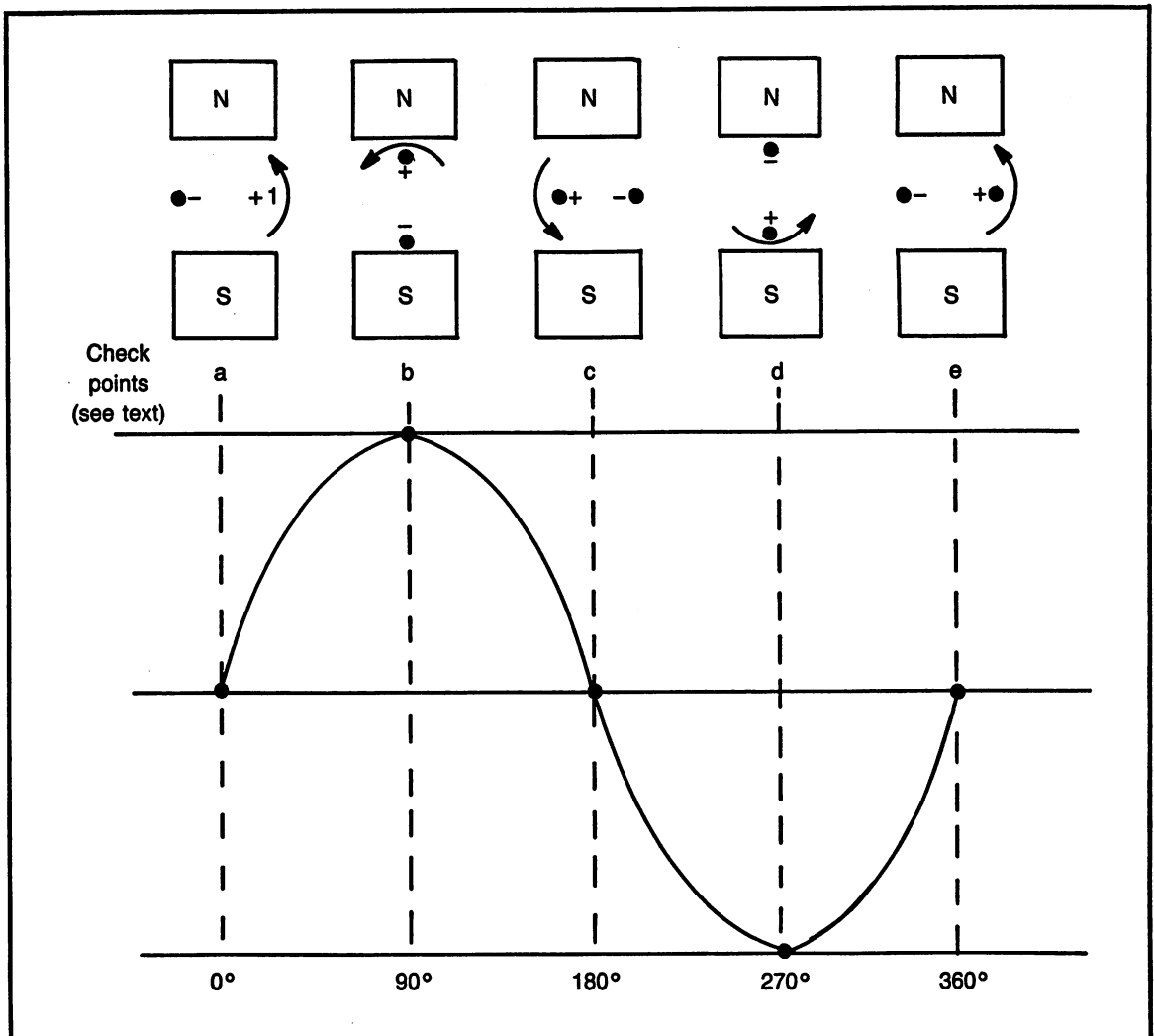


Fig. 11-3. One cycle of a sine wave produced by rotating loop of wire in a two pole generator.

of the voltage. Notice, on the graph, the voltage increased from the zero position, in a positive direction to maximum voltage at point "b". This point occurs at 90 degrees and is $\frac{1}{4}$ of the way through the cycle.

Point "c" marks the wire at a point where it is again exactly in line with the lines of force. Again, the induced voltage is zero. Notice the curve as it drops from maximum to zero. This zero point occurs at 180 degrees, $\frac{1}{2}$ way through the complete cycle. As the wire leaves the 180 degree point, it is traveling towards the south pole.

Point "d" shows the wire exactly perpendicular to the lines of force and directly in line with the south pole. Notice the polarity markings on the wire. The + is now at the south and the - is at the north. This is a condition that is opposite from point "b". The voltage in this direction produces a negative polarity. The graph shows a maximum voltage developed at point "d", but it is in the negative direction. This maximum negative voltage occurs at a point 270 degrees of rotation, $\frac{3}{4}$ of a complete cycle.

Point "e" is where the wire returns to the starting position and the cycle repeats itself.

How often the cycles repeats itself depends on two factors: the number of poles in the generator and the speed of rotation. The actual voltage developed depends on two factors: the strength of the magnetic fields and the speed of rotation. It is not necessary for an electronics student to be concerned about the operation of a generator other than the basic principles of operation.

PLOTTING A SINE WAVE

Plotting the shape of the sine wave can be performed with a mathematical formula. In this way, it is possible to determine the voltage at any instant in time, based on the electrical degrees of the cycle.

Note: electrical degrees means how many degrees of a cycle. Mechanical degrees means how many degrees of rotation. When dealing with electricity, the number of degrees will be the electrical degrees.

Instantaneous Voltage

There are several points along the sine wave that have significant value. Instantaneous voltages are found at any instant along the sine wave, based on the number of degrees.

Formula #21.

Instantaneous Voltage of a Sine Wave

$$v = V_{\max} \times \text{sine } \theta$$

v (lower case v) is the instantaneous voltage, or the voltage at an instant.

V_{\max} (upper case V) is the maximum voltage the sine wave reaches.

Sine θ (or $\sin \theta$) is the trigonometric function, which can be calculated on a calculator. It is multiplied times the maximum voltage. θ is the Greek letter theta and it represents the number of degrees of the cycle.

Calculating and Plotting One Cycle

Formula #21, the instantaneous voltage formula will be used to plot one cycle of a sine wave. The calculations are performed on an electronic calculator for every 15 degrees. This will provide points for the graph to plot a fairly nice curve.

Table 11-1. Voltage Formula.

| Degrees | Voltage | Degrees | Voltage |
|---------|---------|---------|---------|
| 0 | 0 | 180 | 0 |
| 15 | 25.9 | 195 | -25.9 |
| 30 | 50.0 | 210 | -50.0 |
| 45 | 70.7 | 225 | -70.7 |
| 60 | 86.6 | 240 | -86.6 |
| 75 | 96.6 | 255 | -96.6 |
| 90 | 100 | 270 | -100 |
| 105 | 96.6 | 285 | -96.6 |
| 120 | 86.6 | 300 | -86.6 |
| 135 | 70.7 | 315 | -70.7 |
| 150 | 50.0 | 330 | -50.0 |
| 165 | 25.9 | 345 | -25.9 |
| 180 | 0 | 360 | 0 |

For this sample, the sine wave has a maximum voltage of 100. This value is selected to simplify the calculations. Any value of maximum voltage can be used.

Results of the calculations are shown in Table 11-1. One sample calculation is shown below for 45 degrees. The graph of these sample calculations is shown in Fig. 11-4.

Formula: $v = V_{\max} \times \text{sine } \theta$

Substituting: $v = 100 \text{ volts} \times \text{sine } 45^\circ$

Fine the sine of 45 degrees on the calculator.

Sine $45^\circ = .707$

Substituting: $v = 100 \text{ volts} \times .707$

Solving: $v = 70.7 \text{ volts}$

Note: this sample calculation is the point on a sine wave called the rms value, to be discussed later.

UNITS OF AMPLITUDE

Amplitude is a term used to describe a waveform in terms of its height. It must be clearly understood that a particular waveform can be either voltage or current, although voltage is the most common form of waveforms. Therefore, to simplify the discussion, when dealing with amplitude, it will be described as voltage.

Amplitude is a term used to describe the quantity, or amount, of voltage. Keep in mind how the oscilloscope is used to measure dc voltages, although dc voltages are a straight line, the line "jumps" to

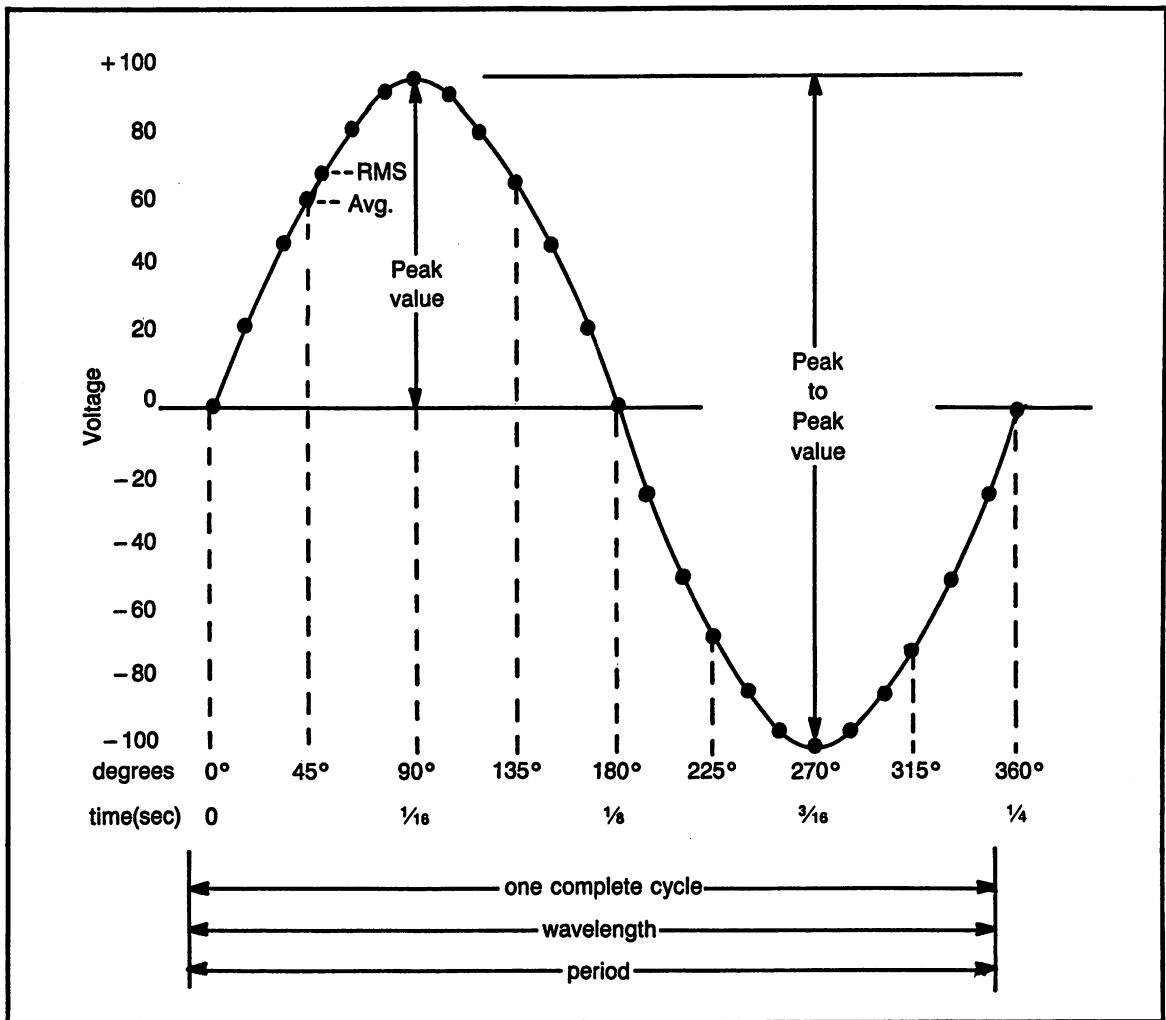


Fig. 11-4. Plotting one cycle of a sine wave using the formula: $v = V_{\max} \times \sin \theta$.

a certain amplitude. Therefore, the oscilloscope measurement of dc voltage is a measure of the height, or amplitude of the wave (straight line) above a reference line.

The amplitude of a sine wave can be described by any of four terms; average, RMS, peak, peak to peak. These four terms can be interchanged mathematically. Refer to Fig. 11-4 and Table 11-1 to examine the four values of amplitude.

Peak

The peak value is the maximum height of the waveform. This measurement is made in reference

to the center/zero reference line. The peak value can be measured as either positive or negative.

Although it is possible to have waveforms that have the positive peak a different value from the negative peak, that is not the case with a sine wave. A sine wave is a symmetrical waveform, with the positive peak equal to the negative peak.

The sine wave in Fig. 11-4 has a peak value of 100 volts. Figure 11-5 shows five different sine waves. Each sine wave in this figure has a peak amplitude of 6 volts.

The basic formulas to convert from one value to the next are based on the peak value.

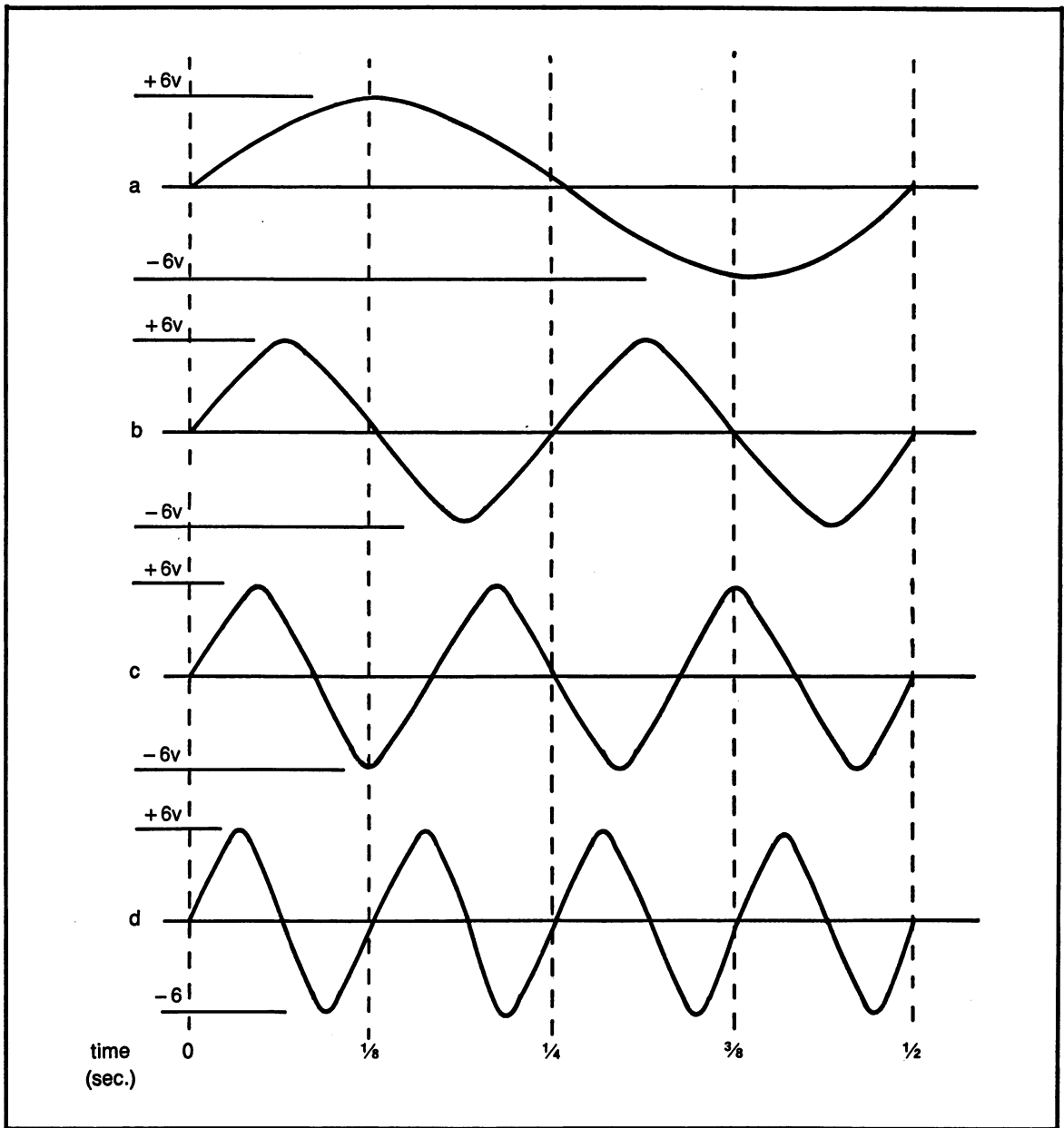


Fig. 11-5. Four sine waves with different frequencies, all having the same amplitude.

Peak to Peak

The peak to peak value is a measurement from one peak to the other.

Quite often this is the easiest measurement to make on the oscilloscope because it is sometimes hard to determine the exact center to make a peak

measurement. It is always relatively easy to simply count the divisions from one peak to the other.

Because a sine wave is symmetrical, the peak to peak value is always twice the peak value. Figure 11-4 is 200 volts peak to peak and Fig. 11-5 is 12 volts peak to peak.

Formula #22. Peak to Peak from Peak.

$$\text{peak to peak} = 2 \times \text{peak}$$

RMS

Rms is a significant value because that is what an ac voltmeter will read. It is also the "effective" value, which means that an ac rms voltage will have the same results as an equivalent amount of dc voltage.

Rms is the effective value of the sine wave and occurs at a point 70.7% of the peak value. The rms value is at 45 degrees, half way between 0 degrees and 90 degrees. Even though it is half way in degrees, the instantaneous voltage at this point is 70.7% of the maximum. The sine of 45 degrees is .707 for the purpose of making the calculation.

Rms stands for "root mean square" which is a mathematical expression.

The rms value of the sine wave in Fig. 11-4 is 70.7 volts and Fig. 11-5 is 4.24 volts.

Formula #23. Rms from Peak.

$$\text{rms} = .707 \times \text{peak}$$

Average

The average value of 1/2 the sine wave is 63.6% of the peak value.

In order to determine the average, the instantaneous value of every point along 1/2 of the sine wave would have to be considered and the average taken of those values.

It is very important to notice that a sine wave is equal in both negative and positive. Therefore, if the average of the entire sine wave were to be considered, the result would be zero. Whenever the term average is used for a sine wave, it considers only 1/2 of the waveform.

The average value becomes a very important calculation in advanced electronics. For example, it will be used to calculate the output voltages of power supplies.

The average value of the sine wave in Fig. 11-4 is 63.6 volts and Fig. 11-5 is 3.82 volts.

Formula #24. Average from peak

$$\text{Average} = .636 \times \text{peak}$$

Sample Problems: Converting Amplitudes

SP#11-1. Given: 20 volts peak; convert to rms.

Formula: $\text{rms} = \text{peak} \times .707$

Substituting: $\text{rms} = 20 \times .707$

Solving: $\text{rms} = 14.14$ volts

Table 11-2. Summary of Amplitude Formulas.

| Given Value | Peak | Peak to Peak | RMS | Average |
|--------------|----------------|-----------------|---------------------------|---------------------------|
| Peak | — | mult. by 2 | mult. by .707 | mult. by .636 |
| Peak to Peak | divide by 2 | — | mult. by $\frac{.707}{2}$ | mult. by $\frac{.636}{2}$ |
| RMS | divide by .707 | peak \times 2 | — | mult. by .9 |
| Average | divide by .636 | peak \times 2 | peak \times .707 | — |

Note: to use the conversion factors in this table; first find the given value in the left hand column, then find the desired value to be converted to by looking in the top row. The given value is multiplied or divided by the conversion factor.

SP#11-2. Given: 20 volts peak; convert to peak to peak.

Formula: $p\text{-to-p} = 2 \times \text{peak}$
 Substituting: $p\text{-to-p} = 2 \times 20$
 Solving: $p\text{-to-p} = 40$ volts

SP#11-3. Given: 20 volts peak; convert to average.

Formula: $\text{avg} = \text{peak} \times .636$
 Substituting: $\text{avg} = 20 \times .636$
 Solving: $\text{avg} = 12.72$ volts

SP#11-4. Given: 280 volts p-to-p; convert to peak.

Formula: $\text{peak} = \frac{p\text{-to-p}}{2}$
 Substituting: $\text{peak} = \frac{280}{2}$
 Solving: $\text{peak} = 140$ volts

SP#11-5. Given: 156 volts rms; convert to peak.

Formula: $\text{peak} = \frac{\text{rms}}{.707}$
 Substituting: $\text{peak} = \frac{156}{.707}$
 Solving: $\text{peak} = 220$ volts

SP#11-6. Given: 63.6 volts average; convert to peak.

Formula: $\text{peak} = \frac{\text{Avg}}{.636}$
 Substituting: $\text{peak} = \frac{63.6}{.636}$
 Solving: $\text{peak} = 100$ volts

Practice Problems: Units of Amplitude

For problems 1-10, use the given value to find the others.

- (1) Given: 30 volts peak
 Find: a) rms b) p-to-p c) avg
- (2) Given: 100 volts peak
 Find: a) p-to-p b) avg c) rms
- (3) Given: 80 volts p-to-p

- Find: a) rms b) peak c) avg
- (4) Given: 260 volts p-to-p
 Find: a) peak b) avg c) rms
- (5) Given: 70 volts rms
 Find: a) peak b) p-to-p c) avg
- (6) Given: 12 volts rms
 Find: a) avg b) p-to-p c) peak
- (7) Given: 16 volts avg
 Find: a) rms b) peak c) p-to-p
- (8) Given: 120 volts avg
 Find: a) peak b) p-to-p c) rms
- (9) Given: 85 volts rms
 Find: a) peak b) p-to-p c) avg
- (10) Given: 70 volts peak
 Find: a) p-to-p b) avg c) rms

With problems 11-15, the drawing will supply either peak or p-to-p. State which is given and find the other three values.

- (11) Figure 11-6. Given? _____
 Find: a) p-to-p b) peak c) rms d) avg

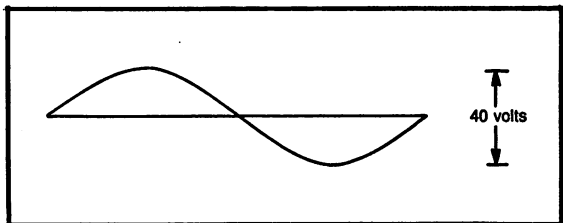


Fig. 11-6. Problem 11.

- (12) Figure 11-7. Given? _____
 Find: a) p-to-p b) peak c) rms d) avg

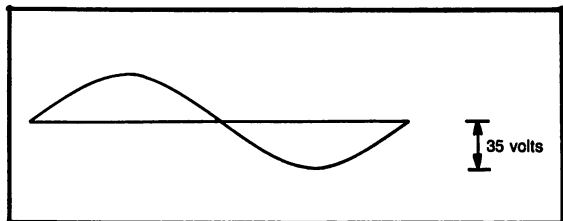


Fig. 11-7. Problem 12.

- (13) Figure 11-8. Given? _____
 Find: a) p-to-p b) peak c) rms d) avg

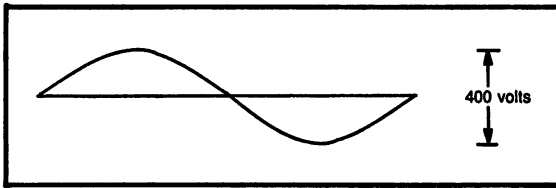


Fig. 11-8. Problem 13.

- (14) Figure 11-9. Given? _____
 Find: a) p-to-p b) peak c) rms d) avg

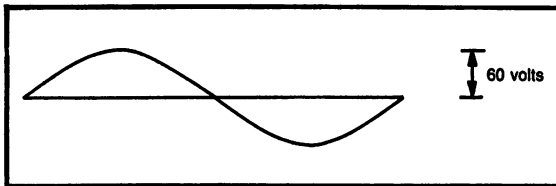


Fig. 11-9. Problem 14.

- (15) Figure 11-10. Given? _____
 Find: a) p-to-p b) peak c) rms d) avg

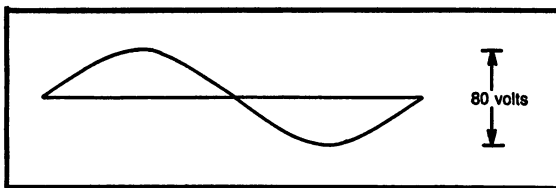


Fig. 11-10. Problem 15.

UNITS OF TIME

When a waveform is measured in the horizontal direction, the measurements can have many different names. Refer to Fig. 11-4, there are five different ways to measure in the horizontal direction; degrees, time, one cycle, wavelength, period and frequency (not shown in this figure).

Each of these measurements have very specific purposes and relationships in describing and understanding the nature of the waveform.

Degrees

As discussed earlier in this chapter, degrees are used to measure a particular point in the cycle with 360 degrees being a complete cycle. There are several key points which are usually described in terms of degrees, for example; 180 degrees is $\frac{1}{2}$

cycle, which is the point where the sine wave crosses from a positive voltage to a negative voltage. At 180 degrees, the voltage is zero. At 90 degrees, the sine wave is at its positive peak value and at 270 degrees, the sine wave is at its negative peak value. 45 degrees is rms and 39.5 degrees is average.

Cycle

One complete cycle is the point where the waveform repeats itself. Notice, the sine wave starts at a point of zero volts and goes in a positive direction. The next time the waveform is again at this point is at 360 degrees.

With each successive cycle, the waveform again starts at zero degrees and ends at 360 degrees.

Figure 11-5 shows four different waveforms all with the same frequency. Figure 11-5A shows a sine wave that is only one cycle. Notice, at no point does the sine wave repeat itself. In this figure, the time reference is $\frac{1}{2}$ second. Frequency is a calculation that uses time.

Figure 11-5B is two complete cycles. In the same length of time as Fig. 11-5A, the sine wave repeats itself. There are two cycles in $\frac{1}{2}$ second, one cycle takes place in $\frac{1}{4}$ second.

Figure 11-5C is three complete cycles and Fig. 11-5D is four complete cycles.

To determine the number of cycles, count how many times the sine wave crosses the zero point with the voltage increasing in the positive direction. Do not count when the wave crosses zero in the negative direction.

Period

The period of a waveform is the length of time it takes to complete one cycle. It has been demonstrated that a cycle can be measured in degrees, with 360 being a complete cycle. There is no specific length of time to complete a cycle. The length of time is based on the frequency of the waveform.

Using the wire and two pole generator as a sample, if the wire makes one complete revolution in one second, then the sine wave will have a period of one second. If the speed is increased, the wire

will pass by the magnetic poles more often and the length of time will decrease to complete one cycle.

The term period is measured in time units.

Time

The time required for a sine wave to complete its cycle is a measurement that can be made on an oscilloscope to determine the frequency of the waveform. The oscilloscope is calibrated in the horizontal direction in units of time.

Frequency

Frequency is the number of times a waveform repeats itself in one second. Frequency is measured in cycles per second (cps), also called Hertz (Hz). Frequency can be calculated as the inverse (reciprocal) of time.

Formula #25. Frequency as the Reciprocal of Time Period.

$$f = \frac{1}{t}$$

The sine wave plotted in Fig. 11-4 has a period of $\frac{1}{4}$ second. Therefore, the frequency is:

Formula: $f = \frac{1}{t}$

Substituting: $f = \frac{1}{.25 \text{ seconds}}$

Solving: $f = 4 \text{ hertz}$

The four sine waves shown in Fig. 11-5 have different frequencies. Figure 11-5A; period of $\frac{1}{2}$ second, frequency of 2 Hz. Figure 11-5B; period of $\frac{1}{4}$ second, frequency of 4 Hz. Figure 11-5C; period of .1667 seconds ($\frac{1}{2}$ second divided by 3), frequency of 6 Hz. Figure 11-5D; period $\frac{1}{8}$ second, frequency of 8 Hz.

Wavelength

Wavelength is a term used especially with radio waves. It is the length of a sine wave when it

travels through air. A low frequency will have a much longer wavelength than a high frequency sine wave. Further discussion of wavelength is beyond the scope of a book on dc and ac building blocks.

Practice Problems: Units of Time

Part A. Calculate the period of the following frequencies.

- (1) 10 Hz
- (2) 50 Hz
- (3) 60 Hz
- (4) 100 Hz
- (5) 500 Hz
- (6) .7 kHz
- (7) 1 kHz
- (8) 1.5 kHz
- (9) 7.5 kHz
- (10) 10 kHz
- (11) 12 kHz
- (12) 15 kHz
- (13) 20 kHz
- (14) 50 kHz
- (15) 75 kHz
- (16) 100 kHz
- (17) .5 MHz
- (18) 1 MHz
- (19) 1.5 MHz
- (20) 100 MHz

Part B. Calculate the frequency of the following periods.

- (21) 5 sec
- (22) 10 sec
- (23) .1 s
- (24) .5 s
- (25) .01 s
- (26) .02 s
- (27) .05 s
- (28) .001 s
- (29) .003 s
- (30) .005 s
- (31) 15 ms
- (32) 16.67 ms
- (33) 20 ms
- (34) 60 ms
- (35) 100 ms
- (36) .1 ms

- (37) .01 ms
- (38) 20 μ s
- (39) 5 μ s
- (40) 1 μ s

USING AN OSCILLOSCOPE TO MEASURE A SINE WAVE

The oscilloscope is the best instrument available for measuring a sine wave, or any other waveform. The oscilloscope can show exactly what the waveform looks like, to detect any distortion. The scope measures voltage and time. The time measurement makes it possible to calculate the frequency.

At this point, the student is familiar with most of the controls on the scope. This section will examine the remainder of the scope controls and introduce a new piece of test equipment, the signal generator.

Before making any connections, read the following subsections for the necessary background information. It will make it much easier to follow the step by step hands-on procedure.

Signal Generator

A signal generator is an instrument that will generate different types of waveforms. The frequencies produced are in the audio range (unless the generator produces radio frequencies, which should not be used for this exercise). The audio range of frequencies is from 10 Hz to 20,000 Hz.

The signal generator, or audio generator, can produce sine waves, square waves, and triangular waves. For this exercise, it is best to start with the sine waves. The student should examine the effects of the other waveforms available, at a later date.

The output of the signal generator has two controls; frequency and amplitude. The frequency control determines the output frequency. The amplitude control determines the amount of output voltage.

AC Voltmeter

The ac voltmeter is usually part of a multimeter. In fact, the multimeter that has been used as an ohmmeter, dc voltmeter and dc milliammeter is the same one that will now be used as an ac voltmeter.

The ac voltmeter will measure the rms value of a sine wave. It is important to remember that the rms value is calculated with an oscilloscope measurement, because scopes measure peak to peak. The ac voltmeter measures rms values. Because of these differences between instruments, it is important to learn both.

Oscilloscope Controls

When using a signal generator with the scope, it is necessary to trigger the waveform properly or it will not be possible to view a steady waveform.

The trigger must be adjusted to trigger on the channel in use. If the signal is connected to channel 1, it is necessary to trigger on that channel. It will be best to trigger on ac mode and adjust the level for a stable trace (waveform).

The scope's AC-GND-DC switch is best used in the ac position. It is possible to view an ac signal in the dc position, and it will be best for some test conditions, but for now, it should be used in the ac position. The ground reference line should be adjusted to the exact center of the screen.

The volts/div control is a very important control in obtaining a useful and accurate display of the waveform. Figure 11-11, 11-12 and 11-13 show the effects of adjusting the volts/div control. Figure 11-11 is the correct adjustment. Figure 11-12, the volts/div control is set too low. This adjustment allows the waveform to go off the screen. Figure 11-13, the volts/div is set too high. In this case, the waveform is too small to make accurate measurements.

Measuring Frequency on an Oscilloscope

Since an oscilloscope can make measurements in time, it is necessary to use those time measurements and calculate the frequency of a waveform.

Remember, frequency is the reciprocal of time. $f = 1/t$. Once a time measurement is made, simply take the reciprocal to find the frequency.

In order to measure time of a waveform on an oscilloscope, there are a few simply steps to follow:

- (1) Determine the time/div setting. The variable control must be in calibrate.

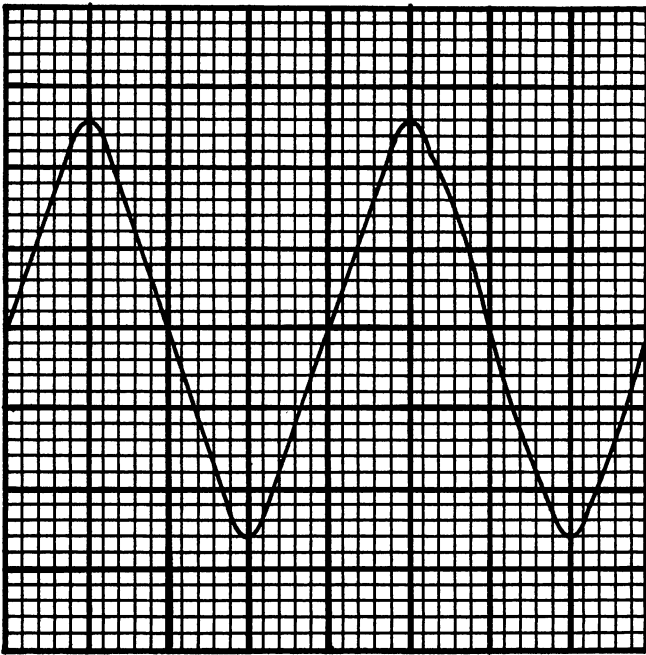


Fig. 11-11. Representation of an oscilloscope display showing a sine wave with the volts per division and time per division correctly adjusted.

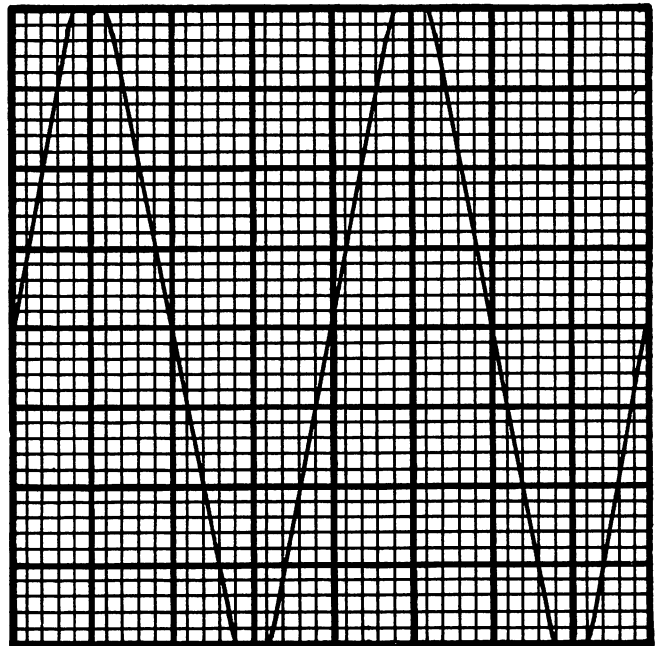


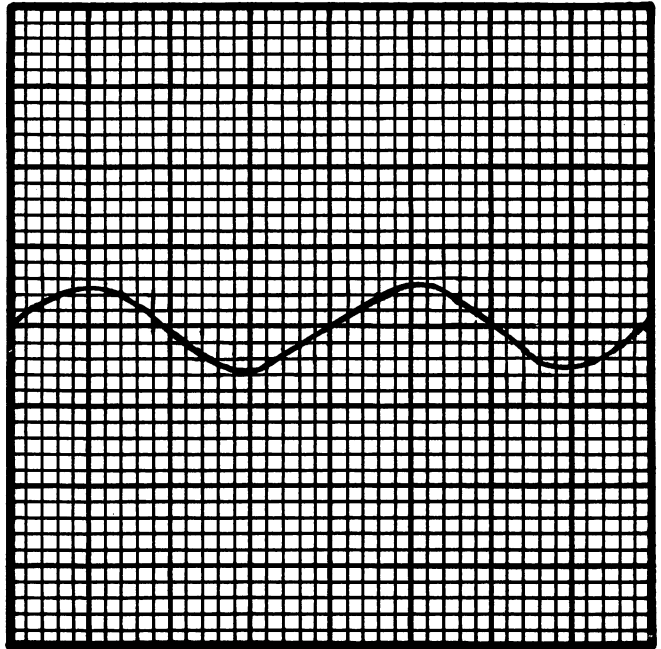
Fig. 11-12. Volts per division expanded too much.

(2) Count the number of divisions from the start of one cycle to the start of the next cycle. The start of a cycle is the point where the waveform crosses the zero axis in the positive direc-

tion. It is best to adjust the ground reference line to the exact center of the screen, this makes the center the zero point.

(3) Multiply the number of divisions by the time/di-

Fig. 11-13. Volts per division not expanded enough.



vision. This will result in the time for one cycle, also called the period.

- (4) Calculate frequency by taking the reciprocal.
 $f = 1/t$.

SP#11-7. Scope setting: 2 ms/div.

No. of div.: 5 div

Period = 2 ms/div \times 5 div

Period = 10 ms

Frequency = 100 Hz ($f = 1/t$)

HANDS-ON PRACTICE WITH SINE WAVES

Equipment needed:

- Oscilloscope
- Signal generator
- Ac voltmeter

- Step 1. Connect a test lead cable to the output of the signal generator. Connect test leads to the input of the scope and an ac voltmeter. Connect all ground wires together, then connect all the "hot" wires together.
- Step 2. Adjust the signal generator for an output frequency of approximately 100 Hz.

(Other frequencies will be examined later.) The output amplitude will be adjusted using the scope.

- Step 3. Adjust the oscilloscope time/div control to 2 ms per div. This setting will enable a display of approximately two cycles, depending on the actual input frequency.
- Step 4. Adjust the scope trigger for a stable display of the waveform. If necessary, adjust the volts/div to enable a proper setting of the trigger. The volts/div will be readjusted after the trigger is set.
- Step 5. Set the volts per division to 1 volts/div. Use the amplitude adjust on the signal generator for a peak to peak voltage of 5 volts. Be sure the variable control is set to calibrate. AC/DC/GND switch on ac and the ground reference line set in the center (using the GND switch). There should be 2½ divisions on each side of the center line.
- Step 6. Calculate the rms value of the sine wave now on display. Use the ac voltmeter to measure the rms value.
- rms formula.....

Calculated rms.....(volts)
 Measured rms.....(volts)

Step 7. Change the volts/div setting to .5 volts/div. Adjust the amplitude to 3 volts peak to peak.
 Peak formula.....
 Calculated peak.....(volts)
 Measured peak.....(volts)
 rms formula.....
 Calculated rms.....(volts)
 Measured rms.....(volts)

Step 8. Using the ac voltmeter, adjust the signal generator to an output voltage of 4 volts rms. Note: if necessary, adjust the oscilloscope volts/div control.
 p-to-p formula.....
 Calculated p-to-p.....(volts)
 Measured p-to-p.....(volts)
 Peak formula.....
 Calculated peak.....(volts)
 Measured peak.....(volts)

Step 9. Using the ac voltmeter, adjust the signal generator to an output voltage of 1 volts rms. Adjust the volts/div, if necessary.
 p-to-p formula.....
 Calculated p-to-p.....(volts)
 Measured p-to-p.....(volts)
 Peak formula.....
 Calculated peak.....(volts)
 Measured peak.....(volts)

Step 10. Adjust the output frequency of the signal generator until the oscilloscope displays exactly two full cycles. Adjust the amplitude to 1 volt rms (step 9). Be sure the variable control is set to calibrate. Time/div was set to 2 ms/div in step 3. Determine the period (time) of one cycle by counting the divisions between the start of one sine wave and the start of the next sine wave. Note: use the horizontal position control to move the waveform so the display has the start of the waveform at exactly the left side of the screen. Record the period and calculate the frequency. Draw on graph paper exactly what is displayed on the scope. Label the

drawing with: p-to-p, peak, rms, period and 0, 90, 180, 270, 360 degrees.

Period.....(time in ms)
 Frequency formula.....
 Calculated freq.....(Hz)

Step 11. Adjust the time/div to 1 ms/div. Adjust the signal generator for two full cycles.
 Period.....(time in ms)
 Frequency formula.....
 Calc. freq.....(Hz)

Step 12. Adjust the time/div for .5 ms/div. Adjust the signal generator for three full cycles.
 Period.....(time in ms)
 Frequency formula.....
 Calc. freq.....(Hz)

Step 13. Pre-calculate the period for the following frequencies. Pre-determine the number of divisions for one cycle. Adjust the signal generator for the desired frequency, based on the pre-determined calculations. Check the frequency dial on the signal generator to verify results of calculations. The scope time/div may have to be adjusted for the different frequencies, which will change the number of divisions, but not the period in time.
 Period formula.....

1000 Hz

Period (ms)
 time/div (setting)
 divisions..... (number)

1500 Hz

Period (ms)
 time/div (setting)
 divisions..... (number)

2000 Hz

Period (ms)
 time/div (setting)
 divisions..... (number)

10,000 Hz

Period (ms)
 time/div (setting)
 divisions..... (number)

- (11) cycle
- (12) period
- (13) frequency
- (14) hertz
- (15) wavelength

Part B. Units of Amplitude Calculations

Use the information given to calculate the unknown values. (Answers are 1 point each.)

- (16) Given: 25 volts peak
Find: a) rms b) p-to-p
- (17) Given: 15 volts peak
Find: a) avg b) rms
- (18) Given: 40 volts p-to-p
Find: a) peak b) rms
- (19) Given: 240 volts p-to-p
Find: a) rms b) avg
- (20) Given: 120 volts rms
Find: a) peak b) p-to-p
- (21) Given: 45 volts rms
Find: a) peak b) avg
- (22) Given: 15 volts avg
Find: a) peak b) rms
- (23) Given: 90 volts avg
Find: a) p-to-p b) peak

- (24) Given: 100 volts peak
Find: a) rms b) avg

- (25) Given: 160 volts p-to-p
Find: a) rms b) avg

Part C. Units of Time Calculations

Use the value given to find the unknown. When a time is given, it is the period of one cycle. (2 points each.)

- (26) Given: 60 Hz Find: period
- (27) Given: 50 ms Find: frequency
- (28) Given: 200 Hz Find: period
- (29) Given: 1 ms Find: frequency
- (30) Given: 2 μ s Find: frequency

Part D. Waveform Analysis

Find the frequency and peak to peak voltage of the sine waves drawn in Figs. 11-15 to 11-24. (Each answer 2 points.)

- (31) Figure 11-15; a) p-to-p voltage b) frequency
- (32) Figure 11-16; a) p-to-p voltage b) frequency
- (33) Figure 11-17; a) p-to-p voltage b) frequency
- (34) Figure 11-18; a) p-to-p voltage b) frequency
- (35) Figure 11-19; a) p-to-p voltage b) frequency
- (36) Figure 11-20; a) p-to-p voltage b) frequency
- (37) Figure 11-21; a) p-to-p voltage b) frequency
- (38) Figure 11-22; a) p-to-p voltage b) frequency
- (39) Figure 11-23; a) p-to-p voltage b) frequency
- (40) Figure 11-24; a) p-to-p voltage b) frequency

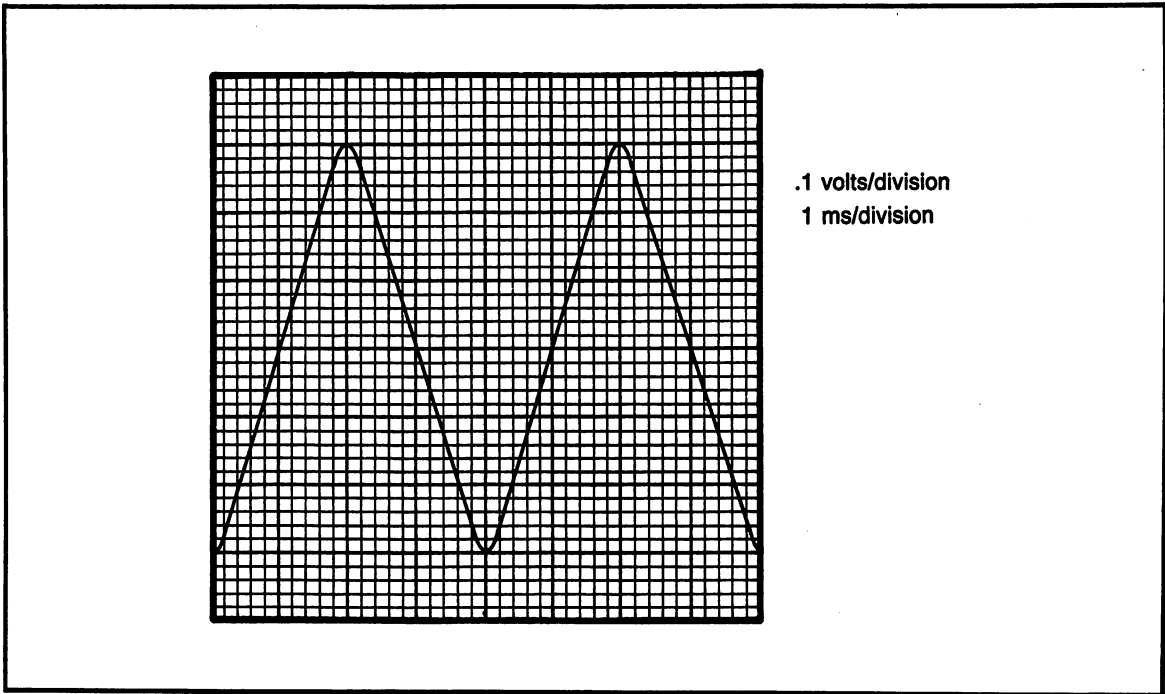


Fig. 11-15. Problem 31.

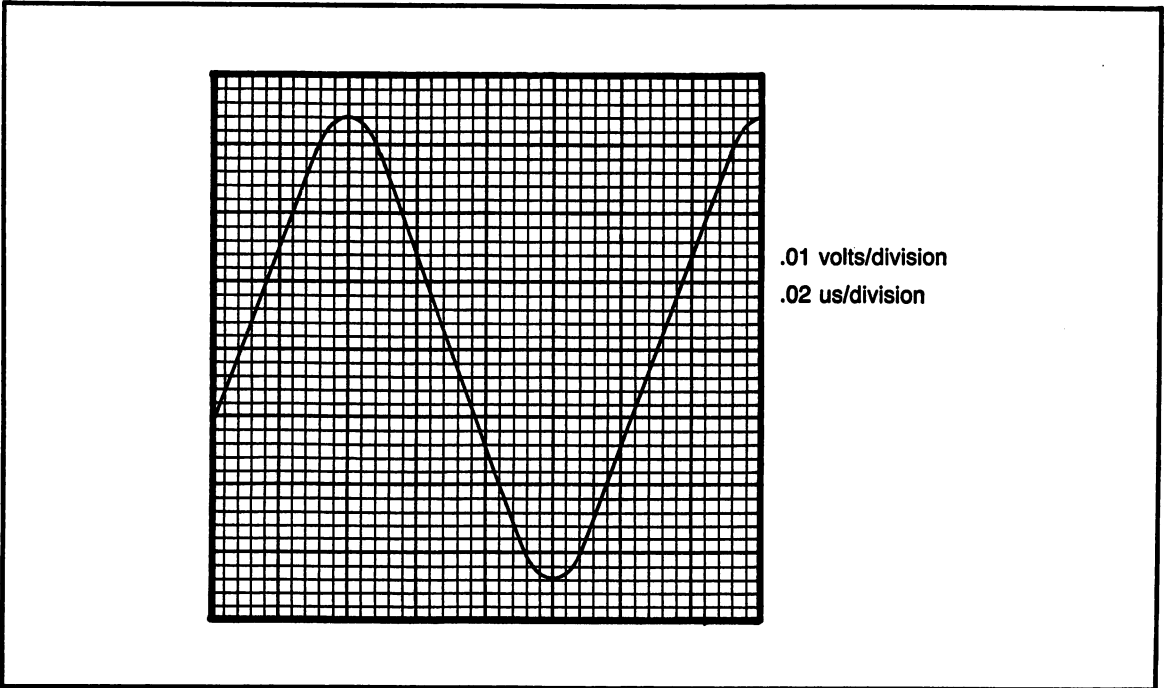


Fig. 11-16. Problem 32.

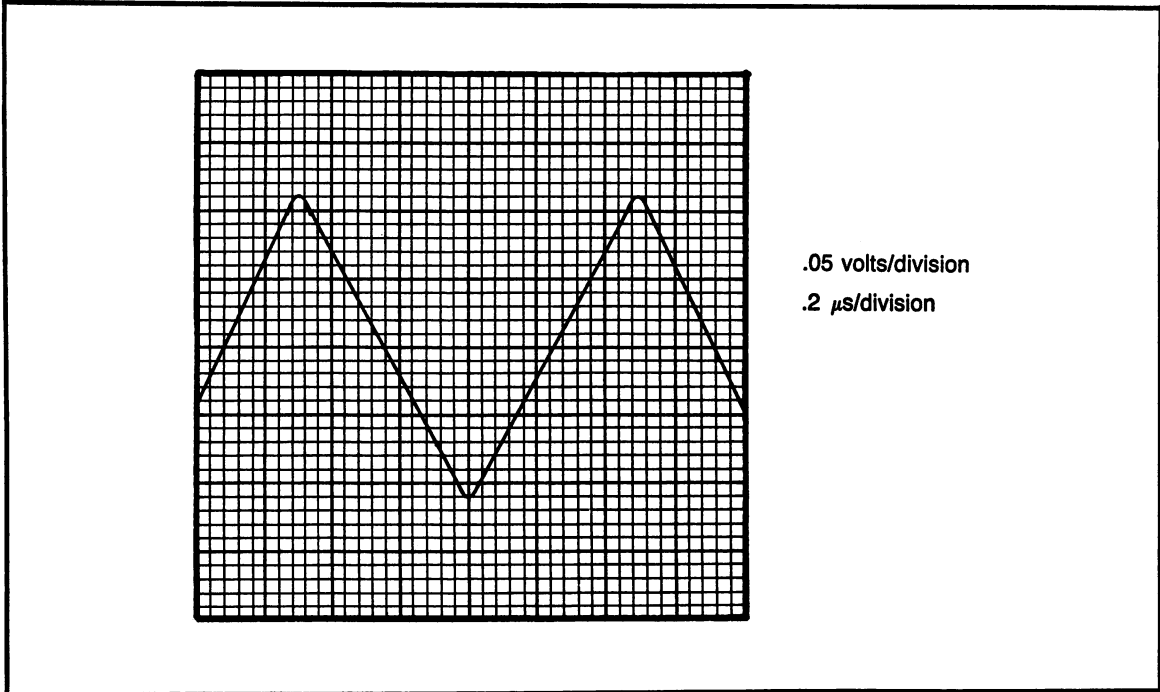


Fig. 11-17. Problem 33: .05 volts/division .2 μ s/division.

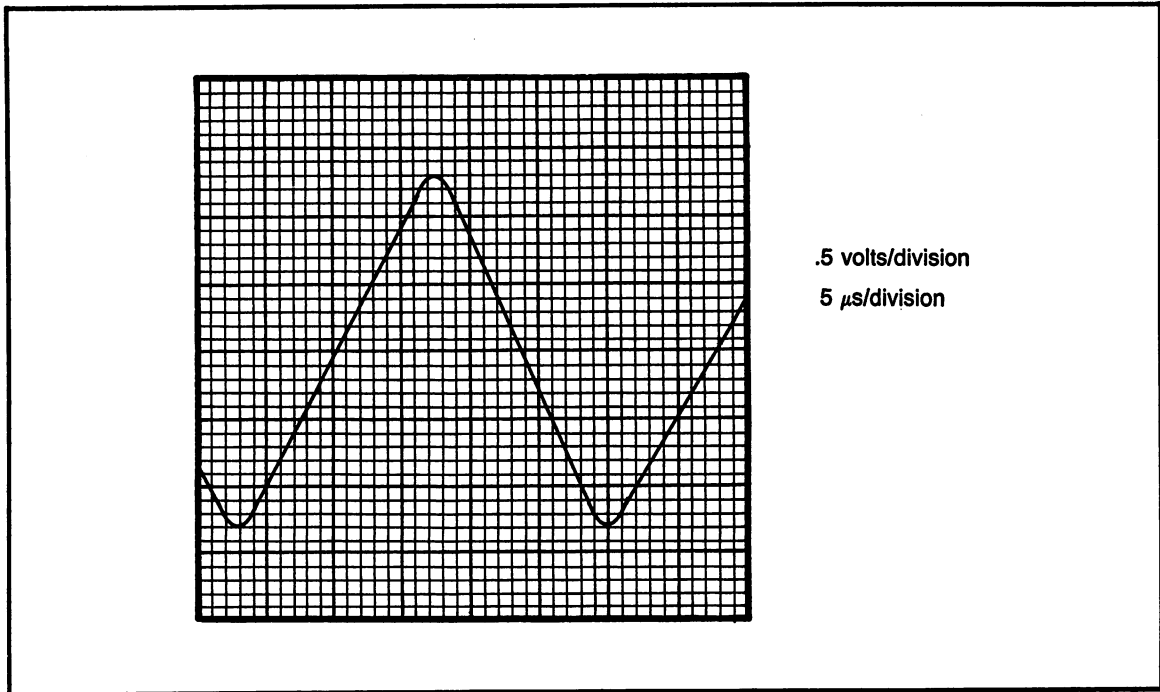


Fig. 11-18. Problem 34: .5 volts/division; 5 μ s/division.

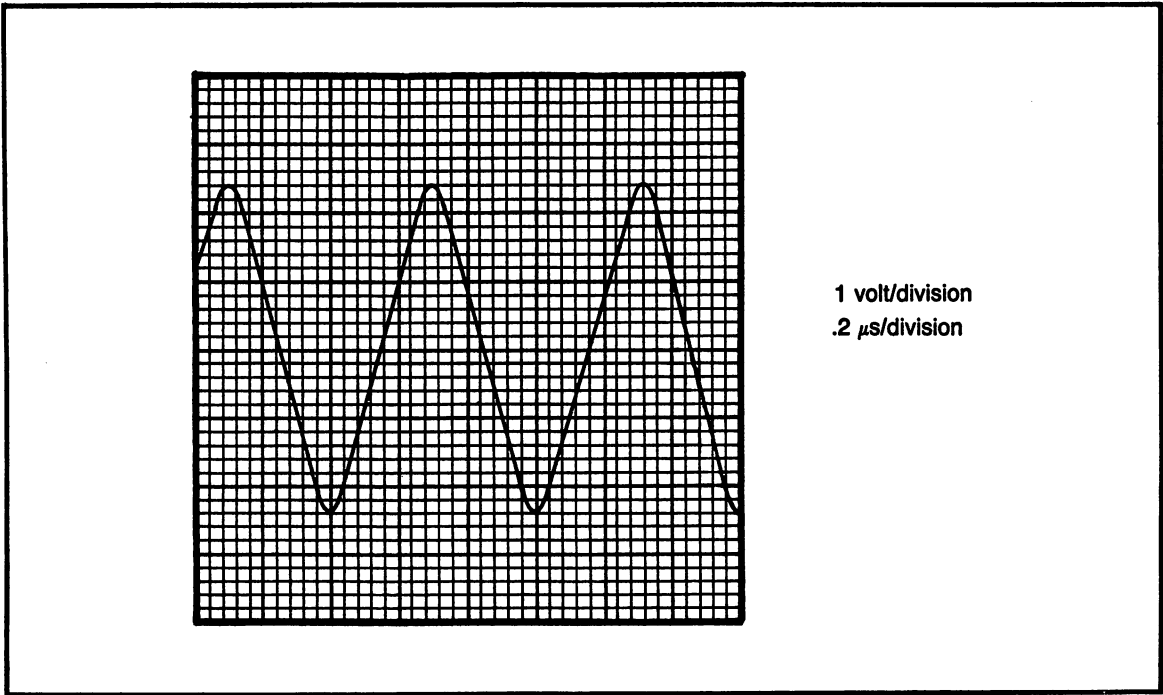


Fig. 11-19. Problem 35: 1 volt/division; .2 μ s/division.

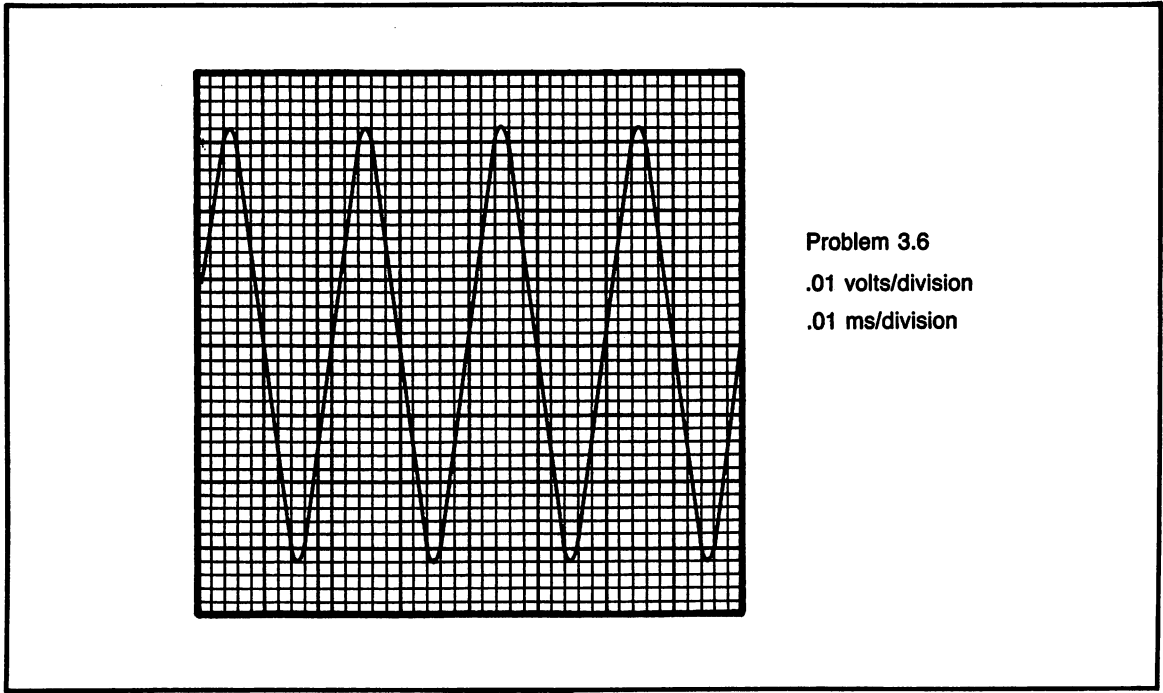


Fig. 11-20. Problem 36: .01 volts/division; .01 ms/division.

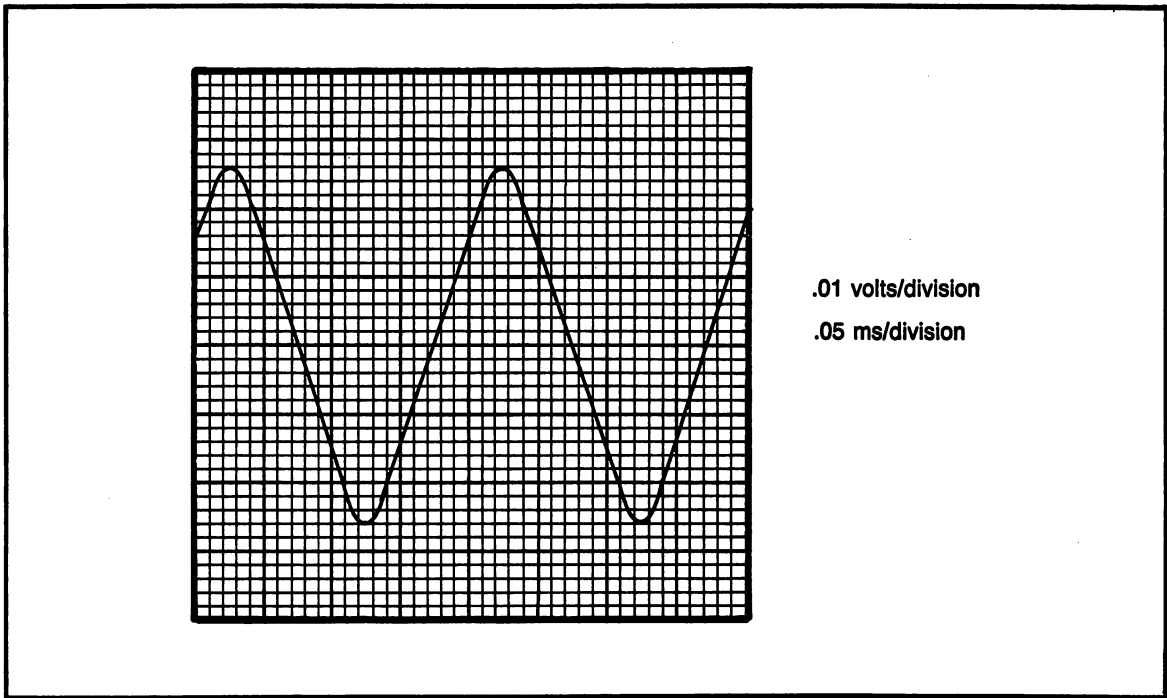


Fig. 11-21. Problem 37: .01 volts/division; .05 ms/division.

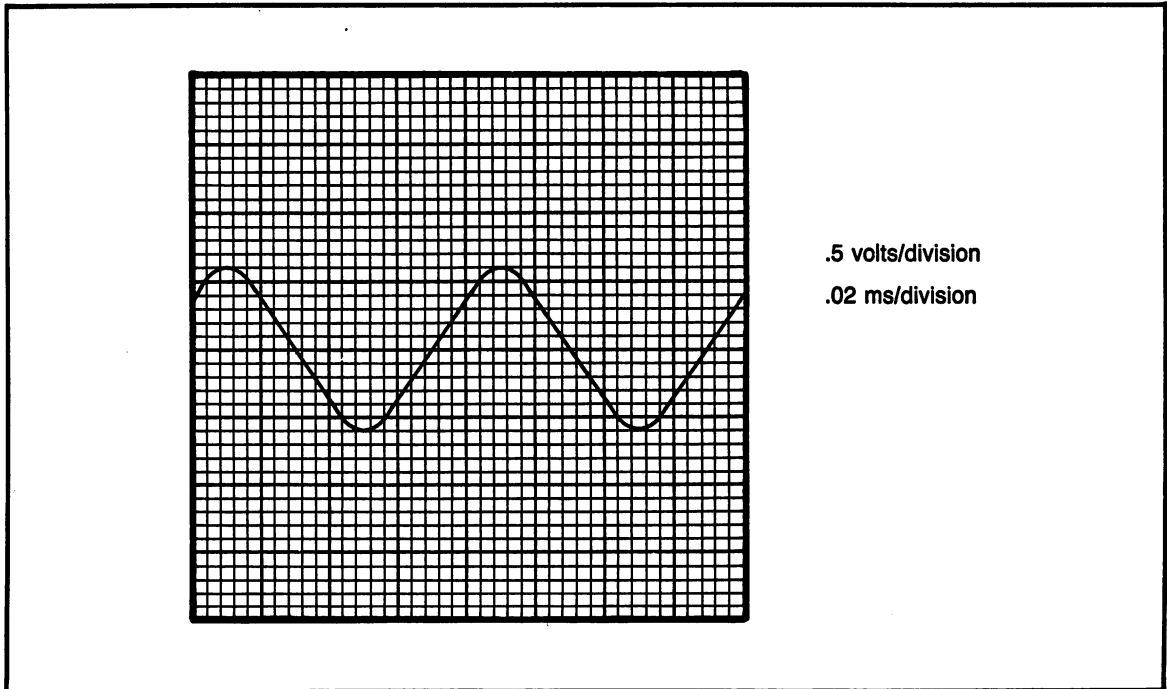


Fig. 11-22. Problem 38: .5 volts/division; .02 ms/division.

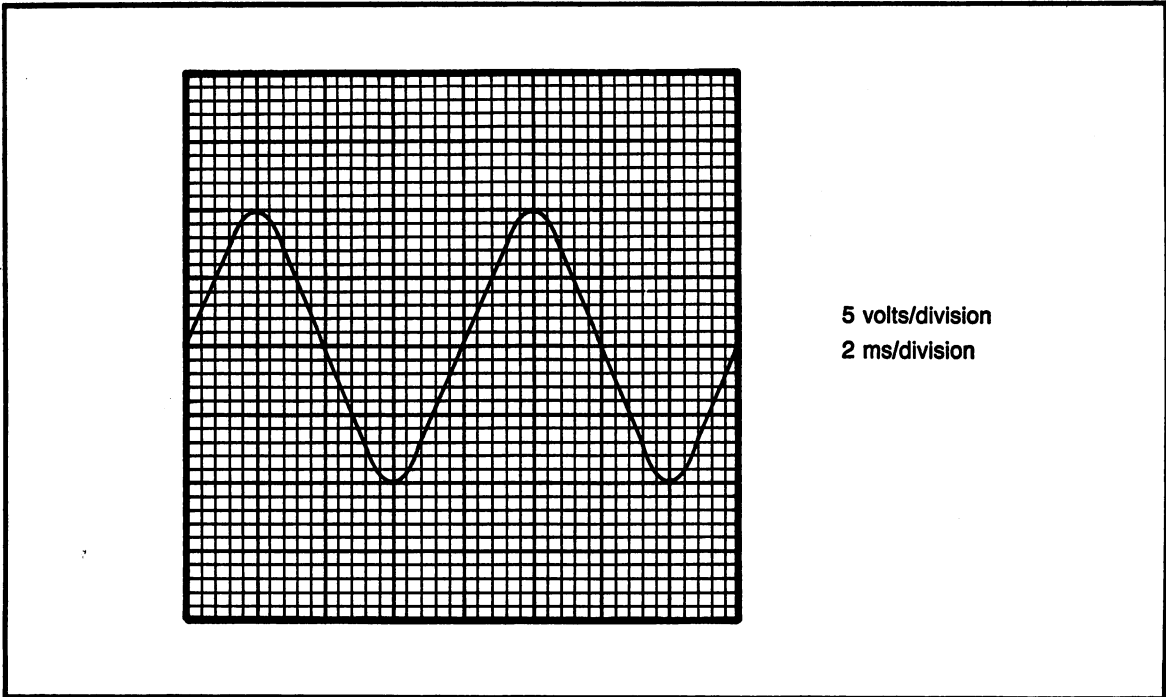


Fig. 11-23. Problem 39: 5 volts/division; 2 ms/division.

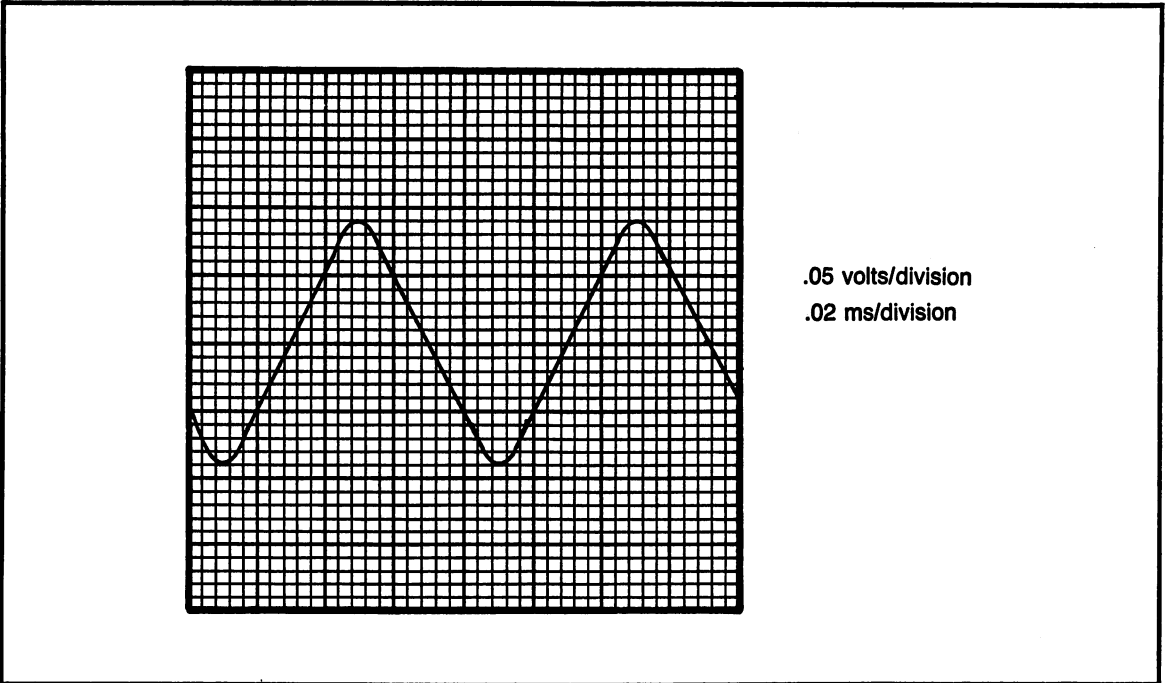


Fig. 11-24. Problem 40: .05 volts/division; .02 ms/division.

Chapter 12

Transformers

Chapter Objectives: To learn what transformers are, how they are constructed and their function. To learn how to calculate transformer relationships and how to perform measurements of voltage, current and resistance.

Chapter Outline:

- Transformer Construction
- Transformer Ratios
- Power and Efficiency
- Variations of Transformers
- DC Voltage with the Transformer
- Hands-On Testing of Transformers
- Programs for this Chapter
- Transformer Competency Test

INTRODUCTION

A transformer is a device that allows an ac voltage, usually a sine wave, to pass from the input to the output through magnetism. The output voltage, compared to the input, has three different possibili-

ties; higher than the input, lower than the input, same as the input.

Because the transformer can be used to change the level of the voltage, it has a very important role in the fields of electricity and electronics. For example, the power company uses a transformer to change the very high voltage used for long distance transmission, to the voltage used in the house. Nearly all electronic devices have a cord to plug into the ac line. When the ac line voltage enters the device, it goes through a transformer to lower the voltage before it goes to the power supply, where it is then changed to a dc voltage.

TRANSFORMER CONSTRUCTION

A transformer is constructed in such a way that magnetism is used to induce voltage in a second wire. The input of the transformer is called the primary and the output is called the secondary. Both the primary and secondary are each a coil of wire (referred to as a winding). When current flows in

a coil, magnetism is developed and when magnetic lines of force cross a coil, voltage is developed.

Primary and Secondary Windings

Figure 12-1 is a set of three simplified drawings of a transformer. Figure 12-1A shows a primary winding alongside a secondary winding. The two windings are not physically connected, but they are connected by the magnetic flux. Figure 12-1B shows the windings wrapped around an iron core. The core is used to concentrate the magnetic lines of force to achieve more complete magnetic coupling. Figure 12-1C is the schematic drawing. Also, in all three drawings of Fig. 12-1, the primary is shown connected to an ac voltage source. The symbol for this is a sine wave inside of a circle. The load is represented by a resistor.

When an ac voltage is applied to the primary of a transformer, current will flow in the primary winding (coil). The ac current in the primary develops a magnetic field. The primary and secondary windings are made in such a way that the magnetic field overlaps the secondary completely.

The magnetic field from the primary induces a voltage in the secondary. The amount of induced voltage in the secondary is determined by the size of the secondary coil as compared to the primary coil.

Transformer Core

The purpose of the transformer core is to concentrate the magnetic field. Thus, it allows more complete coupling of the magnetic lines of force (flux) between the primary winding and the secondary winding.

The core of a transformer is made of soft iron. Soft iron is used because it is an excellent conductor of magnetic flux, and can magnetize and demagnetize very quickly. In the schematic symbol shown in Fig. 12-1C, the two parallel lines between the windings represent the iron core.

Core Losses

There are two types of losses in the core of a transformer that are of particular importance; hys-

teresis loss and eddy current loss.

Hysteresis loss is caused by residual magnetism. This is the magnetism that is left over after a material has been magnetized, then demagnetized. With alternating current, the polarity of the voltage is continuously changing. Since the polarity of the voltage changes, the polarity of the magnetic field also changes. In order to change the polarity of the magnetic field, the magnet must be magnetized, then demagnetized. The frequency of the voltage will affect how severe the hysteresis loss.

Hysteresis loss is minimized by selecting a material that can magnetize and demagnetize very quickly, with a minimum amount of residual magnetism. Soft iron is a good material for this reason.

Eddy current loss is caused by an electrical current being developed in the core, because the core is a conductor. The eddy currents will produce a back-EMF and will have severe effects on allowing the coupling of magnetic flux.

Eddy current loss is minimized by laminating the core. The core is manufactured in layers, with the layers separated by an insulating material. In this way, the magnetic flux can pass through, but the electrical current cannot.

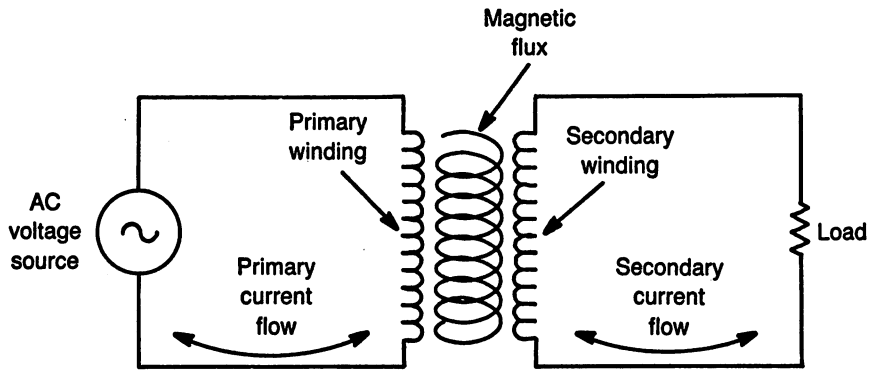
An iron core can only be used with relatively low frequencies, usually in the audio range (20 Hz to 20,000 Hz). High frequency transformers use an air core in order to eliminate the core losses. At low frequencies, the core losses are not severe enough to offset the advantages.

TRANSFORMER RATIOS

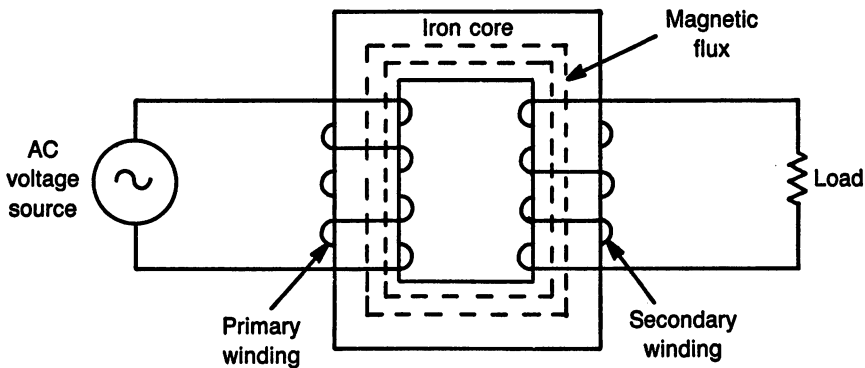
There are four ratios involved with transformers; turns ratio, voltage ratio, current ratio and impedance ratio. These four ratios are used to describe what takes place between the primary and secondary.

Turns Ratio

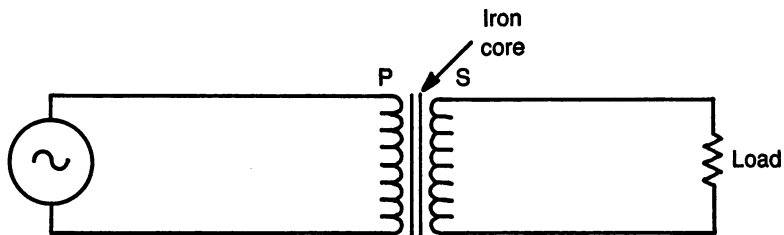
The turns ratio describes the number of turns of the primary as compared to the number of turns of the secondary, or vise-versa. The turns ratio is stated by the formula:



A. Pictorial drawing showing how the magnetic field of the primary induces voltage in the secondary which causes current to flow.



B. Pictorial drawing showing the primary winding and secondary windings wrapped around an iron core.



C. Schematic diagram.

Fig. 12-1. Simplified drawings of a transformer.

Formula #26. Transformer Turns Ratio

$$N_p : N_s \text{ (or) } \frac{N_p}{N_s}$$

N_p stands for turns of the primary.

N_s stands for turns of the secondary.

: (colon) is the symbol for a ratio.

The ratio is stated as primary to secondary, unless otherwise specified.

The turns ratio statement is read as; “turns of the primary to turns of the secondary.” Example:

$$N_p = 10 \text{ and } N_s = 1$$

The turns ratio of this example transformer is 10:1, and is read as; “10 to 1, primary to secondary.”

Usually the turns ratio is stated as part of the specifications of the transformer. It is this ratio that determines how the transformer will operate.

Keep in mind when dealing with the transformer turns ratio that the turns ratio does not state the actual number of turns of wire, it is only a ratio. For example; a ratio of 10:1 is not an actual 10 turns in the primary and 1 in the secondary. The actual number of turns could be 4000 in the primary and 400 in the secondary. Remember, the size of the wire used to make the coil is very small. A small wire is used because it takes up less space and allows a large number of turns to produce a strong enough magnetic field.

Step-Up/Step-Down

The terms “step-up” or “step-down” refer to the results of the transformer action.

Key Point. If the number of turns of the primary is larger than the number of turns of the secondary, the transformer is considered a “step-up” transformer.

Key Point. If the number of turns of the primary is smaller than the number of turns of the secondary, the transformer is considered a “step-down” transformer.

Voltage Ratio

The voltage ratio is probably the most important of the four ratios. It is a direct relationship to

the turns ratio and is used to calculate the amount of voltage that will be produced by the secondary with a certain voltage applied to the primary. The voltage ratio allows the turns ratio to be used as an equation:

Formula #27. Transformer Voltage Ratio

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

N_p is turns of the primary

N_s is turns of the secondary

V_p is voltage of the primary

V_s is voltage of the secondary

The voltage ratio formula is read: “turns of the primary is to turns of the secondary as voltage of the primary is to voltage of the secondary.”

The voltage ratio lends itself to easily determine if the transformer is step-up or step-down. If the voltage of the primary is higher than the voltage of the secondary, the transformer is step-up and if the primary voltage is lower than the secondary voltage, it is step-down.

In order to use the voltage ratio as a formula, three of the four quantities must be known, leaving only one unknown. The equation is then rearranged using “cross multiplication”. Shown below are the four possible ways the formula can be used.

$$N_p = \frac{V_p}{V_s} \times N_s$$

$$N_s = \frac{V_s}{V_p} \times N_p$$

$$V_p = \frac{N_p}{N_s} \times V_s$$

$$V_s = \frac{N_s}{N_p} \times V_p$$

Sample Problems: Voltage Ratios

SP#12-1.

Given: primary voltage = 60 volts, secondary voltage = 15 volts, secondary turns = 2.

Find: primary turns and determine if it is step-up or step-down.

$$\text{Formula: } N_p = \frac{V_p}{V_s} \times N_s$$

$$\text{Substituting: } N_p = \frac{60}{15 \text{ V}} \times 2$$

Solving: $N_p = 8$, step-down.

Note: there are no units with the answer because it is a ratio. The term "turns" may be used, if desired, but it is not technically correct because the ratio is not the actual number of turns of wire in the winding.

SP#12-2.

Given: Primary turns = 20, primary voltage = 10 volts, secondary voltage = 30 volts.

Find: secondary turns and if it is step-up or step-down.

$$\text{Formula: } N_s = \frac{V_s}{V_p} \times N_p$$

$$\text{Substituting: } N_s = \frac{30}{10} \times 20$$

Solving: $N_s = 60$, step-up

SP#12-3.

Given: primary turns = 2, secondary turns = 1, secondary voltage = 20 volts.

Find: primary voltage and if it is step-up or step-down.

$$\text{Formula: } V_p = \frac{N_p}{N_s} \times V_s$$

$$\text{Substituting: } V_p = \frac{2}{1} \times 20 \text{ volts}$$

Solving: $V_p = 40$ volts, step-down

SP#12-4.

Given: primary voltage = 120 volts, primary turns = 1, secondary turns = 4.

Find: secondary voltage and if it is step-up or step-down.

$$\text{Formula: } V_s = \frac{N_s}{N_p} \times V_p$$

$$\text{Substituting: } V_s = \frac{4}{1} \times 120\text{V}$$

Solving: $V_s = 480$ volts, step-up

Current Ratio

The current ratio of a transformer is the inverse of the turns ratio. This means a step-up transformer will step-up the voltage but step-down the current. A step-down transformer will step-up the current.

When a transformer is being selected for a particular circuit, usually the voltage is the determining factor. However, extreme caution must be exercised in terms of current. Keep in mind that fuses, which protect a circuit, have current ratings. In order to correctly determine the proper size fuse, the current of both the primary and secondary must be considered.

The current ratio, stated as a formula:

Formula #28. Transformer Current Ratio

$$\frac{N_p}{N_s} = \frac{I_s}{I_p}$$

N_p is turns of the primary.

N_s is turns of the secondary.

I_s is turns of the secondary.

I_p is turns of the primary.

Notice the inverse relationship.

Impedance Ratio

Impedance is a term used to describe the ac resistance. There are times in electronic circuits where it is necessary to use a transformer to "match impedances". For example; in an audio amplifier, the output impedance of the amplifier might be as high as 5,000 ohms. The amplifier will supply power to an 8 ohm speaker. If this connection were made directly, the 8 ohm speaker would short-out the amplifier because it is such a low resistance. A trans-

former should be used with a 5,000 ohm primary and an 8 ohm secondary.

When the impedances of input and output are matched, there is a maximum transfer of power.

This application of a transformer is beyond the scope of the contents of this book. The impedance ratio is presented here as a means of future reference. Most applications of transformers involve the voltage and current ratios.

Formula #29. Transformer Impedance Ratio

$$\frac{Z_p}{Z_s} = \left[\frac{N_p}{N_s} \right]^2$$

Z_p is impedance of the primary.

Z_s is impedance of the secondary.

N_p is turns of the primary.

N_s is turns of the secondary.

Note that the entire turns ratio is squared.

Calculating the Turns Ratio

The turns ratio can be calculated using the voltage ratio, current ratio, or impedance ratio.

Each of these ratios can be thought of as a fraction. Like common fractions, the size of the numbers in the numerator and denominator can be changed without changing the value of the fraction. For example, each of the following fractions are equal:

$$\frac{1}{2} = \frac{2}{4} = \frac{4}{8} = \frac{10}{20} = \frac{30}{60}$$

Keep in mind that the numerator and denominator can be multiplied or divided by the same number and the value of the fraction remains the same. When reducing the turns ratio of a transformer, do not use decimals in the final ratio.

Sample Problems: Calculating Turns Ratio

SP#12-5.

Given: primary voltage = 36 volts, secondary voltage = 9 volts.

Find: turns ratio.

Formula: $\frac{N_p}{N_s} = \frac{V_p}{V_s}$

Substituting: $\frac{N_p}{N_s} = \frac{36 \text{ V}}{9 \text{ V}}$

To solve: (reduce the voltage ratio to lowest terms)

Solving: $\frac{N_p}{N_s} = \frac{4}{1}$ (step-up)

SP#12-6.

Given: primary voltage = 60 volts, secondary voltage = 120 volts.

Find: turns ratio.

Formula: $\frac{N_p}{N_s} = \frac{V_p}{V_s}$

Substituting: $\frac{N_p}{N_s} = \frac{60 \text{ V}}{120 \text{ V}}$

Solving: $\frac{N_p}{N_s} = \frac{1}{2}$ (step-down)

SP#12-7.

Given: primary current = .06 amps, secondary current = .02 amps.

Find: turns ratio.

Formula: $\frac{N_p}{N_s} = \frac{V_s}{I_p}$

Substituting: $\frac{N_p}{N_s} = \frac{.02 \text{ A}}{.06 \text{ A}}$

Solving: $\frac{N_p}{N_s} = \frac{1}{3}$

Practice Problems: Transformer Ratios

Use the information given to complete the table on page 189.

| Prob. Number | Turns Ratio (P:S) | Primary Voltage (volts) | Second. Voltage (volts) | Primary Current (amps) | Second. Current (amps) | Step up or Step down |
|--------------|-------------------|-------------------------|-------------------------|------------------------|------------------------|----------------------|
| 1 | 10:1 | 120 v | --- | .1 A | --- | --- |
| 2 | 6:1 | --- | 20 v | --- | .6 A | --- |
| 3 | 1:5 | 30 v | --- | --- | .2 A | --- |
| 4 | 1:7 | 17 v | --- | .03 A | --- | --- |
| 5 | --- | 24 v | 96 v | --- | 1 A | --- |
| 6 | --- | --- | 27 v | .2 A | .6 A | --- |
| 7 | --- | 120 v | 60 v | .3 A | --- | --- |
| 8 | --- | 45 v | --- | .1 A | .02 A | --- |
| 9 | --- | 300 v | 50 v | 1 A | --- | --- |
| 10 | --- | 6 v | 120 v | --- | 1 A | --- |

POWER AND EFFICIENCY

Power and efficiency are terms used to describe how well work is performed, taking into account losses in the system.

Power

Power is the term used to describe electrical work performed. In order to have power, there must be both voltage applied and current flow.

Power is a form of energy, which cannot be manufactured or destroyed. Electrical work can be found in many forms, with heat being one of the most common. If heat is produced when it is not desired, then it is considered a loss.

The function of a transformer is to change the voltage applied to the primary winding and the current flowing, into a magnetic field. The magnetic field is used to induce voltage in the secondary winding and allow current to flow.

If the transformer is assumed to be 100% efficient, that is, perfect, then the power applied to the primary of the transformer must equal the power available at the secondary. Another way of stating this is "power in equals power out".

Using the turns ratio, voltage ratio and current ratio, the power of a transformer can be proven to be $P_{in} = P_{out}$:

$$\text{Voltage ratio: } \frac{N_p}{N_s} = \frac{V_p}{V_s}$$

$$\text{Current ratio: } \frac{N_p}{N_s} = \frac{I_s}{I_p}$$

$$\text{Combining ratios: } \frac{V_p}{V_s} = \frac{I_s}{I_p}$$

Using cross-multiplication: $V_p \times I_p = V_s \times I_s$

Basic power formula: $P = I \times V$

Therefore: $P_{pri} = P_{sec}$

The purpose of the above mathematical demonstration is to prove that if a transformer is 100% efficient, there will be no loss of power between the input and the output. It makes sense, therefore, that if the power out is less than the power in, the loss of power is due to transformer losses. Keep in mind that the output power can never be greater than the input power.

Efficiency

Efficiency describes how well work can be performed in a system that is not 100% efficient. A transformer has losses in the core, losses due to heat, losses in the wire itself, losses due to imperfect magnetic coupling, etc.

Even though the list of losses seems impressive, modern transformers are manufactured in such a way that they are able to reduce the losses to a minimum. An efficiency of 80 to 90 percent is common.

It is interesting to note that the efficiency of any system (such as; an oil furnace, gasoline engine, solar energy, etc.) can be calculated using the same formula:

Formula #30. Efficiency

$$\% \text{ eff} = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\%$$

Efficiency is measured in percent.

P_{out} is the power of the secondary.

P_{in} is the power of the primary.

Multiply by 100 to convert to percent.

Sample Problems: Efficiency

SP#12-8.

Given: secondary power = 10 watts, primary power = 12 watts.

Find: efficiency.

$$\text{Formula: } \% \text{ eff} = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100$$

$$\text{Substituting: } \% \text{ eff} = \frac{10 \text{ W}}{12 \text{ W}} \times 100$$

$$\text{Solving: } \% \text{ eff} = 83.3\%$$

SP#12-9.

Given: efficiency = 85%, primary power = 20 watts.

Find: secondary power.

$$\text{Formula: } \% \text{ eff} = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100$$

$$\text{Substituting: } 85\% = \frac{P_{\text{out}}}{20 \text{ W}} \times 100$$

$$\text{Rearranging: } P_{\text{out}} = \frac{85\% \times 20 \text{ W}}{100}$$

$$\text{Solving: } P_{\text{out}} = 17 \text{ watts}$$

SP#12-10.

Given: efficiency = 80%, secondary power = 25 watts

Find: primary power

$$\text{Formula: } \% \text{ eff} = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100$$

$$\text{Substituting: } 85\% = \frac{25 \text{ W}}{P_{\text{in}}} \times 100$$

$$\text{Rearranging: } P_{\text{in}} = \frac{25 \text{ W}}{85\%} \times 100$$

$$\text{Solving: } P_{\text{in}} = 29.4 \text{ watts}$$

Loaded and Unloaded

The loading of a transformer is determined by the amount of current flow in the secondary.

The transformer is considered unloaded if there is no current flow in the secondary. Voltage will still be developed in the secondary windings, but with no current flow, there is no power developed, therefore, efficiency is zero.

If the transformer is fully loaded, it is drawing a current in the secondary equal to an amount that would be produced by 100% efficiency. It is impossible for the transformer to ever reach a 100% fully loaded condition.

As the secondary current increases, toward maximum, the losses in the transformer will start to increase. The result of this increase in losses will cause the voltage of the secondary to decrease.

Practice Problems: Power and Efficiency

Use the given information to find the unknown values.

- Given: eff = 85%, primary power = 5 watts
Find: secondary power
- Given: eff = 80%, primary power = 6 mW
Find: secondary power
- Given: eff = 90%, secondary power = 10 watts
Find: primary power
- Given: eff = 75%, secondary power = 80 mW
Find: primary power
- Given: pri. power = 40 watts, sec. power = 36 watts

- Find: efficiency
6. Given: primary power = 100 mW, secondary power = 60 mW
Find: efficiency
 7. Given: sec. power = .08 watts, pri. power = 120 mW
Find: efficiency
 8. Given: primary voltage = 120 volts, primary current = 2 amps, secondary voltage = 60 volts,
efficiency = 80%
Find: secondary current
 9. Given: primary voltage = 80 volts, primary current = 1 amp, secondary voltage = 20 volts,
secondary current = 3 amps
Find: efficiency
 10. Given: primary voltage = 10 volts, primary current = 1 amp, secondary voltage = 80 volts,
secondary current = .1 amps
Find: efficiency

VARIATIONS OF TRANSFORMERS

There are many variations of the basic transformer. However, in all cases, current flowing in the primary develops a magnetic field. The magnetic field of the primary is coupled to the secondary, where it induces a voltage in the secondary and allows current to flow.

The various types of transformers to follow are representative of the wide range of possibilities.

Nonisolated Transformer

Figure 12-2 shows the schematic diagram of a nonisolated transformer. Notice, the bottom line, labeled ground, is common to both the primary and secondary.

This type of transformer has a very distinct disadvantage, if it is not clear which wire in the secondary is grounded, the hot wire might be connected to the metal chassis of the electric device. In an event like this, it does present a shock hazard.

To check if a transformer is a non-isolation type, use an ohmmeter. Connect one ohmmeter test lead

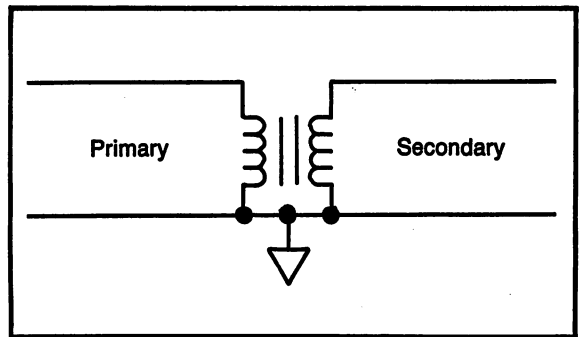


Fig. 12-2. Non-isolation transformer.

to one wire in the secondary. Touch the other ohmmeter test lead to the primary wires. Then check the other secondary wires in the same manner. If the ohmmeter shows any continuity between the primary and the secondary, it is a non-isolation type.

Isolation Transformer

Figure 12-3 shows the schematic diagram of an isolation transformer. Under normal conditions, most transformers are of the isolation type. A transformer manufactured in this manner has no connections between the primary and secondary, except the magnetic field.

The term "isolation transformer" can also refer to a transformer with a 1:1 turns ratio. This type of transformer does not step-up or step-down the voltage, it only provides isolation. Because of the fact that the line voltage available has one side grounded, there are often times when it is necessary not to have one side of the line grounded. The isolation transformer with a 1:1 turns ratio provides the same voltage as provided by the line, except that one side is not grounded.

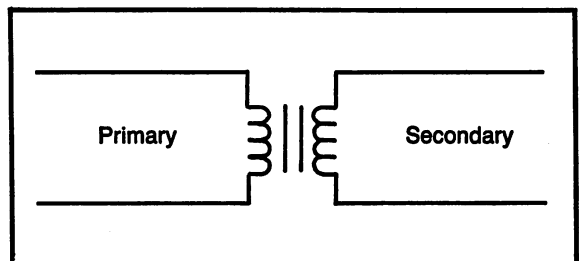


Fig. 12-3. Isolation transformer.

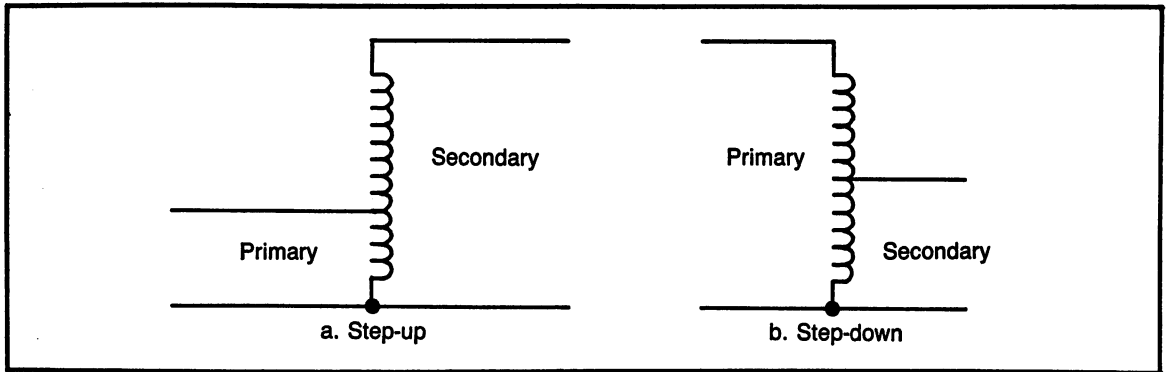


Fig. 12-4. Autotransformer.

Autotransformer

The autotransformer can be either step-up or step down, as shown in Fig. 12-4. This type of transformer uses only one coil of wire. Taps are made into the coil to provide the primary and secondary.

The autotransformer works the same way as any other transformer, with a magnetic field from the primary inducing a voltage in the secondary. The autotransformer is a nonisolation type.

Center-Tap Transformer

The schematic diagram of a center-tap transformer is shown in Fig. 12-5. With this type, the turns ratio is stated for the entire secondary. A wire tap is placed at the center of the transformer's secondary. This has the effect of providing three possible connections; 1) across the entire secondary, 2) from the top to the center, 3) from the bottom to the center.

The voltage available from one side to the center is $\frac{1}{2}$ of the full secondary voltage.

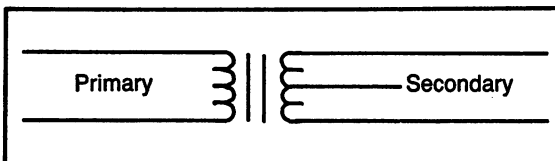


Fig. 12-5. Center-tap transformer.

Multi-Tap Secondary

The schematic diagram of a transformer with a multi-tap secondary is shown in Fig. 12-6. This

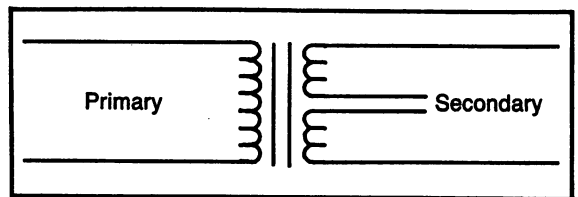


Fig. 12-6. Multi-tap secondary.

transformer has two secondaries, with only one primary. The secondary can be used as a center-tap by connecting the two windings together. By not connecting, the one primary can supply the two separate windings and they would remain completely separate, with only magnetism in common.

Multi-Tap Primary

A multi-tap primary is shown in Fig. 12-7. Although not shown, it is possible for the secondary to have any of the other combinations.

The multi-tap primary is used when it is necessary to have a device that can be wired to either of two voltages. Sometimes, when a device is manufactured, it is not known if it will be used on

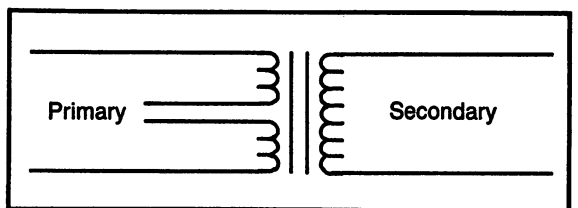


Fig. 12-7. Multi-tap primary.

120 volts or 240 volts. In this case, the multi-tap primary can be wired to either.

The secondary of the transformer will produce the same voltage with either voltage on the primary (assuming the wiring connections are made correctly). Since the secondary voltage is the same, the rest of the circuit will be the same, even though the input voltage can be different.

DC VOLTAGE WITH THE TRANSFORMER

To this point, the voltage applied to a transformer has been an ac sine wave. Other ac waveforms may be used with a transformer, but the transformer action may not permit the wave to have the exact same shape at the secondary, as it did at the primary.

A Changing Voltage is Necessary

When a voltage is to be induced by placing a wire in a magnetic field, it is necessary for the wire to be moving across the magnetic lines of force. The wire must be moving.

When a voltage is developed in an inductor, the voltage only has an effect when the voltage in the coil is changing.

With a transformer, it is necessary to have the changing voltage that is found with a sine wave. The sine wave has a continuously changing voltage. The continuously changing voltage of the sine wave produces the same effect as the wire moving through the lines of force of a magnet.

Therefore, the sine wave will cause a continuously changing magnetic field and will allow a voltage to be developed. The shape of the sine wave will be exactly the same at the secondary as it was at the primary.

Dc Voltages

A dc voltage is a constant voltage. The constant voltage will develop a magnetic field, but its magnetic field does not change. Since there is no change in the magnetic field, there cannot be any voltage induced in the secondary.

If a dc voltage is present at the same time as the ac voltage applied to the primary, the dc will

cause a certain portion of the magnetic field to remain at a fixed level. This is called "saturation" and results in a great deal of distortion. It is possible to have a dc voltage so strong that it will not allow the sine wave to induce any voltage in the secondary.

HANDS-ON TESTING OF TRANSFORMERS

Ohmmeter Testing

Testing a transformer with an ohmmeter prior to applying a voltage insures that there is continuity in the coils. In other words, the coils are good, with no breaks.

1. Set the ohmmeter to the $R \times 100$ scale. Connect the test leads to the primary. Note: the primary usually has two red wires. The reading should be low, with not more than a few hundred ohms. If the reading is high, the coil may be defective. If it is very high, the coil is open. A defective coil in a transformer cannot be fixed unless the break is in the heavier lead wire.

Primary.....(ohms)

2. Connect the ohmmeter to the secondary. Once again, it should be a low reading. If the secondary has more than two wires, be sure and check each wire.

Secondary.....(ohms)

3. Connect the ohmmeter leads from one of the primary wires to both of the secondary wires. The ohmmeter should read infinity, indicating there is no connection. Try this same measurement with the other primary wire.

Primary to secondary.....(ohms)

Voltage Tests

4. For this test, it is best if the transformer selected has an input voltage of 120 volts. If so, connect it directly to the ac line.

Use Caution.

Note: the primary is usually two red wires.

Use an ac voltmeter to measure the actual voltage present on the line, connected to the primary of the transformer. **Do not use the oscilloscope on the primary.**

Primary voltage.....(volts)

- With nothing else connected to the secondary of the transformer, connect the voltmeter to measure the secondary voltage.

Secondary voltage.....(volts)

- Based on the results of the voltage measurements, determine the turns ratio of the transformer being tested.

Turns ratio.....(pri : sec)

- Remove the voltage applied to the transformer and connect the resistors to the secondary, as a load. Then measure the voltage of the secondary. It is normal for the secondary voltage to decrease slightly with a larger current load, that

is; lower resistance. Caution: continuously check the transformer and resistor for heat, if either begins to heat up, discontinue testing. Use both an ac voltmeter and oscilloscope to measure the secondary voltage.

Secondary Voltage

| Load (ohms) | AC voltmeter (rms) | Oscilloscope (p-to-p) |
|-------------|--------------------|-----------------------|
| a) 47 k | | |
| b) 33 k | | |
| c) 22 k | | |
| d) 10 k | | |
| e) 1 k | | |

PROGRAMS FOR THIS CHAPTER

There is one program for this chapter. It contains problems in transformer ratios; turns, voltage, current and problems dealing with efficiency. Figure 12-8 shows a sample of the program.

```

                                TRANSFORMERS
                                SAMPLE PROGRAM:

NOTE: UNITS ARE GIVEN, JUST GIVE
THE NUMERIC VALUE.

GIVEN:

    TURNS RATIO = 10 TO 1
    PRIMARY VOLTAGE = 120 V
    SECONDARY VOLTAGE = ? V

3 .FIND THE UNKNOWN ? 12

                                *****
***** = NEXT, ***** = NEW SELECTION.

```

Fig. 12-8. Transformers program sample.

TRANSFORMERS COMPETENCY TEST

Part A. Definitions

Give a brief description of each of the following terms.

- (1) transformer
- (2) primary of a transformer
- (3) secondary of a transformer
- (4) transformer core (state the function)
- (5) magnetic coupling
- (6) name one of the transformer losses
- (7) transformer turns ratio
- (8) step-up transformer
- (9) step-down transformer
- (10) transformer efficiency

Part B. Transformer Ratios

Use the information given to find the unknown.

Note: all turns ratios are stated primary:secondary.

- (11) Given: turns ratio = 10:1
primary voltage = 100 v
Find: secondary voltage
- (12) Given: turns ratio = 6:1
secondary voltage = 18 v
Find: primary voltage
- (13) Given: turns ratio = 1:5
primary voltage = 12 v
Find: secondary voltage
- (14) Given: turns ratio = 1:8
secondary voltage = 160 v
Find: primary voltage
- (15) Given: turns ratio = 5:1
primary current = 1 amp
Find: secondary current
- (16) Given: turns ratio = 7:1
secondary current = 14 mA

- Find: primary current
(17) Given: turns ratio = 1:3
primary current = .6 amps
Find: secondary current

- (18) Given: turns ratio = 1:4
secondary current = 2 amps
Find: primary current

- (19) Given: primary voltage = 120 V
secondary voltage = 12 V
Find: turns ratio

- (20) Given: primary voltage = 30 V
secondary voltage = 270 V
Find: turns ratio

Part C. Transformer Efficiency

Use the information given to find the unknown.

Note: answers for efficiency must be in percent.

- (21) Given: efficiency = 85%
primary power = 6 watts
Find: secondary power
- (22) Given: efficiency = 80%
secondary power = 10 watts
Find: primary power
- (23) Given: primary power = 3 watts
secondary power = 2 watts
Find: efficiency (in percent)
- (24) Given: primary power = 10 watts
secondary power = 9 watts
Find: efficiency (in percent)
- (25) Given: primary voltage = 120 V
primary current = 2 amps
secondary voltage = 30 V
secondary current = 6 amps
Find: efficiency (in percent)

Chapter 13

Capacitors and Time Constants

Chapter Objectives: To learn the properties of capacitance and to learn how capacitors behave in series and parallel.

To plot and understand the universal time constant curve and examine the effects on inductors and capacitors as they charge and discharge.

To perform calculations with time constants and to apply time constants to RC waveshaping circuits.

Chapter Outline:

- Properties of Capacitance
- Capacitors in Parallel and Series
- Universal Time Constant Curve
- L/R Time Constant
- RC Time Constant
- RC Waveshaping
- Hands-On Practice: Time Constants and

Waveshaping

- Programs for This Chapter
- Capacitors and Time Constants Competency

Test

INTRODUCTION

The chapter will discuss two very important concepts; capacitance and time constants. Capacitance is a characteristic of electronic behavior and it is also an electronic component. A time constant is a method of measuring the effects of either an inductor or capacitor as it charges or discharges. The time constant has many practical applications in electronic circuitry.

PROPERTIES OF CAPACITANCE

The property of capacitance is the ability to store a charge, using conductors and an insulator.

Capacitors are one of the most commonly used components in electronics. Capacitors are used in such applications as: power supply filters, radio tuning circuit filters, electronic timers and timing circuits, waveshaping circuits, electronic flash for cameras, electronic ignition in automobiles, etc. Capacitors can be used in applications using dc or

ac voltages, and the size of the capacitors range from very small to very large.

Unit of Capacitance

The base unit of measure of capacitance is "farad", symbol F. The farad, as a base unit, is much too large for use in measuring practical capacitors. Capacitors will be measured in either microfarads (μF , 10^{-6}) or picofarads (pF , 10^{-12}). Millifarads (mF , 10^{-3}) and nanofarads (nF , 10^{-9}) are generally not used.

The actual size of a capacitor ranges from a small of about 1 pF, used in radio circuits, to a large of about 5000 μF , used as power supply filters.

Schematic Symbol of a Capacitor

When a capacitor is used in a schematic diagram, or in a formula, the symbol is C.

Figure 13-1 shows four different schematic symbols for the capacitor. It is important to note that the capacitor can be used with both ac and dc voltages. When it is used with ac, the capacitor must be nonpolarized. When the capacitor is used with dc, it is best to use one that is polarized.

If a capacitor is polarized, it works best when the positive is connected to the positive side and the negative connected to the negative side. Polarized capacitors can be manufactured with a higher value of capacitance. If a reverse voltage or ac is connected to a polarized capacitor, it could be destroyed.

A "disk" capacitor is the most common type, they are usually round and flat, small in size, $\frac{1}{8}$ to 1 inch in diameter and used for ac. An "electrolytic"

capacitor is the next most common type, they are fairly large physically, cylinder in shape, $\frac{1}{2}$ inch to several inches long and used for dc voltages. Other types of capacitors are made of various materials, each for different applications.

Electrolytic capacitors are a polarized capacitor that can be used only in dc circuits. They look like a small metal cylinder, with the polarity + or - marked at one end. It is essential that the electrolytic capacitor be connected properly and only in dc circuits. The main advantage of electrolytic capacitors is that they can be manufactured to have a small physical size, with a large value of capacitance. They also have a voltage rating of the maximum allowable voltage.

Figure 13-1A shows the schematic symbol of a nonpolarized capacitor. This symbol, with two straight parallel lines, is an older symbol that is now considered obsolete, although it is still used in some books and schematics. The same symbol is also used to represent switch contacts.

Figure 13-1B shows another non-polarized capacitor with the bottom line curved. This is the more accepted symbol for a nonpolarized capacitor.

Figure 13-1C is a polarized capacitor, using the same symbol as Fig. 13-1B, except the straight line is marked with a positive sign. Figures B and C are the most commonly used symbols.

Figure 13-1D is a symbol that is sometimes used to represent an electrolytic capacitor.

Forming Capacitance

In order to form capacitance, the only requirement is to have two conductors separated by an insulator. The amount of capacitance is determined

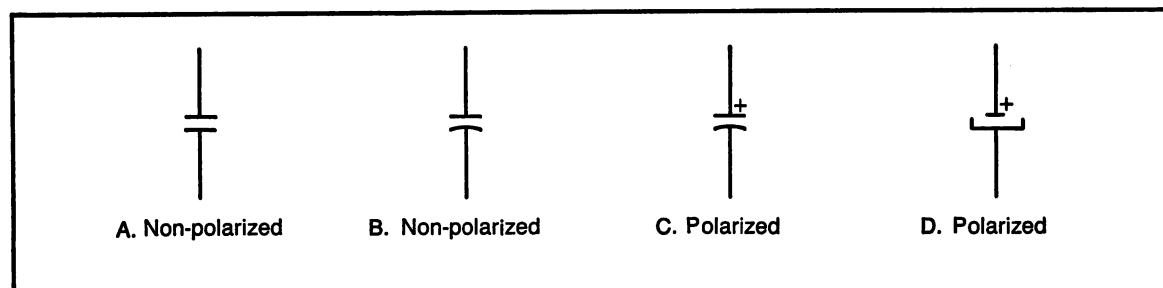


Fig. 13-1. Schematic symbols of capacitors, non-polarized and polarized.

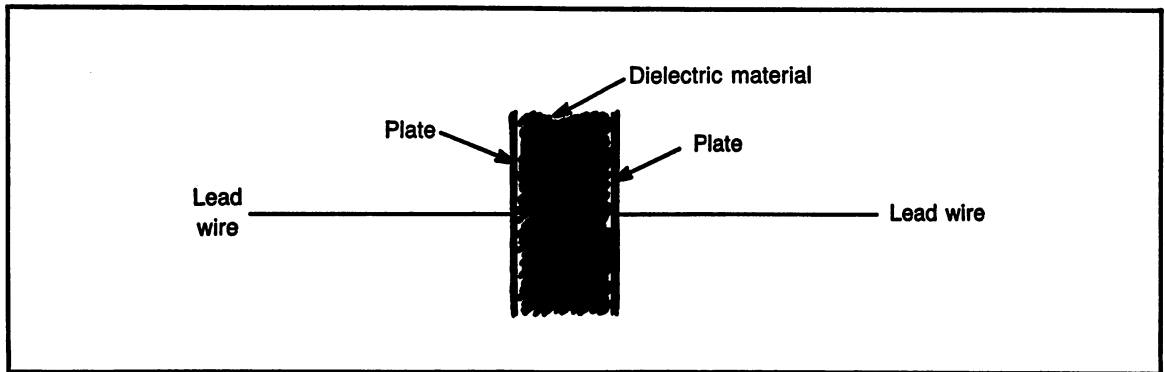


Fig. 13-2. A drawing of a capacitor, showing the plate area and dielectric material.

by the material's ability to store electrical energy.

To build relatively large amounts of capacitance, the size and materials of the conductors and insulator must be considered.

Figure 13-2 is a pictorial drawing of a capacitor. The conductors are not simply two pieces of wire. The lead wires are used to connect the capacitor to the circuit. The conductors of the capacitor are called plates. The plates are parallel to each other and because they are conductors, they provide electrons.

The insulating material of a capacitor is called the dielectric and is shown in Fig. 13-2. The dielectric serves two purposes, it keeps the conductors separated and stores the electrons.

Key Point. Larger value capacitance is produced by either a larger plate area or thinner dielectric.

Charging/Discharging a Capacitor

Figure 13-3 shows a simple dc circuit to demonstrate how a capacitor charges and discharges.

Figure 13-3A is drawn with the switch in the "off" position. No current flows in this circuit. The switch has three positions, "off", "a", and "b". The dc voltage source is shown as a 10 volt supply. The amount of voltage used here is of little importance; 10 volts was selected just to have a number to use. The capacitor shown is a polarized type to have a larger value capacitance. The resistor can be any value for this exercise. Later in this chapter, the actual values of capacitance and resistance will be discussed along with their effects.

In Fig. 13-3B, the switch is placed in position "a". With the switch in this position, the current path is around the outside of the drawing. Current will flow from the negative side of the battery, through the resistor, to the negative side of the capacitor. Since the capacitor plates are separated by a dielectric (insulator), current flow cannot pass through the capacitor. The negative plate and dielectric will collect electrons, giving the negative plate a negative charge.

The negative charge on the negative plate will produce a field, referred to as an electrostatic field, that will repel electrons from the positive side of the capacitor. At the same time, the positive side of the battery will draw electrons from the positive side. Therefore, for every electron that goes to the negative plate, there will be an equal number of electrons that leave the positive plate. This is called "charging the capacitor."

As current flows to charge the capacitor, a voltage will develop across the capacitor. If the charge process is allowed to continue for a long enough period of time, the capacitor will reach a voltage equal to the applied voltage. When the voltage across the capacitor reaches the applied voltage, there will no longer be any current flow because there is no difference in potential between the applied voltage and the capacitor voltage.

The actual amount of current flowing during charge is determined by the difference in voltage between the battery and the capacitor and the amount of resistance in the circuit.

Figure 13-3C, the switch is moved to the "off"

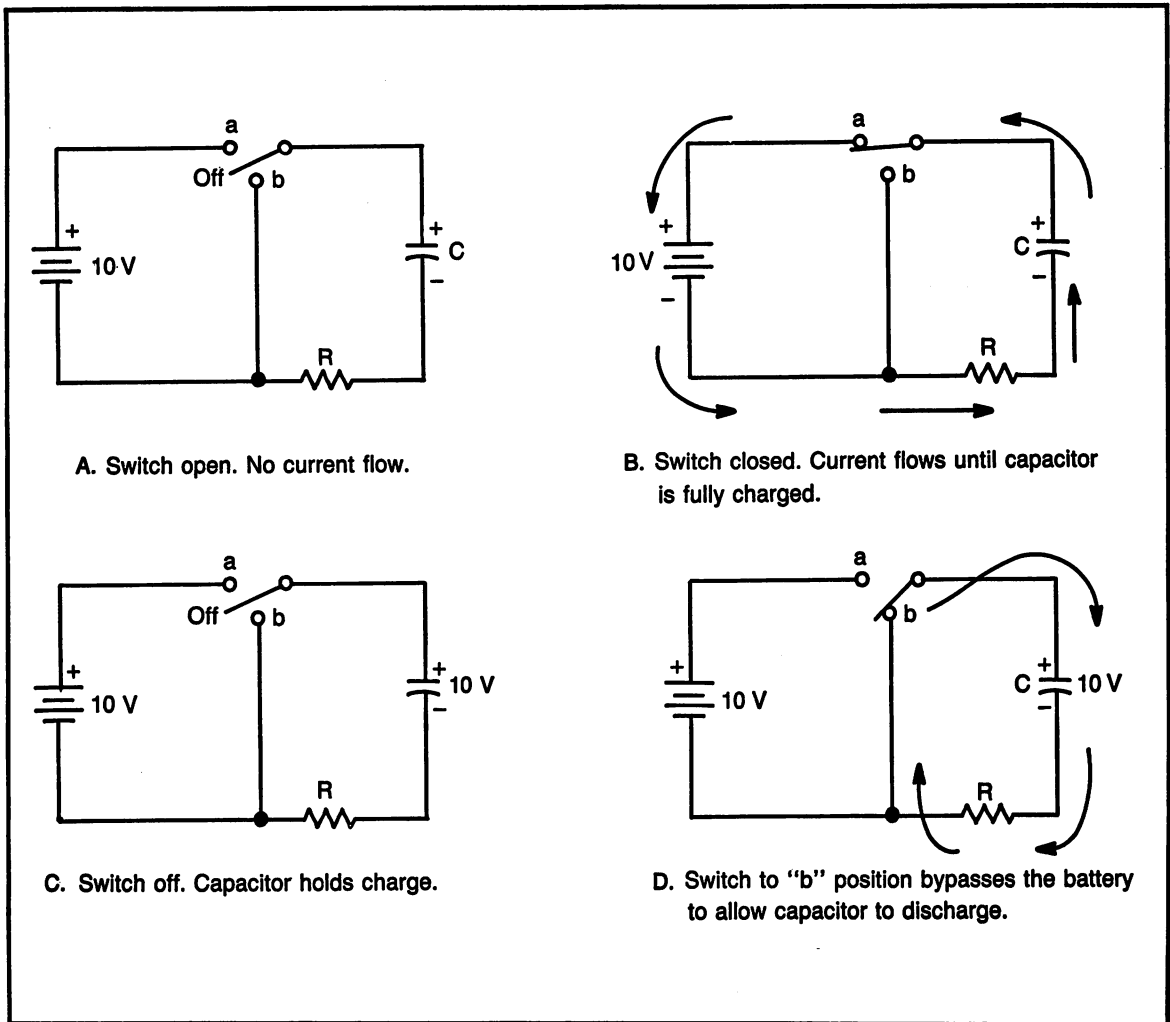


Fig. 13-3. A simple dc circuit to how how a capacitor charges, stores voltages, and discharges.

position again. The circuit now has no current path, either for the battery or for the capacitor. The circuit in this position does not allow the capacitor to equalize the excess of electrons on one side and the lack of electrons on the other side. The capacitor will remain charged until a path is provided for the electrons to flow from one side to the other. In actual practice, the dielectric will leak somewhat and allow the plates to eventually equalize themselves. A good quality electrolytic capacitor can hold a charge for long periods of time, even days.

Figure 13-3D shows the switch moved to the "b" position. In this position, the battery is not in

the circuit at all. The capacitor will supply voltage and current flow to the resistor, through the switch contacts. Current will flow from the negative side of the capacitor to the positive side. As the electrons flow, the charge across the capacitor will decrease until there is no longer a difference between the two plates.

Current flow during discharge is determined by the voltage on the capacitor and the resistance in the circuit.

Notice, the direction of current flow, in relation to the capacitor, is opposite during charge and discharge.

Due to the fact that the charge and discharge of a capacitor does not happen instantly, the voltage across the capacitor cannot change instantly.

Key Point. A capacitor opposes any change in voltage.

CAPACITORS IN PARALLEL AND SERIES

Capacitors, like resistors and other components, can be connected in series and parallel. There are different reasons for wanting to do this, such as; changing the value of the component or improving the voltage or current capabilities.

Capacitors in Parallel

Figure 13-4 shows two capacitors connected in parallel. With the capacitors connected in this way, the two positive plates and the two negative plates will both receive the same charge.

The parallel connection has the effect of increasing the plate area. An increase in plate area will produce a larger capacitance. Therefore, the values of the capacitors are simply added as in the following formula:

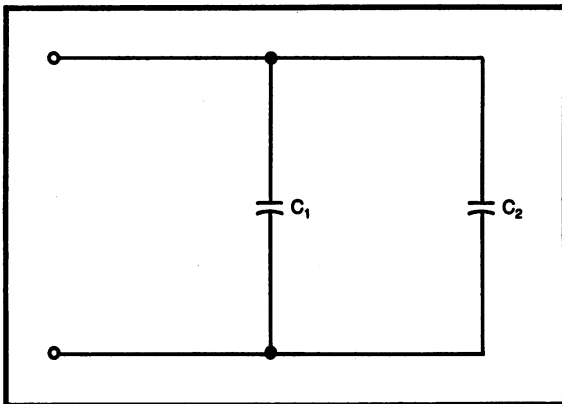


Fig. 13-4. Two capacitors connected in parallel.

Formula #31. Capacitors in Parallel

$$C_T = C_1 + C_2 + C_3 + \dots$$

When capacitors are connected in parallel, the result, in addition to the values adding, is an increase in current capability. Because they are connected in parallel, they both receive the same applied volt-

age. Each capacitor will store a charge of electrons based on its own capacitance value. The current capacity is also based on the capacitance value since that is what determines the amount of electrons stored.

Batteries that are connected in parallel will have the same resultant effect as capacitors in parallel. For example, if two flashlight batteries are connected in parallel, the voltage will still be 1.5 volts, but the total current capability will be double. For example, if each battery could supply current to light a bulb for 3 hours, two of these in parallel would supply current to the same light for 6 hours.

Capacitors in Series

Figure 13-6 shows two capacitors connected in series. When capacitors are connected in this manner, the net result is reduced capacitance. The result can be calculated using the reciprocal formula, the same formula used by resistors in parallel.

Formula #32. Capacitors in Series

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots$$

Figure 13-6 shows how the electrons flow in a circuit with two capacitors in series.

The charge or discharge of capacitors in series is similar to that of a single capacitor. When the electrons leave the negative side of the battery, during charge, they are collected to the negative plate of the closest capacitor. The positive side of the battery will attract electrons from the positive plate of the capacitor closest to that battery terminal. As elec-

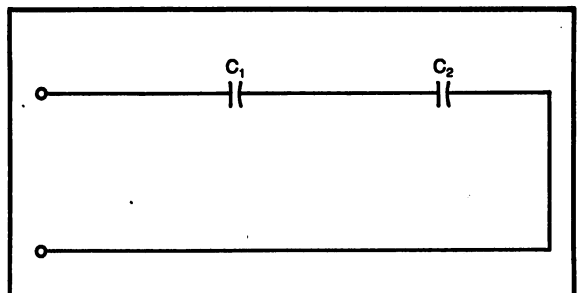


Fig. 13-5. Two capacitors connected in series.

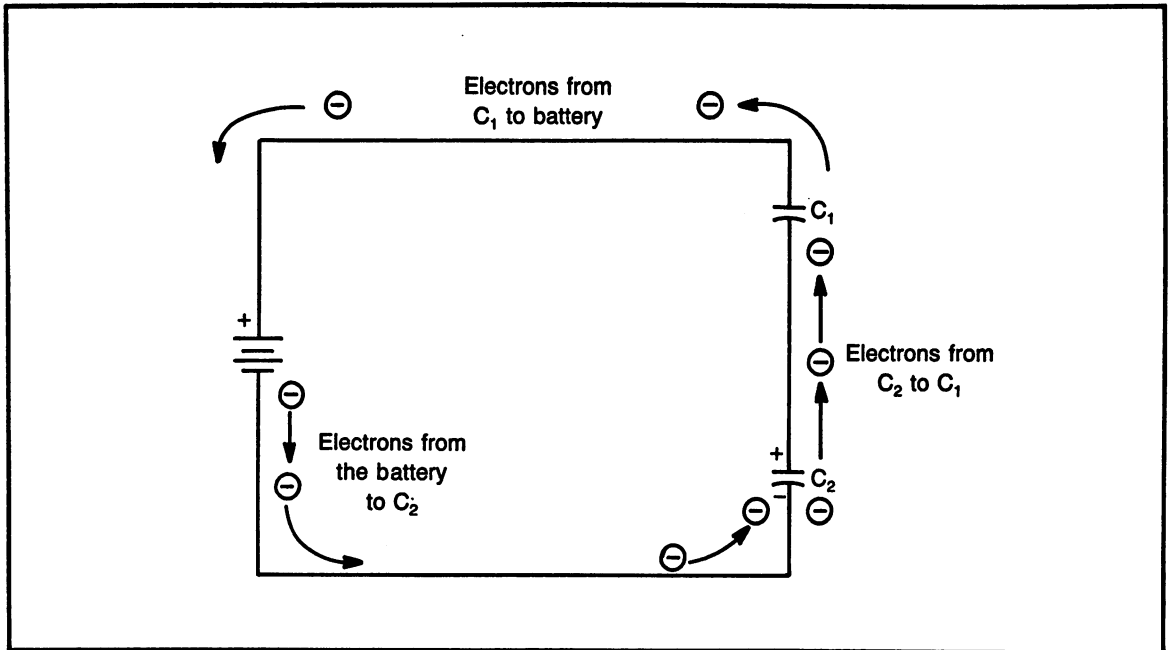


Fig. 13-6. Circuit showing the electron flow with two capacitors in series.

trons are collected on one plate and removed from another plate, there is an electro-static field developed that will allow the plates that are on the "inside of the circuit" to equalize themselves according to the charge on their own capacitor. As a result, both capacitors will charge, but the voltage developed across each depends on the actual capacitance value. Capacitor voltage dividers will explain this point in further detail.

Capacitor Voltage Dividers

A capacitive voltage divider is a circuit with capacitors in series. Figure 13-7 shows two capacitive voltage divider circuits. A capacitive voltage divider can be used to distribute the voltage in a dc circuit.

Notice in Fig. 13-7A, the two capacitors have the same value, therefore they have the same voltage dropped across them. In Fig. 13-7B, the capa-

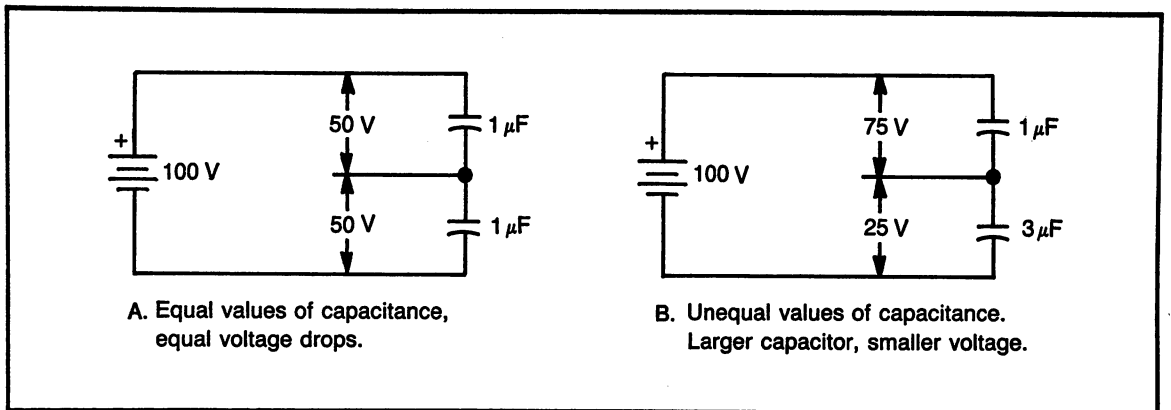


Fig. 13-7. Capacitive voltage dividers.

capacitors have different values. Notice in particular, the larger value capacitor has the smaller voltage drop.

The voltage drop across a capacitor in a voltage divider can be calculated based on a ratio between the opposite capacitor and the total capacitance, as follows:

Formula #33. Capacitive Voltage Divider

$$V_{C1} = \frac{C_2}{(C_1 + C_2)} \times V$$

$$V_{C2} = \frac{C1}{(C_1 + C_2)} \times V$$

V_{C1} is the voltage across C_1 .

V_{C2} is the voltage across C_2 .

V is the voltage applied to the voltage divider.

Calculations for V_{C1} in Figure 13-7B

$$\text{Formula: } V_{C1} = \frac{C_2}{(C_1 + C_2)} \times V$$

$$\text{Substituting: } V_{C1} = \frac{3 \mu\text{F}}{(1 \mu\text{F} + 3 \mu\text{F})} \times 100\text{v}$$

$$\text{Simplifying: } V_{C1} = \frac{3}{4} \times 100\text{v}$$

$$\text{Solving: } V_{C1} = 75 \text{ volts}$$

Calculations for V_{C2} in Figure 13-7B

$$\text{Formula: } V_{C2} = \frac{C_1}{(C_1 + C_2)} \times V$$

$$\text{Substituting: } V_{C2} = \frac{1 \mu\text{F}}{(1 \mu\text{F} + 3 \mu\text{F})} \times 100\text{v}$$

$$\text{Simplifying: } V_{C2} = \frac{1}{4} \times 100\text{v}$$

$$\text{Solving: } V_{C2} = 25 \text{ volts}$$

PRACTICE PROBLEMS: CAPACITANCE

Part A. Parallel Capacitance

Determine the total capacitance of the following capacitors connected in parallel.

- (1) $1 \mu\text{F}$ and $3 \mu\text{F}$
- (2) 5 pF and $.001 \mu\text{F}$ and 10 pF
- (3) $0.01 \mu\text{F}$, $0.001 \mu\text{F}$, $0.22 \mu\text{F}$
- (4) $47 \mu\text{F}$, $47 \mu\text{F}$, $47 \mu\text{F}$
- (5) $500 \mu\text{F}$, $100 \mu\text{F}$, $200 \mu\text{F}$, $300 \mu\text{F}$, $400 \mu\text{F}$

Part B. Series Capacitance

Determine the total capacitance of the following capacitors connected in series. Also, use the supply voltage given to determine the voltage drops across each capacitor.

- (6) $C1 = 1 \mu\text{F}$, $C2 = 2 \mu\text{F}$, $V = 10 \text{ volts}$
- (7) $C1 = 5 \text{ pF}$, $C2 = 10 \text{ pF}$, $V = 10 \text{ volts}$
- (8) $C1 = 0.01 \mu\text{F}$, $C2 = 0.1 \mu\text{F}$, $V = 5 \text{ volts}$
- (9) $C1 = 10 \mu\text{F}$, $C2 = 10 \mu\text{F}$, $V = 15 \text{ volts}$
- (10) $C1 = 0.1 \mu\text{F}$, $C2 = 0.2 \mu\text{F}$, $V = 20 \text{ volts}$

UNIVERSAL TIME CONSTANT CURVE

The time constant is a means of calculating the voltage that will be developed across a capacitor or inductor during either charge or discharge.

A universal time constant curve can be calculated and plotted based on the fact that the charge and discharge pattern will always be the same.

In order to make matters as simple as possible, time constants are always considered for only dc voltages.

Definition of a Time Constant

Key Point. One time constant is defined as the time required to reach 63% of full charge or discharge.

Key Point. Five time constants are defined as the time required to reach full charge or discharge.

The definitions for time constants apply to both inductors and capacitors. Keep in mind, when a dc voltage is applied to an inductor, the current will start to flow in the coil and it will begin to develop a magnetic field. With a capacitor, the current flow will store a charge of electrons. Inductors oppose a change in current, capacitors oppose a change in voltage. In either case, the energy being stored, the magnetic field or the electrons, does not develop instantly. The time required to develop the stored energy is the time constant.

Based on the definition of time constants, the universal time constant curve is developed, see Fig. 13-8. The calculations for this graph will be presented in a moment. Notice there are two curves; charge and discharge. The horizontal base line is labeled in time constants. Note: actual time is determined by the circuit conditions. The vertical axis is labeled in percentage of full charge. Note: actual voltage along the curve is based on the circuit conditions.

Plotting the Charge Curve

Calculating the values along different points along the curve can be performed using two methods:

Method 1. Based on the definition that one

time constant is 63% of full charge, it is possible to calculate each of the five time constants in a full charge. The disadvantage of this method is the fact that the 63% is actually an approximation and it can be used only with whole number time constants (1, 2, 3, 4, 5).

Method 2. Calculations can also be made using the instantaneous charging formula, which will be demonstrated later.

Both methods of calculations will be presented. A summary of the results of these calculations can be found in Table 13-1.

The following are the calculations to plot the charge curve based on one time constant being 63%. Results are summarized in Table 13-1 and dots are shown on the curve in Fig. 13-8.

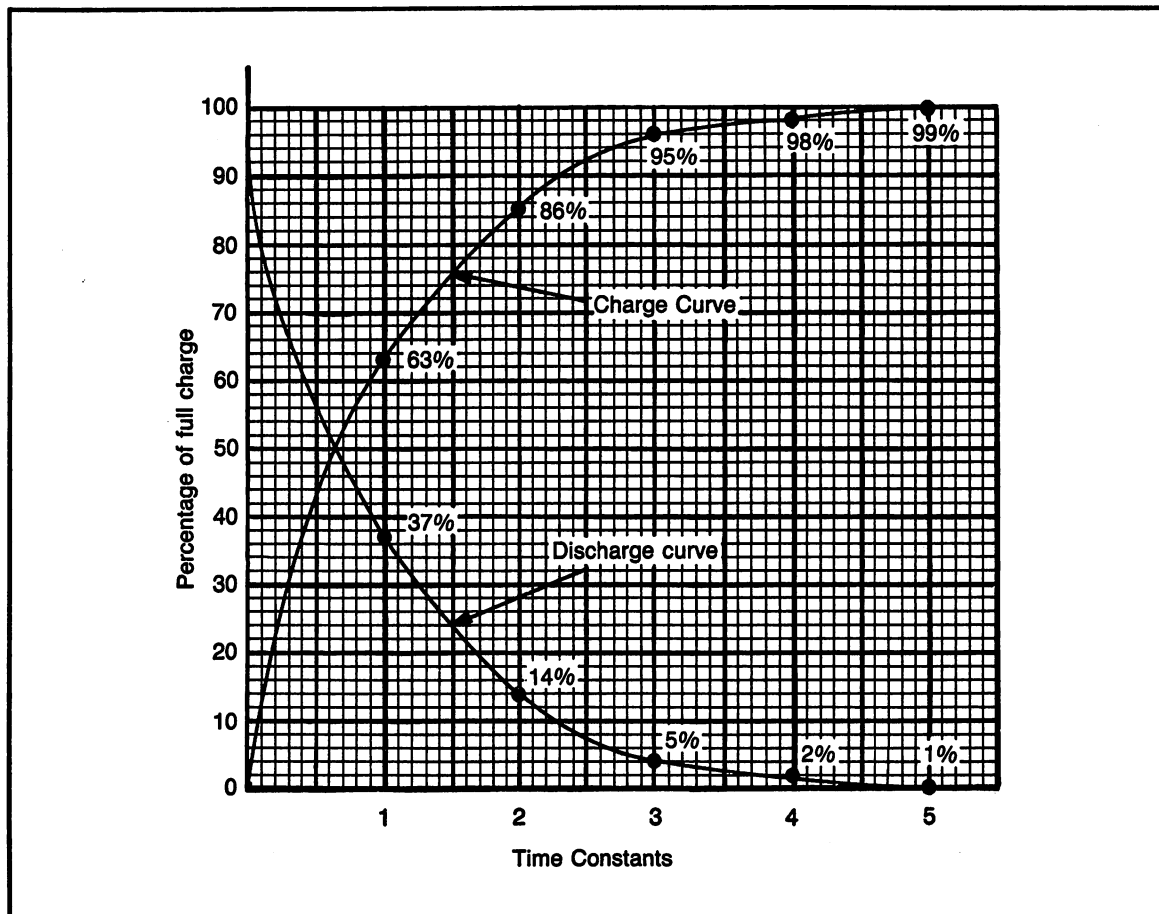


Fig. 13-8. Universal time constant curve.

Table 13-1. Plotting the Universal Time Constant Curve.

| | Percent of Full Charge | | | |
|---------|------------------------|--------|-------------|--------|
| | CHARGING | | DISCHARGING | |
| Time C. | 63% | Instan | 63% | Instan |
| 0 | 0% | 0% | 100% | 100% |
| 1 | 63% | 63.2% | 37% | 36.8% |
| 2 | 86% | 86.5% | 14% | 13.5% |
| 3 | 95% | 95.0% | 5% | 5.0% |
| 4 | 98% | 98.2% | 2% | 1.8% |
| 5 | 99% | 99.3% | 1% | 0.67% |

Plotting the Charge Curve with Time Constants

- (0) Time 0 is considered the starting point. At this moment, the switch is closed and the circuit receives the applied voltage. Current begins flowing.
- (1) First time constant. 63% of the full charge has been completed, leaving 37%.
- (2) Second time constant. Since this has a time of one time constant, the charge during this time will be 63% of the charge remaining, 37%. Therefore, during this time constant, there will be 23% of the charge ($.63 \times .37 = .23$). If this portion of the charge is added to the first time constant (63% + 23%), the charge so far will be 86% with 14% remaining.
- (3) Third time constant. This time constant will allow 63% of the amount remaining, 14%. Therefore, during this portion of the charge curve will be 9% of the total charge ($.63 \times .14 = .09$). After completion of the third time constant, there is 5% of the full charge remaining (63% + 23% + 9% = 95%).
- (4) Fourth time constant. This time constant will charge 63% of the charge remaining, 5%. During this portion of the charge will be 3% of the total amount ($.63 \times .05 = .03$). After completion of this time constant, there will be 2% of the full charge remaining (63% + 23% + 9% + 3% = 98%).
- (5) Fifth time constant. Again, 63% of the remaining will be charged ($.63 \times .02 = .01$). This portion brings the completed charge to within 1% of the applied voltage. This is considered

full charge because it is necessary to take into account that circuit losses will not allow the charged voltage to ever reach the applied voltage.

Charge Curve with Instantaneous Values

Analysis of the charge curve using instantaneous values is considerably more accurate than only at the points of a time constant.

Plotting the curve using the time constants is acceptable because it does provide enough points to determine the shape of the curve. If the voltage at a certain point in time is desired, it can be found reasonably close using the curve.

If it is necessary to determine the exact value of charge at any point in time, calculate it using the instantaneous charge formula:

Formula #34. Instantaneous Charging Voltage

$$\% \text{ of full charge} = (1 - e^{-T}) \times 100\%$$

e is the natural log.

T is the time constant.

This formula can be used for any point along the charge curve. It is not necessary to use whole numbers as the time constant.

The following is a sample calculation showing how to use the formula. Results in Table 13-1 are for each of the five time constants. The sample calculation is performed for 1 time constant.

Example of Instantaneous Charge Voltage

Formula: $\% \text{ charge} = (1 - e^{-T}) \times 100\%$

Substituting: $\% = 1 - e^{-1} \times 100\%$

Simplifying: $\% = (1 - .368) \times 100\%$

Simplifying: $\% = .632 \times 100\%$

Solving: $\% \text{ of full charge} = 63.2\%$

The advantage of using this formula is the fact that it will find the value of any point along the curve. The disadvantage is that it is more difficult to use and harder to remember than the 63% method.

Plotting the Discharge Curve Using 63%

- (0) At time zero, the discharge is about to start. At this time it is considered a full charge,

regardless of the voltage present. Current starts to flow allowing the discharge to begin.

- (1) First time constant. 63% of the voltage has now been discharged, leaving 37% of the full charge.
- (2) Second time constant. 63% of the remaining will be discharged here. 23% of the complete discharge occurs during this period ($.63 \times .37 = .23$), leaving the remaining charge at 14% of the starting point ($100\% - [63\% + 23\%] = 14\%$).
- (3) Third time constant. ($.63 \times .14 = .09$). Charge remaining after the third time constant is 5% ($100\% - [63\% + 23\% + 9\%] = 5\%$).
- (4) Fourth time constant. ($.63 \times .05 = .03$). Charge after the fourth time constant is 2% ($100\% - [63\% + 23\% + 9\% + 3\%] = 2\%$).
- (5) Fifth time constant. Less than 1 percent remains to be discharged, therefore, this is considered fully discharged.

Discharge Curve with Instantaneous Values

The discharge curve can also be calculated using an exponential formula. This method produces very accurate results and it is possible to make the calculations of instantaneous values at any point along the discharge curve. The formula is as follows:

Formula #35. Instantaneous Discharge Voltage

$$\% \text{ of full charge} = e^{-T} \times 100\%$$

Example of Instantaneous Discharge Voltage:

Sample is for second time constant.

Formula: $\% = e^{-T} \times 100\%$

Substituting: $\% = e^{-2} \times 100\%$

Simplifying: $\% = .135 \times 100\%$

Solving: $\% = 13.5\%$ remaining after 2 time constants

L/R TIME CONSTANT

The L/R time constant is used when there is an inductor in the circuit. The actual circuit values will determine the length of time for an inductor to charge or discharge. Keep in mind, when an induc-

tor charges, current flows through the coil of wire and a magnetic field is developed. Building of the magnetic field to full strength does take an amount of time.

Calculating the L/R Time Constant

The definition of one time constant is 63% of full charge. The actual length of time of one time constant depends on the values of inductance and resistance in the charge and discharge paths.

Formula #36. L/R Time Constant

$$T = \frac{L}{R}$$

T is time in seconds of one time constant

L is inductance in Henrys

R is resistance in Ohms

Figure 13-9 is an inductive circuit to be used to demonstrate use of the L/R time constant. Notice in Fig. 13-9, there are two paths for current to flow. The current paths are in opposite directions and labeled charge and discharge.

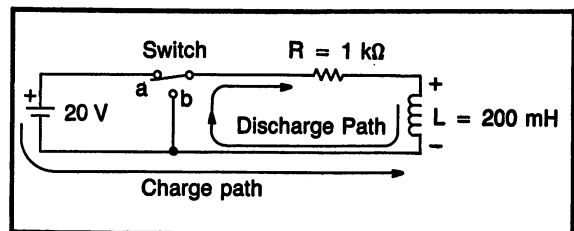


Fig. 13-9. A circuit to demonstrate the L/R time constant.

The charge path of the inductor in Fig. 13-9 is from the negative side of the battery, through the inductor, through the resistor, through the switch in position "a", and return to the positive side of the battery. Notice, the inductor is labeled with a polarity. This shows the polarity of the magnetic field in relation to the charging voltage.

To calculate the value of a time constant in this circuit, use the circuit values as follows:

$$\text{Formula: } T = \frac{L}{R}$$

$$\text{Substituting: } T = \frac{200 \text{ mH}}{1 \text{ kilohm}}$$

$$\text{Solving: } T = .2 \text{ ms}$$

$$\text{One time constant} = .2 \text{ ms}$$

$$\text{Five time constants} = 1 \text{ ms (full charge)}$$

This circuit, like all circuits, follows the universal time constant curve. Knowing the value of one time constant provides the curve with a relationship to actual time.

After a period of 1 ms, five time constants, the inductor is fully charged. If voltage is applied after this time, the charge current will be limited by only the resistor. This full charge current can be calculated using Ohms' law, as follows:

$$\text{Formula: } I = \frac{V}{R}$$

$$\text{Substituting: } I = \frac{20 \text{ v}}{1 \text{ kilohm}}$$

$$\text{Solving: } I = 20 \text{ mA}$$

The current flowing after full charge is reached, will remain constant as long as the voltage is applied. If the switch is placed in position "b", the charging voltage is removed and a discharge path is provided.

The magnetic field needs a path to release its energy. The discharge of energy will be opposite the charge path because it must flow from negative to positive of the polarity on the inductor. The circuit shown in Fig. 13-9 has the same value resistance in both the charge and discharge paths. The time constant for charge and discharge will be the same since the value of resistance is the same.

Different Charge and Discharge Resistances

Figure 13-10 is an inductive circuit with different values of resistance in the charge and discharge

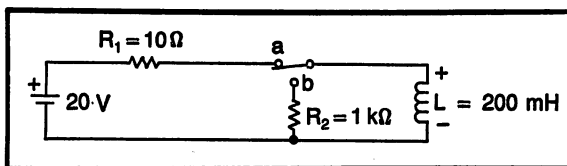


Fig. 13-10. An inductive circuit with different time constants for charge and discharge.

paths. Having the different values of resistance allows for a different time constant for both charge and discharge.

The time constant for charge is:

$$\text{Formula: } T = \frac{L}{R}$$

$$\text{Substituting: } T = \frac{200 \text{ mH}}{10 \text{ Ohms}}$$

$$\text{Solving: } T = 20 \text{ ms (charge)}$$

The time constant for discharge is:

$$\text{Formula: } T = \frac{L}{R}$$

$$\text{Substituting: } T = \frac{200 \text{ mH}}{1000 \text{ Ohms}}$$

$$\text{Solving: } T = .2 \text{ ms (discharge)}$$

Notice that the time constant of an inductive circuit is lowered by a larger value resistance. Keep in mind, the full period of time for charge or discharge is 5 time constants.

When the discharge resistance is larger than the charge resistance, a voltage larger than the supply voltage will develop across the discharge resistor.

Charging current for Fig. 13-10 can be calculated as follows:

$$\text{Formula: (Ohm's law) } I = \frac{V}{R}$$

$$\text{Substituting: } I = \frac{20 \text{ volts}}{10 \text{ Ohms}}$$

$$\text{Solving: } I = 2 \text{ amps}$$

The current calculated is after full charge of at least 100 ms. ($5 \times 20\text{ms}$). If, after full charge is reached, the switch is moved from the charging position "a" to the discharge position "b", the magnetic field of the inductor will try to maintain the same amount of current flow.

During discharge, the magnetic field, of the inductor, will supply current to resistor R_2 . The amount of current flow during discharge starts at the maximum charge current and drops at a rate following the universal time constant curve.

The discharge current will cause a voltage drop across the discharge resistor equal to an amount as calculated by Ohm's law, as follows:

Formula: (Ohm's law) $V = I \times R$
 Substituting: $V = 2 \text{ amps} \times 1 \text{ kilohm}$
 Solving: $V = 2,000 \text{ volts}$

The calculated 2,000 volts is an instantaneous voltage developed for a very short period of time at the start of discharge.

High Voltage Developed By Opening an L/R Circuit

Figure 13-11 shows a representational diagram of the older-type ignition system of an automobile. R_1 represents the dc resistance of the ignition coil, L is the ignition coil, the switch is the points contacts, R_2 represents the resistance of the spark plug gap. This figure is only for the purpose of understanding circuit concepts.

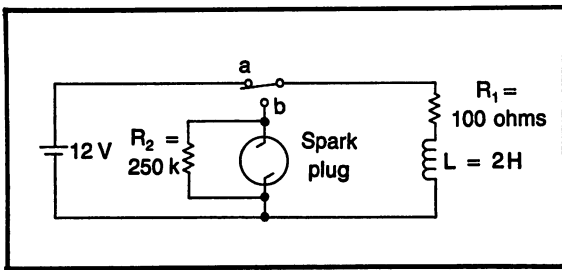


Fig. 13-11. High voltage developed by opening an R-L circuit.

As we know, there must be an extremely large voltage developed across the spark plug in order to cause a spark to jump the gap. To determine how much voltage will be developed; first, calculate the full charge current, second, use the charge current, with Ohm's law, to calculate the discharge voltage developed.

Charge current:

$$\text{Formula: } I = \frac{V}{R}$$

$$\text{Substituting: } I = \frac{12 \text{ volts}}{100 \text{ Ohms}}$$

$$\text{Solving: Full charge current} = .12 \text{ amps}$$

Voltage developed:

$$\text{Formula: } V = I \times R$$

$$\text{Substituting: } V = .12 \text{ amps} \times 250 \text{ kilohms}$$

$$\text{Solving: } V = 30,000 \text{ volts}$$

The principle of a high voltage developed when opening an inductive circuit must be taken into consideration when wiring such devices as large electric motors. A large electric motor has a very large inductor for its windings. When the power is switched off, a large voltage will be produced across the switch. When this happens, a spark will jump across the switch contacts. A situation like this can cause severe damage to the switch. A capacitor can be placed in parallel with the switch contacts to absorb the spark.

RC TIME CONSTANT

In the field of electronics, when the term "time constant" is used, it will usually bring to a technician's mind a circuit with a resistor and capacitor. Although a capacitor is used in applications other than just time constant circuits, the time constant is a very important application.

The universal time constant curve applies to capacitive circuits as well as it does to inductive circuits. The definitions of 1 time constant is 63% of full charge (or discharge). Full charge or discharge is reached after a period of 5 time constants.

Formula #37. RC Time Constant

$$T = R \times C$$

T is 1 time constant in seconds
 R is resistance in Ohms
 C is capacitance in farads

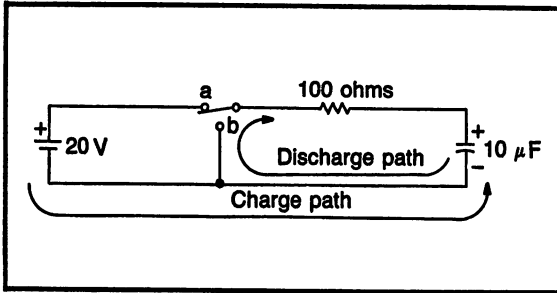


Fig. 13-12. A circuit to demonstrate the R-C time constant.

Figure 13-12 shows a circuit to demonstrate the principle of the RC time constant. This circuit has the same value resistance for both the charge and discharge paths, therefore, the same value of time constant for both charge and discharge.

When the switch is placed in position “a”, the capacitor is allowed to charge. Along with the circuit resistance, the charge current is determined by the difference between the applied voltage and the capacitor’s voltage. Initially, the charge current is highest, determined by only circuit resistance. As the charge continues, the current will decrease.

As a capacitor stores electrons, a voltage is developed across the capacitor terminals. The full charge voltage will be equal to the applied voltage.

Time constant of Fig. 13-12:

Formula: $T = R \times C$

Substituting: $T = 100 \text{ Ohms} \times 10 \mu\text{F}$

Solving: $T = 1000 \mu\text{s}$ or 1 ms

Full charge = 5 ms

Notice that in Fig. 13-12, the discharge path has the same value resistance. Current flow during discharge is opposite to the current flow during charge.

High Current by Shorting a Capacitor

The electronic flash units used with modern cameras require a high amount of current for a very short period of time. Shorting a charged capacitor is the method used to produce this high current even though small batteries are used in the flash unit.

Figure 13-13 is a representative schematic dia-

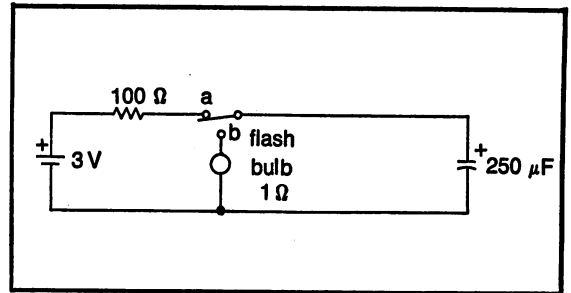


Fig. 13-13. Schematic for an electronic flash unit in a camera.

gram of an electronic flash unit. The battery shown has 3 volts. This represents two “AA” batteries (which are the most commonly used size). The 100 ohm resistor is only in the charge path. It is used to limit the current drain from the batteries. Changing the size of this resistor will affect the battery’s current drain, during charge, and the amount of time required to charge the capacitor each time the flash is fired. The size of the capacitor is limited by the physical size of the flash unit.

When the capacitor is fully charged, it will have 3 volts across it. When discharged, the capacitor will discharge through the 1 Ohm flash bulb, which produces a current of 1 amp (using Ohm’s law). This high current can be produced for only a very short period of time. The capacitor will be fully discharged in only 1.25 ms, but the flash bulb will produce a very high intensity light from the high current for the short period of time.

Practice Problems: Time Constants

Use the schematic diagrams in Figs. 13-14 to 13-23 to solve the following time constant problems:

Part A. Inductive time constant circuits.

In problems 1 through 5, find:

- a. one time constant during charge
- b. full charge time
- c. full charge current
- d. one time constant during discharge
- e. full discharge time
- f. voltage developed at first instant of discharge

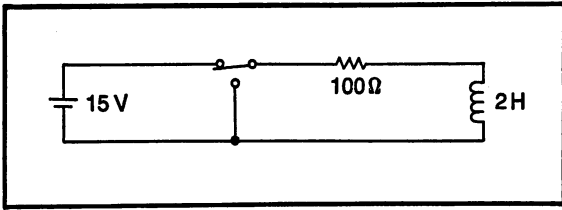


Fig. 13-14. Problem 1.

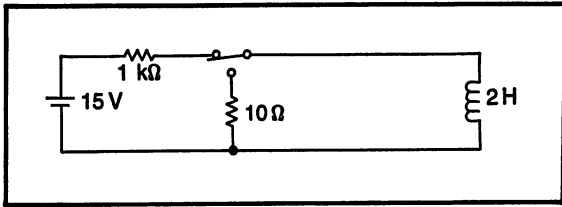


Fig. 13-15. Problem 2.

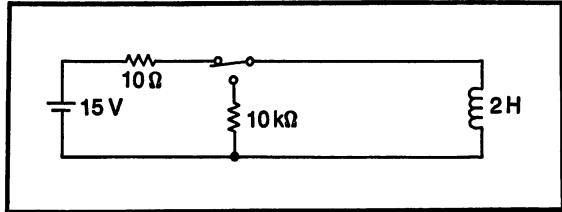


Fig. 13-16. Problem 3.

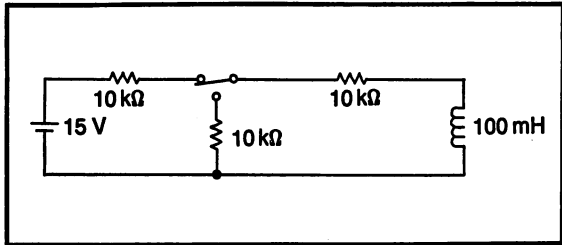


Fig. 13-17. Problem 4.

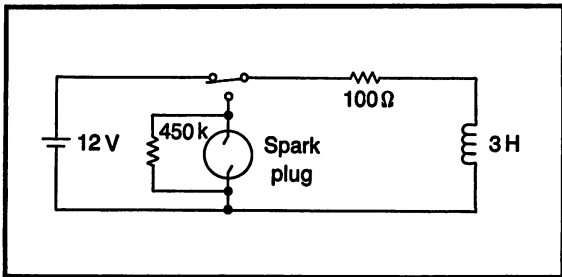


Fig. 13-18. Problem 5.

Part B. Capacitive time constant circuits.

In problems 6 through 10, find:

- one time constant during charge
- full charge time
- full charge voltage
- one time constant during discharge
- full discharge time
- current developed at first instant of discharge

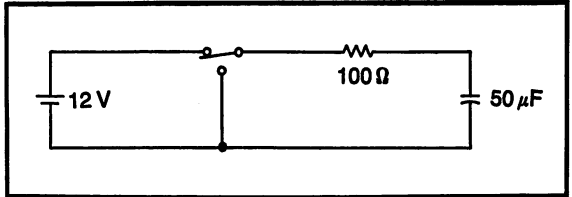


Fig. 13-19. Problem 6.

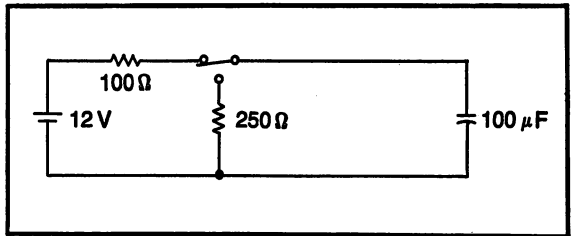


Fig. 13-20. Problem 7.

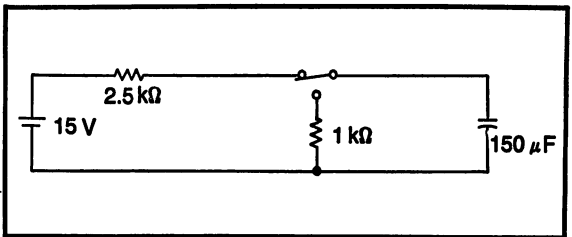


Fig. 13-21. Problem 8.

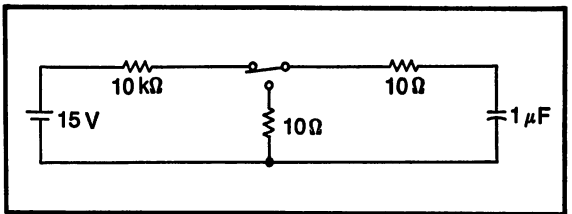


Fig. 13-22. Problem 9.

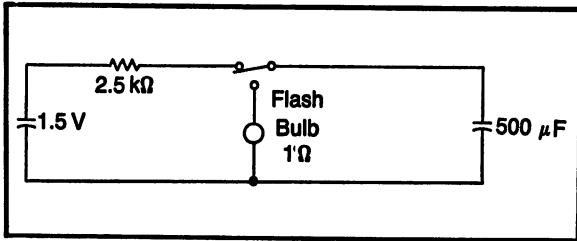


Fig. 13-23. Problem 10.

RC WAVESHAPING

Waveshaping circuits are a useful application of the RC time constant. Waveshaping with a square wave presents a very dramatic application to show the effects of capacitor action and time constants.

Differentiation and Integration

Differentiation and integration are words used to label the series RC circuits used in waveshaping. The only difference between the two circuits is where the output is taken from. Although it is possible to use any type of waveform, a square wave is usually used. The results with a square wave are more pronounced and easier to predict. The square waves used are a type that will switch from zero to a positive peak, this makes calculations much easier.

A differentiator is identified as having the output taken across the resistor, as shown in Fig. 13-24. An integrator is identified as having the output taken across the capacitor, as shown in Fig. 13-25.

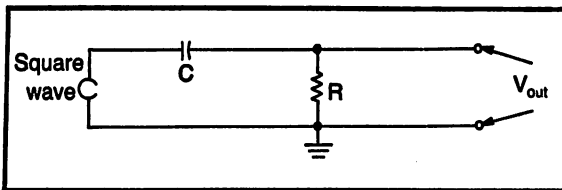


Fig. 13-24. Differentiator.

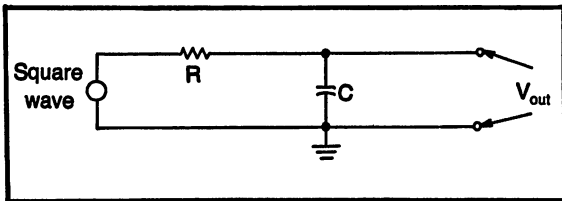


Fig. 13-25. Integrator.

A differentiator usually has a short time constant. The primary used for this type of circuit is to produce positive and negative spikes. This will be discussed in further detail later in this chapter.

An integrator usually has a medium to long time constant. Since the output is taken across the capacitor, it will result in a waveform that represents the capacitor charging and discharging. The integrator is used to modify the shape of the input square wave.

Waveshaping Circuits

The following sections discussed waveshaping circuits with short, medium, long and very long time constants. The circuits and their respective waveforms are found in Figs. 13-26 through 13-29. Each circuit has an output across both the capacitor and resistor and the respective waveforms are drawn. It is presented in this manner to simplify the discussion.

To further simplify the understanding of the circuit, each of the four circuits to be discussed will use the same 1 kHz square wave input. They all have the same value capacitor. The only change between the circuits is the value of the resistor, which changes the time constant.

It is necessary to determine the “on” and “off” times of the square wave. In the case of this demonstration, the square wave input is symmetrical, with the on and off times being the same. The period of a 1 kHz waveform is 1 ms (period = 1/frequency). The period is one full cycle, therefore, the “on” time is .5 ms and the “off” time is .5 ms.

The “on” time is the period of time when the square wave is producing a positive voltage. During this time, the capacitor will receive a charging voltage. The “off” time is the period of time when the square wave is not producing any voltage. During this time, the capacitor will supply voltage to the circuit, using the power supply as a discharge path.

Short Time Constant

A short time constant is defined as allowing the capacitor more than enough time to reach full charge during the “on” time of the input square wave.

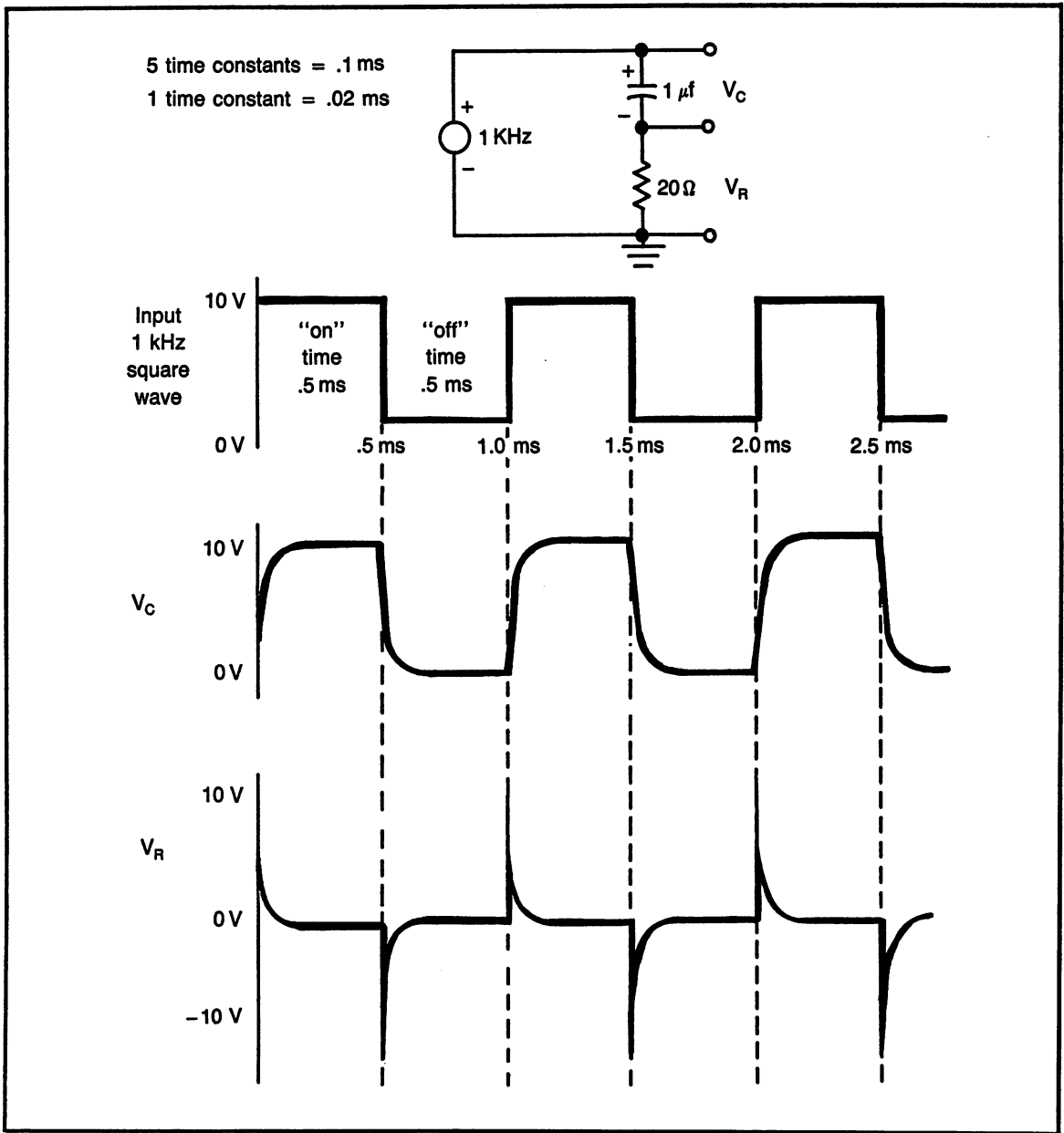


Fig. 13-26. Short time constant.

Since the square wave is symmetrical, the capacitor will also have more than enough time to fully discharge during the “off” time.

Figure 13-26 is the short time constant circuit. The input square wave is plotted with the times marked off when the changes occur. V_C , the mid-

dle waveform is the voltage across the capacitor, as seen with an oscilloscope. V_R , the bottom waveform is the voltage developed across the resistor, as seen with an oscilloscope.

The time constant of this circuit is 20 microseconds. The capacitor will reach full charge in 100

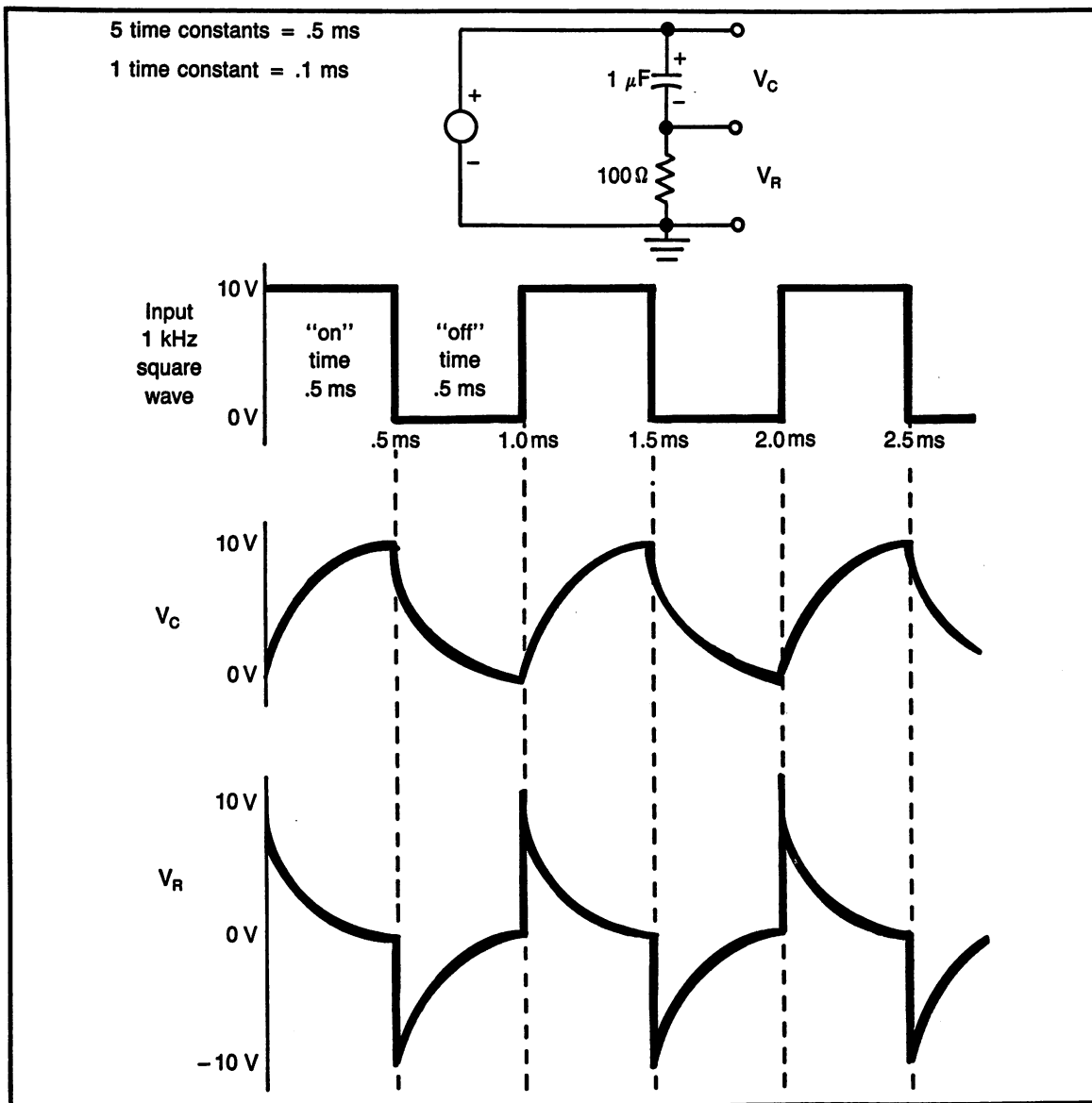


Fig. 13-27. Medium time constant.

microseconds, or .1 milliseconds. Therefore, the capacitor will reach full charge in approximately one-fifth of the time allowed by the input square wave.

Whatever voltage, of the applied square wave, that is not dropped across the capacitor is dropped across the resistor; $V_C + V_R = V_{\text{Applied}}$. Then, as the capacitor charges, the voltage potential in the

circuit will decrease and the current flow will also decrease. Finally, when the capacitor is fully charged, the circuit will have no current flow, therefore no voltage will be developed across the resistor.

Examining the first “on” time, the capacitor very quickly charges, then holds a constant 10 volts for the remainder of the “on” time. The resistor

initially has the applied 10 volts dropped across it, but as the capacitor charges, the voltage across the resistor drops to zero.

When the input square wave switches to "off", the capacitor is allowed to discharge through the power supply and circuit resistance. At the first instant of the "off" time, the capacitor is fully charged and is the only source of voltage in the circuit. The capacitor has a voltage polarity that is opposite the polarity of the power supply, therefore, the voltage applied to the resistor will be of an opposite polarity. The voltage across the resistor will be a negative voltage equal to the capacitor voltage, at every instant of the discharge. The resistor voltage is therefore plotted as a negative spike.

The square wave then repeats the cycle; it switches to "on", the capacitor charges and the resistor voltage is positive. The square wave switches to "off", the capacitor becomes the circuit voltage, with an opposite polarity and the resistor voltage is negative.

Medium Time Constant

A medium time constant circuit is defined as having a time constant that allows the capacitor to reach full charge during the "on" time, with little or no time to spare. Figure 13-27 shows a medium time constant circuit. Only the resistor value is changed from the previous circuit. The time constant in this circuit is 100 microseconds. Full charge is 500 microseconds, or .5 milliseconds, which is equal to the "on" time.

The square wave will allow the capacitor to charge during the "on" time. The resistor will have a voltage equal to the applied voltage minus the capacitor voltage. When the square wave switches to the "off" time, the capacitor will supply voltage to the circuit, with a negative polarity. The resistor during the "off" time will have a negative voltage.

Long Time Constant

Both the long time constant circuit, shown in Fig. 13-28, and the extra long time constant circuit, shown in Fig. 13-29, have time constants that are longer than the time allowed by the input square

wave. The capacitor does not have enough time to fully charge or discharge. The capacitor will store a small amount of the charge voltage and will eventually reach a level where it is very close to the applied voltage. When this happens, the resistor voltage will be centered around the center line. This type of circuit uses the capacitor as a "dc blocking capacitor". It allows the changing voltage to pass through, but blocks the steady dc voltage.

Voltage calculations for the long and extra long time constant circuits must be performed using the instantaneous charge and discharge formulas.

HANDS ON PRACTICE: TIME CONSTANTS AND WAVESHAPING

This hands-on experience will apply the knowledge learned about: a) the universal time constant curve, b) charge and discharge of capacitors, c) RC time constants, d) RC waveshaping. The student will also be required to use a dual trace oscilloscope and a signal generator.

The actual component values of the resistor and capacitor may vary, depending on the components available.

The short and medium time constant circuits shown in Fig. 13-26, 13-27 are to be used as samples, there are some differences, however. Notice, the circuits shown in the sample figures use different resistor values to produce different time constants. This exercise will maintain constant circuit values and allow the frequency of the signal generator to change to produce a different on/off time.

COMPONENT VALUES

| | <u>Recommended</u> | <u>Actual</u> |
|------------|--------------------|---------------|
| Resistor: | 10 kilohms | _____ |
| Capacitor: | .001 μ F | _____ |
| | | _____ |

Step 1. Connect the leads of the capacitor and resistor together, as shown in the sample figures, so they are in series. Record the actual component values in the space provided, above.

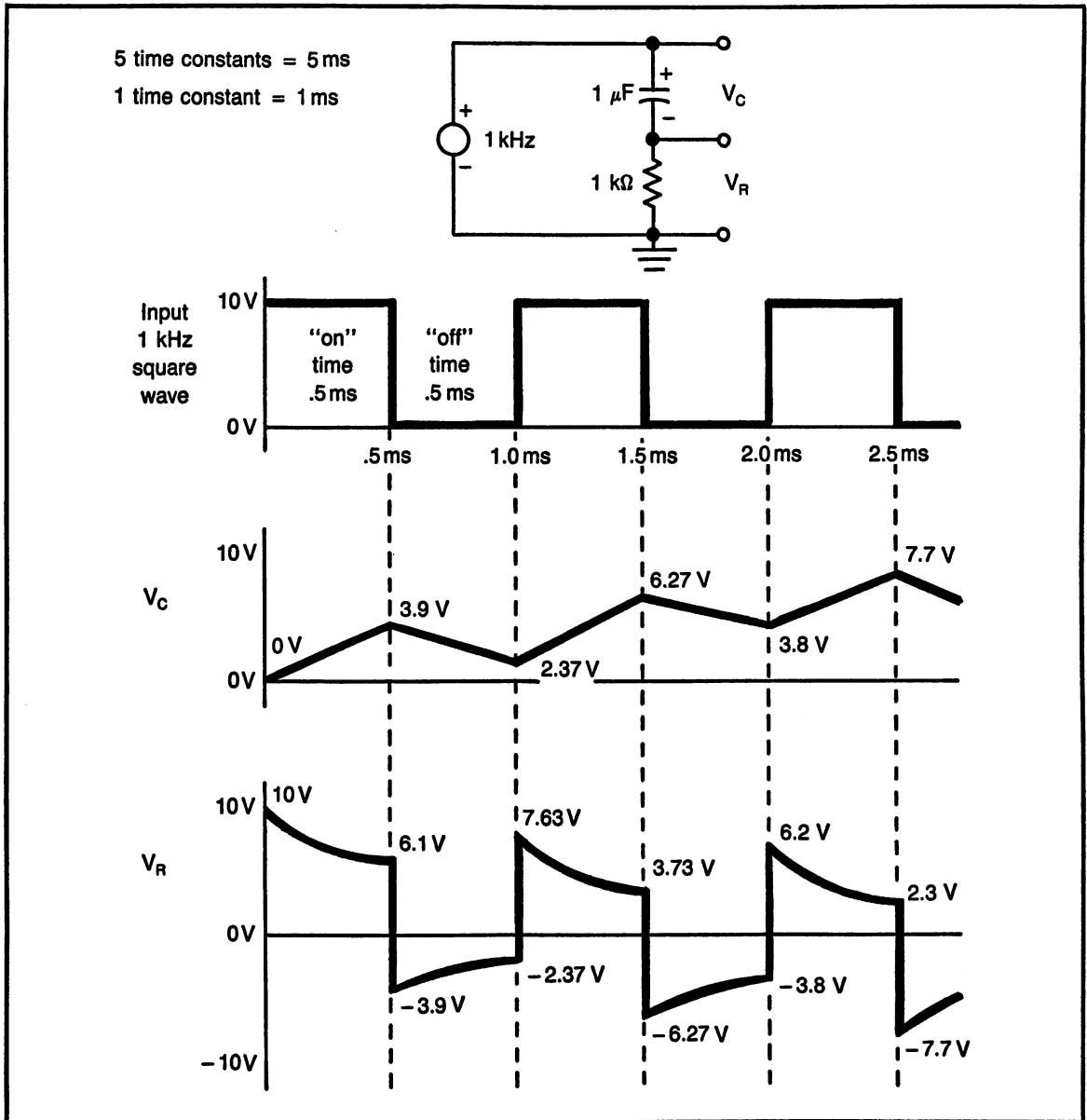


Fig. 13-28. Long time constant.

Step 2. Connecting test equipment:

a. Connect the ground wires from the dual trace oscilloscope and signal generator to the bottom of the capacitor (opposite to the schematic shown). It is absolutely

necessary to have all of the grounds connected together.

b. Connect the "hot" lead from the signal generator to the top of the resistor.
c. Adjust the oscilloscope for dual trace operation. Trigger on channel 1.

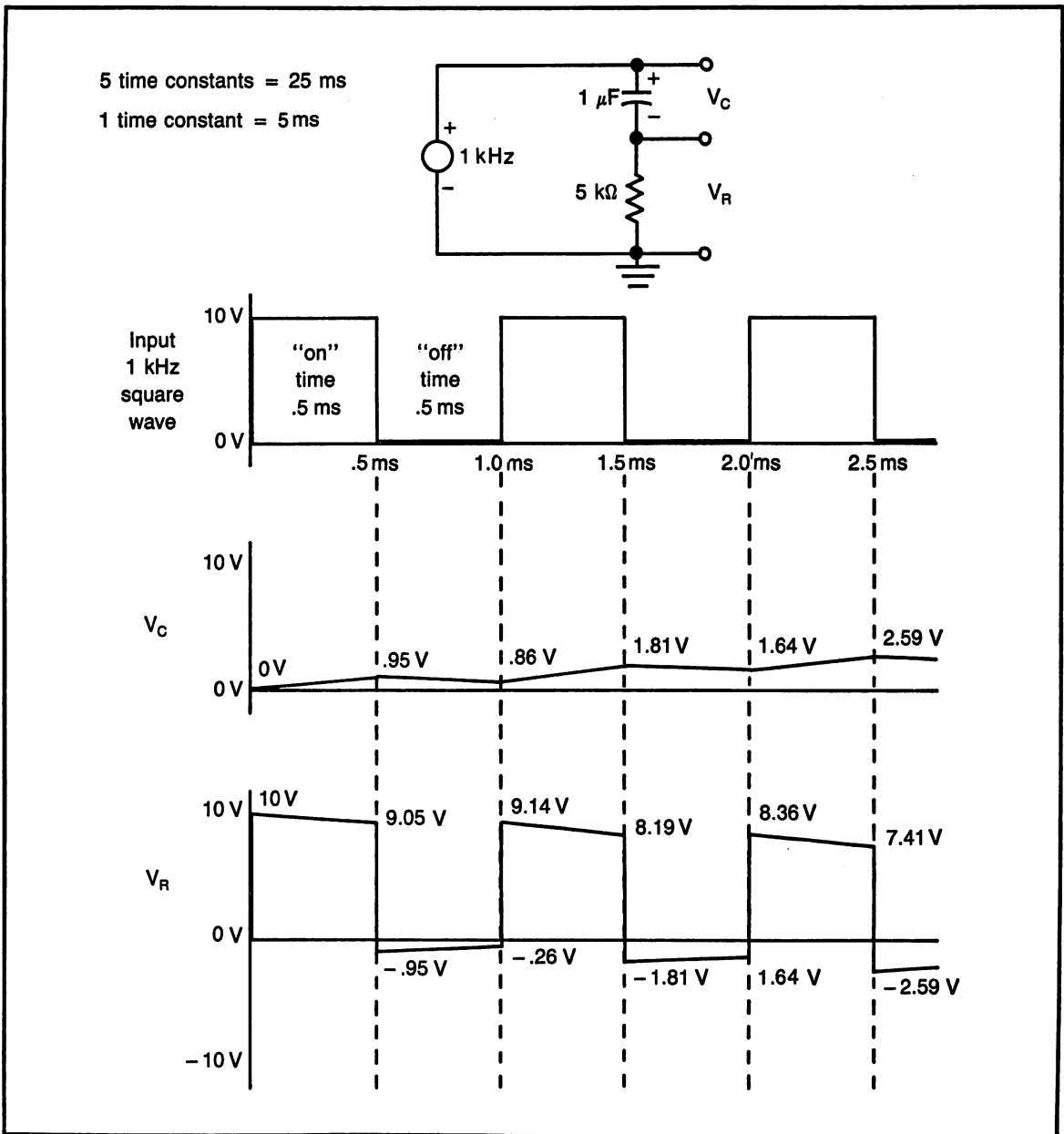


Fig. 13-29. Very long time constant.

- d. Adjust the signal generator for square wave operation with a frequency of approximately 20 kHz. (Note: later in this exercise, the frequency will be set to a different value.)
- e. Connect channel 1 of the scope to the top

- of the resistor; this will measure the square wave from the generator.
- f. Connect channel 2 of the scope to the junction between the resistor and capacitor; this will measure the voltage across the capacitor.

- g. Adjust the scope's time/div for approximately 3 full cycles of the input square wave. Be sure scope is properly triggered.
- h. Adjust scope's volts/div on each channel to allow each channel to use only $\frac{1}{2}$ of the screen, channel 1 on top and channel 2 on the bottom.

Step 3. If the test equipment is properly set up and adjusted, the top waveform (channel 1) should display the square wave. The bottom waveform (channel 2) should display the voltage across the capacitor, labeled V_c in the sample figures. The following will be on the same sheet of graph paper, using the samples provided as a guide.

- a. Draw the schematic diagram of the circuit connected (note: it is slightly different from the sample). Show the connections for the scope and generator. Include component values.
- b. Measure (using the oscilloscope) the actual period and frequency of the square wave and record below.

period = _____

frequency = _____

"on" time = _____

"off" time = _____

- c. Draw the square wave shown on the scope; label the "on" and "off" times.
- d. Draw the capacitor voltage as shown on the scope. Make certain it is drawn correctly with respect to the square wave.
- e. With the component values used in the circuit, calculate the value of one time constant and the value for full charge/discharge. Record below and on the graph paper.

one time constant = _____

full charge time = _____

- f. On the back of the graph paper, give a brief explanation of the capacitor voltage curve.

Step 4. Changing test equipment connections. *Do not change oscilloscope or generator settings. If necessary, check settings by adjusting according to step 3a.*

- a. Disconnect the circuit used in the previous steps.
- b. Connect the ground wires to the bottom of the resistor.
- c. Connect the signal generator "hot" lead to the top of the capacitor.
- d. Connect the scope, channel 1 to the top of the capacitor to measure the square wave.
- e. Connect the scope, channel 2 to the junction between the resistor and the capacitor, to measure the voltage developed across the resistor.

Step 5. If the test equipment has been properly connected, the same square wave used in previous steps should be present on channel 1. Channel 2 should display a waveform similar to the one shown in the sample labeled V_R . Using the same graph paper as in step 3:

- a. Again, using the square wave as a reference, draw the curve of the resistor voltage.
- b. On the back of the graph paper, explain the shape of the waveform. Explain why the resistor voltage is negative during the capacitor discharge time (square wave "off" time).
- c. Label this completed graph paper "Medium Time Constant", as shown in Fig. 13-27.

Step 6. Adjust the frequency of the signal generator to approximately 4000 Hz. This will pro-

Part B. Formulas

State the formula for each of the following:

- Total capacitance for capacitors in series.
- Total capacitance for capacitors in parallel.
- Voltage across C_1 of a two-capacitor voltage divider.
- Voltage across C_2 of a two-capacitor voltage divider.
- Inductive time constant.
- Capacitive time constant.
- Period when given frequency.
- Frequency when given period.
- “on” time of a square wave.
- “off” time of a square wave.

Part C. General Questions”

- Describe how a capacitor is formed.
- If the dielectric is made thinner, does the value of capacitance increase or decrease?
- Describe how a capacitor charges and discharges.
- A capacitor opposes any change in (voltage or current).
- An inductor opposes any change in (voltage or current).

Part D. Capacitors in Parallel

Determine the total capacitance of the following capacitors connected in parallel.

- $2 \mu\text{F}$ and $5 \mu\text{F}$
- $30 \mu\text{F}$ and $30 \mu\text{F}$ and $30 \mu\text{F}$

- $.01 \mu\text{F}$ and $.05 \mu\text{F}$ and $.02 \mu\text{F}$
- 10 pF and 25 pF and 100 pF
- $1 \mu\text{F}$ and $220,000 \text{ pF}$

Part E. Capacitors in Series

Determine the total capacitance of the following capacitors connected in series.

- $2 \mu\text{F}$ and $5 \mu\text{F}$
- $30 \mu\text{F}$ and $30 \mu\text{F}$ and $30 \mu\text{F}$
- $.01 \mu\text{F}$ and $.05 \mu\text{F}$ and $.02 \mu\text{F}$
- 10 pF and 25 pF and 100 pF
- $1 \mu\text{F}$ and $220,000 \text{ pF}$

Part F. Capacitive Voltage Dividers

Determine the voltage drop across each of the following capacitors, connected as a voltage divider. The voltage given is the supply voltage. (Note: there are two answers required for each problem, 1 test point each.)

- $V = 10$ volts, $C_1 = 2 \mu\text{F}$, $C_2 = 3 \mu\text{F}$
- $V = 15$ volts, $C_1 = 1 \mu\text{F}$, $C_2 = 2 \mu\text{F}$
- $V = 20$ volts, $C_1 = 3 \mu\text{F}$, $C_2 = 4 \mu\text{F}$
- $V = 25$ volts, $C_1 = 6 \text{ pF}$, $C_2 = 9 \text{ pF}$
- $V = 30$ volts, $C_1 = 10 \text{ pF}$, $C_2 = 20 \text{ pF}$

Part G. Time Constant Circuits

Problems 36 through 40 use the inductive circuit in Fig. 13-31.

- 1 time constant of charge
- time for full charge
- full charge current

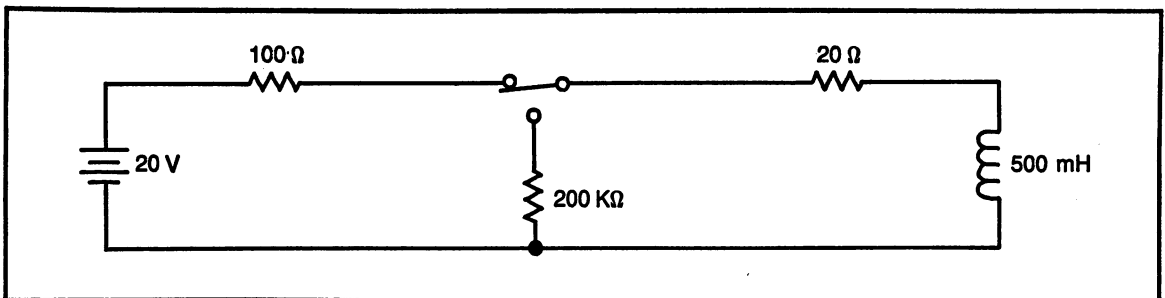


Fig. 13-31. Problems 36-40.

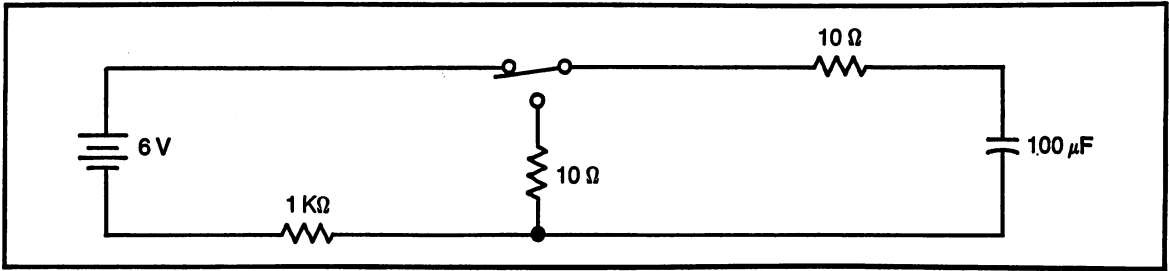


Fig. 13-32. Problems 41-45.

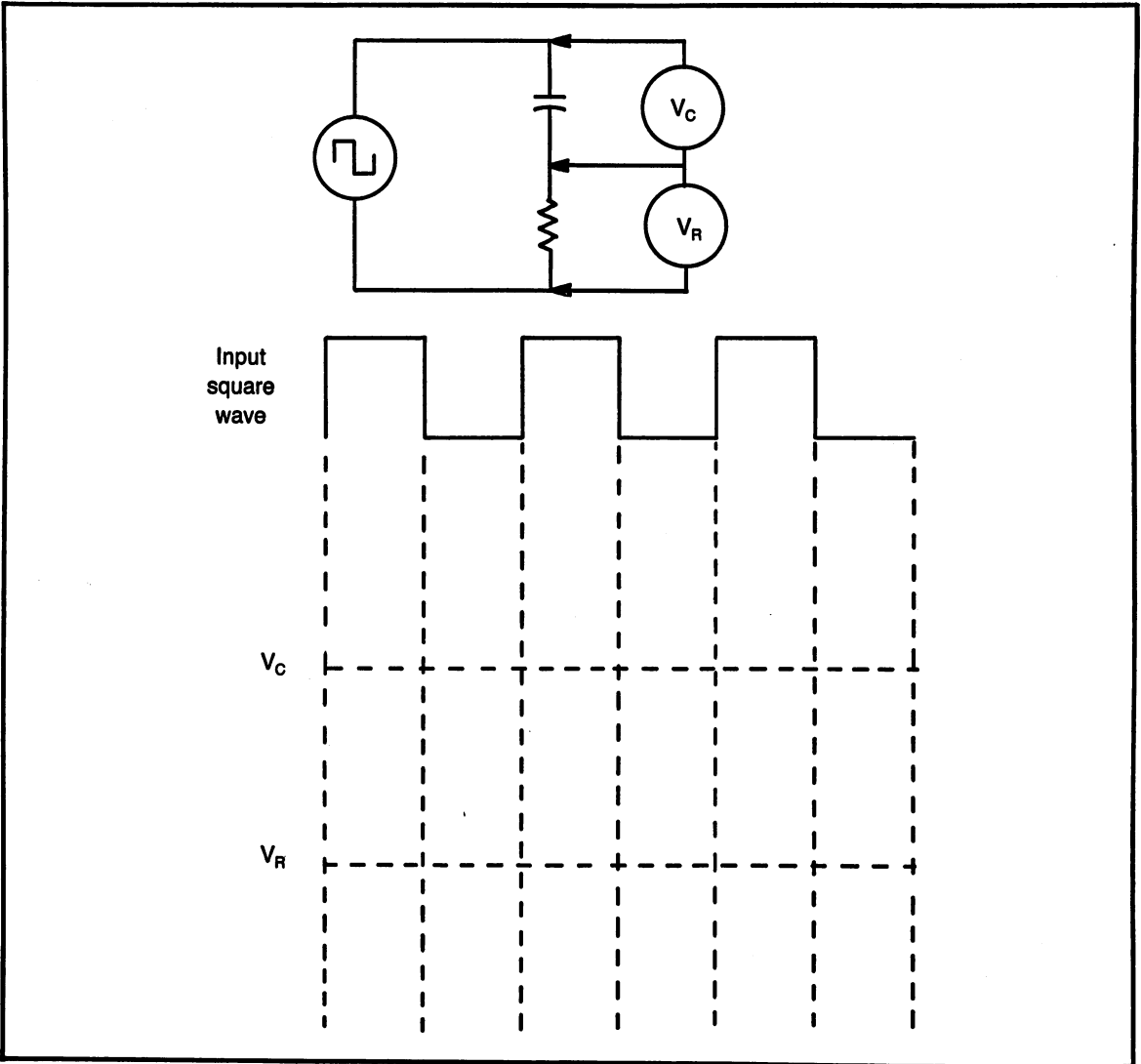


Fig. 13-33. Problems 46-50.

39. time for full discharge
40. voltage developed at first instant of discharge

Problems 41 through 45 use the capacitive circuit in Fig. 13-32.

41. 1 time constant of charge
42. time for full charge
43. full charge voltage
44. time for full discharge
45. current developed at first instant of discharge

Part H. Waveshaping

Figure 13-33 is a schematic diagram of a waveshaping circuit and its graph. Use the information given to answer the following questions.

Given: square wave frequency = 5000 Hz
resistance = 200 ohms
capacitance = 0.1 microfarads

Find:

- 46a. "on" time
- 46b. "off" time
- 47a. 1 time constant
- 47b. full charge time
48. How is this circuit classified?
 - a. short time constant
 - b. medium time constant
 - c. long time constant
49. Draw the curve of the capacitor voltage.
50. Draw the curve of the resistor voltage.

Chapter 14

AC Circuits

Chapter Objectives: To make calculations with inductive and capacitive reactance. To use phasors to solve for impedance in circuits containing both resistance and reactance. To analyze the effects of reactance on power dissipation.

Chapter Outline:

- Reactance
- Phasor Analysis
- Reactive Circuits
- Ac Power
- Measuring Phase Angle On an Oscilloscope
- Hands-On Practice Measuring Phase Angle
- Programs for This Chapter
- AC Circuits Competency Test

INTRODUCTION

A circuit containing an inductor and/or a capacitor with a resistor will respond somewhat differently when an ac voltage is applied, than if the circuit had only resistance.

Inductors and capacitors are classified as reactive components because an ac voltage will cause them to have resistance that will vary with the frequency of the ac voltage. A combination of reactance and resistance is called impedance.

Power in an ac circuit will also be affected by the presence of reactive components. The phase angle of a circuit is the relationship between voltage and current in an ac circuit.

This chapter will also present a hands-on exercise with the oscilloscope to gain experience in measuring phase angle.

REACTANCE

Reactance is defined as the ac resistance of an inductor or capacitor. Reactance has a unit of measure of ohms, as does resistance. Since inductors and capacitors are devices that store energy, they cannot simply charge and discharge instantly. It is the charging and discharging that acts like a form of resistance to the ac signal. This section deals with cal-

culating the reactance in both inductive and capacitive circuits.

Key Point. Reactance has the unit of measure of ohms.

Inductive Reactance

Inductive reactance is the reactance in a circuit containing an inductor. There are two factors that effect the amount of reactance; frequency of the ac signal and the value of the inductor. When the frequency and/or the value of inductance is lowered, the inductive reactance becomes lower, to the point where the frequency is 0 Hz (dc) and the inductive reactance is 0 ohms. Inductive reactance uses the symbol X_L .

Formula #38. Inductive Reactance, X_L

$$X_L = 2 (\pi) f L$$

Note: all terms are multiplied on the right side of the equation.

$2 (\pi)$ is 2 times the Greek letter (π). (π) = 3.14, therefore 6.28 can be substituted for $2(\pi)$ in the formula.

f is frequency, measured in hertz.

L is inductance, measured in Henrys.

Sample Problems: Inductive Reactance

Note: in the problems below, parentheses () are used around a number to indicate multiplication.

SP#14-1.

Given: frequency = 10 kHz

inductance = 5 mH

Find: inductive reactance

Formula: $X_L = 2 (\pi) f L$

Substituting: $X_L = (6.28) (10 \text{ kHz}) (5 \text{ mH})$

Solving: $X_L = 314 \text{ ohms}$

SP#14-2.

Given: frequency = 2000 Hz

inductive reactance = 800 ohms

Find: inductance

Formula: $X_L = 2 (\pi) f L$

Rearranging: $L = \frac{X_L}{2(\pi) f L}$

Substituting: $L = \frac{800 \text{ ohms}}{(6.28) (2000 \text{ Hz})}$

Solving: $L = 63.7 \text{ mH}$

SP#14-3.

Given: inductive reactance = 15 kilohms

inductance = 2 Henrys

Find: frequency

Formula: $X_L = 2 (\pi) f L$

Rearranging: $f = \frac{X_L}{2(\pi) f L}$

Substituting: $f = \frac{15 \text{ kilohms}}{(6.28)(2H)}$

Solving: $f = 1200 \text{ Hz}$

Capacitive Reactance

Capacitive reactance is the ac resistance from a capacitor and is measured in ohms. The value of capacitive reactance is affected by two quantities; frequency and value of capacitance. When the frequency and/or the capacitance is reduced, the capacitive reactance becomes larger, to a point where the frequency is 0 Hz (dc), the reactance is infinity.

Capacitive reactance uses the symbol X_C .

Formula #39. Capacitive Reactance, X_C

$$X_C = \frac{1}{2 (\pi) f C}$$

X_C is capacitive reactance, measured in ohms.

$2(\pi) = 6.28$

f is frequency, measured in hertz (Hz).
C is capacitance, measured in farads.

Sample Problems: Capacitive Reactance

Note: in the problems below, parentheses () are used around a number to indicate multiplication.

SP#14-4.

Given: frequency = 10 kHz
capacitance = .5 μ F

Find: capacitive reactance

$$\text{Formula: } X_C = \frac{1}{2 (\pi) f C}$$

$$\text{Substituting: } X_C = \frac{1}{(6.28) (10 \text{ kHz}) (.5 \mu\text{F})}$$

$$\text{Solving: } X_C = 31.8 \text{ ohms}$$

SP#14-5.

Given: frequency = 25 kHz
capacitive reactance = 1.2 kilohms

Find: capacitance

$$\text{Formula: } X_C = \frac{1}{2 (\pi) f C}$$

$$\text{Rearranging: } C = \frac{1}{2 (\pi) f X_C}$$

$$\text{Substituting: } C = \frac{1}{(6.28) (25 \text{ kHz}) (1.2 \text{ kilohms})}$$

$$\text{Solving: } C = .005 \mu\text{F}$$

SP#14-6.

Given: capacitive reactance = 100 ohms
capacitance = .47 μ F

Find: frequency

$$\text{Formula: } X_C = \frac{1}{2 (\pi) f C}$$

$$\text{Rearranging: } f = \frac{1}{2 (\pi) X_C C}$$

$$\text{Substituting: } f = \frac{1}{(6.28) (100 \text{ ohms}) (.47 \mu\text{F})}$$

$$\text{Solving: } f = 3390 \text{ Hz}$$

Practice Problems: Reactance

Part A. Inductive Reactance.

Use the information given to calculate the inductive reactance.

1. f = 1000 Hz, L = 100 mH; find X_L
2. X_L = 1000 ohms, f = 10 kHz; find L
3. X_L = 200 ohms, f = 10 kHz; find L
4. X_L = 200 ohms, L = 16 mH; find f
5. X_L = 600 ohms, L = 16 mH; find f
6. f = 5000 Hz, L = 2 H; find X_L
7. X_L = 400 ohms, f = 10 kHz; find L
8. X_L = 1000 ohms, L = 16 mH; find f
9. L = 50 μ H, f = 3 MHz; find X_L
10. L = 50 mH, f = 0 Hz (dc); find X_L

Part B. Capacitive Reactance.

Use the information given to calculate the capacitive reactance.

11. f = 1000 Hz, C = .001 μ F; find X_C
12. X_C = 1.59 kilohms, f = 1000 Hz; find C
13. X_C = 15.9 ohms, C = 1 μ F; find f
14. X_C = 15.9 kilohms, f = 1000 Hz; find C
15. X_C = 159 ohms, C = 1 μ F; find f
16. f = 10 kHz, C = 150 μ F; find X_C
17. f = 0 Hz (dc), C = 10 μ F; find X_C
18. f = 100 MHz, C = 1 μ F; find X_C
19. f = 1 GHz, C = 1 pF; find X_C
20. f = 1 Hz, C = 1 pF; find X_C

PHASOR ANALYSIS

Phasor analysis is a method of solving ac circuits using a combination of vectors and trigonometry. (This sounds more complicated than it really is.)

The word "phasor" is a combination of two words; vector and phase. A vector is a line that

represents the magnitude (size) and direction of some number, phase is the resultant angle.

Reactance, either inductive or capacitive, causes a phase shift between the circuit voltage and current. This phase shift is called the phase angle or operating angle of the circuit. To determine the phase shift and to show the relationship between resistance and reactance, a right triangle can be drawn. The sides of the triangle represent the relative sizes of resistance and reactance and the hypotenuse represents the relative size of the impedance, the combined total ac resistance. The enclosed angle becomes the phase shift.

Drawing a Phasor Triangle

When solving electrical circuits, there are three types of phasor triangles; impedance, voltage and current. When drawing these triangles, there are certain basic rules to follow: (Note: sample problems will be shown later in this chapter with the triangles drawn.)

Resistance. plotted on the horizontal. All values dealing with resistance, such as; resistance (in ohms), voltage drop across the resistor, current through the resistor.

Reactance, X (X_L or X_C). plotted vertically, forming a right angle with resistance. All values dealing with reactance, such as; reactance (in ohms), voltage drop across the reactive component, current through the reactive component. The phasor for reactance can be plotted either up or down, depending if the circuit is series or parallel and if it is inductive or capacitive.

Totals. the hypotenuse of the right triangle. The hypotenuse is always longer than either of the other two sides and will be at some angle between 0 and 90 degrees. The totals are; total ac resistance (impedance, Z, measured in ohms), total applied voltage, total circuit current.

Phase Angle. phase angle is represented by the Greek letter theta, θ , and is measured in degrees. The phase angle is the phase shift in the circuit, between the resistive and reactive components. It is the angle in the triangle formed between the resistance and the hypotenuse.

Calculations with Phasor Triangles

There are two basic calculations to be made with the phasor triangles; hypotenuse and angle theta. These two basic calculations can be rearranged to allow solving for all quantities of the triangles, but it is not necessary.

Hypotenuse. Pythagorean's theorem ($a^2 = b^2 + c^2$) is used to solve for the magnitude of the hypotenuse. Using the impedance triangle for an example: $Z^2 = R^2 + X^2$

The formula can be written easier by taking the square root of both sides.

Formula #40. Hypotenuse of a Right Triangle

a. Impedance triangle.

$$Z = \sqrt{R^2 + X^2}$$

b. Voltage triangle.

$$V_T = \sqrt{V_R^2 + V_X^2}$$

c. Current triangle.

$$I_T = \sqrt{I_R^2 + I_X^2}$$

Phase Angle. $\tan \theta = \text{opposite/adjacent}$. This is the trigonometric function used to find theta.

Formula #41. Phase Angle, Theta, θ

$$\tan \theta = \frac{\text{opposite}}{\text{adjacent}}$$

a. Impedance triangle.

$$\theta = \tan^{-1} \frac{X}{R}$$

b. Voltage triangle.

$$\theta = \tan^{-1} \frac{V_X}{V_R}$$

c. Current triangle.

$$\theta = \tan^{-1} \frac{V_X}{V_R}$$

Note: \tan^{-1} is the same as the arctan. It is expressed as “the angle whose tangent is. . .”

Note: to find \tan^{-1} on a calculator; first press the 2nd function key (2nd F or INV or ARC), then the tan key.

Note: to properly use this formula; first divide X (reactance) by R (resistance), then find \tan^{-1} .

REACTIVE CIRCUITS

There are four basic types of reactive circuits; inductance in series with resistance, inductance in parallel with resistance, capacitance in series with resistance and capacitance in parallel with resistance. It is also possible, as will be examined in the next chapter, to have combinations of these basic circuits.

Although each type of circuit has a different set of characteristics, the phasor diagrams and calculations are quite similar, which will simplify the circuit analysis.

Inductive Reactance In Series with Resistance

In any series circuit, current is the same throughout the circuit. An inductor causes the current to “lag” the voltage by 90 degrees. It is this “lagging” current that makes it necessary to plot a voltage triangle and impedance triangle for series circuits. The resultant voltage (total circuit voltage) will be the hypotenuse of the triangle and will be at an angle equal to the phase angle, also called the operating angle.

When solving a series inductive circuit, follow these guidelines:

1. Solve for impedance, Z , using an impedance triangle. Inductive reactance, X_L , phasor is plotted at a positive 90 degrees (up), resistance, R , phasor is plotted at 0 degrees (horizontal), impedance phasor is the hypotenuse.
2. Circuit current is found using Ohm’s law with impedance and total voltage.
3. Voltage drops, V_R and V_L are found using Ohm’s law with circuit current and the values of resistance and inductive reactance.

4. Solve for total circuit voltage, V_T , using a voltage triangle. Inductive voltage, V_L (or V_{XL}), phasor is plotted at a positive 90 degrees (up), resistive voltage, V_R , phasor is plotted at 0 degrees, total voltage, V_T , is the hypotenuse.
5. Phase angle, theta, θ , is the angle of the hypotenuse of either triangle. The phase angle in a series inductive circuit will be positive.

Sample Problem: Series Inductive Reactance

SP#14-7. Series circuit, schematic diagram, Fig. 14-1.

Given: $R = 350$ ohms, $X_L = 500$ ohms
 $V = 100$ volts

Find: Z , θ , I , V_R , V_L

Step 1. Impedance triangle, Fig. 14-2.

- a. Plot the phasors using the given values of R and X_L

X_L

- b. Pythagorean’s theorem to solve for Z .

$$\text{Formula: } Z = \sqrt{R^2 + X_L^2}$$

$$\text{Substituting: } Z = \sqrt{350^2 + 500^2}$$

$$\text{Solving: } Z = 610 \text{ ohms}$$

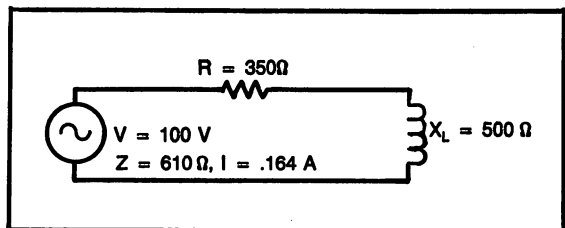


Fig. 14-1. Schematic diagram for sample problem 14-7.

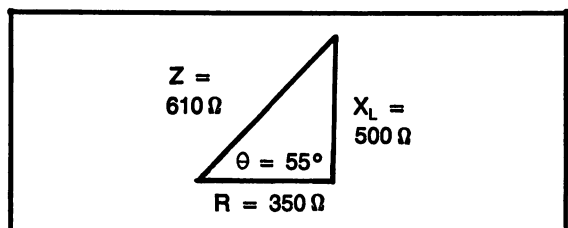


Fig. 14-2. Impedance triangle for sample problem 14-7.

Step 2. Theta, θ , using the impedance triangle.

$$\text{Formula: } \theta = \tan^{-1} \frac{X_L}{R}$$

$$\text{Substituting: } \theta = \tan^{-1} \frac{500}{350}$$

$$\text{Solving: } \theta = 55 \text{ degrees}$$

Step 3. Circuit current using Ohm's law.

$$\text{Formula: } I = \frac{V}{Z}$$

$$\text{Substituting: } I = \frac{100 \text{ volts}}{610 \text{ ohms}}$$

$$\text{Solving: } I = .164 \text{ amps}$$

Step 4. Voltage triangle, Fig. 14-3.

- a. Voltage drop across the resistor, V_R , using Ohm's law.

$$\text{Formula: } V = I \times R$$

$$\text{Substituting: } V_R = .164 \text{ amps} \times 350 \text{ ohms}$$

$$\text{Solving: } V_R = 57.4 \text{ volts}$$

- b. Voltage drop across the inductor, V_L , using Ohm's law.

$$\text{Formula: } V = I \times X_L$$

$$\text{Substituting: } V_L = .164 \text{ amps} \times 500 \text{ ohms}$$

$$\text{Solving: } V_L = 82.0 \text{ volts}$$

- c. V_R and V_L do not simply add to equal the total voltage, as would be the case in a dc circuit. The voltages must be added using phasors, Pythagorean's theorem.

$$\text{Formula: } V = \sqrt{V_R^2 + V_L^2}$$

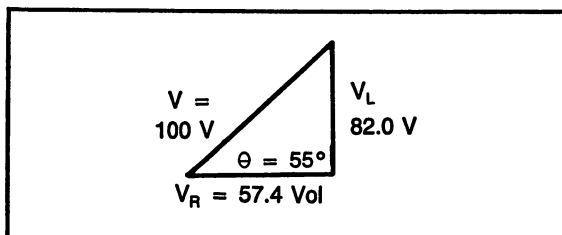


Fig. 14-3. Voltage triangle for sample problem 14-7.

$$\text{Substituting: } V = \sqrt{57.4^2 + 82.0^2}$$

$$\text{Solving: } V = 100 \text{ volts}$$

Inductive Reactance in Parallel with Resistance

Voltage is the same throughout a parallel circuit. In a parallel circuit, the current divides to the individual branches according to the size of the resistance, or impedance, of each branch. In a parallel circuit with inductive reactance, the current in the inductive branch will "lag" the resistive branch by 90 degrees. This means there is a 90 degree phase shift between the two currents. Because of the 90 degree phase shift, it is necessary to calculate total current using a phasor triangle.

When solving a parallel circuit with inductive reactance, follow these guidelines:

1. Calculate individual branch current, using Ohm's law with the applied voltage and branch resistance or reactance.
2. Draw the current triangle with resistive current, I_R at zero degrees (horizontal) and inductive reactance current, I_L at -90 degrees (down). The vector drawn down represents the lagging phase shift. The hypotenuse of the triangle is total current, I_T .
3. Calculate total circuit impedance using Ohm's law with total circuit current and applied voltage.
4. Calculate phase angle theta using the current triangle. The phase angle in a parallel inductive circuit is negative.

Sample Problem: Parallel Inductive Reactance

SP#14-8. Parallel circuit, Fig. 14-4.

$$\text{Given: } R = 200 \text{ ohms, } X_L = 150 \text{ ohms}$$

$$V = 25 \text{ volts}$$

$$\text{Find: } I_R, I_{XL}, I_T, Z, \text{ theta}$$

Step 1. Current triangle, Fig. 14-5.

- a. Calculate resistive current, I_R .

$$\text{Formula: } I = \frac{V}{R}$$

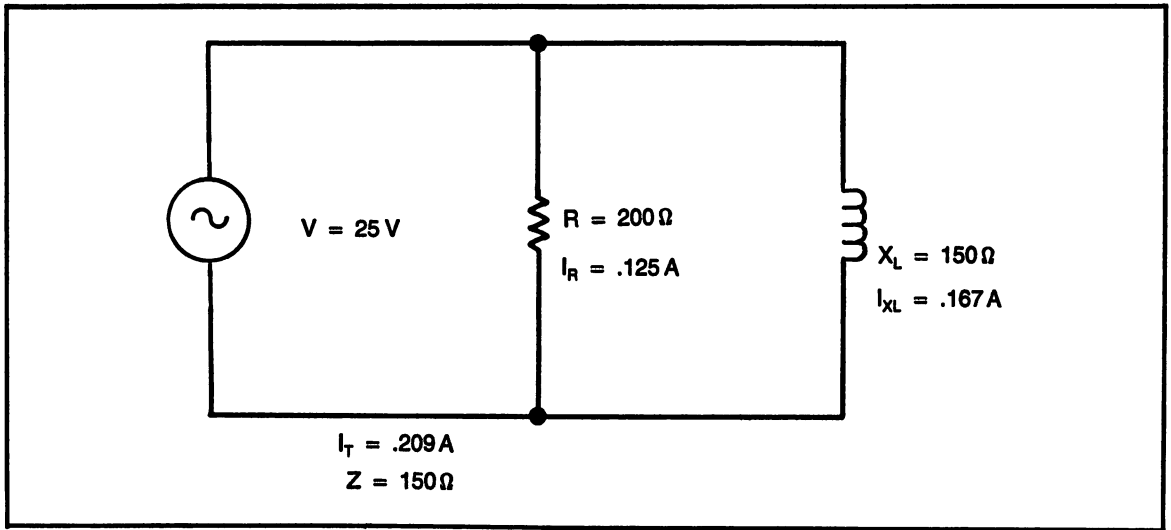


Fig. 14-4. Schematic diagram for sample problem 14-8.

Substituting: $I = \frac{25 \text{ volts}}{200 \text{ ohms}}$

Solving: $I_R = .125 \text{ amps}$

b. Calculate inductive current, I_{XL} .

Formula: $I = \frac{V}{X_L}$

Substituting: $I = \frac{25 \text{ volts}}{150 \text{ ohms}}$

Solving: $I_{XL} = .167 \text{ amps}$

c. Solve for current total, I_T , using Pythagorean's theorem.

Formula: $I_T = \sqrt{I_R^2 + I_{XL}^2}$

Substituting: $I_T = \sqrt{.125^2 + .167^2}$

Solving: $I_T = .209 \text{ amps}$

d. Solve for theta, θ , using the current triangle.

Formula: $\theta = \tan^{-1} \frac{I_{XL}}{I_R}$

Substituting: $\theta = \tan^{-1} \frac{.167}{.125}$

Solving: $\theta = -53.2 \text{ degrees}$

Note: theta is a negative angle because the inductive current is plotted negative in the current triangle.

Step 2. Solve for Z using Ohm's law with total current and applied voltage.

Formula: $Z = \frac{V}{I}$

Substituting: $Z = \frac{25 \text{ volts}}{.167 \text{ amps}}$

Solving: $Z = 150 \text{ ohms}$

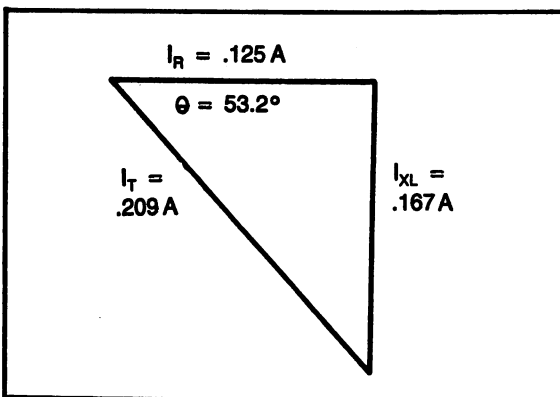


Fig. 14-5. Current triangle for sample problem 14-8.

Capacitive Reactance In Series with Resistance

As in any series circuit, current is the same throughout the circuit. In a circuit with capacitance, the capacitor stores voltage, which causes the voltage across the capacitor to “lag” the voltage across the resistor. Therefore, when solving a series capacitive circuit, it is necessary to draw the voltage triangle and the impedance triangle.

To solve a series capacitive circuit, follow these guidelines:

1. Solve for impedance, Z , using an impedance triangle. Capacitive reactance, X_C , phasor is plotted at a negative 90 degrees (down), resistance, R , phasor is plotted at 0 degrees (horizontal), impedance phasor is the hypotenuse.
2. Circuit current is found using Ohm’s law with impedance and total voltage.
3. Voltage drops, V_R and V_C are found using Ohm’s law with circuit current and the values of resistance and capacitive reactance.
4. Solve for total circuit voltage, V_T , using a voltage triangle. Capacitive voltage, V_C (or V_{XC}), phasor is plotted at a negative 90 degrees (down), resistive voltage, V_R , phasor is plotted at 0 degrees, total voltage, V_T , is the hypotenuse.

5. Phase angle, theta, θ , is the angle of the hypotenuse of either triangle. The phase angle in a series capacitive circuit will be negative.

Note: Capacitive reactance has properties that are opposite the properties of inductive reactance. Solving the two types of circuits is very similar, bearing in mind opposite phasors.

Sample Problem: Series Capacitive Reactance

SP#14-9. Series circuit, schematic diagram, Fig. 14-6.

Given: $R = 500 \text{ ohms}$, $X_C = 500 \text{ ohms}$

$V = 20 \text{ volts}$

Find: Z , θ , I , V_R , V_C

Step 1. Impedance triangle, Fig. 14-7.

- a. Plot phasors using given values of R and X_C .
- b. Pythagorean’s theorem to solve for Z .

$$\text{Formula: } Z = \sqrt{R^2 + X_C^2}$$

$$\text{Substituting: } Z = \sqrt{500^2 + 500^2}$$

$$\text{Solving: } Z = 707 \text{ ohms}$$

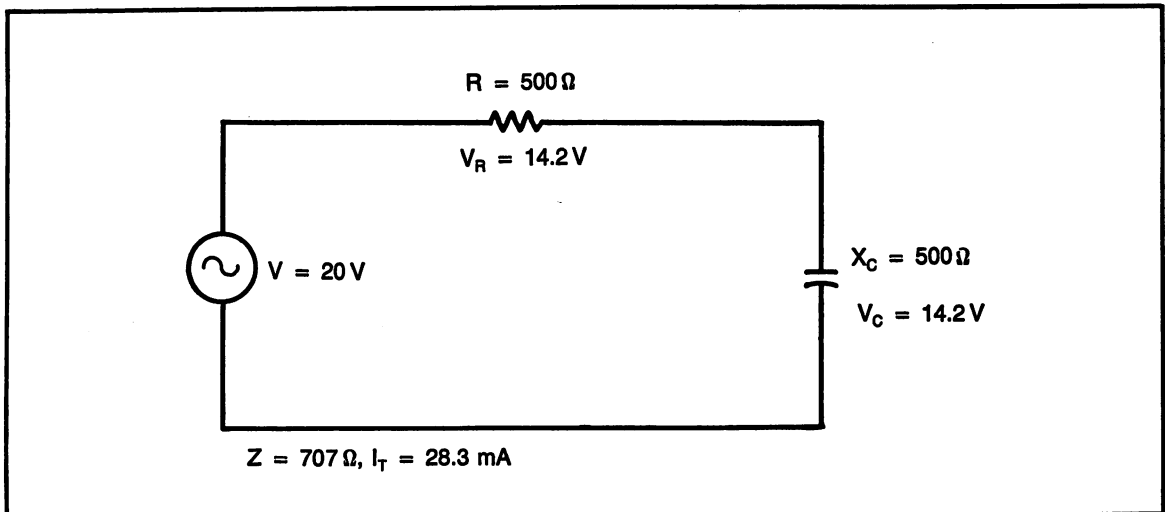


Fig. 14-6. Schematic diagram for sample problem 14-9.

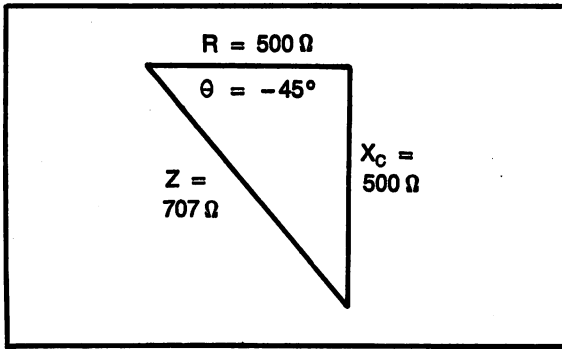


Fig. 14-7. Impedance triangle for Fig. 14-9.

c. Theta, θ , using the impedance triangle.

$$\text{Formula: } \theta = \tan^{-1} \frac{X_C}{R}$$

$$\text{Substituting: } \theta = \tan^{-1} \frac{500}{500}$$

$$\text{Solving: } \theta = -45 \text{ degrees}$$

Step 2. Circuit current using Ohm's law.

$$\text{Formula: } I = \frac{V}{Z}$$

$$\text{Substituting: } I = \frac{20 \text{ volts}}{707 \text{ ohms}}$$

$$\text{Solving: } I = 28.3 \text{ mA}$$

Step 3. Voltage triangle, Fig. 14-8.

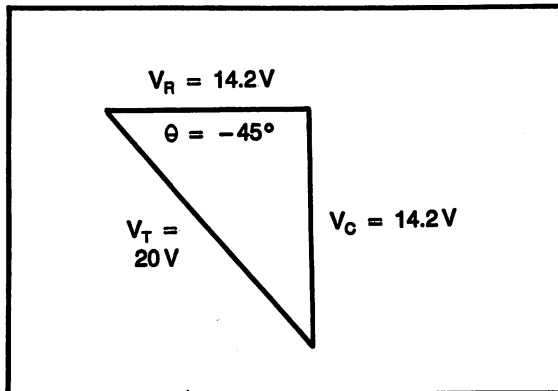


Fig. 14-8. Voltage triangle for sample problem 14-9.

a. Voltage drop across the resistor, V_R , using Ohm's law.

$$\text{Formula: } V = I \times R$$

$$\text{Substituting: } V_R = 28.3 \text{ mA} \times 500 \text{ ohms}$$

$$\text{Solving: } V_R = 14.2 \text{ volts}$$

b. Voltage drop across the inductor, V_C , using Ohm's law.

$$\text{Formula: } V = I \times X_C$$

$$\text{Substituting: } V_C = 28.3 \text{ mA} \times 500 \text{ ohms}$$

$$\text{Solving: } V_C = 14.2 \text{ volts}$$

c. V_R and V_C do not simply add to equal the total voltage, as would be the case in a dc circuit. The voltages must be added using phasors, Pythagore's theorem.

$$\text{Formula: } V = \sqrt{V_R^2 + V_C^2}$$

$$\text{Substituting: } V = \sqrt{14.2^2 + 14.2^2}$$

$$\text{Solving: } V = 20 \text{ volts}$$

Capacitive Reactance in Parallel with Resistance

As in any parallel circuit, voltage is the same throughout the circuit. That means the voltage applied to each branch of the parallel circuit will be the same. Reactance in a parallel circuit causes a phase shift in the branch current and the resultant total current. A parallel circuit with capacitance will have the capacitive current "lead" the resistive current. The phase shift between reactance and resistance is always 90 degrees.

To solve a circuit with capacitance in parallel with resistance, follow these guidelines:

1. Calculate individual branch currents, using Ohm's law with the applied voltage and branch resistance or reactance.
2. Draw the current triangle with resistive current, I_R at zero degrees (horizontal) and capacitive reactance current, I_C at +90 degrees (up). The vector drawn up represents the leading phase shift. The hypotenuse of the triangle is total current, I_T .

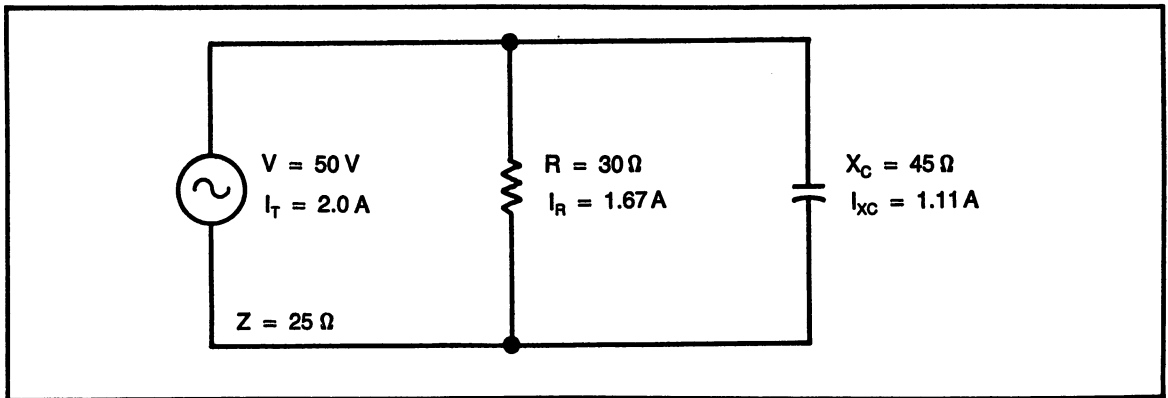


Fig. 14-9. Schematic diagram for sample problem 14-10.

3. Calculate total circuit impedance using Ohm's law with total circuit current and applied voltage.
4. Calculate phase angle theta using the current triangle. The phase angle in parallel capacitive circuit is positive.

**Sample Problem:
Parallel Capacitive Reactance**

SP#14-10. Parallel circuit, Fig. 14-9.

Given: $R = 30$ ohms,
 $V = 50$ volts

Find: I_R , I_{XC} , I_T , Z , theta

Step 1. Current triangle, Fig. 14-10.

- a. Calculate resistive current, I_R .

$$\text{Formula: } I = \frac{V}{R}$$

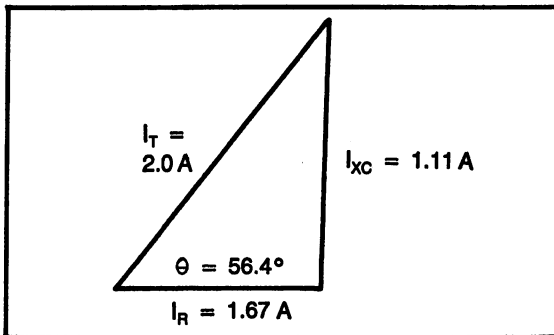


Fig. 14-10. Current triangle for sample problem 14-10.

$$\text{Substituting: } I = \frac{50 \text{ volts}}{30 \text{ ohms}}$$

$$\text{Solving: } I_R = 1.67 \text{ amps}$$

- b. Calculate capacitive current, I_{XC} .

$$\text{Formula: } I = \frac{V}{X_C}$$

$$\text{Substituting: } I = \frac{50 \text{ volts}}{45 \text{ ohms}}$$

$$\text{Solving: } I_{XC} = 1.11 \text{ amps}$$

- c. Solve for current total, I_T , using Pythagorean's theorem.

$$\text{Formula: } I_T = \sqrt{I_R^2 + I_{XC}^2}$$

$$\text{Substituting: } I_T = \sqrt{1.67^2 + 1.11^2}$$

$$\text{Solving: } I_T = 2.0 \text{ amps}$$

- d. Solve for theta, θ , using the current triangle.

$$\text{Formula: } \theta = \tan^{-1} \frac{I_{XC}}{I_R}$$

$$\text{Substituting: } \theta = \tan^{-1} \frac{1.67}{1.11}$$

$$\text{Solving: } \theta = +56.4 \text{ degrees}$$

Note: theta is a positive angle because the capacitive current is plotted positive in the current triangle.

Step 2. Solve for Z using Ohm's law with total current and applied voltage.

$$\text{Formula: } Z = \frac{V}{I}$$

$$\text{Substituting: } Z = \frac{50 \text{ volts}}{2.0 \text{ amps}}$$

$$\text{Solving: } Z = 25 \text{ ohms}$$

AC POWER

Having reactance in an ac circuit changes the relationship of power dissipated. There are four quantities related to the power in an ac circuit; true power, reactive power, apparent power and power factor.

True Power, P_R , Watts

True power, also called real power is the power dissipated in pure resistance. This is the power that is not affected by the reactive component and is measured in watts. It is calculated using the same method in any type of circuit. The calculation for true power is current through the resistor, times the voltage across the resistor. It is also possible to use all of the same formulas for power as were used in dc circuits.

Formula #42. True Power, Watts.

$$P_R = I_R \times V_R$$

P_R is true power (real power), in watts

I_R is resistor current

V_R is resistor voltage

Reactive Power, P_x , VARs

Reactive power, measured in VAR, is the power in a reactive component. The unit VAR stands for "Volt-Ampere-Reactive". In a purely reactive circuit, there is no power actually dissipated because power can only be dissipated in resistance. Since there is current flow and voltage even in a purely reactive circuit, it is necessary to calculate the power associated with the reactive component.

Formula #43. Reactive Power, VARs

$$P_x = I_x \times V_x$$

P_x is reactive power in VAR

I_x is reactive current

V_x is reactive voltage

Apparent Power, P_A , VA

Apparent power is the total circuit power in an ac circuit containing both resistance and reactance. It is called apparent power because it is the calculated power using total current and total voltage. The units VA comes from "Volt-Ampere".

Formula #44. Apparent Power, VA

$$P_A = I_T \times V_T$$

P_A is apparent power in VA

I_T is total current

V_T is total applied voltage

Power Factor, PF, No Units

Power factor is the ratio of real power to apparent power. It is a pure number, with no units. The easiest method of calculating power factor is to find the cosine of the phase angle, theta.

Formula #45. Power Factor, PF

$$PF = \cosine \theta$$

Practice Problems:

Reactance, Impedance, Ac Power

Part A. Use Fig. 14-11 for problems 1-5. Find: Z, I, V_R , V_L , theta, P_R , P_x , P_A , PF.

1. $R = 450 \text{ ohms}$, $X_L = 600 \text{ ohms}$

2. $R = 825 \text{ ohms}$, $X_L = 550 \text{ ohms}$

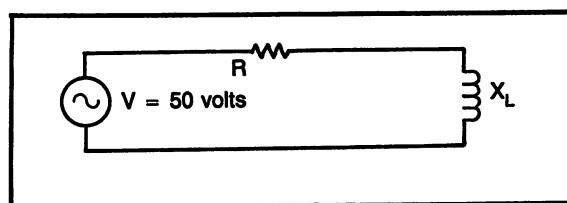


Fig. 14-11. Problems 1-5.

3. $R = 250$ ohms, $X_L = 300$ ohms
4. $R = 375$ ohms, $X_L = 375$ ohms
5. $R = 600$ ohms, $X_L = 450$ ohms

Part B. Use Fig. 14-12 for problems 6-10. Find: I_R , I_L , I_T , Z , theta, P_R , P_X , P_A , PF.

6. $R = 250$ ohms, $X_L = 300$ ohms
7. $R = 450$ ohms, $X_L = 300$ ohms
8. $R = 125$ ohms, $X_L = 275$ ohms
9. $R = 750$ ohms, $X_L = 500$ ohms
10. $R = 450$ ohms, $X_L = 450$ ohms

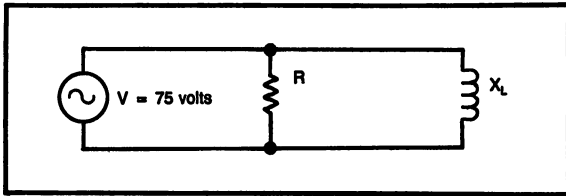


Fig. 14-12. Problems 6-10.

Part C. Use Fig. 14-13 for problems 11-15. Find: Z , I , V_R , V_C , theta, P_R , P_X , P_A , PF.

11. $R = 300$ ohms, $X_C = 325$ ohms
12. $R = 250$ ohms, $X_C = 450$ ohms
13. $R = 500$ ohms, $X_C = 300$ ohms
14. $R = 750$ ohms, $X_C = 800$ ohms
15. $R = 250$ ohms, $X_C = 250$ ohms

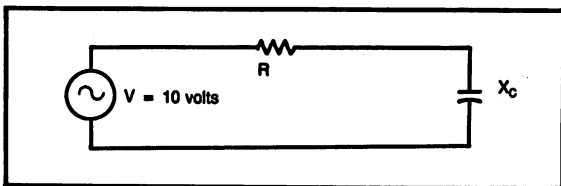


Fig. 14-13. Problems 11-15.

Part D. Use Fig. 14-14 for problems 16-20. Find: I_R , I_C , I_T , Z , theta, P_R , P_X , P_A , PF.

16. $R = 350$ ohms, $X_C = 325$ ohms
17. $R = 200$ ohms, $X_C = 325$ ohms
18. $R = 500$ ohms, $X_C = 425$ ohms
19. $R = 775$ ohms, $X_C = 900$ ohms
20. $R = 100$ ohms, $X_C = 325$ ohms

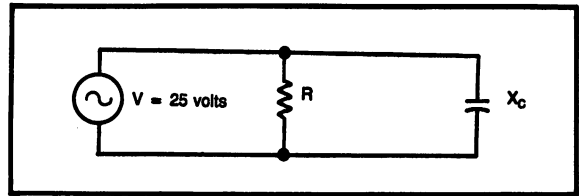


Fig. 14-14. Problems 16-20.

MEASURING PHASE ANGLE WITH AN OSCILLOSCOPE

To measure the phase angle with an oscilloscope, it is necessary to compare the voltage across the reactive component to the circuit voltage. A dual trace oscilloscope is necessary.

Review of the Oscilloscope Screen

Reading the scope screen is critical when making measurements. The screen is divided into "blocks", with the lines going up used for voltage measurements and the lines going across used for time measurements.

Each "block" on the screen represents 1 division as related to the volts/division and the time/division controls.

Each division is sub-divided into subdivisions, with four subdivisions per division. The subdivisions allow reading to one decimal place (.2, .4, .6, .8, 1.0).

Degrees per Division

When measuring frequency on a scope, it is necessary to measure the time of one cycle. This is done by counting the number of divisions in one cycle and multiplying by the time per division.

When measuring phase angle on the scope, it is not necessary to measure time, but only the number of divisions in one cycle. Since one cycle contains 360 degrees and the number of divisions can be counted, it is possible to determine the number of degrees per division.

Keep in mind, phase angle measurements require comparing the difference between two sine waves. The phase angle is measured in degrees, but the measurement is the number of divisions difference between the two waveforms.

Formula #46. Degrees per Division, From an Oscilloscope

$$\frac{\text{deg}}{\text{div}} = \frac{360 \text{ degrees}}{\# \text{ divisions}}$$

Phase Angle

Once it is known how many degrees per division there are for a sine wave, the phase angle is found by determining the # of divisions difference between the two waveforms and multiplying by the deg/div.

Formula #47. Phase Angle, from an Oscilloscope

$$\theta = \# \text{ div} \times \frac{\text{deg}}{\text{div}}$$

Triggering the Oscilloscope

When using a dual trace oscilloscope with two different waveforms, it is necessary to determine which waveform will be used by the scope to start the trace on the left.

Refer to Fig. 14-15. This figure shows a scope with two sine waves present. One wave is the applied voltage, V_A , and the other is the inductor voltage, V_L . Here, the scope is triggered on the input voltage. Notice, V_A starts at the zero axis line, while V_L looks like it started prior to this point.

Refer to Fig. 14-16. This figure shows a scope with two sine waves, but this drawing has the scope triggered on V_L , and V_A looks like it started late.

Figures 14-15 and 14-16 are of the same circuit, in fact, the values of R and X_L are equal, giving a 45 degree phase angle. The phase angle is positive because V_L leads V_A , as would be expected in a series inductive circuit. One difference between these two figures is that 14-15 has the time per division control set faster than 14-16. Notice that although the degrees per division is different, the measurement of phase angle is the same.

**Sample Problems:
Phase Angle Measurements**

SP#14-11. Refer to Fig. 14-15.

Note: count the divisions at the center, ground reference line.

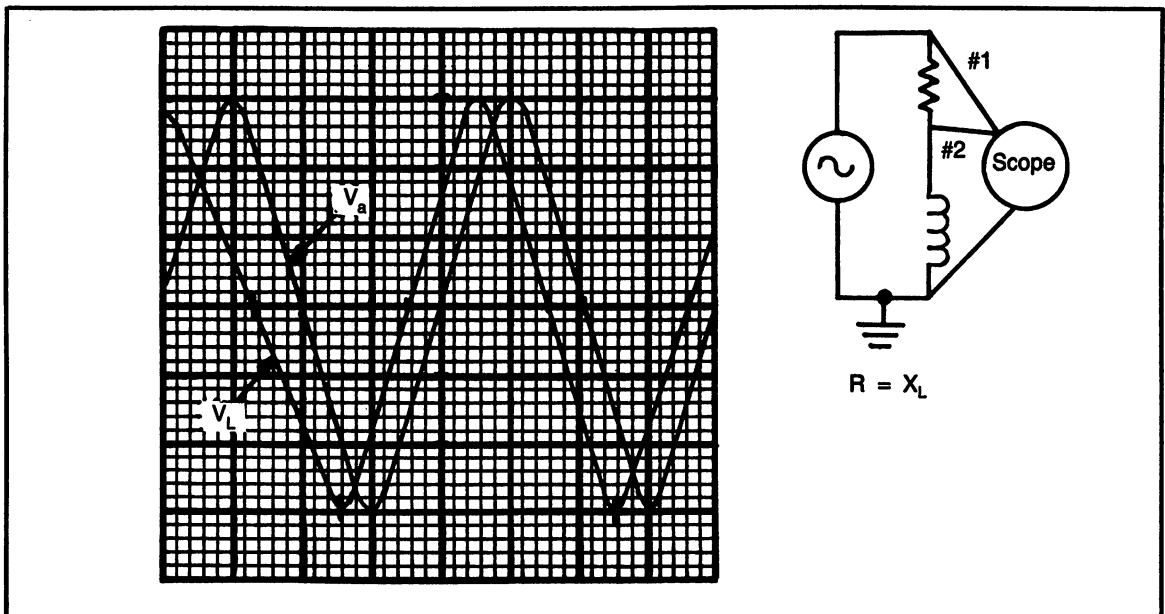


Fig. 14-15. 45° phase angle. Scope triggers on the input voltage. $R = X_L$.

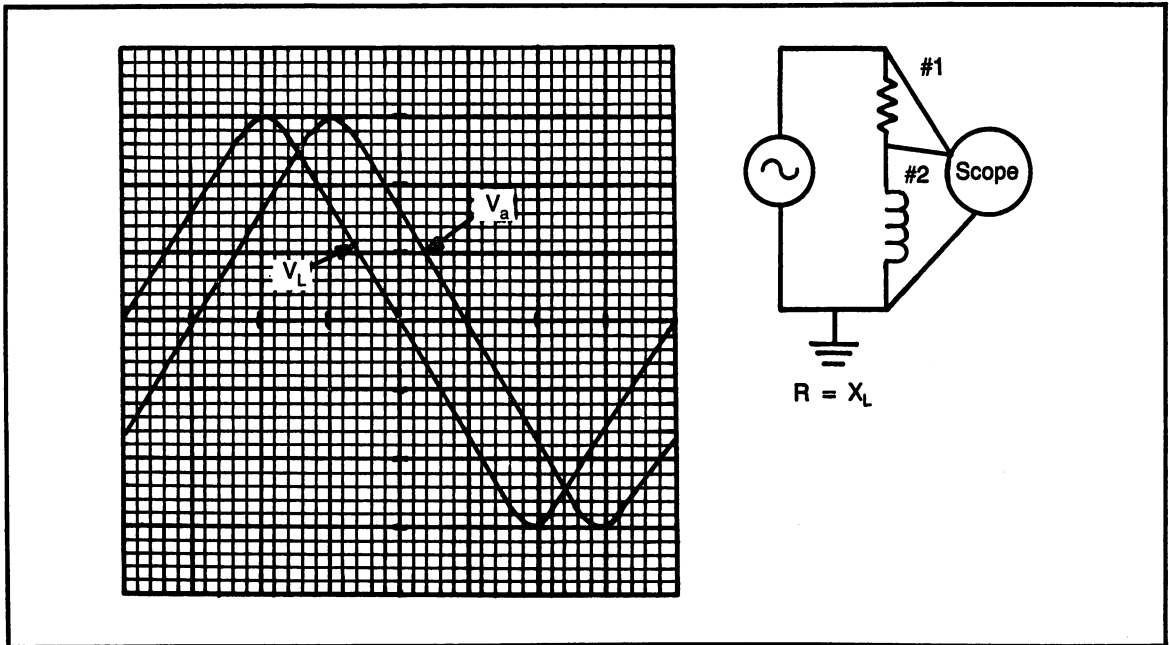


Fig. 14-16. 45° phase angle. Scope triggers on the inductor voltage. $R = X_L$.

- Step 1. Count the number of divisions in one complete cycle. In this sample, the applied voltage, V_A , is the trigger voltage and would be the best waveform to use.
 1 cycle = 4 divisions

- Step 2. Divide the number of degrees in one cycle by the number of divisions in one cycle.

$$\frac{\text{deg}}{\text{div}} = \frac{360 \text{ degrees}}{4 \text{ divisions}}$$

$$\frac{\text{deg}}{\text{div}} = 90$$

- Step 3. Determine the difference between the two waveforms by counting the number of divisions between the two waveforms, accurate to one decimal place.

.5 div diff

- Step 4. Multiply the divisions difference by the degrees per division to determine the

degrees difference between the sine waves; the phase angle.

$$.5 \text{ div} \times 90 \frac{\text{deg}}{\text{div}} = 45 \text{ deg}$$

phase angle = 45 degrees

SP#14-12. Refer to Fig. 14-16.

- Step 1. Divisions in 1 cycle.
 1 cycle = 8 divisions

- Step 2. Degrees per division

$$\frac{\text{deg}}{\text{div}} = \frac{360 \text{ degrees}}{8 \text{ divisions}}$$

$$\frac{\text{deg}}{\text{div}} = 45$$

- Step 3. Number of divisions difference.
 1 div diff

Step 4. Div diff \times deg/div
 1 div \times 45 deg/div
 phase angle = 45 degrees

SP#14-13. Refer to Fig. 14-17.

Step 1. Divisions in 1 cycle.
 1 cycle = 8 divisions

Step 2. Degrees per division

$$\frac{\text{deg}}{\text{div}} = \frac{360 \text{ degrees}}{8 \text{ divisions}}$$

$$\frac{\text{deg}}{\text{div}} = 45$$

Step 3. Number of divisions difference.
 0 div diff

Step 4. Div diff \times deg/div
 1 div \times 45 deg/div
 phase angle = 0 degrees (in phase)
 (reactance value very small)

SP#14-14. Refer to Fig. 14-18

Step 1. Divisions in 1 cycle.
 1 cycle = 8 divisions

Step 2. Degrees per division

$$\frac{\text{deg}}{\text{div}} = \frac{360 \text{ degrees}}{8 \text{ divisions}}$$

$$\frac{\text{deg}}{\text{div}} = 45$$

Step 3. Number of divisions difference.
 2 div diff

Step 4. Div diff \times deg/div
 2 div \times 45 deg/div
 phase angle = 90 degrees
 (resistance value very small)

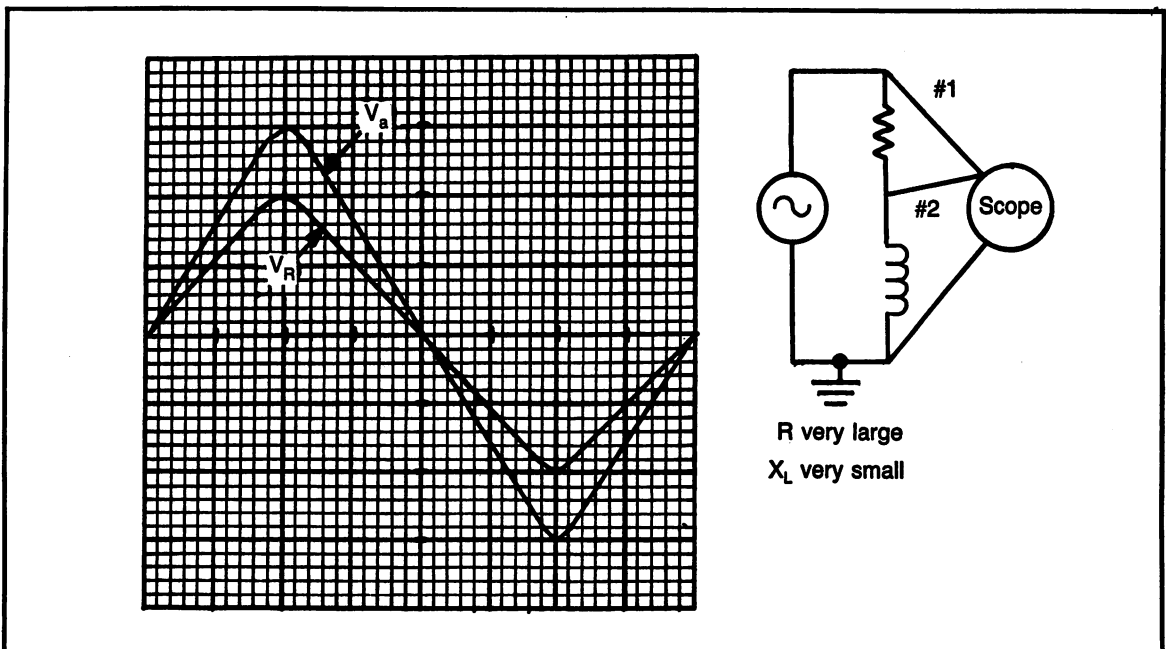


Fig. 14-17. 0° phase angle. R very large compared to X_L .

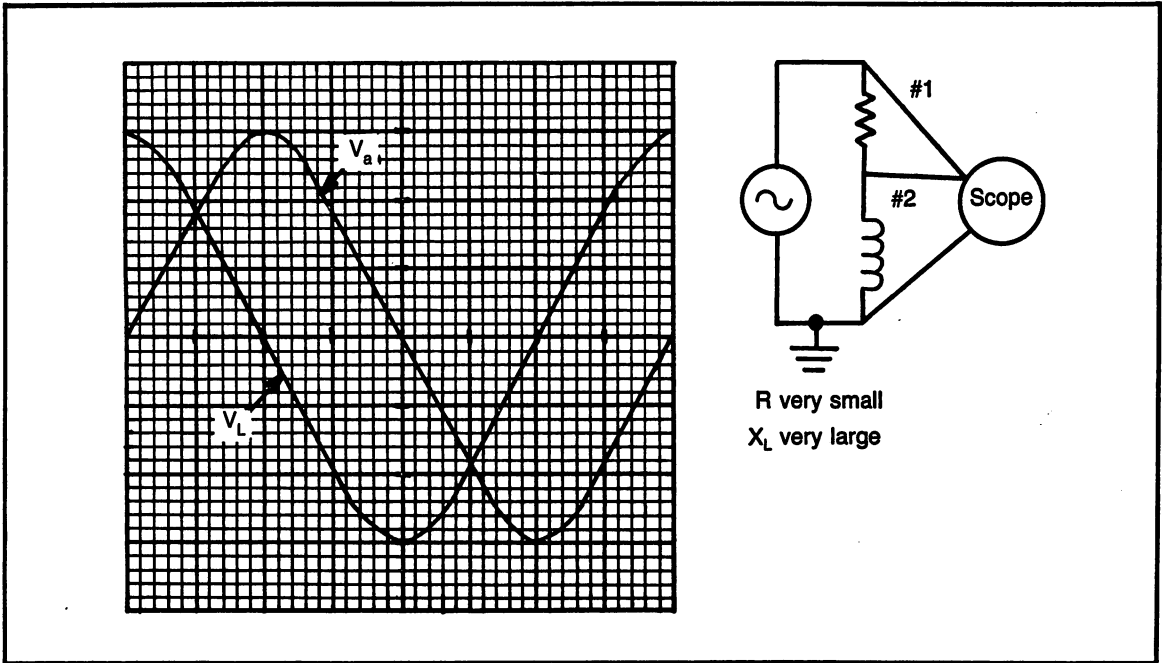


Fig. 14-18. 90° phase angle. R very small compared to X_L .

Practice Problems: Phase Angle

Figures 14-19 to 14-28 are practice problems in reading an oscilloscope screen to measure phase angle. To simplify matters, all 10 drawings are from

circuits containing inductive reactance. The scope is triggered on the applied voltage. The phase angles are all positive, the inductor voltage leads the applied voltage.

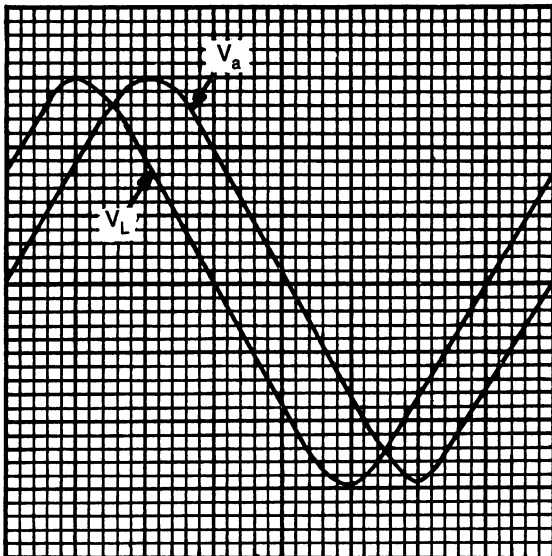


Fig. 14-19. Problem 1. a) _____ b) _____ c) _____ d) _____

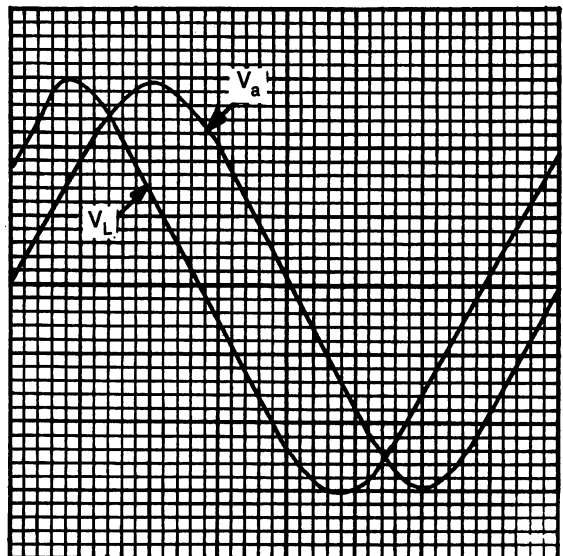


Fig. 14-20. Problem 2. a) _____ b) _____ c) _____ d) _____

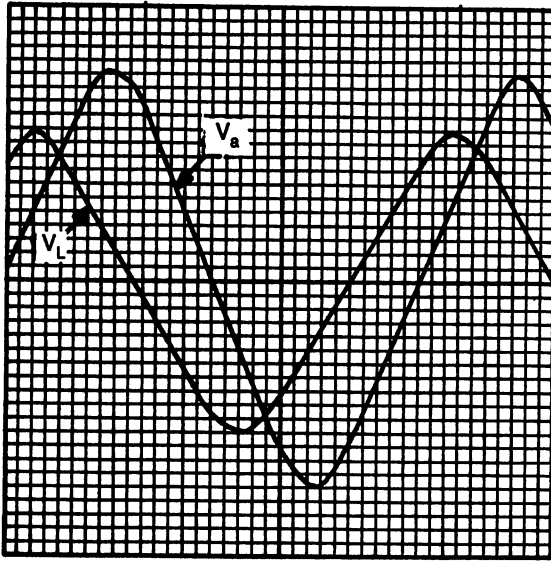


Fig. 14-21. Problem 3. a) ___ b) ___ c) ___ d) ___

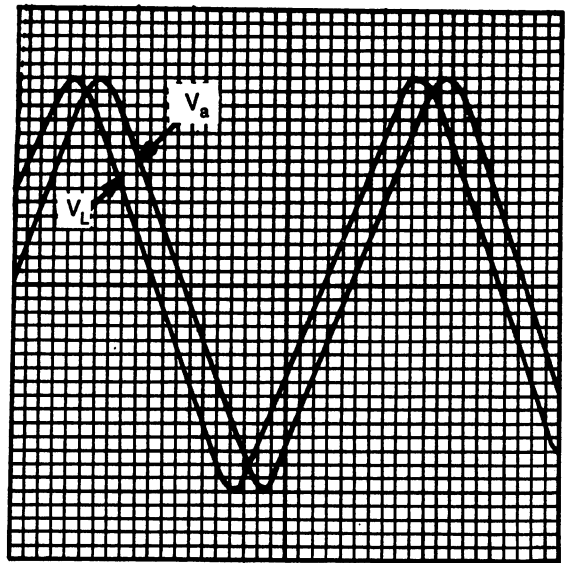


Fig. 14-23. Problem 5. a) ___ b) ___ c) ___ d) ___

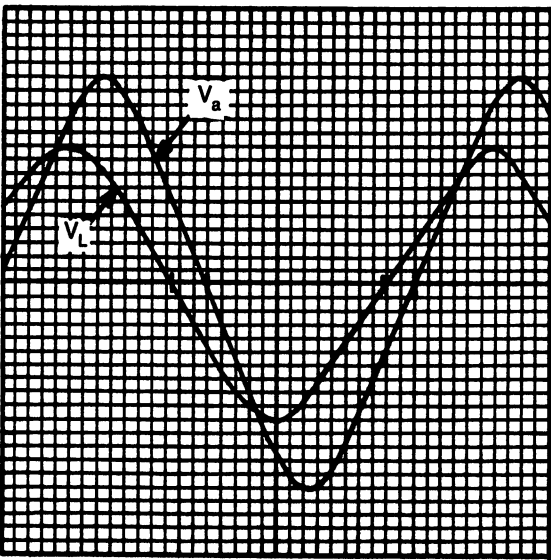


Fig. 14-22. Problem 4. a) ___ b) ___ c) ___ d) ___

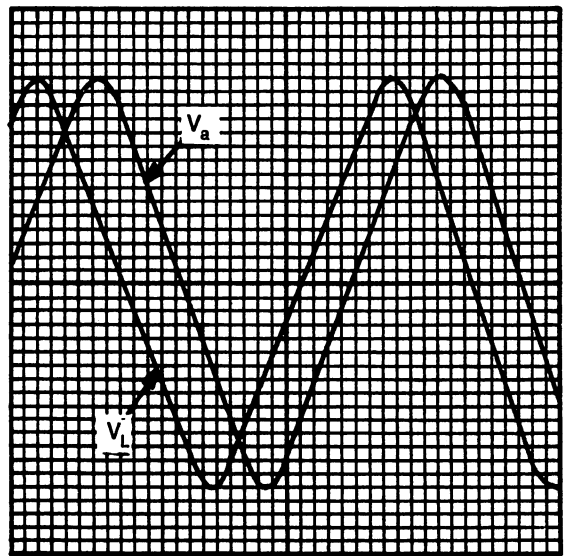


Fig. 14-24. Problem 6. a) ___ b) ___ c) ___ d) ___

The hands-on practice in the next section contains capacitive circuits, which have a negative phase angle.

Determine the following for each figure: a. divisions in 1 cycle. b. degrees per division. c. # divisions difference. d. phase angle.

HANDS-ON PRACTICE: MEASURING PHASE ANGLE

This hands-on experience is intended to serve two purposes; first, practice with phasor analysis and second, measurements of the phase angle using the oscilloscope. The two parts to this exercise will give

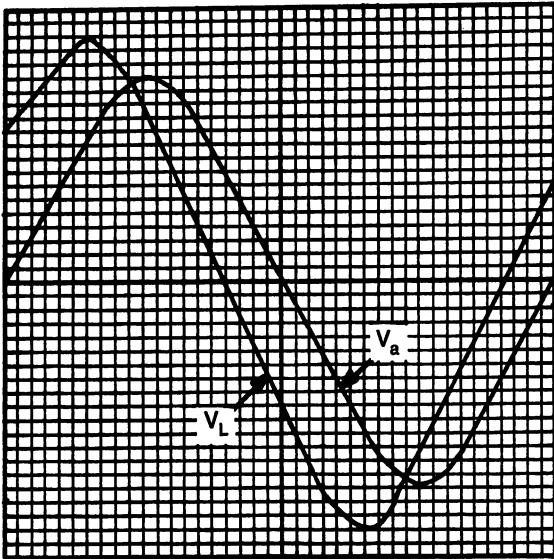


Fig. 14-25. Problem 7. a) ___ b) ___ c) ___ d) ___

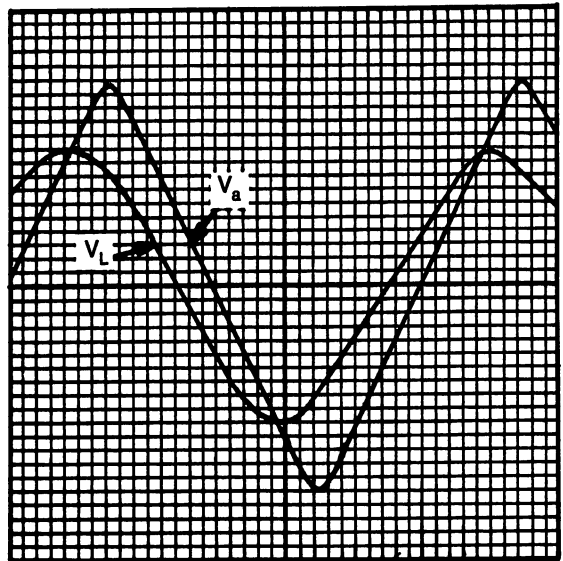


Fig. 14-27. Problem 9. a) ___ b) ___ c) ___ d) ___

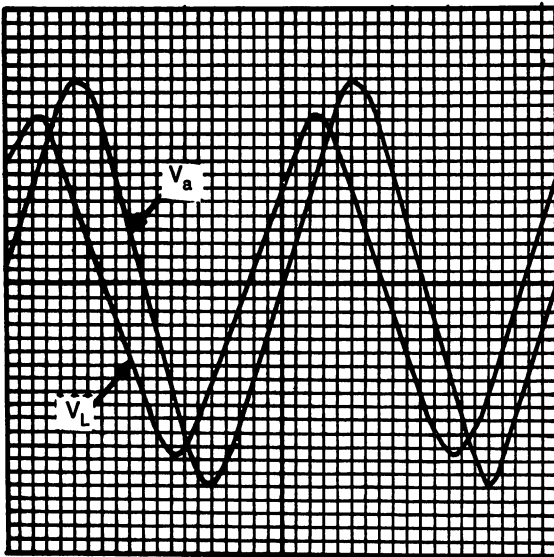


Fig. 14-26. Problem 8. a) ___ b) ___ c) ___ d) ___

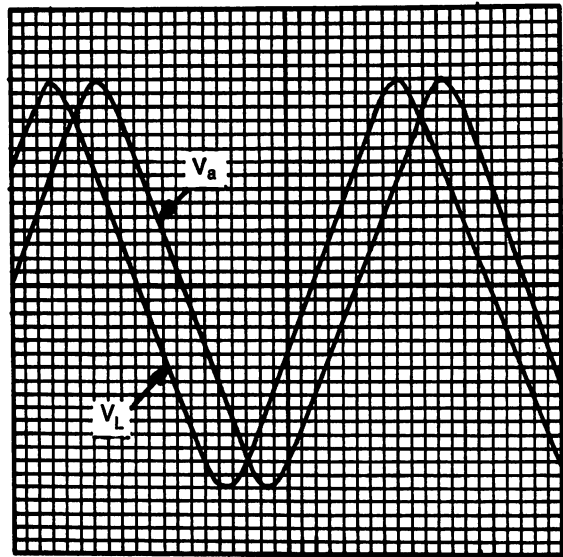


Fig. 14-28. Problem 10. a) ___ b) ___ c) ___ d) ___

a theoretical and visual demonstration of the effects on phase angle as the reactance is varied.

A series resistor/capacitor circuit has been chosen for this exercise because this is the simplest type of circuit to use for phase angle measurements. The actual value of the components is not critical since the frequency will be varied to change the capaci-

tive reactance.

Before proceeding with the hands-on portion of this exercise, the student should complete the list of formulas and the calculated values in Table 14-1. This is necessary to provide the needed information and background to obtain maximum learning efficiency.

Examine the schematic diagram and sample drawing of an oscilloscope display, in Fig. 14-29. Note the relationship of the two sine waves in the drawing.

CIRCUIT VALUES

Recommended:

Resistor: 10 kilohms

Capacitor: 0.001 μ F

Applied voltage: 10 volts peak to peak

Actual:

FORMULAS: (to be supplied by the student)

Capacitive reactance (ohms): $X_C =$

Impedance (ohms): $Z =$

Current (amps): $I =$

Voltage across the resistor (volts): $V_R =$

Voltage across the capacitor (volts): $V_C =$

Phase angle, theta (degrees): $\theta =$

Degrees/division on scope: deg/div =

of divisions difference between waveforms:

div =

Phase angle, theta, on scope (degrees).

$\theta =$

Step 1. Observations made from calculations at the frequency of 15,000 Hz.

a. What is the approximate relationship be-

- tween resistance and reactance?
- b. What is the approximate relationship of voltage drops across the resistor and capacitor?
- c. What is the approximate value of theta?
- d. What is the approximate shape of the voltage and impedance triangles?

Step 2. Observations made from the calculations as the frequency increases ABOVE 15,000 Hz.

- a. How does the relationship between resistance and reactance change?
- b. How does the relationship of the voltage drops change?
- c. How does theta change?
- d. How does the shape of the triangles change?

Step 3. Observations made from the calculations as the frequency decreases BELOW 15,000 Hz.

- a. How does the relationship between resistance and reactance change?
- b. How does the relationship of the voltage drops change?
- c. How does theta change?

Table 14-1. Calculated Values.

| FREQUENCY | X_C | Z | I | V_R | V_C | θ |
|-----------|-------|---|---|-------|-------|----------|
| 15,000 Hz | | | | | | |
| 20,000 Hz | | | | | | |
| 25,000 Hz | | | | | | |
| 30,000 Hz | | | | | | |
| 35,000 Hz | | | | | | |
| 40,000 Hz | | | | | | |
| 45,000 Hz | | | | | | |
| 50,000 Hz | | | | | | |
| ***** | | | | | | |
| 10,000 Hz | | | | | | |
| 7,500 Hz | | | | | | |
| 5,000 Hz | | | | | | |
| 2,500 Hz | | | | | | |

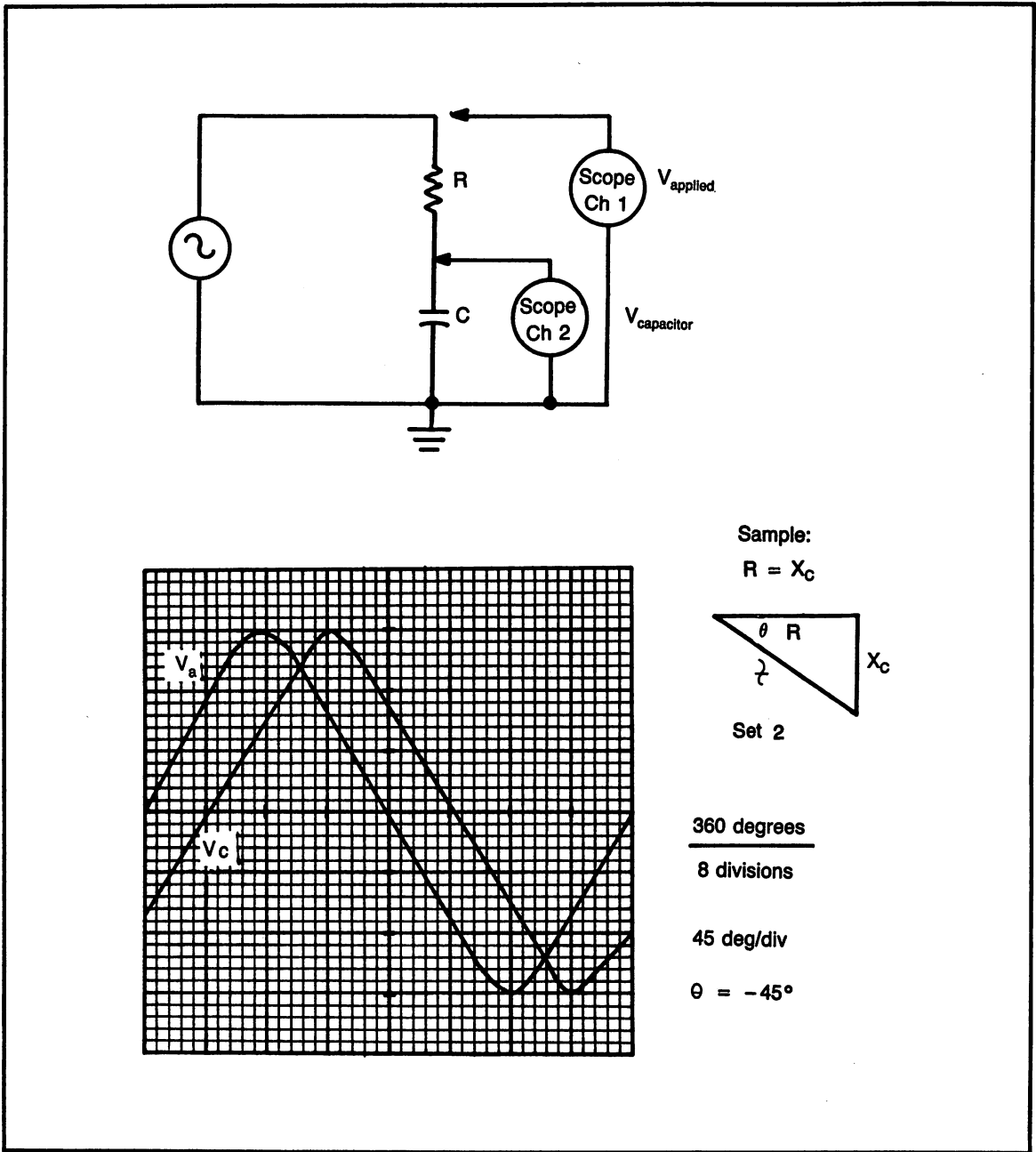


Fig. 14-29. Schematic and scope drawing for hands-on exercise measuring phase angle.

d. How does the shape of the triangles change?

Step 4. Connect the oscilloscope as shown in Fig. 14-29; channel 1 on the applied voltage and

channel 2 across the capacitor.

a. Make certain that all ground wires are connected to the same point, on one side of the capacitor.

- b. Set the applied voltage (from the signal generator) to 10 volts peak to peak.
- c. Adjust the signal generator to the desired frequency (starting with 15,000 Hz).
- d. Adjust the oscilloscope volts/division control on each channel to make the two sine waves approximately the same size, almost filling the screen.
- e. Adjust the oscilloscope time/division to allow a display of at least one full cycle, as shown in the sample drawing.
- f. Oscilloscope trigger must be adjusted for channel 1, the applied voltage.
- g. Adjust the ground reference line for the exact center of the screen, for both channels.

Step 5. For this step only, use the ground reference switch to remove channel 2 from the display (a straight line).

- a. The remaining sine wave is the resistor voltage. Count the number of divisions in one complete cycle. It is always best to count the divisions at the ground reference line.

- b. Divide this number into 360 and the result is the "deg/div". Record this value in Table 14-2.

Step 6. Switch channel 2 back on to the display. (Two sine waves should be present.)

- a. At the ground reference line, count the number of divisions (to one decimal place) between the two sine waves. Record this value in the table.
- b. Multiply the # of divisions times the deg/div and the result is the phase angle, theta, θ . Note: the phase angle is negative because the capacitor voltage "lags" the applied voltage.

Step 7. Use the above steps, as necessary to complete the table of results, for each frequency.

PROGRAMS FOR THIS CHAPTER

There are 2 programs for this chapter; reactance and phase angle.

The reactance program provides practice in using the formulas for calculating X_L and X_C . Note:

Table 14-2. Measured Values.

| Frequency | <u>Degrees</u> Division | # of Divisions | Phase Angle θ |
|-----------|----------------------------|-------------------|----------------------------|
| 15,000 Hz | | | |
| 20,000 Hz | | | |
| 25,000 Hz | | | |
| 30,000 Hz | | | |
| 35,000 Hz | | | |
| 40,000 Hz | | | |
| 45,000 Hz | | | |
| 50,000 Hz | | | |
| | | | |
| 10,000 Hz | | | |
| 7,500 Hz | | | |
| 5,000 Hz | | | |
| 2,500 Hz | | | |

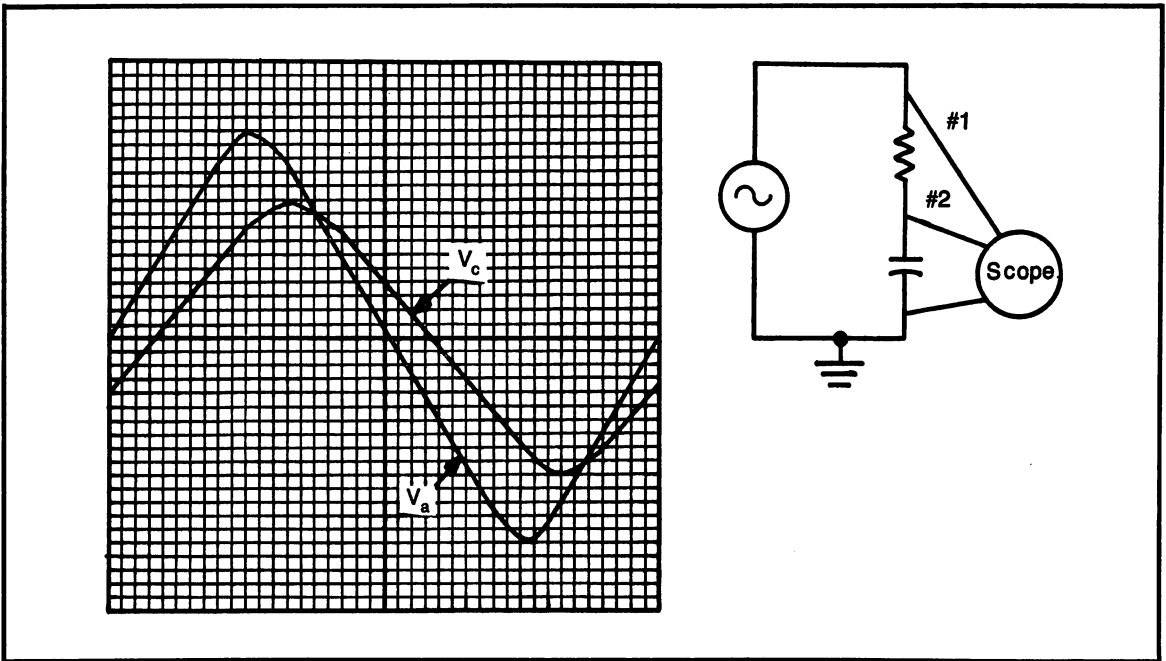


Fig. 14-32. Problem 49.

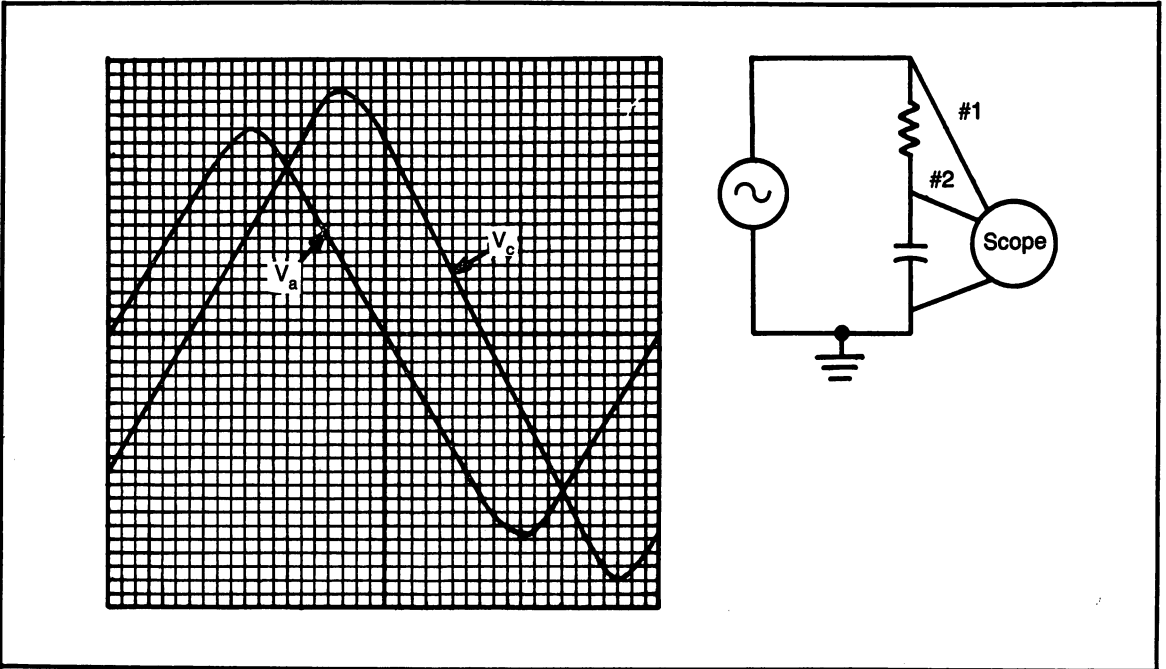


Fig. 14-33. Problem 50.

Find:

34. impedance, Z
35. total current, I
36. voltage across the resistor, V_R
37. voltage across the capacitor, V_C
38. phase angle, theta, θ
39. real power, P_R
40. reactive power, P_X
41. apparent power, P_A
42. power factor, PF

Part G. Parallel Capacitive Reactance

Units must be included with answer.

Given: $R = 150$ ohms, $X_C = 200$ ohms, $V = 100$ volts.

Find:

43. impedance, Z
44. total current, I_T
45. current through the resistor, I_R
46. current through the capacitor, I_C
47. phase angle, theta, θ
48. power factor, PF

Part H. Phase Angle With an Oscilloscope

Figures 14-32 and 14-33 are drawings of sine waves on the oscilloscope screen. Determine the phase angle shown in each drawing.

49. phase angle, theta, θ
50. phase angle, theta, θ

Chapter 15

Resonance

Chapter Objectives: To determine net reactance of circuits containing inductive and capacitive reactance. To examine the effects of resonance on current and voltage when inductive reactance equals capacitive reactance.

Chapter Outline:

- Net Reactance
- The Resonant Effect
- Series Resonance
- Parallel Resonance
- Bandwidth
- Programs for This Chapter
- Resonance Competency Test

INTRODUCTION

A circuit can contain a combination of resistance, inductance and capacitance. There are uses for the various combinations. This chapter will primarily deal with a circuit characteristic called “resonance”, which occurs when the inductive reactance equals the capacitive reactance.

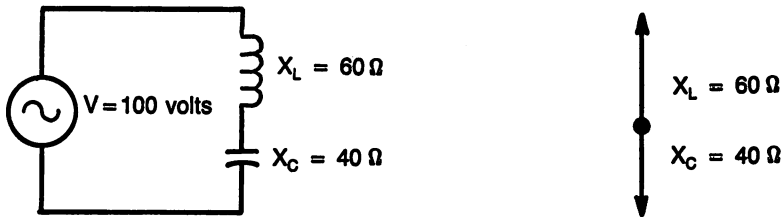
NET REACTANCE

Inductive and capacitive reactance have opposite characteristics and if they are used in the same circuit there will be some cancellation of their effects. Net reactance is the amount of reactance that “appears” to be in the circuit, considering the cancellation.

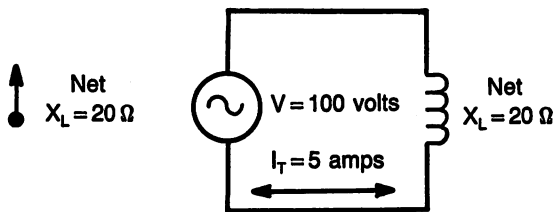
Series Circuits

Figure 15-1 shows a series L-C with its associated vectors. In a series circuit, the vectors are; reactance and voltage. In this sample circuit, resistance is ignored to better demonstrate the cancellation effect of the vectors.

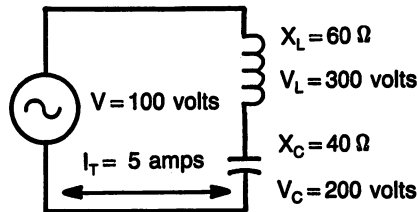
Starting with the original circuit in Fig. 15-1A, notice $X_L = 60$ ohms and $X_C = 40$ ohms. The vector for X_L is plotted up and the vector for X_C is plotted down. The two vectors are subtracted since they are opposite, leaving a net reactance of 20 ohms. The net reactance is inductive because X_L is larger than X_C . This circuit is classified as an “inductive” circuit.



A. L-C series circuit with reactance vectors.



B. Circuit showing net effect.



C. Circuit showing voltage drops and total current.

Fig. 15-1. Series net reactance sample problem 15-1.

Total current is calculated based on the net reactance, using Ohm's law. If resistance were also included in this circuit, an impedance triangle would be drawn and impedance calculated. The circuit with the single inductor, Fig. 15-1B is the net reactance, including the total current and applied voltage.

Voltage across each component is calculated based on the total current and Ohm's law. Notice, in Fig. 15-1C, how the voltage across the components is considerably higher than the applied voltage. This can only occur in a circuit with both

inductance and capacitance. It is a result of the charging and energy storage capabilities of the individual components.

Sample Problem: Series Net Reactance

SP#15-1. Refer to Fig. 15-1.

Given: Figure 15-1A, $X_L = 60$ ohms, $X_C = 40$ ohms

$V = 100$ volts

- Find:
- net reactance
 - state if net is L or C
 - total current, I_T
 - inductive voltage drop, V_L
 - capacitive voltage drop, V_C

- Find net reactance by subtracting X_L and X_C .
Net = 20 ohms, shown in Fig. 15-1B.
- The larger of X_L or X_C determines the net effect.
Net is L, shown in Fig. 15-1B.
- Total current is found using Ohm's law with the applied voltage and net reactance.
 $I_T = 5$ amps, shown in Fig. 15-1B.
- Inductive voltage drop is found by using Ohm's law with the total current and inductive reactance.
 $V_L = 300$ volts, shown in Fig. 15-1C.
- Capacitive voltage drop is found by using Ohm's law with the total current and capacitive reactance.
 $V_C = 200$ volts, shown in Fig. 15-1C.

Parallel Circuits

In a parallel circuit, it is current that has a phase shift and therefore, it is the individual branch currents that will cancel.

Figure 15-2 shows a circuit with an inductor in parallel with a capacitor. The reactance values of the two components have been selected the same as the values of the series circuit, Fig. 15-1, the previous sample problem, $X_L = 60$ ohms, $X_C = 40$ ohms.

Voltage is the same throughout the parallel circuit, so the individual branch currents are calculated using the applied voltage, 120 volts, with Ohm's law.

Notice, the branch current for the inductor is smaller than the branch current for the capacitor because the inductor has a larger value of reactance. The vectors are drawn for each branch current and the resultant current is the total current.

The total current is smaller than the branch currents. Between the inductor and capacitor there is a certain amount of "circulation current" flowing. The circulation current is a result of the charge and discharge of the inductor and capacitor.

This circuit, Fig. 15-2, is classified as "capacitive" because the capacitor has the largest current.

Sample Problem: Parallel Net Reactance

SP#15-2. Refer to Fig. 15-2.

Given: Figure 15-2A, $X_L = 60$ ohms, $X_C = 40$ ohms
 $V = 120$ volts

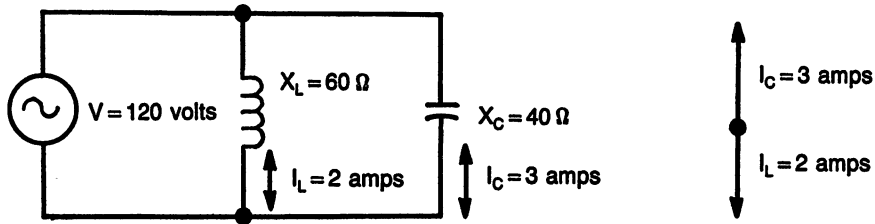
- Find:
- inductive current, I_L
 - capacitive current, I_C
 - net current (total current), I_T
 - net reactance
 - state if net is L or C

- Inductive current is calculated using Ohm's law with the applied voltage and inductive reactance.
 $I_L = 2$ amps, shown in Fig. 15.2A.
- Capacitive current is found using the same method as inductive current.
 $I_C = 3$ amps, shown in Fig. 15-2A.
- Net current is also called total current because it is the current from the power supply. Subtract the branch currents.
 $I_T = 1$ amp, shown in Fig. 15-2B.
- Net reactance is the reactance that would allow the total current to flow. Use Ohm's law with the applied voltage and net reactance.
Net = 120 ohms, shown in Fig. 15-2B.
- The circuit is determined if it is L or C by which has the largest current.
Circuit is net C.

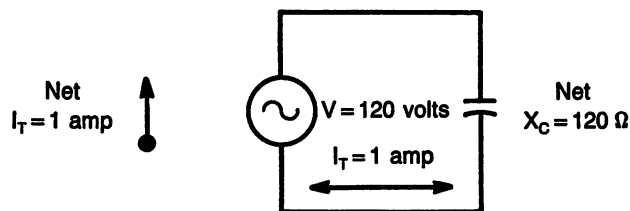
Practice Problems: Net Reactance

Part A. Series Circuits. With each of the following series circuits, find:

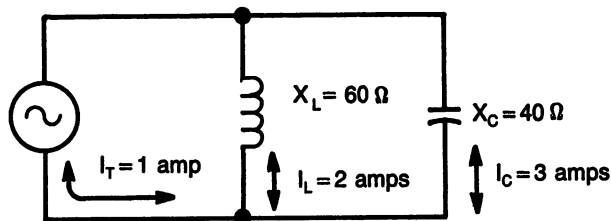
- net reactance
- state if net is L or C
- total current, I_T
- inductive voltage drop, V_L
- capacitive voltage drop, V_C



A. L-C parallel circuit with current vectors.



B. Circuit showing net effect.



C. Circuit showing reactance and branch currents.

Fig. 15-2. Parallel net reactance sample problem 15-2.

- | | |
|--|---|
| <p>(1) $X_L = 150$ ohms, $X_C = 275$ ohms, $V = 10$ volts (2) $X_L = 50$ ohms, $X_C = 75$ ohms, $V = 15$ volts (3) $X_L = 250$ ohms, $X_C = 175$ ohms, $V = 20$ volts (4) $X_L = 750$ ohms, $X_C = 550$ ohms, $V = 25$ volts (5) $X_L = 450$ ohms, $X_C = 500$ ohms, $V = 30$ volts (6) $X_L = 150$ ohms, $X_C = 125$ ohms, $V = 10$ volts (7) $X_L = 15$ ohms, $X_C = 25$ ohms, $V = 10$ volts (8) $X_L = 350$ ohms, $X_C = 375$ ohms, $V = 15$ volts (9) $X_L = 300$ ohms, $X_C = 375$ ohms, $V = 20$ volts</p> | <p>(10) $X_L = 150$ ohms, $X_C = 200$ ohms, $V = 10$ volts</p> <p>Part B. Parallel Circuits. With each of the following parallel circuits, find:</p> <p>a. inductive current, I_L b. capacitive current, I_C c. net current (total current, I_T)</p> |
|--|---|

- d. net reactance
e. state if net is L or C

- (11) $X_L = 30$ ohms, $X_C = 40$ ohms, $V = 10$ volts
 (12) $X_L = 35$ ohms, $X_C = 50$ ohms, $V = 15$ volts
 (13) $X_L = 50$ ohms, $X_C = 40$ ohms, $V = 20$ volts
 (14) $X_L = 300$ ohms, $X_C = 350$ ohms, $V = 25$ volts
 (15) $X_L = 150$ ohms, $X_C = 100$ ohms, $V = 10$ volts
 (16) $X_L = 20$ ohms, $X_C = 25$ ohms, $V = 15$ volts
 (17) $X_L = 250$ ohms, $X_C = 240$ ohms, $V = 15$ volts
 (18) $X_L = 60$ ohms, $X_C = 40$ ohms, $V = 30$ volts
 (19) $X_L = 40$ ohms, $X_C = 45$ ohms, $V = 15$ volts
 (20) $X_L = 80$ ohms, $X_C = 60$ ohms, $V = 40$ volts

THE RESONANT EFFECT

The definition of resonance is when $X_L = X_C$. The effect of this is significant by the fact that one reactance can cancel the effects of the other reactance. In a series circuit, there appears to be no reactance, only resistance. In a parallel circuit, there appears to be an open circuit.

Both parallel and series resonant circuits are used, with their application depending on which characteristic is required.

Calculating the Resonant Frequency

The formula to calculate the resonant frequency is shown below, as formula #48. The formula is found by using the definition of resonance; $X_L = X_C$ and their respective formulas as follows:

$$X_L = 2 (\pi) f L$$

and

$$X_C = \frac{1}{2 (\pi) f C}$$

if

$$X_L = X_C$$

then:

$$2 (\pi) f L = \frac{1}{2 (\pi) f C}$$

Therefore, solving for f:

Formula #48. Frequency of Resonance

$$f_r = \frac{1}{2 (\pi) \sqrt{L C}}$$

When solving for the resonant frequency, it is possible to have a wide range of component values of L (inductance) and C (capacitance). To demonstrate this concept, Table 15-1 shows five different combinations of L and C that will produce the resonant frequency of 1 MHz. Notice, the table also includes the value of reactance for each combination.

The different combinations of X_L and X_C are selected based on their reactances and the particular application.

Table 15-1. L-C Combinations Resonant at 1 MHz.

| L (μ H) | C (pF) | $X_L = X_C$ Reactance (Ohms) |
|--------------|--------|---------------------------------|
| 23.9 | 1060 | 150 |
| 120 | 212 | 750 |
| 239 | 106 | 1500 |
| 478 | 53 | 3000 |
| 2390 | 10.6 | 15,000 |

Sample Problems: Resonant Frequency

SP#15-3. Calculate the value of resonant frequency.

Given: $L = 239 \mu$ H, $C = 106$ pF

Find: f_r

$$\text{Formula: } f_r = \frac{1}{2(\pi) \sqrt{LC}}$$

$$\text{Substituting: } f_r = \frac{1}{6.28 \times \sqrt{239 \mu\text{H} \times 106 \text{pF}}}$$

$$\text{Solving: } f_r = 1 \text{ MHz}$$

Note: to solve this, first perform the multiplication inside the square root sign. Second, take the square root. Third, multiply by 6.28. Last, take the reciprocal.

Practice Problems: Resonant Frequency

Use the information given to find the resonant frequency.

- (1) Given: $L = 10 \text{ mH}$, $C = 25 \text{ }\mu\text{F}$
Find: f
- (2) Given: $L = 35 \text{ mH}$, $C = 200 \text{ }\mu\text{F}$
Find: f
- (3) Given: $L = 75 \text{ mH}$, $C = .005 \text{ }\mu\text{F}$
Find: f
- (4) Given: $L = .3 \text{ H}$, $C = 25 \text{ pF}$
Find: f
- (5) Given: $L = 15 \text{ }\mu\text{H}$, $C = .68 \text{ }\mu\text{F}$
Find: f
- (6) Given: $L = 35 \text{ }\mu\text{H}$, $C = 6.5 \text{ pF}$
Find: f
- (7) Given: $L = .55 \text{ H}$, $C = .33 \text{ }\mu\text{F}$
Find: f
- (8) Given: $L = 250 \text{ mH}$, $C = 7 \text{ }\mu\text{F}$
Find: f
- (9) Given: $L = 17.3 \text{ }\mu\text{H}$, $C = 3.7 \text{ }\mu\text{F}$
Find: f
- (10) Given: $L = 1.5 \text{ H}$, $C = 3.5 \text{ }\mu\text{F}$
Find: f

SERIES RESONANCE

Any series circuit has the characteristic that the current must flow through all series components. In a series resonant circuit, where $X_L = X_C$, the reactance is canceled resulting in near zero impedance.

Normally, a series resonant circuit is used in a condition where it is desired to pass only the resonant frequency and filter out any other. An example is an antenna.

Minimum Impedance at Resonance

In an actual working circuit, the inductor, since it is made from a coil of wire, has a certain amount of resistance. That amount of resistance is a charac-

Table 15-2. Reactance at Frequencies Near 1 MHz.

| $L = .239 \text{ H}, C = .106 \text{ }\mu\text{F}$ | | | | |
|--|-----------------|-----------------|---------------|-----|
| Freq. (Hz) | X_L (Ohms) | X_C (Ohms) | Net (Ohms) | L/C |
| 600 | 900 | 2500 | 1600 | C |
| 800 | 1200 | 1875 | 675 | C |
| 1000 | 1500 | 1500 | 0 | |
| 1200 | 1800 | 1250 | 550 | L |
| 1400 | 2100 | 1070 | 1030 | L |

teristic of the inductor and will be present in the circuit at any frequency, whether or not it is at resonance. Because of the built-in circuit resistances, when X_L and X_C cancel each other there still remains a small amount of impedance.

Refer to Table 15-2 for a summary of the values of reactance at frequencies above and below the resonant frequency of 1000 Hz. The net is the difference between X_L and X_C , with the L/C column showing which had the higher reactance.

Maximum Current at Resonance

A series resonant circuit has a characteristic minimum impedance at resonance, therefore, there must be maximum current flow at resonance. The only resistance in the circuit at resonance is the resistance of the coil.

Refer to Fig. 15-3. A series resonant circuit is drawn showing the inductor, capacitor and the resistance of the inductor's coil, labeled r_s . The resonant frequency is 1000 Hz, as calculated in Table 15-2. Accompanying the schematic diagram in Fig. 15-3 is the "bell curve" of current vs frequency.

The bell curve shows the resonant frequency at the center peak. At the resonant frequency, the current is at a maximum value. On either side of the "center", resonant frequency, the current drops off very quickly. Referring to Table 15-2, notice the net reactance increases above and below center frequency.

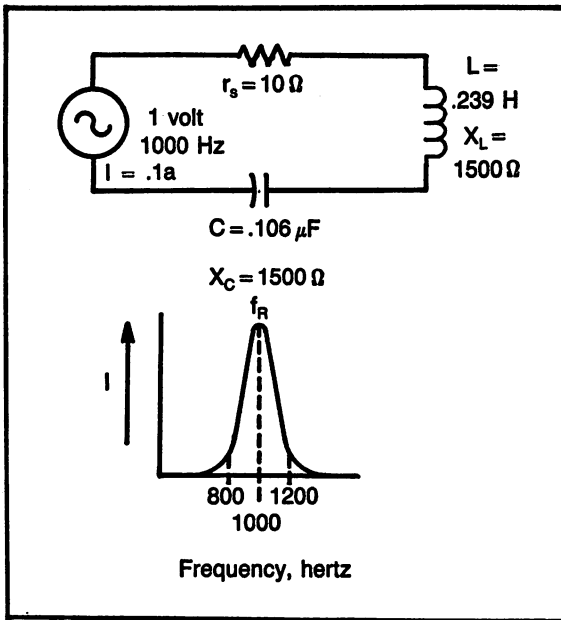


Fig. 15-3. Series resonant circuit and the bell curve of current vs. frequency.

Effect Above and Below Resonant Frequency

As discovered from the bell curve, one of the effects above and below resonant frequency is the current will decrease. The results on Table 15-2 show the net reactance to be either capacitive or inductive.

Notice in Table 15-2, below resonant frequency, the net reactance is capacitive and above resonant frequency, the net reactance is inductive. The characteristics of a series circuit are determined, not by the reactance, but by the voltage drops. The voltage drop will be largest across the largest value of reactance.

A capacitive circuit has a lagging, negative, phase angle. An inductive circuit has a leading, positive, phase angle.

Key Point. A series resonant circuit is capacitive below resonance and inductive above resonance.

PARALLEL RESONANCE

A parallel circuit has voltage common throughout the circuit, with current dividing to the individual branches.

In a parallel resonant circuit, where X_L and X_C cancel, the inductor and capacitor produce a current that circulates only in the two components. The circulating current is called the “flywheel” effect, where the inductor charges the capacitor and the capacitor charges the inductor. The circulating current does not flow in the rest of the circuit.

The circulating current in a parallel resonant circuit reaches a maximum at resonance. Any signal that has a frequency equal to resonance will support the circulating current, but cannot pass by the parallel circuit, therefore, the resonant frequency has the effect of being stopped. Any other frequency will pass by the parallel circuit, being ignored.

An application for the parallel resonant circuit is in the tuning of a radio, where each amplifier section is transformer coupled to the next stage. A transformer will pass the most voltage when the current in the primary is the largest, at resonant frequency. The transformer primary is the inductor in the parallel resonant circuit.

Maximum Impedance at Resonance

The term maximum impedance means that the signal cannot pass through, such as an open circuit. Figure 15-4 shows the schematic diagram of a parallel resonant circuit and the current and impedance curves. The impedance curve shows a maximum impedance at resonance, where at other frequencies, there is less impedance. This means that at the resonant frequency, the power supply “sees” the parallel resonant circuit as an open circuit.

Minimum Current at Resonance

In Fig. 15-4, the current curve shows that the current drops to near zero at the resonant frequency. The current represented in this figure is the current from the power supply. At non-resonant frequencies, the current increases, as the reactance of either branch decreases.

Effect Above and Below Resonant Frequency

Refer to Table 15-2. Below resonant frequency, X_L is decreasing and X_C is increasing. Therefore, below resonance, there will be more inductive cur-

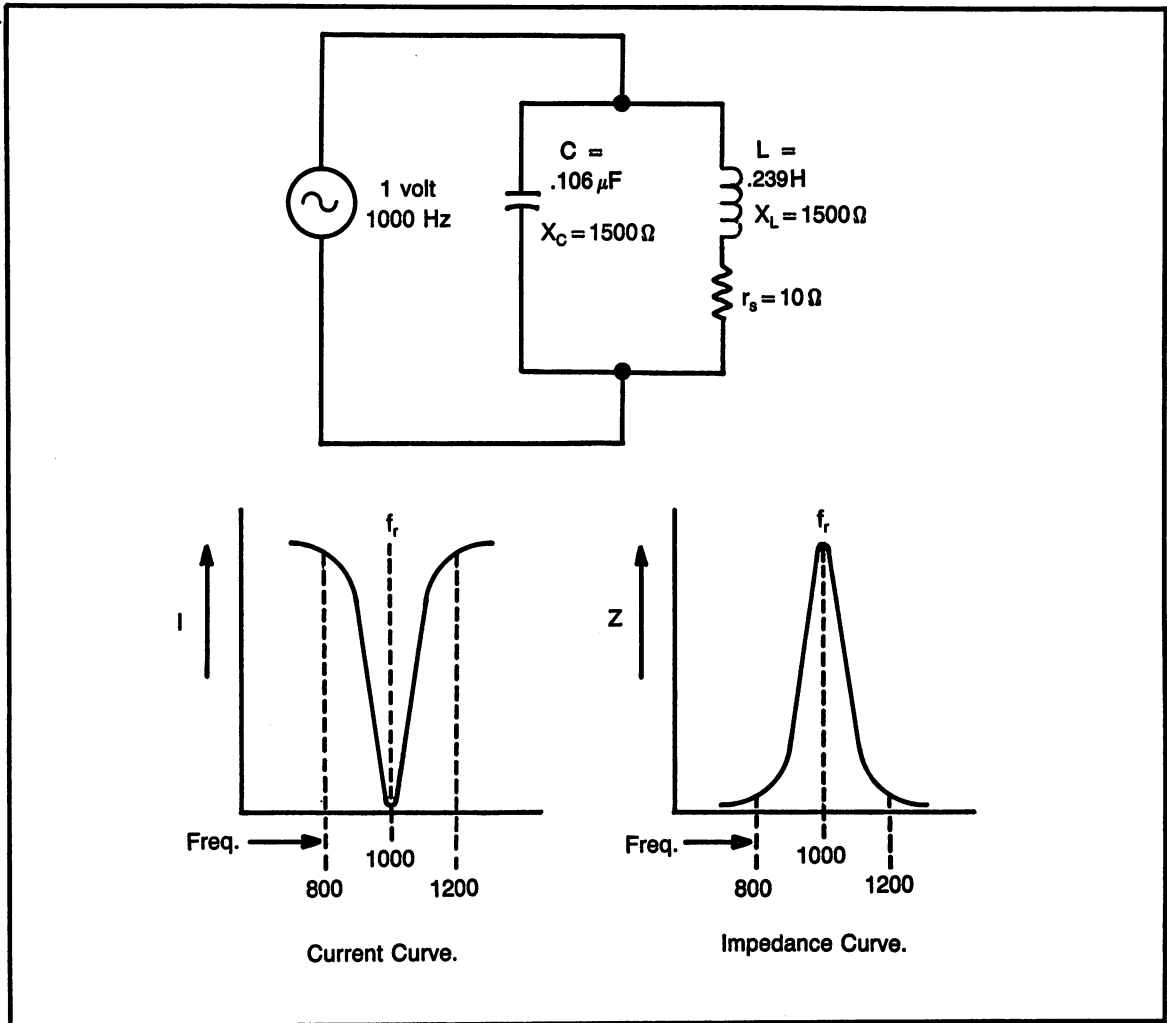


Fig. 15-4. Parallel resonant circuit and the bell curves of current vs. frequency and impedance vs. frequency.

rent and the circuit will have inductive characteristics.

Above resonant frequency, X_C is decreasing and X_L is increasing. Therefore, above resonance, there will be more capacitive and the circuit will have capacitive characteristics.

Key Point. A parallel resonant circuit is inductive below resonance and capacitive above.

BANDWIDTH

The bandwidth of a circuit is the width of the bell curve. It essentially describes how the resonant

circuit responds to frequencies that are above and below the resonant frequency.

70.7%, -3dB, Half-Power

The terms 70.7%, -3dB and half-power all refer to bandwidth and are exactly the same point on the bell curve. Each of the terms is explained below:

70.7% is a percentage of the maximum value of the response curve (bell curve). The response curve can be plotted in voltage or current. Therefore, it is 70.7% of the maximum voltage or current.

-3dB. refers to a point that is down (-) 3dB

(decibels) from the maximum value. Decibels is a unit of measure, usually associated with power. -3dB is the half-power point.

Half-Power. refers to the point where the output power is $\frac{1}{2}$ of the input power. Since response curves are plotted in voltage or current, it is necessary to exercise Ohm's law and the power formulas to demonstrate that $\frac{1}{2}$ power = 70.7%.

Bandwidth

Bandwidth is defined as the range of frequencies on the response curve that have a response of at least 70.7%. The bandwidth describes how well the resonant circuit acts as a filter, and how it responds to frequencies near the resonant frequency. Refer to Fig. 15-5.

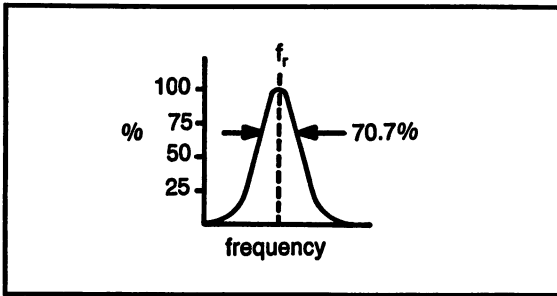


Fig. 15-5. Bell curve showing the 70.7% response point.

Bandwidth is also described as the “selectivity” of the resonant circuit. A smaller, narrower, bandwidth is more selective of which frequencies it will accept. A larger, wider, bandwidth is less selective and will accept a larger range of frequencies.

Q of a Resonant Circuit

The Q is a measure of the “quality” or “figure of merit” of the resonant circuit. A larger value of Q results in a narrower bandwidth. A smaller value of Q results in a wider bandwidth.

Refer to Fig. 15-6. There are three bell curves, each with a different Q. The curve with a Q of 80 has a bandwidth of 10kHz, the Q of 40 has a bandwidth of 20kHz and the Q of 10 has a bandwidth of 80kHz. Depending on the application, each of these curves could be the desired effect.

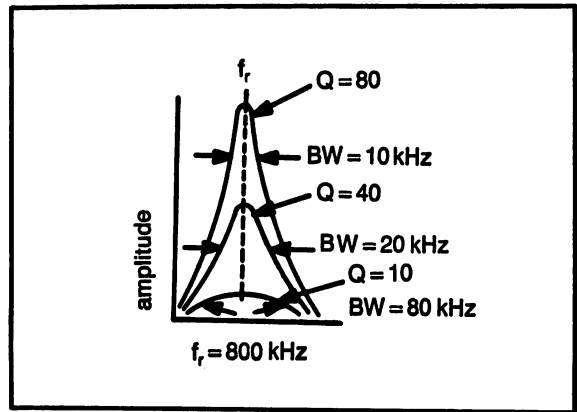


Fig. 15-6. Three bell curves, each with the same resonant frequency, with different Q.

PROGRAMS FOR THIS CHAPTER

There is one program for this chapter. Figure 15-7 is the program sample for the resonance program.

Included in the program are questions on calculations with the resonant frequency formula, and calculations with net reactance. Keep in mind with net reactance problems, if there is no resistance in the circuit, the reactances are simply subtracted and current and voltage calculations are made with Ohm's law, and do not require the use of vectors and Pythagorean's theorem.

RESONANCE COMPETENCY TEST

Part A. Net Reactance; Series Circuits

With each of the following series circuits, find:
 a. net reactance. b. state if net is L or C. c. total current, I_T . d. inductive voltage drop, V_L . e. capacitive voltage drop, V_C .

- (1) $X_L = 100$ ohms, $X_C = 250$ ohms, $V = 10$ volts
- (2) $X_L = 75$ ohms, $X_C = 50$ ohms, $V = 25$ volts
- (3) $X_L = 35$ ohms, $X_C = 50$ ohms, $V = 50$ volts
- (4) $X_L = 200$ ohms, $X_C = 100$ ohms, $V = 25$ volts
- (5) $X_L = 150$ ohms, $X_C = 140$ ohms, $V = 100$ volts

Part B. Net Reactance; Parallel Circuits

With each of the following parallel circuits, find:

Final Exam: Dc and Ac Building Blocks

- Engineering notation
- Ohm's law
- Power formulas
- DC circuits
- Sine wave analysis
- Transformers
- Inductors and capacitors
- Time constants
- Reactance, impedance and AC power
- Resonance

ENGINEERING NOTATION

Convert the given numbers to the units shown.

- | | | |
|--------------|-------|---------|
| (1) .005 A | _____ | mA |
| (2) 65.7 mV | _____ | V |
| (3) 5,600 kW | _____ | W |
| (4) 87 MHz | _____ | kHz |
| (5) 1500 pF | _____ | μ F |

OHM'S LAW

Use Ohm's law to find the unknown value. The proper unit must be included with each answer.

- | | | |
|---------------------|---------------|---------|
| (6) R = 200 ohms | I = .5 amps | Find: V |
| (7) V = 15 volts | R = 60 ohms | Find: I |
| (8) I = 20 mA | V = 30 volts | Find: R |
| (9) R = 2.2 kilohms | V = 6 volts | Find: I |
| (10) I = 15 mA | R = 3 kilohms | Find: V |

POWER FORMULAS

Use the power formulas to find the unknown value. The proper unit must be included with each answer.

- | | | |
|-------------------|--------------|---------|
| (11) V = 25 volts | I = .02 amps | Find: P |
| (12) I = 3 amps | R = 40 Ohms | Find: P |
| (13) R = 50 Ohms | V = 10 volts | Find: P |

- (14) $P = 60$ watts $V = 120$ volts Find: I
 (15) $I = .5$ amps $P = 2$ watts Find: V

DC CIRCUITS

Refer to the schematic diagram for each problem.

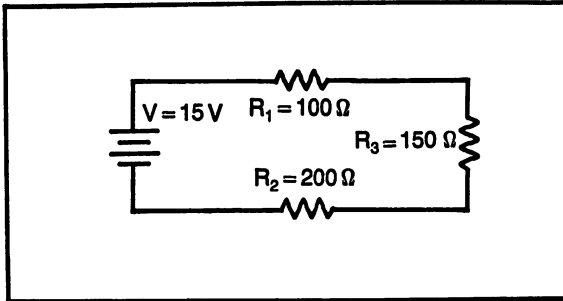


Fig. Ex2-1. Problem 16. Find the voltage drop across R_3 .

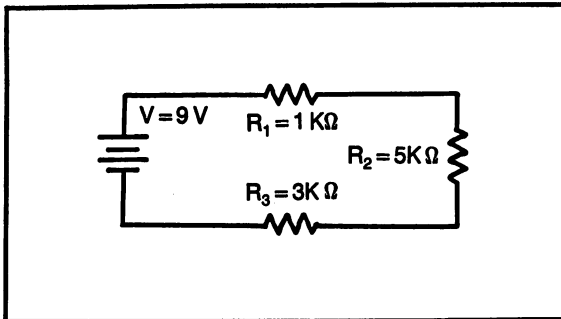


Fig. Ex2-2. Problem 17. Determine the total current.

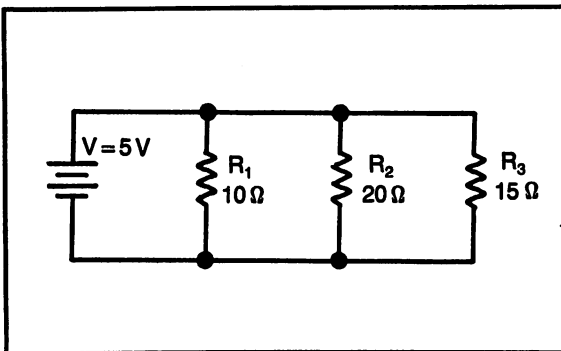


Fig. Ex2-3. Problem 18. Calculate the current in R_2 .

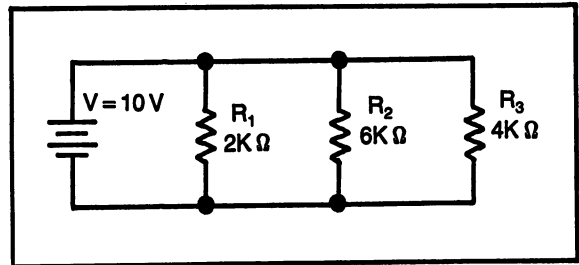


Fig. Ex2-4. Problem 19. Find the total resistance.

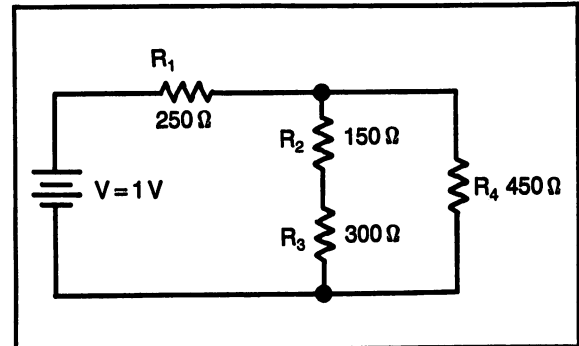


Fig. Ex2-5. Problem 20. Calculate the total resistance.

SINE WAVE ANALYSIS

Convert the information given to the unknown.

- | | |
|---------------------------------|--------------------|
| (21) Given: 15 volts peak | Find: rms |
| (22) Given: 33 volts rms | Find: peak to peak |
| (23) Given: 60 volts peak | Find: average |
| (24) Given: frequency = 1500 Hz | Find: period |
| (25) Given: period = 16.7 ms | Find: frequency |

TRANSFORMERS

Use the information given to find the unknown.
 Note: turns ratios are stated as Pri:Sec.

- | | |
|--------------------------------|------------------------------|
| (26) Given: turns ratio = 8:1 | primary voltage = 40 volts |
| Find: secondary volts | |
| (27) Given: turns ratio = 1:6 | primary voltage = 10 volts |
| Find: secondary volts | |
| (28) Given: turns ratio = 12:1 | secondary voltage = 10 volts |
| Find: primary voltage | |

- (29) Given: turns ratio = 1:5
secondary voltage = 100 volts
Find: primary voltage
- (30) Given: secondary power = 6 watts
primary power = 8 watts
Find: efficiency (percentage)

INDUCTORS AND CAPACITORS

All answers must have proper units.

- (31) Determine the total inductance of two inductors connected in series; .5 H and 1 H.
- (32) Determine the total inductance of two inductors connected in parallel; 25 mH and 30 mH.
- (33) Determine the total capacitance of two capacitors connected in series; 2 μF and 4 μF .
- (34) Determine the total capacitance of two capacitors connected in parallel; 10 pF and 15 pF.
- (35) Find the voltage across C_1 of the following capacitive voltage divider: $V = 10$ volts, $C_1 = 2 \mu\text{F}$ and $C_2 = 5 \mu\text{F}$.

TIME CONSTANTS

- (36) Determine the value of 1 time constant when; $C = 2 \mu\text{F}$ and $R = 3$ kilohms.
- (37) Determine the value of 1 time constant when; $L = 25$ mH and $R = 50$ ohms.
- (38) Calculate the time for full charge; $C = 50 \mu\text{F}$ and $R = 200$ ohms.
- (39) Calculate the time for full charge; $L = .5$ mH

and $R = 2$ kilohms.

- (40) What percentage of full charge will be reached in 1 time constant?

REACTANCE, IMPEDANCE AND AC POWER

All answers must have correct units.

- (41) Calculate X_C when; $f = 2500$ Hz and $C = 4 \mu\text{F}$.
- (42) Calculate X_L when; $f = 600$ Hz and $L = 150$ mH.
- (43) Calculate the impedance of a circuit with $R = 250$ ohms in series with $X_L = 150$ ohms.
- (44) Calculate the impedance of a circuit with $R = 500$ ohms in parallel with $X_C = 750$ ohms.
- (45) Which power is the largest in an ac circuit? (watts, VARs, VA)

RESONANCE

- (46) Calculate the resonant frequency of; $L = 24$ mH and $C = 4 \mu\text{F}$.
- (47) Calculate the resonant frequency of; $L = 6$ mH and $C = .05 \mu\text{F}$
- (48) Find the net reactance of a series circuit with $X_L = 175$ ohms and $X_C = 200$ ohms.
- (49) Find the net reactance of a parallel circuit with $X_L = 50$ ohms and $X_C = 40$ ohms, $V = 10$ volts.
- (50) A series resonant circuit below resonance is net (L or C).

Appendix A:

Glossary

Alternating Current (ac). current or voltage that periodically changes direction.

Ampere (A). Unit of measure of current, also know as amp.

Amplitude. The height of a waveform. It can be measured in; peak or peak to peak.

Analog. Constantly moving. When used in reference to meters, it is the type with a needle.

Apparent power. The total power of an ac circuit, unit of measure is VA.

Average. A measurement along a sine wave at 63.6% of the maximum amplitude.

Bandwidth. The group or band of frequencies with a response of 70.7% or better along the bell curve.

Bell curve. A curve showing the response of a filter circuit to various frequencies.

Capacitance (C). An electrical component with the ability to store a charge of electrons.

Competency. The ability to perform a task satisfactorily.

Conductor. Any substance that allows the flow of electricity.

Continuity. Continuously connected. When used in reference to an electric circuit, it is a complete current path.

Current (I). The flow of electricity, unit of measure is ampere.

Cycle. When a waveform repeats itself, unit of measure is hertz.

Dielectric. An insulator between the two plates of a capacitor.

Digital. Operates in a pulsating manner, either on or off. When used in reference to meters, it is the type that has a numerical display.

Direct current (dc). Current or voltage that stays always positive or always negative.

Electrolytic. A type of capacitor whose capacitance is formed only when the proper polarity is applied to the terminals.

Eddy current. An undesirable current flowing in the core of a transformer.

Electromagnetic. A magnet that is produced by electricity flowing through a coil of wire.

Electromotive force (EMF). Another name for voltage.

Electrons. The part of the atom that actually moves to produce electricity.

Engineering notation. A modification to scientific notation by replacing the powers of 10 with multiplier names.

Exponential notation. A modification to scientific notation by replacing the powers of 10 with the letter E.

Farad (F). Unit of measure of capacitance.

Flux. Another term used for a magnetic field.

Frequency. Cycles per second, CPS. Unit of measure is hertz.

Fuse. A device used to break a circuit when there is an excessive amount of current flow.

Giga. (G). A prefix used as a multiplier name in engineering notation to represent 10^9 .

Ground. A point of zero volts.

Henry (H). Unit of measure of inductance.

Hertz (Hz). Unit of measure of frequency.

Hysteresis. The energy required to produce a magnetic field.

Impedance (Z). AC resistance, unit of measure is Ohms.

Inductance (L). An electrical component with the ability to produce a magnetic field.

Instantaneous. At a particular instant in time.

Insulator. Any substance that will not allow the flow of electricity.

Kilo- (k). A prefix used as a multiplier name in engineering notation to represent 10^3 .

Mega- (M). A prefix used as a multiplier name in engineering notation to represent 10^6 .

Micro- (μ). A prefix used as a multiplier name in engineering notation to represent 10^{-6} .

Milli- (m). A prefix used as a multiplier name in engineering notation to represent 10^{-3} .

Nano- (n). A prefix used as a multiplier name in engineering notation to represent 10^{-9} .

Nominal. A desired value of a component.

Ohm (Ω). Unit of measure of resistance.

Open circuit. A circuit that does not have a

complete electrical path due to a break in the conductor.

Parallel circuit. A circuit connected in such a manner to allow the same voltage to be applied to all circuit components.

Parameter. The values of a circuit; resistance, current, voltage, power.

Peak. The maximum amplitude of a waveform in either the positive or negative direction.

Peak to Peak. The amplitude of a waveform measured from positive peak to negative peak.

Period. A measurement of the time of a wave to complete one cycle.

Phase angle (θ). The relationship between the reactive voltage (or current) and the circuit voltage (or current).

Phasor. A line drawn to represent the size and direction of an ac voltage or current.

Pico- (p). A prefix used as a multiplier name in engineering notation to represent 10^{-12} .

Potentiometer. A variable resistor.

Power (P). Work performed by electricity, unit of measure is watt.

Primary. The input to a transformer.

Reactance (X). The ac resistance of a capacitor (X_C) or inductor (X_L), unit of measure is Ohm.

Reactive power. The ac power of a circuit associated with reactive component, unit of measure is VAR.

Relay. An electro-magnetic device used to operate a switch.

Resistance (R). The opposition to the flow of electricity, unit of measure is ohm.

Resonance. An electrical characteristic when $X_L = X_C$.

Rheostat. A variable resistor.

Rms. A measure along a waveform equal to 70.7% of the peak value.

Scientific notation. Writing of numbers using powers of 10.

Secondary. The output of a transformer.

Series circuit. A circuit connected in such a manner so the current must flow through each component equally.

Short. An electrical condition where the nor-

mal electrical path is shortened to allow the electricity to bypass the load, causing excessive current flow.

Solenoid. An electro-magnetic device used to move a metal bar.

Tera- (T). A prefix used as a multiplier name in engineering notation to represent 10^{12} .

Time constant. The time required for a capacitor or inductor to charge to 63% of full charge.

True power. The ac power of a pure resistive component, unit of measure is Watts.

Transformer. An electrical device that magnetically couples two coils of wire to allow electricity to pass from one coil to the other.

VA. Volt-ampere, unit of measure of the total power of an ac circuit.

VAR. Volt-ampere-reactive, unit of measure of the ac power of a reactive component.

Voltage (V or E). The force that causes electrical current flow, unit of measure is volt.

Wattage (W). Unit of measure of power, also called watts.

Appendix B:

Formulas

#1. Ohm's law to solve for voltage.

$$V = I \times R$$

#2. Ohm's law to solve for current.

$$I = \frac{V}{R}$$

#3. Ohm's law to solve for resistance.

$$R = \frac{V}{I}$$

#4. Power formula using the $V \times I$ relationship.

$$P = V \times I$$

#5. Power formula using I and R.

$$P = I^2 \times R$$

#6. Power formula using V and R.

$$P = \frac{V^2}{R}$$

#7.7. Total resistance in a series circuit.

$$R_T = R_1 + R_2 + R_3 + \dots$$

#8. Voltage drops in a series circuit.

$$V_T = V_1 + V_2 + V_3 + \dots$$

#9. IR drops in a series circuit.

$$V_T = IR_1 + IR_2 + IR_3 + \dots$$

#10. Total power for all dc circuits.

$$P_T = P_{R1} + P_{R2} + P_{R3} + \dots$$

#11. Total current in a parallel circuit.

$$I_T = I_1 + I_2 + I_3 + \dots$$

#12. Total resistance in a parallel circuit, using total current (Ohm's law).

$$R_T = \frac{V}{I_T}$$

#13. Total resistance in a parallel circuit, reciprocal formula.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

#14. Short cut formula for total resistance with two resistors in parallel.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

#15. Short cut formula for total resistance with equal values of resistors in parallel.

$$R_T = \frac{R}{n} \quad \frac{\text{(resistance value)}}{\text{(number of resistors)}}$$

#16. Series inductors, no mutual inductance.

$$L_T = L_1 + L_2 + L_3 + \dots$$

#17. Series inductors, aiding mutual inductance.

$$L_T = L_1 + L_2 + 2L_M$$

#18. Series inductors, opposing mutual inductance.

$$L_T = L_1 + L_2 - 2L_M$$

#19. Series inductors with aiding OR opposing mutual inductance.

$$L_T = L_1 + L_2 + /- 2L_M$$

#20. Inductors in parallel, reciprocal formula.

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \dots$$

#21. Instantaneous voltage of a sine wave.

$$V = V_{\max} \times \sin \theta$$

#22. Peak to peak from peak.

$$\text{peak to peak} = 2 \times \text{peak}$$

#23. Rms from peak.

$$\text{Rms} = .707 \times \text{peak}$$

#24. Average from peak.

$$\text{Average} = .636 \times \text{peak}$$

#25. Frequency as the reciprocal of time.

$$f = \frac{1}{t}$$

#26. Transformer turns ratio.

$$N_p : N_s \text{ (or) } \frac{N_p}{N_s}$$

#27. Transformer voltage ratio.

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

#28. Transformer current ratio.

$$\frac{N_p}{N_s} = \frac{I_s}{I_p}$$

#29. Transformer impedance ratio.

$$\frac{Z_p}{Z_s} = \left(\frac{N_p^2}{N_s^2} \right)$$

#30. Efficiency.

$$\% \text{ eff} = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\%$$

#31. Capacitors in parallel.

$$C_T = C_1 + C_2 + C_3 + \dots$$

#F2332. Capacitors in series.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots$$

#33. Capacitive voltage divider.

$$V_{C1} = \frac{C_2}{(C_1 + C_2)} \times V$$

$$V_{C2} = \frac{C_1}{(C_1 + C_2)} \times V$$

#34. Instantaneous charging voltage.

$$\% \text{ of full charge} = (1 - e^{-T}) \times 100\%$$

#35. Instantaneous discharge voltage.

$$\% \text{ of full charge} = e^{-T} \times 100\%$$

#36. L/R time constant.

$$T = \frac{L}{R}$$

#37. RC time constant.

$$T = R \times C$$

#38. Inductive reactance, X_L .

$$X_L = 2 (\pi) f L$$

#39. Capacitive reactance, X_C .

$$X_C = \frac{1}{2 (\pi) f C}$$

#40. Hypotenuse of a right triangle.

a. Impedance triangle.

$$Z = \sqrt{R^2 + X^2}$$

b. Voltage triangle.

$$V_T = \sqrt{V_R^2 + V_X^2}$$

c. Current triangle.

$$I_T = \sqrt{I_R^2 + I_X^2}$$

#41. Phase angle, theta, θ .

$$\tan \theta = \frac{\text{opposite}}{\text{adjacent}}$$

a. Impedance triangle

$$\theta = \tan^{-1} \frac{X}{R}$$

b. Voltage triangle.

$$\theta = \tan^{-1} \frac{V_X}{V_R}$$

c. Current triangle.

$$\theta = \tan^{-1} \frac{I_X}{I_R}$$

#42. True power, watts.

$$P_R = I_R \times V_R$$

#43. Reactive power, VARs.

$$P_X = I_X \times V_X$$

#44. Apparent power, VA.

$$P_A = I_T \times V_T$$

#45. Power factor, PF.

$$PF = \cos \theta$$

#46. Degrees per division, from an oscilloscope.

$$\frac{\text{deg}}{\text{div}} = \frac{360 \text{ degrees}}{\# \text{ divisions}}$$

#47. Phase angle, from an oscilloscope.

$$\theta = \# \text{ div} \times \frac{\text{deg}}{\text{div}}$$

#48. Frequency of resonance.

$$f_r = \frac{1}{2 (\pi) \sqrt{L C}}$$

Appendix C: Schematic Symbols

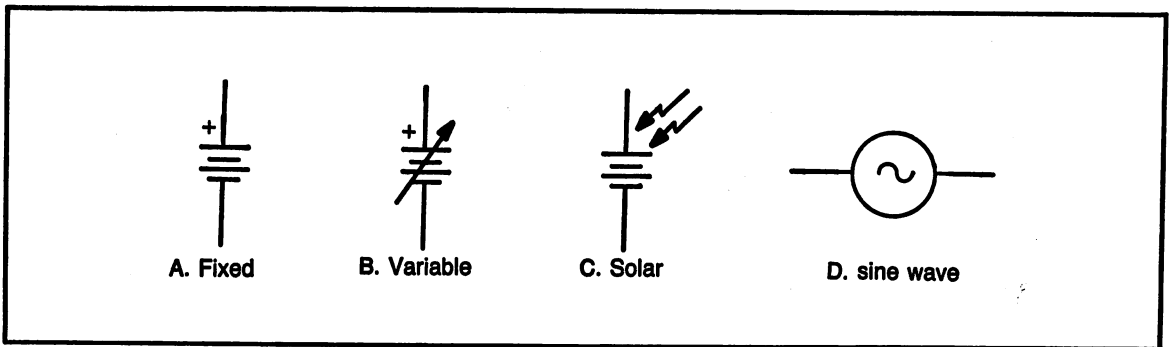


Fig. C-1. Voltage sources.

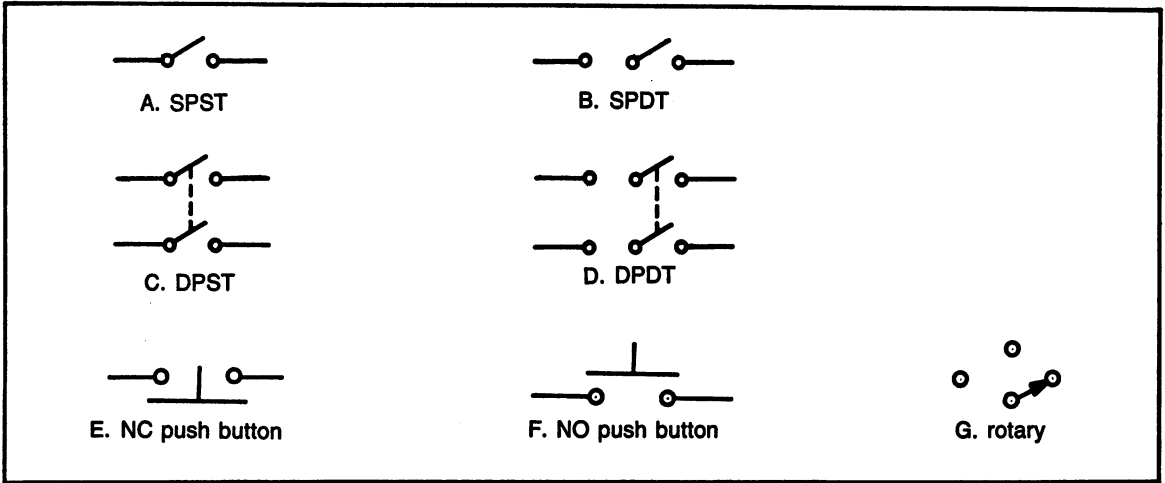


Fig. C-2. Switches.

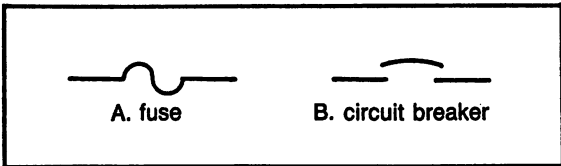


Fig. C-3. Current overload protection.

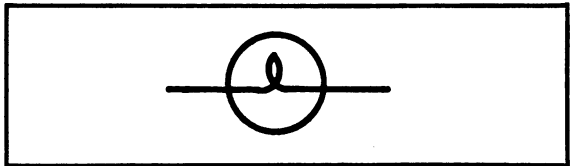


Fig. C-4. Lamp.

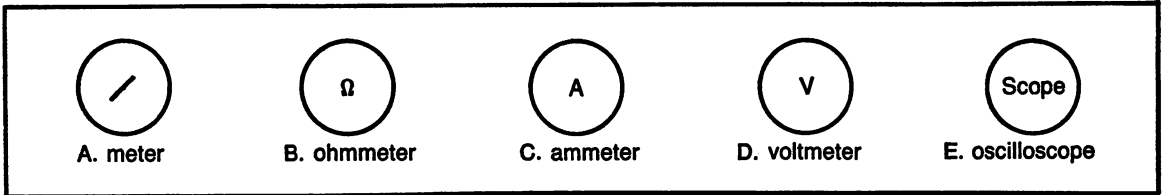


Fig. C-5. Test meters.

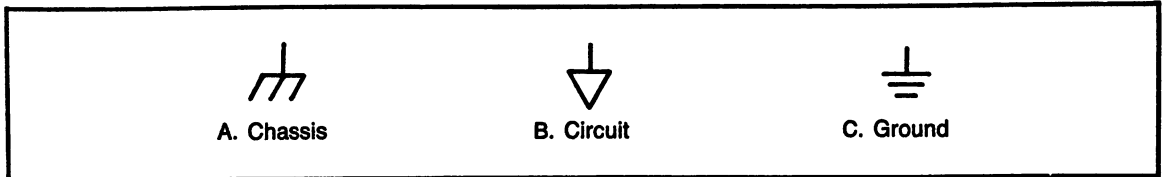


Fig. C-6. Circuit commons.

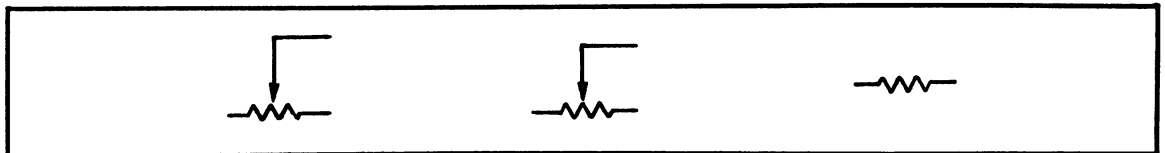


Fig. C-7. Resistors.

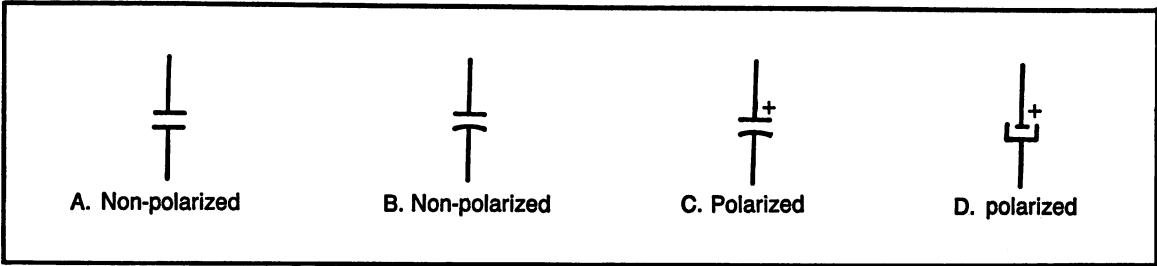


Fig. C-8. Capacitors.

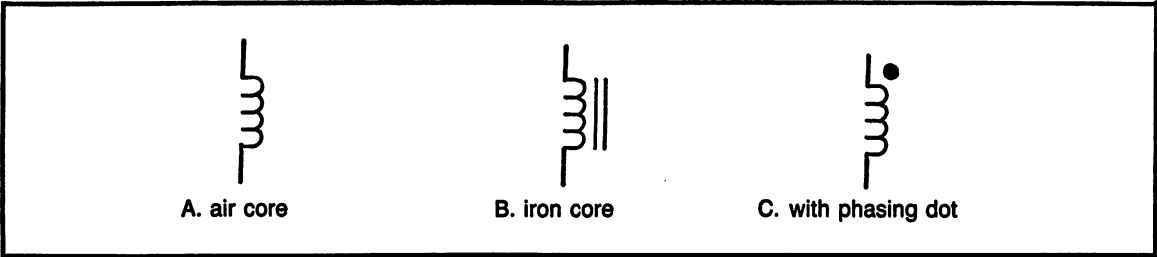


Fig. C-9. Inductors.

Fig. C-10. Relay

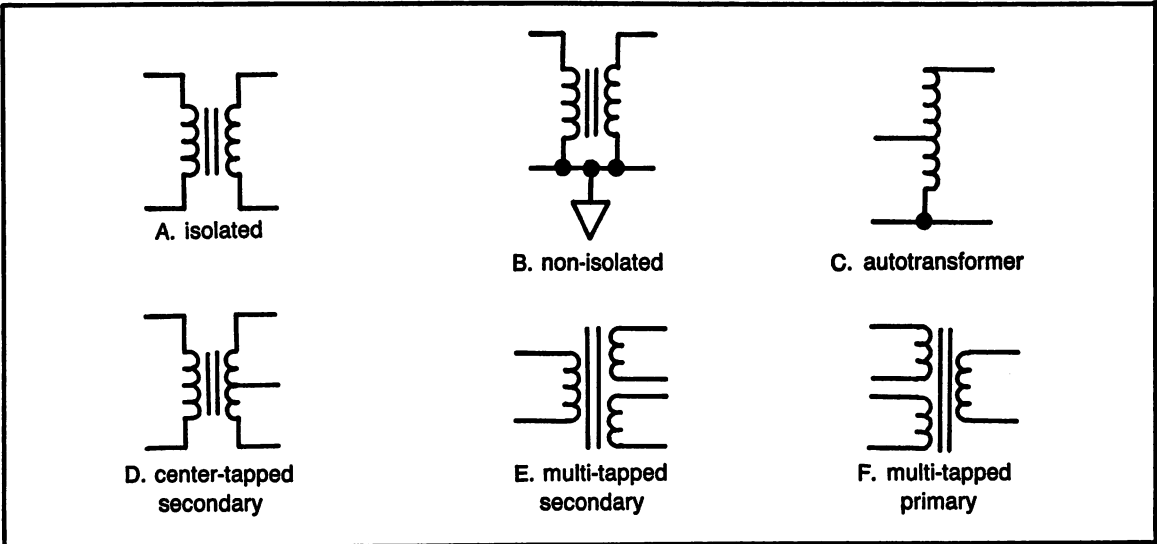
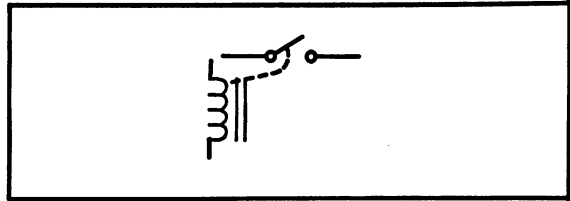


Fig. C-11. Transformers.

Appendix D:

Answers to Exams

CHAPTER 1. SAFETY TEST

- (1) a (2) b (3) b (4) b (5) d
(6) a (7) b (8) a (9) c (10) c
(11) c (12) a (13) b (14) a (15) c
(16) d (17) a (18) a (19) b (20) b

CHAPTER 3. SHOP MATH PRETEST

(1) $\frac{2}{5}$ $\frac{3}{10}$ $\frac{1}{4}$ $\frac{1}{8}$

(2) $\frac{7}{8}$ $\frac{3}{4}$ $\frac{9}{16}$ $\frac{17}{32}$

(3) $2\frac{1}{2}$

(4) $15\frac{11}{15}$

(5) $23\frac{11}{18}$

(6) $\frac{3}{4}$

(7) $1\frac{1}{2}$

(8) $12\frac{1}{12}$

- (9) 15
(11) increase
(13) 59.861
(15) 14.6102
(17) 32.15
(19) 113.06
(21) .0026
(23) .6
(25) 109.4
(27) .875
(29) 5.8
(31) 3.5

- (10) 1
(12) decrease
(14) 97.6
(16) 7
(18) 643.875
(20) .7
(22) 108.981
(24) 145.833
(26) .4
(28) 3.857
(30) 1.5

(32) $\frac{1}{3}$

(33) $\frac{3}{5}$

(34) $\frac{5}{8}$

(35) $3\frac{3}{10}$

(36) $6\frac{1}{4}$

(37) $8\frac{2}{5}$

$$(38) 4 \frac{3}{100}$$

$$(39) 7 \frac{3}{4}$$

$$(40) -2$$

$$(41) 6$$

$$(42) 3$$

$$(43) -12$$

$$(44) -7$$

$$(45) -15$$

$$(46) -.2$$

$$(47) -18$$

$$(48) 2.1$$

$$(49) -4$$

$$(50) -1 \frac{3}{8}$$

$$(51) -2$$

$$(52) \frac{4}{15}$$

$$(53) -1$$

$$(54) -11$$

$$(55) 1 \frac{1}{6}$$

$$(56) 4$$

$$(57) 9$$

$$(58) -8$$

$$(59) 27$$

$$(60) 5$$

$$(61) 9$$

$$(62) 2.8$$

$$(63) .2$$

$$(64) .25 \text{ \& } 25\%$$

$$(65) \frac{1}{2} \text{ \& } 50\%$$

$$(66) \frac{1}{3} \text{ \& } .333$$

$$(67) \frac{1}{8} \text{ \& } 12.5\%$$

$$(68) .375 \text{ \& } 37.5\%$$

$$(69) \frac{1}{1000} \text{ \& } .001$$

$$(70) \frac{2}{5} \text{ \& } 40\%$$

$$(71) 105/95$$

$$(72) 283.5/256.5$$

$$(73) 363/297$$

$$(74) 564/376$$

$$(75) 1010/990$$

$$(76) 2310/2090$$

$$(77) 3850/3150$$

$$(78) 5635/4165$$

$$(79) 8874/8526$$

$$(80) 11000/9000$$

$$(81) x = 5$$

$$(82) y = -10$$

$$(83) a = 5$$

$$(84) a = 2$$

$$(85) y = 2$$

$$(86) y = 20$$

$$(87) x = -8$$

$$(88) x = -2$$

$$(89) x = 0$$

$$(90) x = 2$$

$$(91) A = 75$$

$$(92) F = 68$$

$$(93) C = 4.44$$

$$(94) d = 125$$

$$(95) h = 16$$

$$(96) L = 60$$

$$(97) R = 60$$

$$(98) x = 1.33$$

$$(99) R_T = 18.5$$

$$(100) X_L = 31.4$$

CHAPTER 3. PRACTICE PROBLEMS: FRACTIONS

$$(1) \frac{11}{3}$$

$$(2) \frac{94}{7}$$

$$(3) \frac{81}{20}$$

$$(4) \frac{5}{3}$$

$$(5) \frac{35}{6}$$

$$(6) \frac{31}{8}$$

$$(7) \frac{13}{5}$$

$$(8) \frac{43}{10}$$

$$(9) \frac{68}{9}$$

$$(10) \frac{11}{4}$$

$$(11) 4 \frac{3}{4}$$

$$(12) 6 \frac{1}{6}$$

$$(13) 9 \frac{1}{3}$$

$$(14) 4 \frac{5}{8}$$

$$(15) 4$$

$$(16) 1 \frac{9}{25}$$

$$(17) 5 \frac{2}{9}$$

$$(18) 2 \frac{3}{4}$$

$$(19) 9$$

$$(20) 4$$

$$(21) \frac{7}{16} \quad \frac{1}{2} \quad \frac{5}{8} \quad \frac{3}{4}$$

$$(22) \frac{5}{64} \quad \frac{3}{32} \quad \frac{1}{8} \quad \frac{3}{16}$$

$$(23) \frac{4}{10} \quad \frac{12}{25} \quad \frac{1}{2} \quad \frac{51}{100}$$

$$(24) \frac{15}{16} \quad 1 \quad 1\frac{1}{64} \quad 1\frac{1}{32}$$

$$(25) 5\frac{3}{64} \quad 5\frac{1}{4} \quad 5\frac{1}{3} \quad 5\frac{4}{9}$$

CHAPTER 3. PRACTICE PROBLEMS: ARITHMETIC WITH FRACTIONS

$$(1) \frac{1}{8} \qquad (2) 2$$

$$(3) \frac{3}{4} \qquad (4) \frac{1}{4}$$

$$(5) \frac{2}{5} \qquad (6) 1\frac{5}{16}$$

$$(7) 1\frac{7}{30} \qquad (8) \frac{11}{21}$$

$$(9) 4 \qquad (10) \frac{2}{7}$$

$$(11) 2\frac{2}{3} \qquad (12) 1\frac{3}{4}$$

$$(13) 9\frac{2}{7} \qquad (14) \frac{1}{3}$$

$$(15) 5\frac{13}{30} \qquad (16) 5\frac{4}{7}$$

$$(17) \frac{27}{35} \qquad (18) \frac{5}{16}$$

$$(19) 1\frac{3}{8} \qquad (20) \frac{3}{4}$$

CHAPTER 3. PRACTICE PROBLEMS: DECIMALS

- | | |
|-------------|----------------|
| (1) 14.99 | (2) .3 |
| (3) 1.2 | (4) 3.21 |
| (5) 10.37 | (6) .09 |
| (7) .0215 | (8) 6.2 |
| (9) 55.712 | (10) 4.43 |
| (11) .006 | (12) .52 |
| (13) 39.962 | (14) 91.091 |
| (15) 2040 | (16) .00000606 |
| (17) .796 | (18) 31,847 |
| (19) 318.47 | (20) 10.6 |
| (21) .375 | (22) .4 |
| (23) .1875 | (24) 2.333 |
| (25) 5.125 | |

$$(26) 1\frac{3}{10} \qquad (27) \frac{2}{3}$$

$$(28) \frac{9}{1000} \qquad (29) \frac{4}{10}$$

$$(30) \frac{5}{16}$$

CHAPTER 3. PRACTICE PROBLEMS: PERCENT TOLERANCE

- | | |
|---------------|-------------------|
| (1) 105/95 | (2) 517/423 |
| (3) 1032/688 | (4) 1100/900 |
| (5) 1725/1275 | (6) 2222/2178 |
| (7) 3366/3234 | (8) 4935/4465 |
| (9) 7480/6120 | (10) 11,000/9,000 |

CHAPTER 3. PRACTICE PROBLEMS: POSITIVE AND NEGATIVE NUMBERS

- | | |
|----------|---------|
| (1) 27 | (2) -7 |
| (3) -2 | (4) -12 |
| (5) 1 | (6) -6 |
| (7) -8 | (8) -9 |
| (9) 9 | (10) 20 |
| (11) -3 | (12) 4 |
| (13) 8 | (14) 10 |
| (15) -42 | (16) 40 |
| (17) 0 | (18) -9 |
| (19) -4 | (20) 2 |
| (21) + | (22) + |

- (23) + (24) +
 (25) - (26) -
 (27) - (28) -
 (29) + (30) -

- (7) $37\frac{1}{3}$ (8) $2\frac{1}{8}$
 (9) 70 (10) $9\frac{13}{21}$

**CHAPTER 3. PRACTICE
 PROBLEMS: SOLVING EQUATIONS**

- (1) $x = 5$ (2) $x = 4$
 (3) $y = -10$ (4) $y = -4$
 (5) $a = 5$ (6) $a = 1$
 (7) $a = 2$

(8) $x = \frac{1}{4}$

- (9) $y = 2$ (10) $x = 9$
 (11) $y = 20$ (12) $y = 1$
 (13) $x = 25$ (14) $x = 2$
 (15) $y = 1$

**CHAPTER 3. PRACTICE
 PROBLEMS: FORMULAS**

- (1) $I = 4$ (2) $R = 5$
 (3) $P = 500$ (4) $W = 2500$
 (5) $R = 40$ (6) $I = 5$
 (7) $R_T = 35$ (8) $R_1 = 250$
 (9) $R_T = 7.1$ (10) $R_2 = 30$
 (11) $R_T = 20$ (12) $R_1 = 200$
 (13) $X_L = 125.6$ (12) $f = 60$
 (15) $X_C = 1000$

**CHAPTER 3. SHOP
 MATH COMPETENCY TEST**

(1) $\frac{11}{20}$ $\frac{3}{5}$ $\frac{7}{10}$ $\frac{12}{15}$

(2) $\frac{2}{3}$ $\frac{5}{6}$ $\frac{11}{12}$ $\frac{23}{24}$

(3) $3\frac{1}{6}$ (4) $7\frac{3}{8}$

(5) $\frac{31}{32}$ (6) $\frac{1}{2}$

- (11) decrease (12) increase
 (13) 50.141 (14) 119.7
 (15) 15.9103 (16) 8
 (17) 41.23 (18) 75.625
 (19) 555.555 (20) .9
 (21) .0029 (22) 18.981
 (23) .8 (24) 18.62
 (25) 84.7875 (26) .6
 (27) .625 (28) 14
 (29) 4.167 (30) 1.33
 (31) 2.33

(32) $\frac{2}{3}$ (33) $\frac{3}{10}$

(34) $\frac{5}{8}$ (35) $5\frac{3}{5}$

(36) $6\frac{3}{4}$ (37) $6\frac{1}{2}$

(38) $4\frac{1}{20}$ (39) $5\frac{1}{4}$

- (40) -4 (41) 20
 (42) 4 (43) -18
 (44) -7 (45) -42
 (46) -.2 (47) -72
 (48) 2.2 (49) -5

(50) $-1\frac{1}{2}$ (51) $-\frac{1}{2}$

(52) $\frac{1}{3}$ (53) $\frac{1}{4}$

(54) -11 (55) 63

(56) $-\frac{1}{6}$

- (57) 0 (58) -1
 (59) 80 (60) .75 & 75%

- (61) $\frac{1}{4}$ & 25%
- (62) $\frac{2}{3}$ & .666
- (63) $\frac{1}{8}$ & 12.5%
- (64) .375 & 37.5%
- (65) $\frac{1}{1000}$ & .001
- (66) $\frac{3}{5}$ & 60%
- (67) $\frac{1}{200}$ & .005
- (68) $\frac{1}{5}$ & 20%
- (69) $\frac{3}{40}$ & .075
- (70) $\frac{21}{200}$ & .105
- (71) 101/99
- (72) 275.4/264.6
- (73) 346.5/313.5
- (74) 517/423
- (75) 816/544
- (76) 1100/900
- (77) 6325/4675
- (78) 8610/7790
- (79) 11500/8500
- (80) 10.1/9.9
- (81) $x = 4$
- (82) $y = -17$
- (83) $a = 8$
- (84) $a = 8$
- (85) $x = 3$
- (86) $x = -4$
- (87) $y = 10$
- (88) $a = -25$
- (89) $x = -8$
- (90) $x = -2$
- (91) $A = 72$
- (92) $F = -40$
- (93) $C = 0$
- (94) $d = 110$
- (95) $h = 16$
- (96) $L = 30$
- (97) $R_T = 7.5$
- (98) $R_T = 4.167$
- (99) $X_C = .637$
- (100) $X_L = 62.8$

CHAPTER 4. PRACTICE PROBLEMS: ROUNDING NUMBERS

- (1) 6410 (2) 4720
- (3) 5350 (4) 9880
- (5) 103,000 (6) 340,000
- (7) 120,000 (8) 209,000
- (9) 327 (10) 452
- (11) 1000 (12) 224
- (13) 56.3 (14) 69.5
- (15) 10.6 (16) 25.9
- (17) 1.06 (18) 3.53
- (19) 5.99 (20) 8.91
- (21) .0036 (22) .00268
- (23) .00556 (24) .00667
- (25) .00333 (26) .01
- (27) .9 (28) .87
- (29) .505 (30) .96

CHAPTER 4. PRACTICE PROBLEMS: WRITING IN SCIENTIFIC NOTATION

- (1) $8.76 \times 10^5 = 8.76E5$
- (2) $1.03 \times 10^9 = 1.03E9$
- (3) $4.3 \times 10^4 = 4.3E4$
- (4) $2.5 \times 10^1 = 2.5E1$
- (5) $6.9 \times 10^0 = 6.9E0$
- (6) $3 \times 10^{-3} = 3E-3$
- (7) $3.2 \times 10^{-6} = 3.2E-6$
- (8) $4.5 \times 10^{-5} = 4.5E-5$
- (9) $1.59 \times 10^{-9} = 1.59E-9$
- (10) $5 \times 10^{-1} = 5E-1$
- (11) $1.2 \times 10^9 = 1.2E9$
- (12) $5.32 \times 10^6 = 5.32E6$
- (13) $3.5 \times 10^{-2} = 3.5E-2$
- (14) $4.5 \times 10^{-2} = 4.5E-2$
- (15) $6.7 \times 10^1 = 6.7E1$
- (16) $2.5 \times 10^1 = 2.5E1$
- (17) $3.5 \times 10^{-5} = 3.5E-5$
- (18) $2 \times 10^{-7} = 2E-7$
- (19) $5.6 \times 10^{-8} = 5.6E-8$
- (20) $9.5 \times 10^0 = 9.5E0$
- (21) 480,000 (22) 850,000
- (23) 3,000 (24) .00025
- (25) 250 (26) .01
- (27) .055 (28) 68,000,000
- (29) .000000000025 (30) 10

**CHAPTER 4. PRACTICE PROBLEMS:
CONVERTING ENGINEERING NOTATION**

- (1) 5,600 k Ω & 5.6 M Ω
- (2) 273 kHz & .273 MHz
- (3) 2,900,000 mW & 2.9 kW
- (4) 15,000 mA & .015 kA
- (5) 3.5 mV & 3500 μ V
- (6) 125 mH & 125,000 μ H
- (7) .05 μ F & 50 nF
- (8) 8.7 μ s & .0087 ms
- (9) .25 W & .00025 kW
- (10) .0015 kV & 1.5 V
- (11) 55 μ A & .000055 A
- (12) .000000001 s & .001 μ s
- (13) 630,000 Hz & .630 MHz
- (14) 250 mW & 250,000,000 W
- (15) .75 A & 750 mA
- (16) 5,000 mV & 5 V
- (17) .025 mV & 25,000 nV
- (18) 750 nA & .00000075 A
- (19) .05 μ F & 50,000 pF
- (20) .00000000005 s & .00005 μ s
- (21) .150 nF & .000150 μ F
- (22) 75,000 k Ω & .075 G Ω
- (23) 3,000 Hz & 3 kHz
- (24) 1,200,000 MW & 1,200,000,000,000 W
- (25) 5,000 MHz & 5 GHz

**CHAPTER 4. PRACTICE PROBLEMS:
ARITHMETIC OPERATIONS**

- | | |
|------------------|------------------|
| (1) 5.5 kilohms | (2) 1100 ohms |
| (3) 48.1 MW | (4) 100 V |
| (5) 1.75 A | (6) 3.3 mW |
| (7) .45 mH | (8) .011 μ F |
| (9) 10 kV | (10) 5 μ F |
| (11) 150 V | (12) 7.5 V |
| (13) 60 V | (14) .75 W |
| (15) 500 μ W | (16) 4 mA |
| (17) 2.5 kilohms | (18) .5A |
| (19) 100 kV | (20) 10 W |

**CHAPTER 4. ENGINEERING NOTATION
COMPETENCY TEST**

- | | |
|-------------|-------------|
| (1) 104,000 | (2) 556,000 |
| (3) 321 | (4) 598 |

- | | |
|---------------------------|----------------------------|
| (5) 640 | (6) 231 |
| (7) .714 | (8) .0909 |
| (9) .667 | (10) .333 |
| (11) 8.76×10^5 | (12) 3.2×10^3 |
| (13) 9.8×10^8 | (14) 1.2×10^6 |
| (15) 3.5×10^{-7} | (16) 1.89×10^{-4} |
| (17) 2×10^{-4} | (18) 1.8×10^0 |
| (19) 2.5×10^6 | (20) 3.6×10^{-8} |
| (21) 2.5E5 | (22) 1.8E3 |
| (23) 6.8E7 | (24) 5.6E2 |
| (25) 2.5E-10 | (26) 3.57E-6 |
| (27) 1.3E-3 | (28) 9.8E-4 |
| (29) 5.6E3 | (30) 4.7E-3 |
| (31) 25 kV | (32) 1250 mA |
| (33) .0255 W | (34) 3500 Hz |
| (35) 15 μ H | (36) .680 mH |
| (37) 1,500,000,000 pF | (38) 37 Megohms |
| (39) 82 μ V | (40) .96 mA |
| (41) 13.8 kilohms | (42) 740 ohms |
| (43) 26.5 MW | (44) 125 μ V |
| (45) 500 V | (46) 15 V |
| (47) 2.5 W | (48) 8 mA |
| (49) 5 kilohms | (50) 3 kV |

**CHAPTER 5. PRACTICE PROBLEMS:
RESISTOR COLOR CODE**

(All answers in Ohms).

- | | |
|--------------------------|------------|
| (1) 100 | (2) 270 |
| (3) 1.5 k | (4) 2.2 k |
| (5) 3.9 k | (6) 5.6 k |
| (7) 10 k | (8) 15 k |
| (9) 47 k | (10) 82 k |
| (11) 120 k | (12) 680 k |
| (13) 3.3 M | (14) 10 |
| (15) 1 | |
| (16) brown-red-brown | |
| (17) orange-orange-brown | |
| (18) orange-white-brown | |
| (19) brown-black-red | |
| (20) brown-grey-red | |
| (21) red-violet-red | |
| (22) yellow-violet-red | |
| (23) blue-grey-red | |

- (24) grey-red-red
- (25) brown-black-orange
- (26) brown-red-orange
- (27) brown-black-green
- (28) brown-grey-blue
- (29) brown-black-black
- (30) yellow-black-gold
- (31) $150 \pm 10\%$ & 165/135
- (32) $220 \pm 5\%$ & 231/209
- (33) $470 \pm 20\%$ & 564/376
- (34) $560 \pm 10\%$ & 616/504
- (35) $3.3 \text{ k} \pm 5\%$ & 3465/3135
- (36) $6.8 \text{ k} \pm 20\%$ & 8160/5440
- (37) $12 \text{ k} \pm 10\%$ & 13200/10800
- (38) $18 \text{ k} \pm 5\%$ & 18900/17100
- (39) $1.2 \text{ M} \pm 20\%$ & 1.44 M/.96M
- (40) $39 \text{ M} \pm 10\%$ & 42.9 M/35.1M
- (41) brown-grey-black-gold
- (42) brown-grey-brown-silver
- (43) red-violet-brown-no color
- (44) blue-grey-brown-gold
- (45) orange-white-red-silver
- (46) grey-red-red-silver
- (47) red-red-orange-silver
- (48) orange-orange-orange-gold
- (49) red-violet-green-gold
- (50) brown-green-blue-no color

CHAPTER 5. DC CIRCUIT COMPONENTS COMPETENCY TEST

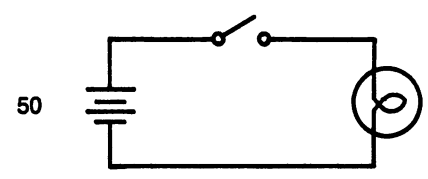
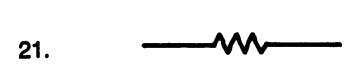
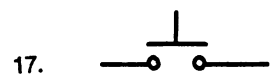
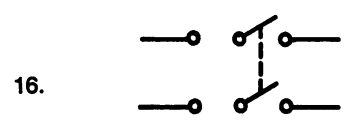
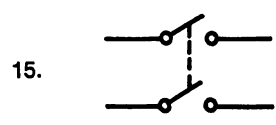
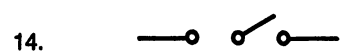
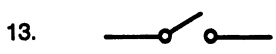
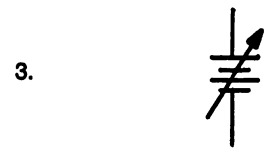
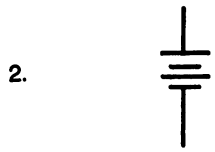
- (1) 1.5 volts
- (2) (See Fig. D-1.)
- (3) (See Fig. D-1.)
- (4) low
- (5) high
- (6) 18 AWG
- (7) 14 AWG
- (8) 0
- (9) short
- (10) infinite
- (11) open
- (12) closed
- (13) (See Fig. D-1.)
- (14) (See Fig. D-1.)

- (15) (See Fig. D-1.)
- (16) (See Fig. D-1.)
- (17) (See Fig. D-1.)
- (18) (See Fig. D-1.)
- (19) fuse
- (20) (See Fig. D-1.)
- (21) (See Fig. D-1.)
- (22) (See Fig. D-1.)
- (23) .47 kilohms
- (24) 33,000 ohms
- (25) .15 megohms
- (26) 8600 ohms
- (27) 4700 ohms
- (28) 1200 kilohms
- (29) 18,000,000 ohms
- (30) .22 megohms
- (31) 100 ohms
- (32) 2.2 kilohms
- (33) 56 kilohms
- (34) 680 kilohms
- (35) 3.9 megohms
- (36) $150 \pm 10\%$ & 165/135
- (37) $4.7 \text{ k} \pm 5\%$ & 4935/4465
- (38) $33 \text{ k} \pm 20\%$ & 39.6 k/26.4 k
- (39) $100 \text{ k} \pm 10\%$ & 110 k/90 k
- (40) $82 \text{ M} \pm 10\%$ & 90.2 M/73.8 M
- (41) brown-black-black-silver
- (42) red-violet-brown-gold
- (43) orange-orange-brown-no color
- (44) brown-black-red-silver
- (45) brown-grey-red-gold
- (46) yellow-violet-red-silver
- (47) blue-grey-red-no color
- (48) brown-black-orange-gold
- (49) brown-black-green-silver
- (50) (See Fig. D-1.)

CHAPTER 6: OHMMETER WRITTEN COMPETENCY TEST

- (1) A. infinity B. 20 ohms
C. 9 ohms D. 4 ohms
E. 0 ohms
- (2) A. 100 ohms B. 40 ohms
C. 15 ohms D. 7.5 ohms

CHAPTER 5 DC CIRCUIT COMPONENTS COMPETENCY TEST

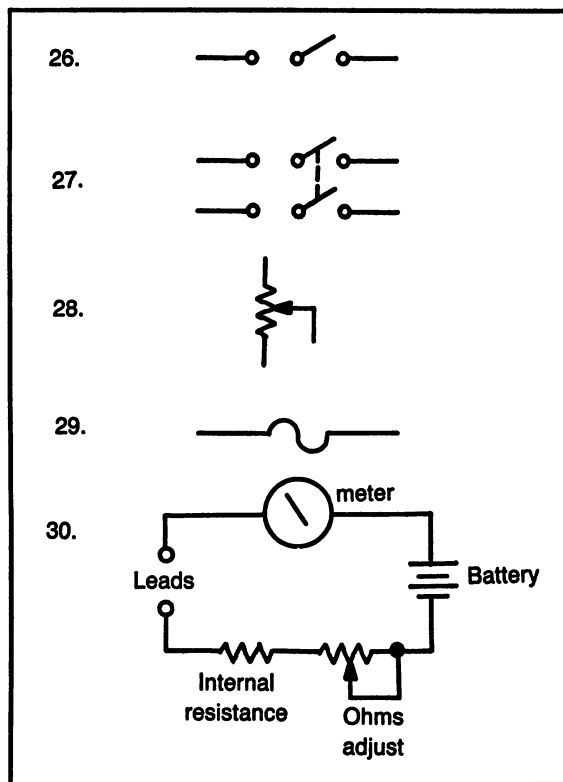


- E. .5 ohms
- (3) A. 7000 Ohms B. 2500 ohms
 C. 1000 ohms D. 560 ohms
 E. 100 ohms
- (4) A. infinity B. 600 kohms
 C. 180 kohms D. 71 kohms
 E. 25 kohms
- (5) A. 5000 ohms B. 3000 ohms
 C. 1700 ohms D. 800 ohms
 E. 350 ohms
- (6) bad (open) (7) good
 (8) 0 ohms (9) infinity
- (10) 150 ohms
 (11) 495 kohms or infinity
 (12) 70 kohms (13) 1 kohms
 (14) 0
 (15) Short the leads together and adjust for zero.
 (16) no ($120 \pm 5\%$, min 114)
 (17) yes ($3900 \pm 10\%$, max 4290)
 (18) no ($47,000 \pm 10\%$, min 42,300)
 (19) no ($10 \pm 5\%$, min 9.5)
 (20) no ($220 \pm 10\%$, max 242)
 (21) 1200 kilohms
 (22) 33,000 ohms
 (23) 1.5 volts
 (24) 500 milliwatts
 (25) 250 microamps
 (26) (See Fig. D-2.)
 (27) (See Fig. D-2.)
 (28) (See Fig. D-2.)
 (29) (See Fig. D-2.)
 (30) (See Fig. D-2.)

CHAPTER 7. PRACTICE PROBLEMS: OHM'S LAW

- (1) 20 V (2) 125 V
 (3) 30 V (4) 22 V
 (5) 4 A (6) .10 A
 (7) .3 A (8) 2 mA
 (9) 20 Ω (10) 200 Ω
 (11) 5 k Ω (12) 200 Ω
 (13) 50 V (14) 45 V
 (15) .3 mA

CHAPTER 6 OHMMETER WRITTEN COMPETENCY TEST



CHAPTER 7. PRACTICE PROBLEMS: OHM'S LAW AND POWER FORMULAS

- (1) $V = 30 \text{ V}$ and $P = 450 \text{ W}$
 (2) $V = 2.5 \text{ V}$ and $R = 1.25 \Omega$
 (3) $R = 10 \text{ k}\Omega$ and $P = 1 \text{ W}$
 (4) $I = 50 \text{ A}$ and $P = 12.5 \text{ kW}$
 (5) $I = 6.67 \text{ mA}$ and $R = 2250 \Omega$
 (6) $V = 3.16 \text{ V}$ and $I = 3.16 \text{ mA}$
 (7) $V = 250 \text{ V}$ and $P = 6.25 \text{ W}$
 (8) $V = 12.5 \text{ V}$ and $R = 6250 \Omega$
 (9) $R = 10 \text{ k}\Omega$ and $P = .25 \text{ W}$
 (10) $I = 2 \text{ mA}$ and 10 mW
 (11) $I = 6 \text{ mA}$ and $P = 36 \text{ mW}$
 (12) $R = 4 \text{ ohms}$ and $I = 3 \text{ amps}$
 (13) $P = 12 \text{ W}$ and $R = 3 \text{ ohms}$
 (14) $R = 240 \text{ ohms}$ and $I = .5 \text{ A}$
 (15) $I = .0638 \text{ mA}$ and $P = .19 \text{ mW}$

**CHAPTER 7. DC CIRCUITS:
RELATIONSHIPS, FORMULAS AND
MEASUREMENTS COMPETENCY TEST**

- (1) opposition to the flow of electricity
- (2) electrical driving force also called potential difference
- (3) flow of electricity
- (4) work performed
- (5) from negative to positive
- (6) current flows in only one direction
- (7) current flow alternates direction
- (8) if one side of the formula increases, the other side increases
- (9) if one side of the formula increases, the other side decreases
- (10) the positive and negative of a dc voltage
- (11) meter with a needle
- (12) changes the range of a voltmeter
- (13) changes the range of an ammeter
- (14) internal resistance of an ohmmeter
- (15) percent accuracy, stated for full scale
- (16) 600 V
- (17) .1 W
- (18) 600 ohms
- (19) 60 μ W
- (20) 20 mA
- (21) 14.4 W
- (22) .365 mA
- (23) 3.16 V
- (24) 2 V
- (25) 400 ohms
- (26) 4 A
- (27) 150 ohms
- (28) 50 μ W
- (29) 120 V
- (30) 20 μ A
- (31) (See Fig. D-3.)
- (32) (See Fig. D-3.)
- (33) (See Fig. D-3.)
- (34) (See Fig. D-3.)
- (35) (See Fig. D-3.)
- (36) 4.4 V
- (37) 6 V
- (38) 8 V
- (39) .14 mA
- (40) .3 mA
- (41) .5 mA
- (42) 1.75 V
- (43) 2.25 V
- (44) 2.5 V
- (45) 0 mA
- (46) 100 mA
- (47) 300 mA
- (48) 4000 ohms
- (49) 2000 ohms
- (50) 1000 ohms

**CHAPTER 9. PRACTICE PROBLEMS:
SERIES CIRCUITS**

- (1) $I_T = .2$ A, $R_T = 250$ ohms, $V_{R1} = 20$ V, $V_{R2} = 30$ V, $P_{R1} = 4$ W, $P_{R2} = 6$ W
- (2) $I_T = 50$ mA, $R_T = 300$ ohms, $V_{R1} = V_{R2} = V_{R3} = 5$ V, $P_{R1} = P_{R2} = P_{R3} = .25$ W

- (3) $I_T = 50$ mA, $R_T = 280$ ohms
- (4) $I_T = 3$ A, $V = 150$ V
- (5) $I_T = 1.5$ A, $R_T = 80$ ohms, $V = 120$ V
- (6) $R_T = 2.5$ k Ω , $R_1 = 1.5$ k Ω
- (7) $R_T = 800$ ohms, $R_3 = 100$ ohms, $V = 80$ V
- (8) $I_T = 25$ mA, $R_2 = 320$ ohms, $V_{R1} = 4$ V
- (9) $I_T = 400$ mA, $V = 32$ V
- (10) $I_T = 2$ A, $R_2 = 20$ ohms, $V = 120$ V

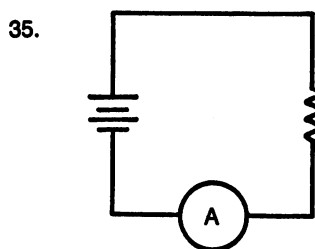
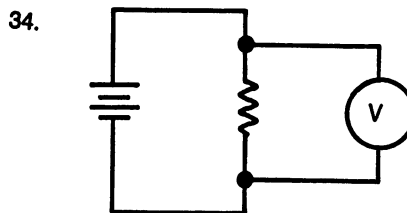
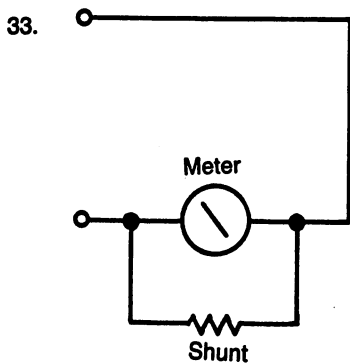
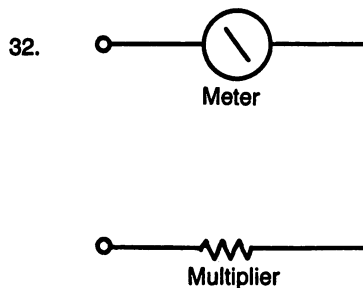
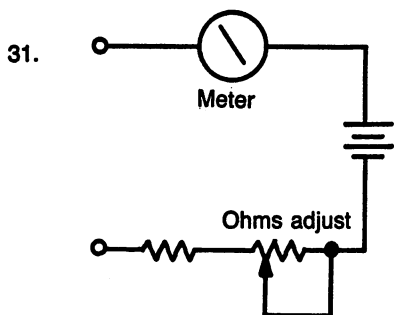
**CHAPTER 9. PRACTICE PROBLEMS:
PARALLEL CIRCUITS**

- (1) $R_T = 13.6$ ohms, $I_T = 1.83$ A, $I_A = 1$ A, $I_B = .5$ A, $I_C = .33$ A
- (2) $R_T = 513$ ohms, $I_T = 29$ mA
- (3) $R_T = 40$ ohms
- (4) $R_T = 125$ ohms
- (5) $R_3 = 1500$ ohms
- (6) $R_4 = 33.3$ ohms
- (7) $R_T = 200$ ohms, $I_T = 100$ mA, $R_3 = 1000$ ohms
- (8) $R_T = 60$ ohms, $I_A = .333$ A, $I_B = .2$ A, $I_C = .133$ A
- (9) $R_T = 200$ ohms, $I_A = 50$ mA, $I_B = 16.7$ mA, $I_C = I_D = 33.3$ mA
- (10) $R_T = 9.1$ ohms, $I_A = 1$ A, $I_B = .364$ A, $I_C = .637$ A, $I_D = .228$ A, $I_E = .409$ A, $I_F = .228$ A, $I_G = .182$ A

**CHAPTER 9. PRACTICE PROBLEMS:
COMPLEX CIRCUITS**

- (1) $R_T = 2.2$ k Ω , $I_T = 20$ mA, $V_{R1} = 20$ V, $V_{R2} = 24$ V, $V_{R3} = 24$ V, $I_{R2} = 12$ mA, $I_{R3} = 8$ mA
- (2) $R_T = 4$ k Ω , $I_T = 5$ mA, $V_{R1} = 5$ V, $V_{R2} = 1.5$ V, $V_{R3} = 1.5$ V, $V_{R4} = 13.5$ V, $I_{R2} = 2.21$ mA, $I_{R3} = 2.68$ mA
- (3) $R_T = 50$ ohms, $I_T = 100$ mA, $V_{R1} = 1$ V, $V_{R2} = V_{R3} = .5$ V, $V_{R4} = 1$ V, $V_{R5} = V_{R6} = .5$ V, $V_{R7} = V_{R8} = 1$ V, $I_{R2} = I_{R5} = 50$ mA
- (4) $R_T = 315$ ohms, $I_T = 31.8$ mA, $I_{R1} = 31.8$ mA, $I_{R2} = 21.2$ mA, $I_{R3} = 10.6$ mA, $I_{R4} = 31.8$ mA, $I_{R5} = 20$ mA, $I_{R6} = 8$ mA, $I_{R7} = 4$ mA, $V_{R1} = 3.18$ V, $V_{R2} = V_{R3} = 5.72$ V, $V_{R4} = .7$ V, $V_{R5} = V_{R6} = V_{R7} = .4$ V
- (5) $R_T = 133$ ohms, $I_T = 75$ mA, $I_{R2} = 50$ mA, $I_{R3} = 25$ mA, $V_{R1} = 7.5$ V, $V_{R2} = 2.5$ V, $V_{R3} = 2.5$ V

CHAPTER 7 COMPETENCY TEST



- (6) $R_T = 16.9$ ohms
- (7) $R_T = 100$ ohms
- (8) $R_T = 1$ k Ω
- (9) $R_T = 275$ ohms, $I_T = 200$ mA
- (10) $R_T = 2520$ ohms, $I_T = 39.7$ mA

CHAPTER 9. DC CIRCUIT ANALYSIS COMPETENCY TEST

- (1) b
- (2) b
- (3) a
- (4) a
- (5) b
- (6) a
- (7) a
- (8) d
- (9) b
- (10) a
- (11) 50 ohms
- (12) .2 A

- (13) 8 V
- (15) .2 A
- (17) .525 A
- (19) .17 A
- (21) 40 ohms
- (23) 5 V
- (25) 3.125 V
- (14) 2 V
- (16) 32.4 ohms
- (18) .142 A
- (20) .213 A
- (22) .25 A
- (24) 5 V

EXAM #1. DC BUILDING BLOCKS

- (1) d
- (3) b
- (5) c
- (7) 15,000 mA
- (9) .250 W
- (11) 10 ohms
- (13) 5,600 ohms
- (15) 680 k Ω
- (17) (See Fig. D-4)
- (19) (See Fig. D-4)
- (21) 0 ohms
- (23) 4 k Ω
- (25) 1 k Ω
- (27) 4 A
- (29) 125 V
- (31) 2 W
- (33) 2.5 V
- (35) 1.25 ohms
- (37) (See Fig. D-4)
- (39) 3.5 divisions
- (41) 2.25 V
- (43) 0 mA
- (45) 300 mA
- (47) voltage
- (49) 2 A
- (2) b
- (4) b
- (6) 5,600 kHz
- (8) 3.5 mV
- (10) .025 mV
- (12) 270 ohms
- (14) 47 k Ω
- (16) (See Fig. D-4)
- (18) (See Fig. D-4)
- (20) (See Fig. D-4)
- (22) infinity
- (24) 2 k Ω
- (26) 20 V
- (28) 20 ohms
- (30) 2 mA
- (32) 450 W
- (34) 6.67 mA
- (36) (See Fig. D-4)
- (38) (See Fig. D-4)
- (40) 1.75 V
- (42) 2.5 V
- (44) 100 mA
- (46) current
- (48) 1000 ohms
- (50) 4 k Ω

CHAPTER 10. PRACTICE PROBLEMS: INDUCTANCE

- (1) 1200 μ H
- (3) 470 mH
- (5) 66.7 mH
- (7) 220 mH
- (9) 220 mH
- (2) 90 mH
- (4) (4) 3.75 mH
- (6) 200 mH
- (8) 180 mH
- (10) 180 mH

CHAPTER 10. MAGNETISM AND INDUCTANCE COMPETENCY TEST

- (1) The lines of force from north to south.

- (2) Invisible field surrounding a magnet.
- (3) Left-over magnetism.
- (4) Holds magnetism for a short period of time.
- (5) Holds magnetism for a long period of time.
- (6) Opposes magnetic lines of force.
- (7) Electricity through a coil of wire.
- (8) To concentrate the magnetic field.
- (9) Electro-magnet that moves a bar.
- (10) Electro-magnet that operates a switch.
- (11) Voltage produced within its own coil.
- (12) Voltage produced by a magnetic field.
- (13) Inductance.
- (14) Henry.
- (15) Ability to produce a magnetic field with electricity.
- (16) Separate magnetic fields interact.
- (17) Schematic symbol showing polarity of magnetic field.
- (18) $L_T = L_1 + L_2 + L_3 + \dots$

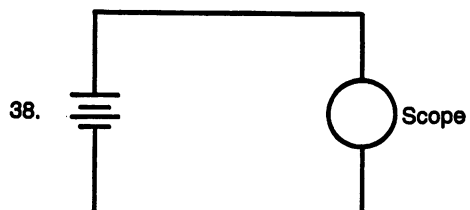
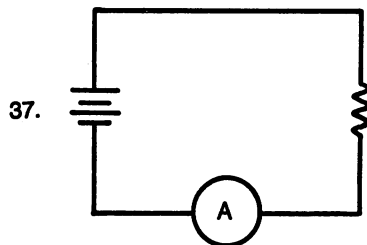
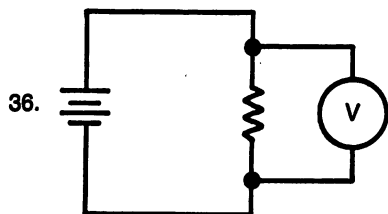
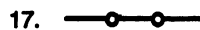
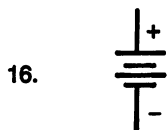
$$(19) \frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \dots$$

- (20) Unit of inductance.
- (21) 130 mH
- (22) 800 mH
- (23) 13 H
- (24) 42.8 mH
- (25) 50 mH

CHAPTER 11. PRACTICE PROBLEMS: UNITS OF AMPLITUDE

- (1) a) 21.2 b) 60 c) 19.1
- (2) a) 200 b) 63.6 c) 70.7
- (3) a) 28.3 b) 40 c) 25.4
- (4) a) 130 b) 82.7 c) 91.9
- (5) a) 99 b) 198 c) 63
- (6) a) 10.8 b) 34 c) 17
- (7) a) 17.8 b) 25.2 c) 50.3
- (8) a) 189 b) 377 c) 133
- (9) a) 120 b) 240 c) 76.5
- (10) a) 140 b) 44.5 c) 49.5
- (11) p-to-p = 40, peak = 20, rms = 14.1, Avg = 12.7
- (12) peak = 35, p-to-p = 70, rms = 24.7, Avg = 22.3
- (13) p-to-p = 400, peak = 200, rms = 141, Avg = 127

DC BUILDING BLOCKS: EXAM # 1



- (14) peak = 60, p-to- = 120, rms = 42.4, Avg = 38.2
 (15) p-to-p = 80, peak = 40, rms = 28.3, Avg = 25.4

**CHAPTER 11. PRACTICE PROBLEMS:
 UNITS OF TIME**

- | | |
|-------------------|-------------------|
| (1) .1 s | (2) .02 s |
| (3) .0167 | (4) .01 s |
| (5) 2 ms | (6) 1.43 ms |
| (7) 1 ms | (8) .667 ms |
| (9) .133 ms | (10) .1 ms |
| (11) 83.3 us | (12) 66.6 μ s |
| (13) 50 μ s | (14) 20 μ s |
| (15) 13.3 μ s | (16) 10 μ s |
| (17) 2 μ s | (18) 1 μ s |
| (19) .667 μ s | (20) .01 μ s |
| (21) .2 Hz | (22) .1 Hz |
| (23) 10 Hz | (24) 2 Hz |
| (25) 100 Hz | (26) 50 Hz |
| (27) 20 Hz | (28) 1000 Hz |
| (29) 333 Hz | (30) 200 Hz |
| (31) 66.7 Hz | (32) 60 Hz |
| (33) 50 Hz | (34) 16.7 Hz |
| (34) 10 Hz | (36) 10 kHz |
| (37) 100 kHz | (38) 50 kHz |
| (39) 200 kHz | (40) 1 MHz |

**CHAPTER 11. SINE WAVE
 ANALYSIS COMPETENCY TEST**

- (1) Waveform periodically changes direction.
- (2) All positive or all negative.
- (3) 120 volts/60 Hz.
- (4) At an instant in time.
- (5) Height of the waveform.
- (6) Maximum in one direction.
- (7) Maximum swing in both directions.
- (8) peak \times .707
- (9) peak \times .636
- (10) From 0 to 360
- (11) When the wave repeats itself.
- (12) Time of one cycle.
- (13) Number of cycles in one second.
- (14) Cycles per second.
- (15) Distance one cycle travels in air.
- (16) a) 17.7 b) 50

- | | |
|---------------|-------------|
| (17) a) 9.54 | b) 10.6 |
| (18) a) 20 | b) 14.4 |
| (19) a) 84.8 | b) 76.3 |
| (20) a) 170 | b) 340 |
| (21) a) 63.6 | b) 40.5 |
| (22) a) 23.6 | b) 16.7 |
| (23) a) 283 | b) 142 |
| (24) a) 70.7 | b) 63.6 |
| (25) a) 56.6 | b) 50.9 |
| (26) 16.7 ms | |
| (27) 20 Hz | |
| (28) 5 ms | |
| (29) 1 kHz | |
| (30) .5 MHz | |
| (31) a) .6 V | b) 250 Hz |
| (32) a) .07 V | b) 8.3 MHz |
| (33) a) .2 V | b) 1 MHz |
| (34) a) 2.5 V | b) 36.3 kHz |
| (35) a) 5 V | b) 1.67 MHz |
| (36) a) .06 V | b) 50 kHz |
| (37) a) .05 V | b) 5 kHz |
| (38) a) 1 V | b) 12.5 kHz |
| (39) a) 20 V | b) 125 Hz |
| (40) a) .15 V | b) 12.5 kHz |

**CHAPTER 12. PRACTICE PROBLEMS:
 TRANSFORMER RATIOS**

- (1) 12 V, 1 A, down
- (2) 120 V, .1 A, down
- (3) 150 V, 1 A, up
- (4) 119 V, .0043 A, up
- (5) 1:4, 4 A, up
- (6) 3:1, 81 V, down
- (7) 2:1, .6A, down
- (8) 1:5, 225 V, up
- (9) 6:1, 6 A, down
- (10) 1:20, 20 A, up

**CHAPTER 12. PRACTICE PROBLEMS:
 POWER AND EFFICIENCY**

- | | |
|------------|------------|
| (1) 4.25 W | (2) 4.8 mW |
| (3) 11.1 W | (4) 107 mW |
| (5) 90% | (6) 60% |
| (7) 66.7% | (8) 3.2 A |
| (9) 75% | (10) 80% |

CHAPTER 12. TRANSFORMERS COMPETENCY TEST

- (1) Uses magnetism to pass voltage from input to output.
- (2) Input.
- (3) Output.
- (4) Concentrates the magnetic field.
- (5) Wire coupled through magnetism.
- (6) Hysteresis or eddy currents.
- (7) Turns of the primary as compared to turns of the secondary.
- (8) Secondary has more turns than the primary.
- (9) Secondary has fewer turns than the primary.
- (10) How well it passes voltage.
- (11) 10 V
- (12) 108 V
- (13) 60 V
- (14) 20 V
- (15) 5 A
- (16) 2 mA
- (17) .2 A
- (18) 8 A
- (19) 10:1
- (20) 1:9
- (21) 5.1 W
- (22) 12.5 W
- (23) 66.7%
- (24) 90%
- (25) 75%

CHAPTER 13. PRACTICE PROBLEMS: CAPACITANCE

- (1) 4 μF
- (2) 1015 pF
- (3) .231 μF
- (4) 141 μF
- (5) 1500 μF
- (6) $C_T = .667 \mu\text{F}$, $V_{C1} = 6.7 \text{ V}$, $V_{C2} = 3.3 \text{ V}$
- (7) $C_T = 3.33 \text{ pF}$, $V_{C1} = 6.7 \text{ V}$, $V_{C2} = 3.3 \text{ V}$
- (8) $C_T = .009 \mu\text{F}$, $V_{C1} = 4.5 \text{ V}$, $V_{C2} = .5 \text{ V}$
- (9) $C_T = 5 \mu\text{F}$, $V_{C1} = 7.5 \text{ V}$, $V_{C2} = 7.5 \text{ V}$
- (10) $C_T = .0667 \mu\text{F}$, $V_{C1} = 13.2 \text{ V}$, $V_{C2} = 6.8 \text{ V}$

CHAPTER 13. PRACTICE PROBLEMS: TIME CONSTANTS

- (1) a) 20 ms b) 100 ms c) .15 A
d) 20 ms e) 100 ms f) 15 V
- (2) a) 2 ms b) 10 ms c) 15 mA
d) .2 s e) 1 s f) .15 V
- (3) a) .2 s b) 1 s c) 1.5 A
d) .2 ms e) 1 ms f) 15 kV
- (4) a) 5 μs b) 25 μs c) .75 mA
d) 5 μs e) 25 μs f) 15 V

- (5) a) 30 ms b) 150 ms c) .12 A
d) 6.67 μs e) 33.3 μs f) 54 kV
- (6) a) 5 ms b) 25 ms c) 12 V
d) 5 ms e) 25 ms f) .12 A
- (7) a) 10 ms b) 50 ms c) 12 V
d) 25 ms e) 125 ms f) 48 mA
- (8) a) .375 s b) 1.8 s c) 15 V
d) .15 s e) .75 s f) 15 mA
- (9) a) 10 ms b) 50 ms c) 15 V
d) 20 μs e) 100 μs f) .75 A
- (10) a) 1.25 s b) 6.25 s c) 1.5 V
d) .5 ms e) 2.5 ms f) 1.5 A

CHAPTER 13. CAPACITORS AND TIME CONSTANTS COMPETENCY TEST

- (1) farad
- (2) the insulator between the two plates of a capacitor
- (3) 63% of full charge
- (4) 5 time constants
- (5) shows the charge and discharge for any circuit

$$(6) \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$$

$$(7) C_T = C_1 + C_2 + \dots$$

$$(8) V_{C1} = \frac{C_2}{C_1 + C_2} \times V$$

$$(9) V_{C2} = \frac{C_1}{C_1 + C_2} \times V$$

$$(10) T = \frac{L}{R}$$

$$(11) T = R \times C$$

$$(12) t = \frac{1}{f}$$

$$(13) f = \frac{1}{t}$$

(14) $\frac{1}{2} \times \text{period}$

(15) $\frac{1}{2} \times \text{period}$

(16) Two conductors separated by an insulator.

(17) Increase

(18) Electrons gather on one plate and vacate the other during charge and equalize themselves during discharge.

(19) voltage

(20) current

(21) $7 \mu\text{F}$ (22) $90 \mu\text{F}$

(23) $.08 \mu\text{F}$ (24) 135 pF

(25) $1.22 \mu\text{F}$ (26) $1.43 \mu\text{F}$

(27) $10 \mu\text{F}$ (28) 5880 pF

(29) 6.67 pF (30) $.18 \mu\text{F}$

(31) $V_{C1} = 6 \text{ V}, V_{C2} = 4 \text{ V}$

(32) $V_{C1} = 10 \text{ V}, V_{C2} = 5 \text{ V}$

(33) $V_{C1} = 11.4 \text{ V}, V_{C2} = 8.57 \text{ V}$

(34) $V_{C1} = 15 \text{ V}, V_{C2} = 10 \text{ V}$

(35) $V_{C1} = 20 \text{ V}, V_{C2} = 10 \text{ V}$

(36) 4.16 ms (37) 20.8 ms

(38) $.167 \text{ A}$ (39) $12.5 \mu\text{s}$

(40) $33,400 \text{ V}$ (41) $.101 \text{ s}$

(42) $.505 \text{ s}$ (43) 15 V

(44) 10 ms (45) $.75 \text{ A}$

(46) a) $.1 \text{ ms}$ b) $.1 \text{ ms}$

(47) a) $20 \mu\text{s}$ b) $100 \mu\text{s}$

(48) medium

(49) refer to Fig. 13-17

(50) refer to Fig. 13-17

CHAPTER 14. PRACTICE PROBLEMS: REACTANCE

(1) 628Ω (2) 15.9 mH

(3) 3.2 mH (4) 1990 Hz

(5) 5970 Hz (6) $62.8 \text{ k}\Omega$

(7) 6.4 mH (8) 9950 Hz

(9) 942Ω (10) 0Ω

(11) $159 \text{ k}\Omega$ (12) $.1 \mu\text{F}$

(13) 10 kHz (14) $.01 \mu\text{F}$

(15) 1 kHz (16) $.106 \Omega$

(17) infinity

(19) 159Ω

(18) 0Ω (approx.)

(20) infinity

CHAPTER 14. PRACTICE PROBLEMS: REACTANCE, IMPEDANCE, AC POWER

(1) $Z = 750 \Omega$

$I = 66.7 \text{ mA}$

$V_R = 30 \text{ V}$

$V_L = 40 \text{ V}$

$\theta = 53.1^\circ$

$P_R = 2 \text{ watts}$

$P_X = 2.67 \text{ VARs}$

$P_A = 3.33 \text{ VA}$

$\text{PF} = .600$

(2) $Z = 992 \Omega$

$I = 50.4 \text{ mA}$

$V_R = 41.2 \text{ V}$

$V_L = 27.7 \text{ V}$

$\theta = 33.7^\circ$

$P_R = 2.08 \text{ watts}$

$P_X = 1.40 \text{ VARs}$

$P_A = 2.5 \text{ VA}$

$\text{PF} = .832$

(3) $Z = 391 \Omega$

$I = 128 \text{ mA}$

$V_R = 32 \text{ V}$

$V_L = 38.4 \text{ V}$

$\theta = 50.2^\circ$

$P_R = 4.09 \text{ watts}$

$P_X = 4.91 \text{ VARs}$

$P_A = 6.39 \text{ VA}$

$\text{PF} = .640$

(4) $Z = 530 \Omega$

$I = 94.3 \text{ mA}$

$V_R = 35.4 \text{ V}$

$V_L = 35.4 \text{ V}$

$\theta = 45^\circ$

$P_R = 3.34 \text{ watts}$

$P_X = 3.34 \text{ VARs}$

$P_A = 4.72 \text{ VA}$

$\text{PF} = .707$

(5) $Z = 750 \Omega$

$I = 66.7 \text{ mA}$

$V_R = 40 \text{ V}$

$V_L = 30 \text{ V}$

- $\theta = 36.9^\circ$
 $P_R = 2.67$ watts
 $P_X = 2$ VARs
 $P_A = 3.33$ VA
 $PF = .800$
- (6) $I_R = .3$ A
 $I_L = .25$ A
 $I_T = .391$ A
 $Z = 192 \Omega$
 $\theta = -39.8^\circ$
 $P_R = 22.5$ watts
 $P_X = 18.8$ VARs
 $P_A = 29.3$ VA
 $PF = .768$
- (7) $I_R = .167$ A
 $I_L = .25$ A
 $I_T = .301$ A
 $Z = 249 \Omega$
 $\theta = -56.3^\circ$
 $P_R = 12.5$ watts
 $P_X = 18.8$ VARs
 $P_A = 22.6$ VA
 $PF = .555$
- (8) $I_R = .6$ A
 $I_L = .273$ A
 $I_T = .659$ A
 $Z = 114 \Omega$
 $\theta = -24.5^\circ$
 $P_R = 45$ watts
 $P_X = 20.5$ VARs
 $P_A = 49.4$ VA
 $PF = .910$
- (9) $I_R = .1$ A
 $I_L = .15$ A
 $I_T = .18$ A
 $Z = 417 \Omega$
 $\theta = -56.3^\circ$
 $P_R = 7.5$ watts
 $P_X = 11.3$ VARs
 $P_A = 13.5$ VA
 $PF = .555$
- (10) $I_R = .167$ A
 $I_L = .167$ A
 $I_T = .236$ A
 $Z = 318 \Omega$
- $\theta = -45^\circ$
 $P_R = 12.5$ watts
 $P_X = 12.5$ VARs
 $P_A = 17.7$ VA
 $PF = .707$
- (11) $Z = 442 \Omega$
 $I = 22.6$ mA
 $V_R = 6.79$ V
 $V_L = 7.35$ V
 $\theta = -47.3^\circ$
 $P_R = .154$ watts
 $P_X = .166$ VARs
 $P_A = .226$ VA
 $PF = .678$
- (12) $Z = 515 \Omega$
 $I = 19.4$ mA
 $V_R = 4.85$ V
 $V_L = 8.74$ V
 $\theta = -60.9^\circ$
 $P_R = .0942$ watts
 $P_X = .170$ VARs
 $P_A = .194$ VA
 $PF = .486$
- (13) $Z = 583 \Omega$
 $I = 17.2$ mA
 $V_R = 8.58$ V
 $V_L = 5.15$ V
 $\theta = -31.0^\circ$
 $P_R = .147$ watts
 $P_X = .0883$ VARs
 $P_A = .172$ VA
 $PF = .857$
- (14) $Z = 1097 \Omega$
 $I = 9.12$ mA
 $V_R = 6.84$ V
 $V_L = 7.29$ V
 $\theta = -46.8^\circ$
 $P_R = .0624$ watts
 $P_X = .0665$ VARs
 $P_A = .0912$ VA
 $PF = .685$
- (15) $Z = 354 \Omega$
 $I = 28.2$ mA
 $V_R = 7.06$ V
 $V_L = 7.06$ V

$$\begin{aligned}\theta &= -45^\circ \\ P_R &= .199 \text{ watts} \\ P_X &= .199 \text{ VARs} \\ P_A &= .282 \text{ VA} \\ PF &= .707\end{aligned}$$

(16)
$$\begin{aligned}I_R &= 71.4 \text{ mA} \\ I_L &= 76.9 \text{ mA} \\ I_T &= 105 \text{ mA} \\ Z &= 238 \Omega \\ \theta &= 47.1^\circ\end{aligned}$$

$$\begin{aligned}P_R &= 1.79 \text{ watts} \\ P_X &= 1.92 \text{ VARs} \\ P_A &= 2.63 \text{ VA} \\ PF &= .681\end{aligned}$$

(17)
$$\begin{aligned}I_R &= 125 \text{ mA} \\ I_L &= 76.9 \text{ mA} \\ I_T &= 147 \text{ mA} \\ Z &= 170 \Omega \\ \theta &= 31.6^\circ\end{aligned}$$

$$\begin{aligned}P_R &= 3.13 \text{ watts} \\ P_X &= 1.92 \text{ VARs} \\ P_A &= 3.68 \text{ VA} \\ PF &= .852\end{aligned}$$

(18)
$$\begin{aligned}I_R &= 50 \text{ mA} \\ I_L &= 58 \text{ mA} \\ I_T &= 77.2 \text{ mA} \\ Z &= 324 \Omega \\ \theta &= 49.2^\circ\end{aligned}$$

$$\begin{aligned}P_R &= 1.25 \text{ watts} \\ P_X &= 1.45 \text{ VARs} \\ P_A &= 1.93 \text{ VA} \\ PF &= .653\end{aligned}$$

(19)
$$\begin{aligned}I_R &= 32.3 \text{ mA} \\ I_L &= 27.8 \text{ mA} \\ I_T &= 42.6 \text{ mA} \\ Z &= 587 \Omega \\ \theta &= 40.7^\circ\end{aligned}$$

$$\begin{aligned}P_R &= .808 \text{ watts} \\ P_X &= .695 \text{ VARs} \\ P_A &= 1.07 \text{ VA} \\ PF &= .758\end{aligned}$$

(20)
$$\begin{aligned}I_R &= 250 \text{ mA} \\ I_L &= 76.9 \text{ mA} \\ I_T &= 262 \text{ mA} \\ Z &= 95.4 \Omega \\ \theta &= 17.1^\circ\end{aligned}$$

$$\begin{aligned}P_R &= 6.25 \text{ watts} \\ P_X &= 1.92 \text{ VARs} \\ P_A &= 6.55 \text{ VA} \\ PF &= .956\end{aligned}$$

CHAPTER 14. PRACTICE PROBLEMS: PHASE ANGLE

(Note: due to the difficulty in reading drawings, student answers may vary.)

- | | | | |
|-----------|-------|--------|---------|
| (1) a) 8 | b) 45 | c) 1 | d) 45 |
| (2) a) 8 | b) 45 | c) 1.2 | d) 54 |
| (3) a) 6 | b) 60 | c) 1 | d) 60 |
| (4) a) 6 | b) 60 | c) .5 | d) 30 |
| (5) a) 5 | b) 72 | c) .4 | d) 28.8 |
| (6) a) 5 | b) 72 | c) .8 | d) 57.6 |
| (7) a) 8 | b) 45 | c) .8 | d) 36 |
| (8) a) 4 | b) 90 | c) .5 | d) 45 |
| (9) a) 6 | b) 60 | c) .5 | d) 30 |
| (10) a) 5 | b) 72 | c) .6 | d) 43.2 |

CHAPTER 14. REACTANCE, IMPEDANCE, AC POWER AND PHASE ANGLES COMPETENCY TEST

- (1) AC resistance of a capacitor or inductor.
 - (2) Total ac resistance.
 - (3) Power of a resistor, measured in watts.
 - (4) Power of a reactive component, measured in VARs.
 - (5) Total circuit power, measured in VA.
- | | |
|--------------------|----------------------|
| (6) 628 Ω | (7) 1256 Ω |
| (8) 4.71 Ω | (9) 1884 Ω |
| (10) 942 Ω | (11) 63.7 k Ω |
| (12) 159 Ω | (13) 73.7 k Ω |
| (14) 3390 Ω | (15) 2.9 Ω |
| (16) 500 Ω | (17) .2 A |
| (18) 60 V | (19) 80 V |
| (20) 53 $^\circ$ | (21) 12 watts |
| (22) 10 VARs | (23) 20 VA |
| (24) .6 | (25) 416 Ω |
| (26) .24 A | (27) .133 A |
| (28) .2 A | (29) -56.3 $^\circ$ |
| (30) 13.3 watts | (31) 20 VARs |
| (32) 24 VA | (33) .559 |
| (34) 170 | (35) .588 A |

DC AND AC BUILDING BLOCKS FINAL EXAM

- | | | | |
|----------------------|-------------------|--------------------|-------------------|
| (1) 5 mA | (2) .0657 V | (25) 60 Hz | (26) 5 V |
| (3) 5,600,000 W | (4) 87,000 kHz | (27) 60 V | (28) 120 V |
| (5) .0015 μ F | (6) 100 V | (29) 20 V | (30) 75% |
| (7) .25 A | (8) 1500 Ω | (31) 1.5 H | (32) 13.6 mH |
| (9) 2.72 mA | (10) 45 V | (33) 1.33 μ F | (34) 25 pF |
| (11) .5 W | (12) 360 W | (35) 7.14 V | (36) 6 ms |
| (13) 2 W | (14) .5 A | (37) .5 ms | (38) 50 ms |
| (15) 4 volts | (16) 5 volts | (39) 1.25 μ s | (40) 63% |
| (17) 1 mA | (18) .25 A | (41) 15.9 Ω | (42) 565 Ω |
| (19) 1.09 k Ω | (20) 475 Ω | (43) 292 Ω | (44) 416 Ω |
| (21) 10.6 V | (22) 93.4 V | (45) VA | (46) 514 Hz |
| (23) 38.2 V | (24) .667 ms | (47) 9190 Hz | (48) 25 Ω |
| | | (49) 200 Ω | (50) C |

Appendix E:

Computer Programs

Fig. E-1. Main menu program.

```

1 REM MENU 301
2 DIM P$(30)
3 PRINTCHR$(147)
4 PRINT"
5 PRINT"          LEARNING ELECTRONICS: THEORY      ";
6 PRINT"          AND EXPERIMENTS WITH           ";
7 PRINT"          COMPUTER-AIDED INSTRUCTION      ";
8 PRINT"          FOR THE COMMODORE 64/128        ";
9 PRINT"          BY: R. JESSE PHAGAN             ";
10 PRINT"          CAI BY: BILL SPAUDING          ";
11 PRINT"
12 FORI=1TO16
13 READP$(I)
14 IF I>9 THEN PRINTTAB(21)CHR$(64+I);CHR$(41);" ";P$(I):GOTO17
15 IFI=9THEN PRINT"TTTTTTTT":PRINTTAB(21)CHR$(64+I);CHR$(41);" ";P$(I):GOTO17
16 PRINTTAB(1)CHR$(64+I);CHR$(41);" ";P$(I)
17 NEXTI
18 DATAINTRODUCTION
19 DATASHOP MATH,ENG.NOTATION,COLOR CODE,OHM METER
20 DATAY&A METER,OHM'S LAW,OSCILLOSCOPE DC,DC ANALYSIS,OSCILLOSCOPE AC
21 DATAPHASE ANGLE,TIME CONSTANTS,MAGNETISM,TRANSFORMERS,REACTANCE,RESONANCE
22 PRINT:PRINT:PRINT:PRINT"CHOOSE BY LETTER?"
23 GETXX$:IFXX$<CHR$(65)ORXX$>CHR$(80)THEN GOTO23
24 LO=(ASC(XX$)-64)
25 PRINT"LOAD"
26 PRINT"LOAD"+CHR$(34)+P$(LO)+CHR$(34)+",8"
27 PRINT"

```



```

4 PRINT" THIS PROGRAM WILL ALLOW THE USER TO PRACTICE SOME OF THE MATH";
5 PRINT" SKILLS USED IN THE ELECTRONICS FIELD.";
6 PRINT" IT OFFERS PRACTICE PROBLEMS FOR THE WORK COVERED IN CHAPTER 3."
7 PRINT"XXXXXXXX"
8 PRINT"          SPACE BAR TO CONTINUE"
9 GET SB$:IF SB$<>CHR$(32)THEN9
10 PRINTCHR$(147)
11 PRINTTAB(15)"NOTES:";PRINT
12 PRINT" 1. OMIT INSIGNIFICANT 0'S IN ANSWERS.";PRINT
13 PRINT" 2. THERE MUST BE A SPACE BETWEEN "
14 PRINT"    WHOLE #'S, AND FRACTION (2 2/3).";PRINT
15 PRINT" 3. ALL ANSWERS MUST BE FOLLOWED BY RETURN KEY."
16 PRINT"XXXXXXXX          SPACE BAR TO CONTINUE."
17 GET H$:IFH$<>CHR$(32)THEN17
18 IF H$=CHR$(32)THEN19
19 RESTORE:CLR:PRINTCHR$(147)
20 PRINT" 1 FRACTION TO DECIMAL";PRINT
21 PRINT" 2 DECIMAL TO FRACTION";PRINT
22 PRINT" 3 MIXED TO IMPROPER";PRINT
23 PRINT" 4 IMPROPER TO PROPER";PRINT
24 PRINT" 5 EVALUATION";PRINT
25 PRINT" 6 OPERATIONS";PRINT
26 PRINT" 7 PERCENT ";PRINT
27 PRINT" 8 + AND - NUMBERS";PRINT
28 PRINT" 9 RETURN TO MAIN MENU";
29 PRINT" IF 9 TURN DISK DRIVE ON."
30 INPUT"WHAT IS THE NUMBER OF YOUR SELECTION";A1
31 IFA1=1THENPRINTCHR$(147):GOSUB42
32 IFA1=2THENPRINTCHR$(147):GOSUB87
33 IFA1=3THENPRINTCHR$(147):GOSUB105
34 IFA1=4THENPRINTCHR$(147):GOSUB123
35 IFA1=5THENPRINTCHR$(147):GOSUB141
36 IFA1=6THENPRINTCHR$(147):GOSUB159
37 IFA1=7THENPRINTCHR$(147):GOSUB180
38 IFA1=8THENPRINTCHR$(147):GOSUB198
39 IFA1=9THENPRINTCHR$(147):GOTO285
40 IF A1<10RA1>9 THENGOTO19
41 IF A1>0 AND A1<10THEN GOTO31
42 B=1:FORI=1TO10
43 PRINTCHR$(147):Z$=""
44 READQ$,A$
45 FORS=1TO5:PRINT:NEXTS
46 PRINTI;". WHAT IS THE DECIMAL EQUIVALENT OF THIS FRACTION?"
47 PRINT:PRINTTAB(15)Q$;
48 INPUT"=";Z$
49 IFZ$=A$THEN GOSUB219 :REM(CORRECT)
50 IFZ$<>A$THEN GOSUB221 :GOTO57 :REM (WRONG)
51 PRINT"XXXXXXXX          SPACE BAR TO CONTINUE."
52 PRINT"          N FOR NEW SELECTION."
53 GETF$:IF F$<>CHR$(32)ANDF$<>CHR$(78)THEN53
54 IFF$=CHR$(32)ANDI=10THENGOSUB229
55 IFF$=CHR$(32)THEN NEXTI
56 IFF$=CHR$(78)THEN229
57 IFI<10THEN NEXTI
58 IFI=10THEN GOTO229
59 REM***FRAC-DEC***
60 DATA1/2,.5,1/4,.25,1/8,.125,2 1/4,2.25,1 1/2,1.5,3/4,.75,2/5,.4,7/8,.875
61 DATA1 3/4,1.75,1/10,.1
62 REM***DEC-FRAC***
63 DATA0.333,1/3,0.0625,1/16,.75,3/4,0.125,1/8,2.25,2 1/4,0.5,1/2,0.25,1/4
64 DATA0.875,7/8,.4,2/5,0.375,3/8
65 REM***MIX-IMPROP***

```

Fig. E-3. Shop math program. (Continued from page 297.)

```

66 DATA2 1/2,5/2,3 2/3,11/3,1 5/8,13/8,1 1/10,11/10,4 2/5,22/5,8 3/4,35/4
67 DATA2 1/6,13/6,1 5/7,12/7,3 1/4,13/4,1 2/5,7/5
68 REM***IMPROP-MIX***
69 DATA22/11,2,9/4,2 1/4,5/3,1 2/3,3/3,1,5/4,1 1/4,7/5,1 2/5,12/10,1 1/5
70 DATA24/8,3,7/3,2 1/3,9/5,1 4/5
71 REM***EVALUATE***
72 DATA1/2,1/8,1/2,1/4,1/2,1/2,1/16,1/8,1/8,1/4,3/16,1/4,5/6,6/7,6/7,2/3,3/4
73 DATA3/4,1/2,2/3,2/3,3/8,1/4,3/8,4/5,3/4,4/5,1/10,1/20,1/10
74 REM***OPERATIONS***
75 DATA1/2,1/8,1/16,1/4,1/8,1/32,1 1/2,1/4,3/8,2/3,1/6,1/9,11/4,2/5,1 1/10
76 DATA1/2,8,1/16,8,1/2,16,1/4,1/2,1/2,1/8,1/4,1/2,1/8,1/2,1/4
77 DATA1/4,1/2,3/4,2 1/8,1 1/8,3 1/4,3/8,2/16,1/2,1/16,3/8,7/16,2 2/6,3/9
78 DATA2 2/3,1/2,1/4,1/4,1/4,3/16,1/16,4/5,2/10,3/5,3/32,1/32,1/16,3/4,1/2,1/4
79 REM***PERCENT***
80 DATA10%,100,10,2%,10,.2,5%,50,2.5,50%,20,10,100%,60,60
81 DATA5%,20,1,45%,8,3,6,20%,150,30,15%,200,30,30%,15,4.5
82 REM***+/- NUMBERS***
83 DATA-1,5,-5,-2,-2,4,8,-2,-16,4,2,8,-3,3,-9
84 DATA8,-2,-4,2,1,-9,-3,3,6,-2,-3,15,-3,-5
85 DATA-5,3,-2,6,-4,2,12,-12,0,-14,-7,-21,10,-5,5
86 DATA5,2,3,-5,2,-7,-8,-4,-4,16,-4,20,-9,7,-16
87 FORH=1TO20:READ W$:NEXTH:B=1:REM ADV
88 FORI=1TO10
89 PRINTCHR$(147):Z$=""
90 READQ$,A$
91 FORS=1TO5:PRINT:NEXTS
92 PRINTI;". WHAT IS THE FRACTION EQUIVALENT OF THIS DECIMAL NUMBER ?"
93 PRINT:PRINTTAB(15)Q$;
94 INPUT="";Z$
95 IFZ$=A$THEN GOSUB219 :REM(CORRECT)
96 IFZ$<>A$THEN GOSUB221 :GOTO103 :REM (WRONG)
97 PRINT"    SPACE BAR TO CONTINUE."
98 PRINT"    N FOR NEW SELECTION."
99 GETF$:IF F$<>CHR$(32)ANDF$<>CHR$(78)THEN99
100 IFF$=CHR$(32)ANDI=10THENGOSUB229
101 IFF$=CHR$(32)THEN NEXTI
102 IFF$=CHR$(78)THEN229
103 IFI<10THEN NEXTI
104 IFI=10THEN229
105 FORH=1TO40:READ W$:NEXTH:B=1:REM ADV ADV
106 FORI=1TO10
107 PRINTCHR$(147):Z$=""
108 READQ$,A$
109 FORS=1TO5:PRINT:NEXTS
110 PRINTI;". CHANGE TO IMPROPER FORM."
111 PRINT:PRINTTAB(15)Q$;
112 INPUT="";Z$
113 IFZ$=A$THEN GOSUB219 :REM(CORRECT)
114 IFZ$<>A$THEN GOSUB221 :GOTO121 :REM (WRONG)
115 PRINT"    SPACE BAR TO CONTINUE."
116 PRINT"    N FOR NEW SELECTION."
117 GETF$:IF F$<>CHR$(32)ANDF$<>CHR$(78)THEN117
118 IFF$=CHR$(32)ANDI=10THENGOSUB229
119 IFF$=CHR$(32)THEN NEXTI
120 IFF$=CHR$(78)THEN229
121 IFI<10THEN NEXTI
122 IFI=10THEN229
123 FORH=1TO60:READ W$:NEXTH:B=1:REM ADV ADV ADV
124 FORI=1TO10

```

```

125 PRINTCHR$(147):Z$=""
126 READQ$,A$
127 FORS=1TO5:PRINT:NEXTS
128 PRINTI;". CHANGE THIS IMPROPER FRACTION TO          PROPER FORM."
129 PRINT:PRINTTAB(15)Q$;
130 INPUT"=";Z$
131 IFZ$=A$THEN GOSUB219 :REM(CORRECT)
132 IFZ$<>A$THEN GOSUB221 :GOTO139 :REM (WRONG)
133 PRINT"XXXXXXXX      SPACE BAR TO CONTINUE."
134 PRINT"          N FOR NEW SELECTION."
135 GETF$:IF F$<>CHR$(32)ANDF$<>CHR$(78)THEN135
136 IFF$=CHR$(32)ANDI=10THENGOSUB229
137 IFF$=CHR$(32)THEN NEXTI
138 IFF$=CHR$(78)THEN229
139 IFI<10THEN NEXTI
140 IFI=10THEN229
141 FORH=1TO80:READ W$:NEXTH:B=1:REM ADV ADV ADV ADV
142 FORI=1TO10
143 PRINTCHR$(147):Z$=""
144 READQ$,U$,A$
145 FORS=1TO5:PRINT:NEXTS
146 PRINTI;". WHICH FRACTION HAS THE GREATER          VALUE?"
147 PRINT:PRINTTAB(8)Q$;" OR ";U$;
148 INPUT"=";Z$
149 IFZ$=A$THEN GOSUB219 :REM(CORRECT)
150 IFZ$<>A$THEN GOSUB221 :GOTO157 :REM (WRONG)
151 PRINT"XXXXXXXX      SPACE BAR TO CONTINUE."
152 PRINT"          N FOR NEW SELECTION."
153 GETF$:IF F$<>CHR$(32)ANDF$<>CHR$(78)THEN153
154 IFF$=CHR$(32)ANDI=10THENGOSUB229
155 IFF$=CHR$(32)THEN NEXTI
156 IFF$=CHR$(78)THEN229
157 IFI<10THEN NEXTI
158 IFI=10THEN229
159 FORH=1TO110:READ W$:NEXTH:B=1:REM ADV
160 FORI=1TO20
161 PRINTCHR$(147):Z$=""
162 READQ$,U$,A$
163 FORS=1TO5:PRINT:NEXTS
164 PRINTI;". PERFORM THE FOLLOWING OPERATIONS.":PRINT
165 IFI<6THEN PRINTTAB(8)Q$;" X ";U$;
166 IFI>5ANDI<11THEN PRINTTAB(8)Q$;" (DIV.BY) ";U$;
167 IFI>10ANDI<16THEN PRINTTAB(8)Q$;" + ";U$;
168 IFI>15ANDI<21THEN PRINTTAB(8)Q$;" - ";U$;
169 INPUT"=";Z$
170 IFZ$=A$THEN GOSUB219 :REM(CORRECT)
171 IFZ$<>A$THEN GOSUB221 :GOTO178 :REM (WRONG)
172 PRINT"XXXXXXXX      SPACE BAR TO CONTINUE."
173 PRINT"          N FOR NEW SELECTION."
174 GETF$:IF F$<>CHR$(32)ANDF$<>CHR$(78)THEN174
175 IFF$=CHR$(32)ANDI=20THENGOSUB229
176 IFF$=CHR$(32)THEN NEXTI
177 IFF$=CHR$(78)THEN229
178 IFI<20THEN NEXTI
179 IFI=20 THENGOSUB229
180 FORH=1TO170:READ W$:NEXTH:B=2:REM ADV
181 FORI=1TO10
182 PRINTCHR$(147):Z$=""
183 READQ$,U$,A$
184 FORS=1TO5:PRINT:NEXTS
185 PRINTI;". SOLVE THE FOLLOWING."
186 PRINT:PRINTTAB(8)Q$;" OF ";U$;

```

Fig. E-3. Shop math program. (Continued from page 299.)

```

187 INPUT "=";Z$
188 IFZ$=A$THEN GOSUB219 :REM(CORRECT)
189 IFZ$<>A$THEN GOSUB221 :GOTO196 :REM (WRONG)
190 PRINT"#####SPACE BAR TO CONTINUE."
191 PRINT"#####N FOR NEW SELECTION."
192 GETF$:IF F$<>CHR$(32)ANDF$<>CHR$(78)THEN192
193 IFF$=CHR$(32)ANDI=10THENGOSUB229
194 IFF$=CHR$(32)THEN NEXTI
195 IFF$=CHR$(78)THEN229
196 IFI<10THEN NEXTI
197 IFI=10THEN229
198 FORH=1TO200:READ W$:NEXTH:B=3:REM ADV
199 FORI=1TO20
200 PRINTCHR$(147):Z$=""
201 READQ$,U$,A$
202 FORS=1TO5:PRINT:NEXTS
203 PRINTI;" . SOLVE THE FOLLOWING."
204 IFI<6THEN PRINTTAB(08)Q$;" X ";U$;
205 IFI>5ANDI<11THEN PRINTTAB(08)Q$;" / ";U$;
206 IFI>10ANDI<16THEN PRINTTAB(08)Q$;" + ";U$;
207 IFI>15ANDI<21THEN PRINTTAB(08)Q$;" - ";U$;
208 INPUT "=";Z$
209 IFZ$=A$THEN GOSUB219 :REM(CORRECT)
210 IFZ$<>A$THEN GOSUB221 :GOTO217 :REM (WRONG)
211 PRINT"#####SPACE BAR TO CONTINUE."
212 PRINT"#####N FOR NEW SELECTION."
213 GETF$:IF F$<>CHR$(32)ANDF$<>CHR$(78)THEN213
214 IFF$=CHR$(32)ANDI=20THENGOSUB229
215 IFF$=CHR$(32)THEN NEXTI
216 IFF$=CHR$(78)THEN229
217 IFI<20 THEN NEXTI
218 IFI=20 THEN229
219 PRINT:PRINTTAB(15)"CORRECT":PRINT:T=T+1
220 RETURN
221 PRINT:PRINTTAB(15)"WRONG! ANSWER IS ";A$:PRINT
222 PRINT:PRINT"#####F1 TO REVIEW HELP HINTS.#####";
223 PRINT"TO CONTINUE.#####N FOR NEW SELECTION."
224 GETJ$:IF J$<>CHR$(32)ANDJ$<>CHR$(133)ANDJ$<>CHR$(78)THEN224
225 IF J$=CHR$(32)THEN RETURN
226 IFJ$=CHR$(133)THEN ON B GOSUB239 ,262 ,274
227 IFJ$=CHR$(78)THEN229
228 RETURN
229 PRINTCHR$(147)
230 FORK=1TO5:PRINT:NEXTK
231 P=(T/I)*100
232 PRINT"YOUR SCORE IS ";P;"%"
233 PRINT:PRINT"FOR ";I;"QUESTIONS ASKED."
234 FORE=1TO4:PRINT:NEXTE
235 PRINT"#####SPACE BAR FOR MENU"
236 GETY$:IFY$<>CHR$(32)THEN236
237 IFY$=CHR$(32)THEN19
238 STOP
239 PRINTCHR$(147);"#####"
240 PRINT" WAS THE ANSWER ENTERED CORRECTLY?
241 PRINT"(SPACE BETWEEN WHOLE #'S, AND FRACTION)":PRINT
242 PRINT" DID YOU CHANGE THE VALUE OF THE PROBLEM?":PRINT
243 PRINT" IS THE ANSWER IN ITS SIMPLEST FORM FOR THE TYPE OF ANSWER?#####"
244 PRINT"#####SPACE BAR FOR MORE, #F3 RETURN TO TEST."
245 GET WE$:IF WE$<>CHR$(32)ANDWE$<>CHR$(134)THEN245

```



```

246 IF WE#=CHR$(32)THEN248
247 IF WE#=CHR$(134)THEN RETURN
248 PRINTCHR$(147):PRINT
249 PRINT"          %SAMPLES%":PRINT
250 PRINT"    FRAC-DEC      1/2 =.5":PRINT
251 PRINT"    DEC-FRAC      .25 =1/4":PRINT
252 PRINT"    MIX-IMPROP     1 1/4 =5/4":PRINT
253 PRINT"    IMPROP-MIX     17/16 =1 1/16":PRINT
254 PRINT"    EVALUATION 1/2 OR 1/4 =1/2":PRINT
255 PRINT"    ADD      1/8 + 1/4 =3/8":PRINT
256 PRINT"    SUBTRACT 1/4 - 1/8 =1/8":PRINT
257 PRINT"    MULT     1/2 X 1/2 =1/4":PRINT
258 PRINT"    DIV. 1/2 (DIV.BY) 3/4 =2/3":PRINT
259 PRINT"          %SPACE BAR% TO CONTINUE.
260 GET RE$:IFRE#<>CHR$(32) THEN260
261 IF RE#=CHR$(32)THEN RETURN
262 PRINTCHR$(147)
263 PRINT"    TO REMOVE THE PERCENT SIGN; MOVE"
264 PRINT"    THE DECIMAL TWO PLACES TO THE LEFT.":PRINT
265 PRINT"    EXAMPLE:":PRINT
266 PRINT"    10% OF 100 =?":PRINT:PRINT
267 PRINT"    100":PRINT
268 PRINT"    X .10 DECIMAL FORM OF 10%"
269 PRINT"    "
270 PRINT"ANSWER= 10":PRINT
271 PRINT"XXXXXXXX %SPACE BAR% TO CONTINUE"
272 GETP$:IFP#<>CHR$(32)THEN272
273 IFP#=CHR$(32)THEN RETURN
274 PRINTCHR$(147)
275 PRINT" MULTIPLICATION AND DIVISION:":PRINT
276 PRINT" SIGNS THE SAME: ANSWER IS POSITIVE.":PRINT
277 PRINT" SIGNS OPPOSITE: ANSWER IS NEGATIVE.":PRINT
278 PRINT:PRINT:PRINT" ADDITION:":PRINT
279 PRINT" THE ANSWER WILL HAVE THE SIGN OF THE    LARGER NUMBER.":PRINT
280 PRINT" SUBTRACTION:":PRINT
281 PRINT" CHANGE THE SIGN OF THE NUMBER TO BE    SUBTRACTED, THEN ADD."
282 PRINT:PRINT:PRINT" %SPACE BAR% TO CONTINUE"
283 GETD$:IFD#<>CHR$(32)THEN283
284 IFD#=CHR$(32)THEN RETURN
285 PRINT"XXXXXXXX    LOADING MENU"
286 PRINTCHR$(6)
287 LOAD"MENU 301",8

```

READY.

Fig. E-4. Engineering notation program.

```

1 REM ENG.NOTATION
2 PRINTCHR$(147):"XXXXXXXX"
3 PRINT"    THIS PROGRAM OFFERS PRACTICE    PROBLEMS FOR THE WORK";
4 PRINT" COVERED IN    CHAPTER 4."
5 PRINT"XXXXXXXX"
6 REM PRINT"          %SPACE BAR% TO CONTINUE"
7 REM GET SB$:IF SB#<>CHR$(32)THENS
8 REM PRINTCHR$(147):"XXXXXXXX"
9 PRINT"    NOTES:":PRINT:PRINT
10 PRINT" 1. OMIT COMMAS IN ANSWERS.":PRINT
11 PRINT" 2. ANSWERS MUST BE FOLLOWED BY %RETURN%."
12 FORL=1TO5:PRINT:NEXTL
13 PRINT"          %SPACE BAR% FOR PROGRAM MENU."
14 GETR$:IF R#<>CHR$(32)THEN14

```

Fig. E-4. Engineering notation program. (Continued from page 301.)

```

15 PRINTCHR$(147):PRINT:PRINT
16 PRINT" 1. SIGNIFICANT FIGURES":PRINT
17 PRINT" 2. ROUNDING":PRINT
18 PRINT" 3. SCIENTIFIC NOTATION":PRINT
19 PRINT" 4. REMOVING POWERS OF TEN":PRINT
20 PRINT" 5. ENGINEERING NOTATION":PRINT
21 PRINT" 6. REMOVING ENG. NOTATION":PRINT
22 PRINT" 7. RETURN TO MAIN MENU"
23 PRINT"    IF 7 TURN DISK DRIVE ON. █"
24 INPUT" ENTER THE NUMBER OF YOUR SELECTION";V:IFV<1ORV>7THENGOTO15
25 RESTORE
26 IFV=1THENGOTO34
27 IFV=2THENX=21:GOTO33
28 IFV=3THENX=42:GOTO33
29 IFV=4THENX=63:GOTO33
30 IFV=5THENX=84:GOTO33
31 IFV=6THENX=105:GOTO33
32 IFV=7THENGOTO138
33 FORN=1TOX:READW$:NEXTW
34 READY$:P=0
35 FORI=1TO10:PRINTCHR$(147)
36 READQ$,A$
37 FORS=1TO5:PRINT:NEXTS
38 PRINTI;"||. ";Y$:Z$=" ":REM***Y$ IS THE QUESTION**
39 PRINT:PRINTTAB(15)Q$;
40 INPUTZ$:REM ***** ANSWER *****
41 IFZ$=A$THEN P=P+1:GOSUB51 :REM ***CORRECT
42 IFZ$<>A$THEN GOSUB52 :GOTO49 :REM ***WRONG
43 PRINT:PRINT" █SPACE BAR█ TO CONTINUE,"
44 PRINT"    █ N █ FOR NEW SELECTION,"
45 GETIF$:IFF$<>CHR$(32)ANDF$<>CHR$(78)THEN45
46 IFF$=CHR$(32)ANDI=10THENGOSUB81 :REM*****SCORE****
47 IFF$=CHR$(32)THENNEXTI
48 IFF$=CHR$(78)THEN81 :REM *****SCORE*
49 IFI<10THENNEXTI
50 IFI=10THEN81
51 PRINT:PRINT"          CORRECT!":RETURN
52 PRINT:PRINT"          WRONG! ";ANSWER=" ";A$;"█"
53 PRINT:PRINT"    █SPACE BAR█ TO CONTINUE,"
54 PRINT"    █ F1 █ FOR HELP HINTS,"
55 PRINT"    █ N █ FOR NEW SELECTION."
56 GET L$:IFL$<>CHR$(32)ANDL$<>CHR$(78)ANDL$<>CHR$(133)THEN56
57 IFL$=CHR$(32)THEN RETURN
58 IFL$=CHR$(78)THEN GOTO81
59 IFL$=CHR$(133)THEN GOSUB90 :RETURN
60 DATAHOW MANY SIGNIFICANT DIGITS DOES          THIS NUMBER HAVE?
61 DATA106,3,100,3,1,00,1,1.50,2,.003,1,2.45,3,0.100,1,2.300,2,5.05,3,10.00,2
62 DATAROUND TO THREE SIGNIFICANT FIGURES.
63 DATA1006,1610,67.52,67.5,123.5,124
64 DATA2,563,2,56,3025,3030,.33333,.333,.4520,.452,5685,5690,3797,3800
65 DATA9995,10000
66 DATACHANGE THE FOLLOWING TO SCIENTIFIC          NOTATION (USE "E" NOTATION).
67 DATA100,1E2,10000,1E4,2500,2.5E3,10.0,1E1,25.5,2.55E1
68 DATA.125,1.25E-1,.001,1E-3,.75,7.5E-1,.0001,1E-4,.500,5E-1
69 DATAREMOVE THE POWER OF TEN FROM THE          FOLLOWING NUMBERS.
70 DATA1E5,100000,2.5E3,2500,3.3E6,3300000,2.5E1,25,5.5E3,5500,5.25E-2,.0525
71 DATA1E-4,.0001,1.25E-1,.125,5E-6,.000005,6E-3,.006
72 DATAWRITE THE FOLLOWING USING          ENGINEERING NOTATION.
73 DATA20000,20KILO,94000000,94MEG,2000000000

```

```

74 DATA2GIGA,25000 ,25KILO,20,20,.025
75 DATA25MILLI,.0001,100MICRO
76 DATA.3,300MILLI,.000000000180,180PICO
77 DATA.000010,10MICRO
78 DATAREMOVE ENGINEERING NOTATION
79 DATAK,2000,4.5K,4500,56K,56000,2M,2000000,500MILLI,.5,20MICRO,.00002
80 DATA180PICO,.00000000018,320M,320000000,10K,10000,20M,20000000
81 REM ***** SCORE *****
82 F=(P/I)*100
83 PRINTCHR$(147)
84 FORM=1T08:PRINT:NEXTM
85 PRINT"          YOUR SCORE IS ";F;"%"
86 PRINT"          FOR ";I;"QUESTIONS ASKED."
87 PRINT:PRINT:PRINT"          SPACE BAR FOR MENU"
88 GETN$:IFN$<>CHR$(32)THEN88
89 IFN$=CHR$(32)THEN15
90 PRINTCHR$(147)
91 ON V GOSUB95 ,100,106 ,112 ,119 ,129
92 PRINT"XXXXXXXX          SPACEBAR TO CONTINUE"
93 GETRR$:IFRR$<>CHR$(32)THEN93
94 IFRR$=CHR$(32)THEN RETURN
95 REM *** SIG DIGITS ***
96 PRINT"XXXXXXXX"
97 PRINT" 1. DID YOU INCLUDE PLACE HOLDING ZEROS?"
98 PRINT" 2. DID YOU ENTER THE NUMBER CORRECTLY?"
99 RETURN
100 REM *** ROUNDING ***
101 PRINT"XXXXXXXX"
102 PRINT" 1. DID YOU ROUND TO THREE SIGNIFICANT DIGITS ?"
103 PRINT" 2. DID YOU ADD 1 TO A DIGIT THAT SHOULD HAVE REMAINED THE SAME?"
104 PRINT" 3. DID YOU FORGET TO ADD 1 TO A DIGIT THAT YOU SHOULD HAVE?"
105 RETURN
106 REM *** SCI NOTE ***
107 PRINT"XXXXXXXX"
108 PRINT" 1. DID YOU USE (E) NOTATION (1.1E5) ?"
109 PRINT" 2. DID YOU CHANGE THE VALUE ?"
110 PRINT" 3. DID YOU USE THE CORRECT EXPONENT ?"
111 RETURN
112 REM *** REMOVE POWERS ***
113 PRINT"XXXXXXXX"
114 PRINT" 1. DID YOU MOVE THE DECIMAL POINT THE CORRECT NUMBER ";
115 PRINT"OF DIGITS ?"
116 PRINT" 2. DID YOU GHANGE THE VALUE ?"
117 PRINT" 3. DID YOU ENTER THE VALUE CORRECTLY ?"
118 RETURN
119 REM *** ENG NOTE ***
120 PRINT"X"
121 PRINT" GIGA MEG KILO          MILLI MICRO NANO PICO"
122 PRINT" | | | | | |          | | | | | | | | | |"
123 PRINT" 000 000 000 000.000 000 000 000XXXXXX"
124 PRINT" 1. HAVE YOU USED ENG NOTATION TO IT'S BEST ABILITY ?"
125 PRINT" 2. DID YOU CHANGE THE VALUE ?"
126 PRINT" 3. HAVE YOU USED THE CORRECT NAME FOR THE POWER ";
127 PRINT"YOU WANTED ?"
128 RETURN
129 REM *** REMOVE ENG ***
130 PRINT"X"
131 PRINT" GIGA MEG KILO          MILLI MICRO NANO PICO"
132 PRINT" | | | | | |          | | | | | | | | | |"
133 PRINT" 000 000 000 000.000 000 000 000XXXXXX"
134 PRINT" 1. DID YOU MOVE THE DECIMAL POINT THE CORRECT NUMBER OF ";
135 PRINT"SPACES FOR THE NAME OF THE POWER OF TEN ?"

```

Fig. E-4. Engineering notation program. (Continued from page 303.)

```

136 PRINT" 2. DID YOU CHANGE THE VALUE ?"
137 RETURN
138 REM **** RETURN TO MENU ***
139 PRINTCHR$(147)
140 PRINT"          LOADING MENU"
141 PRINTCHR$(6)
142 LOAD"MENU 301",8

```

READY.

Fig. E-5. Color code program.

```

1 REM COLOR CODE
2 PRINTCHR$(147)"*****"
3 PRINT" THIS PROGRAM WILL ALLOW THE USER TO PRACTICE READING THE";
4 PRINT" RESISTOR COLOR CODE." THE USER TO DETERMINE THE";
5 PRINT" IT WILL DISPLAY A RESISTOR, AND ASK
6 PRINT" VALUE BY READING THE COLOR CODE."
7 PRINT"*****"
8 PRINT"          SPACE BAR TO CONTINUE."
9 GET SB$: IF SB$<>CHR$(32)THEN9
10 PRINTCHR$(152)
11 POKE53281,11
12 POKE53280,0
13 PRINTCHR$(147)
14 PRINTTAB(10)"RESISTOR COLOR CODE"
15 PRINT
16 PRINTTAB(16)"NOTE:"
17 PRINT
18 PRINTTAB(2)"1. OMIT COMMAS WHEN ENTERING NUMBERS."
19 PRINT:PRINTTAB(03)"EXAMPLE: 1.5K OR 1500 NOT 1,500"
20 PRINT:PRINTTAB(2)"2. ALL ENTERIES MUST BE FOLLOWED BY"
21 PRINT:PRINTTAB(4)"RETURN KEY."
22 PRINT:PRINT"*****          SPACE BAR TO CONTINUE."
23 GETG$: IFG$<>CHR$(32)THEN23
24 IFG$=CHR$(32)THEN25
25 PRINT CHR$(147)
26 PRINTTAB(15)"0=BLK";CHR$(144);"●●●●";CHR$(152):PRINT
27 PRINTTAB(15)"1=BRN";CHR$(149);"●●●●";CHR$(152):PRINT
28 PRINTTAB(15)"2=RED";CHR$(28);"●●●●";CHR$(152):PRINT
29 PRINTTAB(15)"3=ORG";CHR$(129);"●●●●";CHR$(152):PRINT
30 PRINTTAB(15)"4=YEL";CHR$(158);"●●●●";CHR$(152):PRINT
31 PRINTTAB(15)"5=GRN";CHR$(30);"●●●●";CHR$(152):PRINT
32 PRINTTAB(15)"6=BLU";CHR$(154);"●●●●";CHR$(152):PRINT
33 PRINTTAB(15)"7=VIO";CHR$(156);"●●●●";CHR$(152):PRINT
34 PRINTTAB(15)"8=GRY";CHR$(152);"●●●●";CHR$(152):PRINT
35 PRINTTAB(15)"9=WHT";CHR$(05);"●●●●":PRINTCHR$(152)
36 PRINTTAB(07)" ADJUST TINT IF NECESSARY."
37 PRINT:PRINT"          SPACE BAR TO CONTINUE"
38 GETL$: IFL$<>CHR$(32)THEN38
39 IFL$=CHR$(32)GOTO40
40 PRINTCHR$(147)
41 FOR K=1 TO 5:PRINT:NEXTK
42 PRINTTAB(2)"START UP PROCEDURE PLEASE BE PATIENT."
43 GOTO44
44 REM SET SPRITE MEMORY LOCATION
45 POKE2040,192:A=12288
46 POKE2041,193:B=12352

```

```

47 POKE2042,194:C=12416
48 POKE2043,195:D=12480
49 REM **CLEAR SPRITE MEMORY**
50 FOR Z=0 TO63
51 POKE A+Z,0
52 POKE B+Z,0
53 POKE C+Z,0
54 POKE D+Z,0
55 NEXTZ
56 FORPO=3 TO 62
57 POKE A+PO,255
58 POKE B+PO,255
59 POKE C+PO,255
60 POKE D+PO,255
61 NEXT PO
62 REM **SET X,Y LOCATIPONS**
63 V=53248:REM BEGINING VIDEO LOCATION
64 POKEV+29,0:POKEV+23,0
65 POKEV,195:REM X LOCS
66 POKEV+2,160
67 POKEV+4,125
68 POKEV+6,90
69 POKEV+16,0:REM MSBX=0
70 POKEV+1,75 :REM Y LOCS
71 POKEV+3,75
72 POKEV+5,75
73 POKEV+7,75
74 REM SET SPRITE COLORS
75 POKE 53287,1
76 POKE 53288,1
77 POKE 53289,1
78 POKE 53290,1
79 REM SPRITE ENABLE
80 POKE 53269,14
81 REM          SAMPLE QUESTION
82 PRINTCHR$(147)
83 GOSUB140
84 PRINT:PRINTTAB(8)"GRN  BLU  ORG  ":PRINT:PRINT:C=53287
85 POKEC+1,8:POKEC+2,14:POKEC+3,5
86 PRINTTAB(15)"EXAMPLE:":PRINT:PRINT
87 PRINTTAB(11)"WHAT IS THE VALUE"
88 PRINTTAB(11)"OF THIS RESISTOR?";
89 PRINT" 56K"
90 PRINT:PRINTTAB(15)"CORRECT!"
91 PRINT:PRINT:PRINT"          █SPACE BAR█ TO TRY YOUR OWN."
92 GETR$:IFR$(CHR$(32))THEN92
93 IF R$=CHR$(32) GOTO95
94 S=0:I=0
95 REM*****QUESTION LOOP*****
96 FORI=1TO25
97 READL1$,L2$,L3$
98 READB1,B2,B3,A1$,A2$
99 PRINTCHR$(147)
100 GOSUB140
101 PRINT:PRINTTAB(8)L1$;"  ";L2$;"  ";L3$:PRINT:PRINT
102 C=53287
103 POKEC+1,B3:POKEC+2,B2:POKEC+3,B1
104 PRINTTAB(09)I;".WHAT IS THE VALUE"
105 PRINTTAB(11)"OF THIS RESISTOR";
106 INPUTQ$:PRINT
107 IF Q$=A1$ GOTO121
108 IF Q$=A2$ GOTO121

```

Fig. E-5. Color code program. (Continued from page 305.)

```

109 IF Q$<>A1$ANDQ$<>A2$ GOTO110
110 PRINT TAB(15)"WRONG!":PRINT
111 PRINT TAB(5)"  ANSWER IS  ";A1$;" OR ";A2$;"  "
112 PRINT TAB(3)"  SPACE BAR  FOR NEXT.  "
113 PRINTTAB(8)"F1  FOR HELP HINTS."
114 PRINTTAB(8)"N  FOR NEW SELECTION"
115 GETF$: IF F$<>CHR$(32)ANDF$<>CHR$(78)ANDF$<>CHR$(133) THEN GOTO115
116 IF F$=CHR$(78)THEN:GOTO128
117 IF F$=CHR$(32)ANDI=25THENGOTO128
118 IFF$=CHR$(133)THENGOSUB171
119 IFF$=CHR$(32)THENNEXTI
120 GOTO112
121 PRINTTAB(15)"CORRECT!":S=S+1:PRINT
122 PRINTTAB(05)"  SPACE  BAR FOR NEXT":PRINT
123 PRINT:PRINT:PRINT:PRINTTAB(11)"N  FOR MAIN MENU."
124 GETP$: IFF$<>CHR$(32)ANDP$<>CHR$(78)THEN GOTO124
125 IFF$=CHR$(32)ANDI=25THENGOTO128
126 IFF$=CHR$(32)THENNEXTI
127 IFF$=CHR$(78)THEN128
128 IF I=26 THEN I=25:P=(S/(I))*100
129 P=(S/(I))*100
130 POKE 53269,0
131 PRINTCHR$(147):PRINT:PRINT:PRINT:PRINT:PRINT:FOR Q=1 TO 200:NEXT Q
132 PRINT:PRINT:PRINTTAB(12)"YOUR SCORE IS";P;"%"
133 PRINT"  FOR";I;"QUESTIONS ASKED."
134 PRINT"  PLEASE TURN DISK DRIVE ON.  "
135 PRINT:PRINTTAB(6)"PRESS SPACE BAR FOR MAIN MENU."
136 GETW$: IFW$<>CHR$(32)THEN136
137 IFW$=CHR$(32)THENGOTO189
138 FOR J=1 TO4000 :NEXT J
139 GOTO131
140 PRINTCHR$(147)
141 PRINT:PRINT
142 PRINT"
143 PRINT"
144 PRINT"
145 RETURN
146 DATA BRN, BLK, BLK, 9, 0, 0, 10, 10
147 DATA RED, RED, BLK, 2, 2, 0, 22, 22
148 DATA ORG, ORG, RED, 8, 8, 2, 3, 3K, 3300
149 DATA BRN, GRY, ORG, 9, 12, 8, 18K, 18000
150 DATA YEL, VIO, RED, 7, 4, 2, 4, 7K, 4700
151 DATA GRN, BLU, BLK, 5, 6, 0, 56, 56
152 DATA BRN, BLK, BRN, 9, 0, 9, 100, 100
153 DATA GRY, RED, RED, 12, 2, 2, 8, 2K, 8200
154 DATA YEL, VIO, BLK, 7, 4, 0, 47, 47
155 DATA ORG, ORG, YEL, 8, 8, 7, 330K, 330000
156 DATA GRN, BLU, ORG, 5, 6, 8, 56K, 56000
157 DATA BRN, GRY, BRN, 9, 12, 9, 180, 180
158 DATA RED, RED, GRN, 2, 2, 5, 2, 2M, 220000
159 DATA ORG, WHT, RED, 8, 1, 2, 3, 9K, 3900
160 DATA BLU, GRY, BRN, 6, 12, 9, 680, 680
161 DATA ORG, ORG, ORG, 8, 8, 8, 33K, 33000
162 DATA RED, VIO, RED, 2, 4, 2, 2, 7K, 2700
163 DATA BRN, GRN, YEL, 9, 5, 7, 150K, 150000
164 DATA BRN, RED, BLU, 9, 2, 6, 12M, 12000000
165 DATA GRY, RED, BLK, 12, 2, 0, 82, 82
166 DATA GRN, BLU, ORG, 5, 6, 8, 56K, 56000
167 DATA YEL, VIO, YEL, 7, 4, 7, 470K, 470000

```

```

168 DATAORG,ORG,RED,8,8,2,3,3K,3300
169 DATARED,VIO,BLK,2,4,0,27,27
170 DATABRN,RED,ORG,9,2,8,12K,12000
171 PRINTCHR$(147):GOSUB140
172 POKEC,7:POKEC+1,8:POKEC+2,14:POKEC+3,5
173 PRINT:PRINT" THE BAND CLOSER TO ONE END THEN THE OTHERS IS BAND ONE,";
174 PRINT"IT REPRESENTS THE FIRST DIGIT OF THE VALUE, THE NEXT"
175 PRINT" BAND IN IS THE SECOND DIGIT, THE THIRD IS THE MULTIPLIER,";
176 PRINT" AND THE FORTH IF ANY IS THE TOLERANCE RATING";
177 PRINT"(IF NONE THE TOLERANCE IS 20%)."
178 PRINT:PRINT:PRINT" PRESS SPACE BAR TO CONTINUE."
179 GETO$:IFO$<>CHR$(32)THEN179
180 IFO$=CHR$(32)THEN181
181 PRINTTAB(2) "TTTTTTTTTHEREFORE THIS RESISTOR READS:"; "
182 PRINT" GRN (5) BLU (6) ORG (3) "
183 PRINT" SO THE VALUE OF T";
184 PRINT"HIS RESISTOR IS 56000 OR 56K. "
185 PRINT" "
186 PRINT" WE ARE NOT CONCERNED WITH TOLERANCE IN THIS EXERCISE. "
187 PRINT" "
188 RETURN
189 REM*** MENU LOADER ***
190 PRINTCHR$(147)
191 POKE53280,14:POKE53281,6
192 PRINTCHR$(154)
193 PRINT"LOADING MENU"
194 PRINTCHR$(6)
195 LOAD"MENU 301",8

```

READY.

Fig. E-6. Ohmmeter program.

```

1 REM INTRODUCTION
2 PRINT CHR$(147)
3 PRINT"THIS PROGRAM ALLOWS THE USER TO PRACTICE READING A";
4 PRINT" DIGITAL OHM METER."
5 PRINT" IT WILL DISPLAY A DIGITAL TYPE OHM METER WITH THE RANGE";
6 PRINT" SETTING, AND A READING ON IT'S DISPLAY."
7 PRINT" THE USER WILL BE ASKED TO DETERMINE THE RESISTANCE BEING";
8 PRINT" MEASURED."
9 PRINT" THE PROGRAM EXPECTS THE ANSWERS TO BE WITHIN 5% OF THE";
10 PRINT" COMPUTER'S ANSWERS."
11 PRINT" USER SHOULD NOT USE ENG. NOTATION, OR SCIENTIFIC NOTATION."
12 PRINT"SPACEBAR TO CONTINUE"
13 GETSK$:IFSK$<>CHR$(32)THENGOTO13
14 IFSK$=CHR$(32)THEN GOTO93
15 PRINTCHR$(147):REM ** 2 OHM RANGE *
16 PRINT"
17 PRINT"
18 PRINT"
19 PRINT"
20 PRINT"
21 PRINT"
22 PRINT"
23 PRINT"
24 PRINT"
25 PRINT"

```

| | |
|--|---|
| | 2 2 2 2 2 2 0 0 0 M 0 0 K 0 M K 0 0 0 0 0 0 OHMS |
|--|---|

```

26 PRINT"TTTTT";TAB(9)G1$
27 RETURN
28 PRINTCHR$(147):REM* 20 OHM RANGE **

```

Fig. E-6. Ohmmeter program. (Continued from page 307.)

```

29 PRINT"
30 PRINT"
31 PRINT"
32 PRINT"
33 PRINT"
34 PRINT"
35 PRINT"
36 PRINT"
37 PRINT"
38 PRINT"
39 PRINT";TAB(9)G1$
40 RETURN
41 PRINTCHR$(147):REM (200 OHM RANGE)
42 PRINT"
43 PRINT"
44 PRINT"
45 PRINT"
46 PRINT"
47 PRINT"
48 PRINT"
49 PRINT"
50 PRINT"
51 PRINT"
52 PRINT";TAB(9)G1$
53 RETURN
54 PRINTCHR$(147):REM (2K OHM RANGE)
55 PRINT"
56 PRINT"
57 PRINT"
58 PRINT"
59 PRINT"
60 PRINT"
61 PRINT"
62 PRINT"
63 PRINT"
64 PRINT"
65 PRINT";TAB(9)G1$
66 RETURN
67 PRINTCHR$(147):REM (20K RANGE)
68 PRINT"
69 PRINT"
70 PRINT"
71 PRINT"
72 PRINT"
73 PRINT"
74 PRINT"
75 PRINT"
76 PRINT"
77 PRINT"
78 PRINT";TAB(9)G1$
79 RETURN
80 PRINTCHR$(147):REM (2M RANGE)
81 PRINT"
82 PRINT"
83 PRINT"
84 PRINT"
85 PRINT"
86 PRINT"
87 PRINT"

```



```

88 PRINT"
89 PRINT"
90 PRINT"
91 PRINT"TTTT";TAB(9)G1$
92 RETURN
93 REM ** QUESTION LOOP & MAIN PROG *
94 FOR XX=1TO20:PRINTCHR$(147)
95 READCT,G1$,A
96 PRINT"XXXX"
97 ON CT GOSUB15 ,28 ,41 ,54 ,67 ,80
98 LM=A-(A*.005):HM=A+(A*.005)
99 PRINT"XXXXXXXXXX";XX;"||. "; "WHAT IS THE RESISTANCE BEING"
100 INPUT" MEASURED IN OHMS ";ED
101 REM *****CORRECT*****
102 IFED>LM AND ED<HM THEN GOSUB107
103 IFED=LMORED=HM THEN GOSUB107
104 IF ED<LMORED>HM THEN GOSUB115 :REM ***** WRONG *****
105 IF XX=20 THEN GOTO147
106 NEXTXX
107 S=S+1:REM *** CORRECT ***
108 PRINT:PRINT" CORRECT!"
109 PRINT:PRINT" SPACE BAR FOR NEXT"
110 PRINT" N FOR NEW SELECTION"
111 QC$=CHR$(13)
112 GET QC$:IFQC$<>CHR$(32)ANDQC$<>CHR$(78) THEN GOTO112
113 IF QC$=CHR$(32) THEN RETURN
114 IF QC$=CHR$(78) THEN GOTO147 : REM ***SCORE***
115 REM *** WRONG ***
116 PRINT" WRONG! ANSWER IS ";A;" "
117 PRINT:PRINT" SPACE BAR FOR NEXT"
118 PRINT" F1 FOR HELP HINTS"
119 PRINT" N FOR NEW SELECTION"
120 GET SY$:IFSY$<>CHR$(32)ANDSY$<>CHR$(78)ANDSY$<>CHR$(133) THEN GOTO120
121 IF SY$=CHR$(32) THEN RETURN
122 IF SY$=CHR$(133) THEN GOSUB124 :RETURN:REM ** HELP HINTS **
123 IF SY$=CHR$(78) THEN GOTO147 : REM ***SCORE***
124 REM ***** HELP HINTS *****
125 PRINTCHR$(147):G1$="32.50":GOSUB54
126 PRINT"XXXXXXXX"
127 PRINT:PRINT" THE RANGE IS SET FOR 200K, THIS MEANS THE ";
128 PRINT"MAXIMUM RESISTANCE THIS SETTING CAN MEASURE IS 200K OHMS."
129 PRINT" TO INTERPET THE DISPLAY, USE ENGINEERING NOTATION, ";
130 PRINT"THE VALUE DISPLAYED SHOULD BE MULTIPLIED BY 1000 ";
131 PRINT"IF IT IS A K RANGE OR 1000000 IF IT IS A M RANGE."
132 PRINT" SPACE BAR FOR MORE"
133 GET CO$:IF CO$<>CHR$(32) THEN 133
134 PRINT"XXXXXXXXXXXXXXXX"
135 PRINT" THEREFORE THIS METER IS MEASURING A 32500 OHM RESISTOR. ";
136 PRINT" 32.50 X 1000 (K)= 32500. YOUR ANSWER";
137 PRINT" SHOULD BE IN THIS FORM 32500. ";
138 PRINT" ";
139 PRINT" ";
140 PRINT" ";
141 PRINT" ";
142 PRINT" "
143 PRINT" "
144 PRINT" SPACE BAR TO CONTINUE."
145 GET DO$:IFDO$<>CHR$(32) THEN GOTO145
146 IF DO$=CHR$(32) THEN RETURN
147 REM *** SCORE ***
148 TS=(S/XX)*100
149 PRINTCHR$(147)

```

Fig. E-6. Ohmmeter program. (Continued from page 309.)

```

150 FORWW=1TO6:PRINT:NEXTWW
151 PRINT"          YOUR SCORE IS ";TS;"%"
152 PRINT"          FOR";XX;"QUESTIONS ASKED."
153 PRINT"XXXXXXXX  PLEASE TURN DISK DRIVE ON."
154 PRINT"XX      SPACE BAR FOR MAIN MENU."
155 GET MN$:IF MN$<>CHR$(32)THEN GOTO155
156 IF MN$=CHR$(32)THENGOTO178
157 REM *** DATA FOR PROBLEMS ***
158 DATA3,1.500,1500
159 DATA2,15.50,15.50
160 DATA3,6.000,6000
161 DATA4,15.00,15000
162 DATA5,1.500,1500000
163 DATA6,8.300,8300000
164 DATA5,1.999,1999000
165 DATA2,8.500,8.500
166 DATA3,18.00,18000
167 DATA4,150.0,150000
168 DATA5,1.800,1800000
169 DATA6,12.50,12500000
170 DATA2,50.00,50
171 DATA2,89.00,89
172 DATA3,1.200,1200
173 DATA4,56.00,56000
174 DATA5,1.200,1200000
175 DATA6,6.800,6800000
176 DATA3,.7500,750
177 DATA4,12.10,12100
178 REM *** MENU LOADER ***
179 PRINTCHR$(147)
180 PRINT"XX      LOADING MENU"
181 PRINTCHR$(6)
182 LOAD"MENU 301",8

```

READY.

Fig. E-7. Ohm's law program.

```

1 REM OHM'S LAW
2 PRINTCHR$(147);"XX"
3 PRINT" THIS PROGRAM WILL ALLOW THE USER TO PRACTICE OHM'S LAW, AND";
4 PRINT" POWER FORMULAS.XX"
5 PRINT" IT WILL DISPLAY A DC CIRCUIT, AND GIVE TWO OF THE THREE";
6 PRINT" VARIABLES NEEDED FOR THE FORMULA (V=I X R).XX"
7 PRINT" EACH QUESTION HAS TWO PARTS.XX"
8 PRINT" A. SOLVE FOR THE UNKNOWN.XX"
9 PRINT" B. FIND THE POWER DISSIPATED.XX"
10 PRINT" YOU ARE EXPECTED TO BE WITHIN 5% OF THE COMPUTER'S ANSWER.XXXXX"
11 PRINT" SPACE BAR TO CONTINUE."
12 GET SB$:IF SB$<>CHR$(32)THEN12
13 PRINTCHR$(147)
14 PRINT"XXXXXXXX THE METERS IN THE DISPLAY ARE TO DEMONSTRATE";
15 PRINT" THE CORRECT WAY TO CONNECT THEM TO A CIRCUIT ONLY,"
16 PRINT" THEY ARE NOT MEANT TO SUPPLY INFORMATION FOR";
17 PRINT" CALCULATIONS."
18 PRINT"XXXXXXXX SPACE BAR TO CONTINUE"
19 SB$=CHR$(13)
20 GET SB$:IF SB$<>CHR$(32)THEN20

```

```

21 EN=53269
22 PRINTCHR$(147)
23 FORPP=1TO8:PRINT:NEXTPP:PRINT"                WAIT A BIT!"
24 REM SET SPRITE STARTING LOCATIONS
25 POKE2040,192:A=12287:REM*GROUND**
26 POKE2041,193:B=12351:REM*RESISTOR**
27 POKE2042,194:C=12415:REM*LAMP**
28 POKE2043,195:D=12479:REM*LED**
29 POKE2044,196:E=12543:REM*BATTERY**
30 POKE2045,197:F=12607:REM*METER**
31 POKE2046,198:G=12671:REM*SCH METER*
32 POKE2047,199:H=12735:REM***
33 REM CLEAR SPRITE BITES
34 FOR Z=1 TO64
35 POKE A+Z,0
36 POKE B+Z,0
37 POKE C+Z,0
38 POKE D+Z,0
39 POKE E+Z,0
40 POKE F+Z,0
41 POKE G+Z,0
42 POKE H+Z,0
43 NEXTZ
44 REM ***GROUND***
45 POKEA+20,16:POKEA+23,16:POKEA+26,16
46 POKEA+28,15:POKEA+29,255:POKEA+30,224:POKEA+34,3:POKEA+35,255
47 POKEA+36,128:POKEA+41,124
48 REM ***RESISTOR***
49 POKEB+7,8:POKEB+8,136:POKEB+9,128:POKEB+10,245:POKEB+11,85:POKEB+12,95
50 POKEB+13,2:POKEB+14,34:POKEB+15,32
51 REM***LAMP***
52 POKEC+14,252:POKEC+16,1:POKEC+17,2:POKEC+19,2:POKEC+20,49:POKEC+22,4
53 POKEC+23,72:POKEC+24,128:POKEC+25,8:POKEC+26,72:POKEC+27,64:POKEC+28,8
54 POKEC+29,48:POKEC+30,64:POKEC+31,8:POKEC+32,72:POKEC+33,64:POKEC+34,255
55 POKEC+35,135:POKEC+36,255:POKEC+37,2:POKEC+38,1:POKEC+40,1:POKEC+41,2
56 POKEC+44,252
57 REM*** LED ***
58 POKED+17,248:POKED+19,1:POKED+20,4:POKED+22,2:POKED+23,154:POKED+25,4
59 POKED+26,185:POKED+28,255:POKED+30,255:POKED+31,4:POKED+32,185:POKED+34,2
60 POKED+35,154:POKED+37,1:POKED+38,4:POKED+41,248:POKED+29,255
61 REM *** BATTERY ***
62 POKEE+2,32:POKEE+3,8:POKEE+5,32:POKEE+6,62:POKEE+7,15:POKEE+8,255
63 POKEE+9,136:POKEE+13,1:POKEE+14,252:POKEE+19,15:POKEE+20,255
64 POKEE+21,128:POKEE+25,1:POKEE+26,252
65 POKEE+27,28:POKEE+29,32:POKEE+32,32:POKEE+35,32:POKEE+38,32
66 POKEE+40,15:POKEE+41,255:POKEE+42,128
67 POKEE+46,3:POKEE+47,254:POKEE+53,112
68 REM** SCHEM METER ***
69 POKEG+11,126:POKEG+14,129:POKEG+16,1:POKEG+17,16:POKEG+18,128
70 POKEG+19,2:POKEG+20,56:POKEG+21,64:POKEG+22,4:POKEG+23,16:POKEG+24,32
71 POKEG+25,252:POKEG+26,16:POKEG+27,63:POKEG+28,4:POKEG+29,16:POKEG+30,32
72 POKEG+31,2:POKEG+33,64:POKEG+34,1:POKEG+36,128:POKEG+38,129:POKEG+41,126
73 REM *** METER NEEDLE ***
74 FOR H=10TO46 STEP3 :POKEF+H,8 :NEXTH
75 REM SET X,Y LOCATIONS FOR SPRITE
76 V=53248:REM BEGINING VIDEO LOCATION
77 POKEV+29,255:POKEV+23,255
78 POKEV,42:REM X LOCS
79 POKEV+2,120
80 POKEV+4,120
81 POKEV+6,120
82 POKEV+8,250

```

Fig. E-7. Ohm's law program. (Continued from page 313.)

```

83 POKEV+10,60
84 POKEV+12,190
85 POKEV+14,135
86 POKEV+16,0:REM MSBX=0
87 POKEV+1,100:REM Y LOCS
88 POKEV+3,100
89 POKEV+5,84
90 POKEV+7,88
91 POKEV+9,114
92 POKEV+11,0
93 POKEV+13,90
94 POKEV+15,0
95 REM SET SPRITE COLOR
96 POKE 53287,14
97 POKE 53288,14
98 POKE 53289,14
99 POKE 53290,14
100 POKE 53291,14
101 POKE 53292,0
102 POKE 53293,14
103 POKE 53294,1
104 REM SPRITE ENABLE
105 POKE EN,0
106 GX1=V:RX1=V+2:IX1=V+4: LX2=V+6:BX1=V+8:MX1=V+10: SX1=V+12
107 GY1=V+1:RY1=V+3: IY1=V+5:LY2=V+7:BY1=V+9:MY1=V+11:SY1=V+13
108 GOTO130
109 REM***** SUBS *****
110 REM *** CURRENT ***
111 POKESX1,190:POKESY1,90
112 PRINT
113 PRINT"      _____"
114 PRINT:PRINTTAB(23)"A":PRINT"XXXXXXXX"
115 RETURN
116 REM*** SUB CLOSED SWITCH CURRENT**
117 PRINT"      _____"
118 REM*** VOLTS ***
119 POKESX1,118:POKESY1,58
120 PRINT"TTTT"
121 PRINT"
122 PRINT"      |      |
123 PRINT"      |      |
124 PRINT"      |      |
125 PRINT"      |      |" :PRINT"XXXXXXXXXX"
126 RETURN
127 REM *** SUB CLOSED SWITCH VOLT***
128 PRINT"      |      |"
129 PRINT"      |      |"
130 REM ** QUESTION LOOP & MAIN PROG *
131 FOR XX=1TO20:PRINTCHR$(147):AD$=CHR$(32)
132 READCP,CT,A,G1$,G2$,G3$,PD
133 PRINT:PRINTTAB(22) "VOLTAGE=";G1$;" VOLTS"
134 PRINTTAB(22)"CURRENT=";G2$;" AMPS":PRINTTAB(19)"RESISTANCE=";G3$;" OHMS"
135 POKEEN,CP:ON CT GOSUB110,118:IFKP=1THENRETURN
136 LM=A-(A*.05):HM=A+(A*.05)
137 LP=PD-(PD*.05):HP=PD+(PD*.05)
138 PRINTXX;"||. "; "FIND THE MISSING VALUE";
139 INPUT AD
140 KP=1:IF AD>LMANDAD<HM THEN GOSUB155 :REM *****CORRECT*****
141 IFAD=LMORAD=HMTHEN GOSUB155

```

```

142 IF ADCLMORAD>HM THEN GOSUB162 :REM ***** WRONG *****
143 KP=2:PRINT"XXXXXXXXXXXXXXXXXXXX"
144 FOR ER=1TO8
145 KP=2:PRINT"
146 NEXTER
147 PRINT"XXXXXXXXXXXXXXXXXXXX"
148 PRINTXX;"||. "; "HOW MUCH POWER IS DISSIPATED"
149 INPUT" IN WATTS";PA
150 IFPA>LPANDPA<HP THENGOSUB155
151 IFPA=LPOR PA=HP THENGOSUB155
152 IFPA<LPORPA>HP THENGOSUB162
153 IFXX=20GOTO185
154 NEXT XX
155 S=S+.5:REM *** CORRECT ***
156 PRINT:PRINT" CORRECT!"
157 PRINT:PRINT:PRINT" SPACE BAR FOR NEXT"
158 PRINT" N FOR NEW SELECTION"
159 GET SY$:IFSY$<>CHR$(32)ANDSY$<>CHR$(78)THENGOTO159
160 IF SY$=CHR$(32)THEN RETURN
161 IF SY$=CHR$(78)THEN GOTO185 : REM ***SCORE***
162 REM *** WRONG ***
163 IFKP=1THEN PRINT:PRINT" WRONG! ANSWER IS ";A;" "
164 IFKP=2THEN PRINT:PRINT" WRONG! ANSWER IS ";PD;" "
165 PRINT:PRINT" SPACE BAR FOR NEXT"
166 PRINT" F1 FOR HELP HINTS"
167 PRINT" N FOR NEW SELECTION"
168 GET SY$:IFSY$<>CHR$(32)ANDSY$<>CHR$(78)ANDSY$<>CHR$(133)THENGOTO16
169 IF SY$=CHR$(32)THEN RETURN
170 IF SY$=CHR$(133)THEN GOSUB172 :RETURN:REM ** HELP HINTS **
171 IF SY$=CHR$(78)THEN GOTO185 : REM ***SCORE***
172 REM ***** HELP HINTS *****
173 POKEEN,0
174 PRINTCHR$(147)
175 PRINT:PRINT" WITH WHAT IS GIVEN ONE OF THESE FORMULAS
176 PRINT"SHOULD APPLY.":PRINT
177 PRINT" OHM'S LAW POWER FORMULAS"
178 PRINT:PRINT" V= I X R P= I X V"
179 PRINT:PRINT" R= V/I P= I X I X R"
180 PRINT:PRINT" I= V/R P= (E X E)/ R"
181 PRINT:PRINT:PRINT:PRINT" SPACE BAR TO CONTINUE."
182 GET DO$:IFDO$<>CHR$(32) THEN GOTO182
183 IFKP=1ANDDO$=CHR$(32)THENPRINTCHR$(147):GOSUB133
184 IF DO$=CHR$(32)THEN RETURN
185 REM *** SCORE ****
186 POKEEN,0
187 TS=(S/XX)*100
188 PRINTCHR$(147)
189 FORWW=1TO6:PRINT:NEXTWW
190 PRINT" YOUR SCORE IS ";TS;"%"
191 PRINT" FOR";XX;"QUESTIONS ASKED."
192 PRINT" PLEASE TURN DISK DRIVE ON."
193 PRINT" SPACE BAR FOR MAIN MENU."
194 GET MN$:IF MN$<>CHR$(32)THEN GOTO194
195 IF MN$=CHR$(32)THENGOTO217
196 REM *** DATA FOR PROBLEMS ***
197 DATA83,1,5,?,.25,20,1.25
198 DATA83,2,.5,10,?,20,5
199 DATA83,1,40,10,.25,?,2.5
200 DATA83,2,100,20,.2,?,4
201 DATA83,1,50,?,.04,1250,2
202 DATA83,1,2000,40,.02,?,.8
203 DATA83,2,.005,5,?,1000,.025

```

Fig. E-7. Ohm's law program. (Continued from page 311.)

```

204 DATA83,2,.03,15,?,500,.45
205 DATA83,1,4,100,?,25,400
206 DATA83,2,40,12,.3,?,3.6
207 DATA83,2,100,20,.2,?,4
208 DATA83,1,80,?,.16,500,12.8
209 DATA83,1,30,?,2,15,60
210 DATA83,1,12,24,2,?,48
211 DATA83,1,2000,48,.024,?,1.152
212 DATA83,1,1800,36,.02,?,.72
213 DATA83,1,75,?,.15,500,11.25
214 DATA83,1,.2,40,?,200,8
215 DATA83,1,90,18,.2,?,3.6
216 DATA83,1,30,?,.25,120,7.5
217 REM *** MENU LOADER ***
218 PRINTCHR$(147)
219 PRINT"    LOADING MENU"
220 PRINTCHR$(6)
221 LOAD"MENU 301",8

```

READY.

Fig. E-8. V&A meter program.

```

1 REM V&A METER
2 PRINTCHR$(147)
3 PRINT"    THIS PROGRAM WILL ALLOW THE USER TO PRACTICE METER READING."
4 PRINT"    A METER SCALE WILL BE DISPLAYED, THE USER WILL BE ASKED TO SET";
5 PRINT" THE SCALE."
6 PRINT"    THE USER THEN MOVES THE NEEDLE USING THE ASSIGNED FUNCTION ";
7 PRINT"KEYS, AND IS THEN ASKED TO DETERMINE THE VOLTAGE THE METER";
8 PRINT" IS READING."
9 PRINT"    SPACEBAR TO CONTINUE"
10 GET GT$:IF GT$<>CHR$(32)THENGOTO10
11 PRINTCHR$(147)
12 PRINT"    NOTE:"PRINT
13 PRINT"1. THIS PROGRAM IS FOR PRACTICE, ... IS NEVER ENDING.";
14 PRINT" TO EXIT TYPE 86 WHEN ASKED TO SET METER RANGE."
15 PRINT:PRINT"2. WHEN A WRONG ANSWER IS GIVEN, THE COMPUTER GIVES THE";
16 PRINT" CORRECT ANSWER. YOU ARE NOT EXPECTED TO BE AS ACCURATE"
;
17 PRINT", YOU ARE EXPECTED TO BE WITH IN THE FOLLOWING TOLERANCES:"
18 PRINT:PRINT"    30 RANGE +/- .5"
19 PRINT"    300 RANGE +/- 5"
20 PRINT"    3000 RANGE +/- 50"
21 PRINT"    SPACE BAR TO PRACTICE."
22 GETU$:IFU$<>CHR$(32)THEN22
23 IFU$=CHR$(32)THENGOTO24
24 G=0:T=0
25 POKE 53281,12
26 POKE 53280,12
27 PRINT CHR$(147)
28 REM SPRITE MAP LOCATION
29 POKE 2040,192:N=12288
30 REM POKE DATA FOR SPRITE
31 FOR Z=0 TO 62
32 POKEN+Z,0
33 NEXT Z
34 FOR I=0 TO 30 STEP 3

```

```

35 POKEN+D,128
36 NEXT D
37 REM SET COORDINATES X+Y
38 V=53248:REM STARTING VIDEO LOC
39 POKEV,188 :REM X LOC
40 POKEV+16,0:REM X MSB
41 POKEV+1,76:REM Y LOC
42 REM SPRITE COLOR
43 POKE53287,0
44 REM ENABLE
45 POKE53269,PEEK(53269)OR 1
46 POKEV+23,1
47 PRINT CHR$(147):POKEV,188:POKEV+16,0
48 PRINTCHR$(151):PRINT"␣ ENTER (86) AT METER SETTING TO EXIT.":PRINT
49 PRINTTAB(4) " 0 5 10 15 20 25 30"
50 PRINTTAB(4) " | | | | | | |"
51 PRINTTAB(4) " ───────────────────"
52 PRINT:PRINT:PRINT" SET METER RANGE (30, 300, OR 3000)":INPUTP
53 PRINT"␣"
"
54 READM$:M=M+1:IFM=2THEN M=0:RESTORE
55 PRINT"␣ PRESENT SCALE IS";P;M$;" "
56 PRINT" "
57 PRINT" TO SET METER NEEDLE USE FUNCTION KEYS ■ (F5)=LEFT,OR (F7)=RIGHT■"
58 PRINT:PRINT" PRESS SPACE BAR FOR QUESTION."
59 IF P=30THEN Q=1:E=.5
60 IF P=300 THEN Q=10:E=5
61 IF P=3000THEN Q=100:E=50
62 IFP<>30ANDP<>300ANDP<>3000ANDP<>86THEN47
63 IF P=86THEN GOTO88
64 REM METER MOVEMENT X
65 X=188
66 GETA$:IFA$<>CHR$(135)ANDA$<>CHR$(136)ANDA$<>CHR$(32) THEN66
67 IF A$=CHR$(135)THENX=X-1:REMF5L
68 IF A$=CHR$(136)THENX=X+1:REMF7R
69 IF A$=CHR$(32) GOTO78
70 IF X<68 THEN X=68
71 IF X>308 THEN X=308
72 HX=INT(X/256):REM HI BYTE FOR X
73 LX=X-(256*HX):REM LO BYTE X
74 POKEV,LX
75 POKEV+16,(PEEK(V+16)AND254)ORHX
76 POKE650,128:REM CONT MOVEMENT
77 GOTO66
78 LET H=((X-68)/8)*Q:T=T+1:GOSUB82
79 PRINTTAB(5)"■■■■■ PRESS SPACE BAR FOR NEXT ■"
80 GET K$:IF K$<>CHR$(32)GOTO80
81 IF K$=CHR$(32) GOTO47
82 PRINT:PRINTTAB(2)"WHAT IS THE VALUE IN ";M$;
83 R=0:INPUT R
84 IF R>H-E ANDR<H+E THEN86
85 IF R<H THEN87
86 PRINTTAB(15)"■■■■ CORRECT!":G=G+1:RETURN
87 PRINT:PRINTTAB(10)"■■■■ WRONG! ■";H;M$;"■":RETURN
88 PRINTCHR$(147):FOR P=1 TO 8:PRINT:NEXTP
89 POKE53269,PEEK(53269)AND0:IFT=0THENT=1
90 PRINT:PRINTTAB(10)"YOUR SCORE IS";G/T*100;"%"
91 PRINTTAB(10)"FOR";T;"QUESTIONS ASKED"
92 PRINT"■■■■ ■ PLEASE TURN DISK DRIVE ON.■■"
93 PRINT:PRINT" PRESS SPACE BAR FOR MENU."
94 GETM$:IFM$<>CHR$(32)THEN94
95 IF M$=CHR$(32)THEN97

```



```

47 PRINT" |-----| VOLTS/DIV. |
48 PRINT" |-----| "
49 PRINT" |-----| CHANNEL #1 |
50 PRINT" |-----|
51 PRINT" |-----|
52 PRINT" |-----| VOLTS/DIV. |
53 PRINT" |-----| NOT IN USE |
54 PRINT" |-----| CHANNEL #2 |
55 PRINT" |-----|
56 PRINT" |-----|
57 PRINT" |-----|
58 PRINT" |-----|
59 RETURN
60 REM *** SCALE SETTINGS ***
61 PRINT" :IIIIIIIIIIIIIIII";TAB(30)T$
62 PRINT" :XXX";TAB(30)Y$;" :XXXXXXXXXXXX"
63 RETURN
64 REM *** QUESTION LOOP ****
65 FOR K=1 TO20:AA=0
66 GOSUB39
67 READT$,Y$,LO,Q$,A
68 POKEL,LO:POKELL,LO
69 GOSUB60
70 PRINTK;"II.";Q$;
71 INPUTAA:LU=A-(A*.05):HU=A+(A*.05)
72 IFA<0THENLU=A+(A*.05):HU=A-(A*.05)
73 IFAA>LUANDAA<HUTHENGOSUB78:REM*** CORRECT*
74 IFAA=LUORAA=HUTHENGOSUB78:REM*** CORRECT ***
75 IFAA<LUORAA>HUTHENGOSUB85:REM***WRONG**
76 IFK=20THEN GOTO94
77 NEXTK
78 REM *** CORRECT ****
79 PRINTTAB(14)"CORRECT!":S=S+1
80 PRINT:PRINT" SPACE BAR = NEXT, N = NEW SELECTION."
81 GETRR$:IFRR$<>CHR$(32)ANDRR$<>CHR$(78)THEN81
82 IF RR$=CHR$(32)ANDK=20THENGOTO94
83 IF RR$=CHR$(78)THEN RETURN
84 IF RR$=CHR$(78)THENGOTO94
85 REM *** WRONG ***
86 PRINTTAB(12)"WRONG ";A;" "
87 PRINT:PRINT" SPACE BAR = NEXT, F1 = HELP HINTS"
88 PRINT" N = NEW SELECTION"
89 GETWW$:IFWW$<>CHR$(32)ANDWW$<>CHR$(78)ANDWW$<>CHR$(133)THEN89
90 IFWW$=CHR$(32)ANDK=20THENGOTO94
91 IFWW$=CHR$(133)THEN RETURN
92 IFWW$=CHR$(133)THENGOSUB107:RETURN:REM **HELP*
93 IFWW$=CHR$(78)THENGOTO94
94 REM *** SCORE ****
95 POKE53269,0
96 PRINTCHR$(147);" :XXXXXXXX"
97 E=(S/K)*100
98 PRINT" YOUR SCORE IS ";E;"%":PRINT
99 PRINT" FOR";K;"QUESTIONS ASKED."
100 PRINT"X00 PLEASE TURN DISK DRIVE ON."
101 PRINT"X00 SPACE BAR FOR MAIN MENU."
102 GETMM$:IF MM$<>CHR$(32)THEN102
103 IF MM$=CHR$(32)THEN PRINTCHR$(147)
104 PRINT"X00";TAB(12)"LOADING MENU"
105 PRINTCHR$(6)
106 LOAD"MENU 301",8
107 REM *** HELP HINTS ****
108 PRINTCHR$(147):POKE53269,0:PRINT"X00"

```



```

16 FORPP=1T08:PRINT:NEXTPP:PRINT"
17 REM SET SPRITE STARTING LOCATIONS
18 POKE2040,192:A=12267:REM#GROUND**
19 POKE2041,193:B=12351:REM#RESISTOR**
20 POKE2042,194:C=12415:REM#LAMP**
21 POKE2043,195:D=12479:REM#LED**
22 POKE2044,196:E=12543:REM#BATTERY**
23 POKE2045,197:F=12607:REM#METER**
24 POKE2046,198:G=12671:REM#SCH METER*
25 POKE2047,199:H=12735:REM***
26 REM CLEAR SPRITE BITES
27 FOR Z=1 TO64
28 POKE A+Z,0
29 POKE B+Z,0
30 POKE C+Z,0
31 POKE D+Z,0
32 POKE E+Z,0
33 POKE F+Z,0
34 POKE G+Z,0
35 POKE H+Z,0
36 NEXTZ
37 REM ***RESISTOR I *****
38 POKEA+5,32:POKEA+8,32:POKEA+11,16
39 POKEA+14,32:POKEA+17,64:POKEA+20,32:POKEA+23,16:POKEA+26,32
40 POKEA+29,64:POKEA+32,32:POKEA+35,16:POKEA+38,32:POKEA+41,64
41 POKEA+44,32:POKEA+47,32
42 REM ***RESISTOR II ***
43 POKEB+7,8:POKEB+8,136:POKEB+9,128:POKEB+10,245:POKEB+11,85:POKEB+12,95
44 POKEB+13,2:POKEB+14,34:POKEB+15,32
45 REM ***RESISTOR III *****
46 POKEC+5,32:POKEC+8,32:POKEC+11,16
47 POKEC+14,32:POKEC+17,64:POKEC+20,32:POKEC+23,16:POKEC+26,32
48 POKEC+29,64:POKEC+32,32:POKEC+35,16:POKEC+38,32:POKEC+41,64
49 POKEC+44,32:POKEC+47,32
50 REM ***RESISTOR IV ***
51 POKED+7,8:POKED+8,136:POKED+9,128:POKED+10,245:POKED+11,85:POKED+12,95
52 POKED+13,2:POKED+14,34:POKED+15,32
53 REM ***RESISTOR V *****
54 POKEE+5,32:POKEE+8,32:POKEE+11,16
55 POKEE+14,32:POKEE+17,64:POKEE+20,32:POKEE+23,16:POKEE+26,32
56 POKEE+29,64:POKEE+32,32:POKEE+35,16:POKEE+38,32:POKEE+41,64
57 POKEE+44,32:POKEE+47,32
58 REM ***RESISTOR VI *****
59 POKEF+7,8:POKEF+8,136:POKEF+9,128:POKEF+10,245:POKEF+11,85:POKEF+12,95
60 POKEF+13,2:POKEF+14,34:POKEF+15,32
61 REM ***RESISTOR VII *****
62 POKEG+5,32:POKEG+8,32:POKEG+11,16
63 POKEG+14,32:POKEG+17,64:POKEG+20,32:POKEG+23,16:POKEG+26,32
64 POKEG+29,64:POKEG+32,32:POKEG+35,16:POKEG+38,32:POKEG+41,64
65 POKEG+44,32:POKEG+47,32
66 REM ***RESISTOR VIII ***
67 POKEH+7,8:POKEH+8,136:POKEH+9,128:POKEH+10,245:POKEH+11,85:POKEH+12,95
68 POKEH+13,2:POKEH+14,34:POKEH+15,32
69 REM SET X,Y LOCATIONS FOR SPRITE
70 V=53248:REM BEGINING VIDEO LOCATION
71 POKEV+29,255:POKEV+23,255
72 POKEV,44:REM X LOCS
73 POKEV+2,70
74 POKEV+4,95
75 POKEV+6,120
76 POKEV+8,200
77 POKEV+10,170

```

WAIT A BIT!"

Fig. E-10. Dc analysis program. (Continued from page 319.)

```

78 POKEV+12,252
79 POKEV+14,225
80 POKEV+16,0:REM MSBX=0
81 POKEV+1,129:REM Y LOCS
82 POKEV+3,124
83 POKEV+5,129
84 POKEV+7,124
85 POKEV+9,129
86 POKEV+11,124
87 POKEV+13,129
88 POKEV+15,124
89 REM SET SPRITE COLOR
90 POKE 53287,14
91 POKE 53288,14
92 POKE 53289,14
93 POKE 53290,14
94 POKE 53291,14
95 POKE 53292,14
96 POKE 53293,14
97 POKE 53294,14
98 REM SPRITE ENABLE
99 POKE EN,0
100 RA=V:RB=V+2:RC=V+4:RD=V+6:RE=V+8:RF=V+10:RG=V+12:RH=V+14
101 RI=V+1:RJ=V+3:RK=V+5:RL=V+7:RM=V+9:RN=V+11:RO=V+13:RP=V+15
102 GOTO140
103 REM*** 4// & 4 SERIES ***
104 REM *** ALL EIGHT ***
105 POKEEN,255
106 PRINT"      R2  __ R4  __ R6  __  R8":PRINT
107 PRINT"      - R2  __ R4  __ R6  __  R8"
108 PRINT"      "
109 PRINT" R1      R3      R5      R7 "
110 PRINT"      _____"
111 PRINT"RT= ?"
112 RETURN
113 REM *** 4// & 2 SERIES ***
114 POKEEN,125
115 PRINT"      _____ R3  __ R4 ":PRINT
116 PRINT"      "
117 PRINT"      "
118 PRINT" R1      R2      R5      R6 "
119 PRINT"      _____"
120 PRINT"RT= ?"
121 RETURN
122 REM *** FOUR PARALLE ***
123 POKEEN,85
124 PRINT:PRINT
125 PRINT"      _____"
126 PRINT"      "
127 PRINT" R1      R2      R3      R4  RT= ?"
128 PRINT"      _____"
129 PRINT"      "
130 RETURN
131 REM *** SERIES ONLY ***
132 POKEEN,235
133 PRINT"      R2  __ R3  __ R4  __  R5":PRINT
134 PRINT"      - R2  __ R3  __ R4  __  R5"
135 PRINT"      "
136 PRINT" R1      R6 "

```

```

137 PRINT"
138 PRINT"RT= ?"
139 RETURN
140 REM ** QUESTION LOOP & MAIN PROG *
141 FOR XX=1TO20:PRINTCHR$(147):AD$=CHR$(32)
142 READQ$,CT,A,G1$,G2$
143 PRINT"      GIVEN:?"
144 PRINTTAB(8)"EVEN # RESISTORS = ";G1$:PRINT
145 PRINTTAB(9)"ODD # RESISTORS = ";G2$
146 PRINT
147 PRINT"-----"
148 ON CT GOSUB104 ,113 ,122 ,131
149 LM=A-(A*.05):HM=A+(A*.05)
150 PRINT"XX";"||. ";Q$;
151 INPUT AD
152 REM *****CORRECT*****
153 IFAD>LM AND AD<HM THEN GOSUB158
154 IFAD=LMORAD=HMTHENGOSUB158
155 IF AD<LMORAD>HM THEN GOSUB166 :REM ***** WRONG *****
156 IF XX=20 THEN GOTO187
157 NEXTXX
158 S=S+1:REM *** CORRECT ***
159 PRINT:PRINT"      CORRECT!"
160 PRINT:PRINT:PRINT"      SPACE BAR FOR NEXT"
161 PRINT"      N FOR NEW SELECTION"
162 QC$=CHR$(13)
163 GET QC$:IFQC$<>CHR$(32)ANDQC$<>CHR$(78)THENGOTO163
164 IF QC$=CHR$(32)THEN RETURN
165 IF QC$=CHR$(78)THEN GOTO187 :      REM ***SCORE***
166 REM *** WRONG ***
167 PRINT"      WRONG! ANSWER IS ";A;" "
168 PRINT"      SPACE BAR FOR NEXT"
169 PRINT"      F1 FOR HELP HINTS"
170 PRINT"      N FOR NEW SELECTION"
171 GET SY$:IFSY$<>CHR$(32)ANDSY$<>CHR$(78)ANDSY$<>CHR$(133)THENGOTO171
172 IF SY$=CHR$(32)THEN RETURN
173 IF SY$=CHR$(133)THEN GOSUB175 :RETURN:REM ** HELP HINTS **
174 IF SY$=CHR$(78)THEN GOTO187 :      REM ***SCORE***
175 REM ***** HELP HINTS *****
176 POKEEN,0
177 PRINTCHR$(147)
178 PRINT:PRINT"      WITH WHAT IS GIVEN ONE OR BOTH      OF THE FORMULAS ";
179 PRINT"SHOULD APPLY.":PRINT
180 PRINT"      SERIES:"
181 PRINT:PRINT"      RT = R1 + R2 + R3 ETC."
182 PRINT:PRINT"      PARALLEL:"
183 PRINT:PRINT"      1/RT = 1/R1 + 1/R2 + 1/R3 ETC. "
184 PRINT"      SPACE BAR TO CONTINUE."
185 GET DO$:IFDO$<>CHR$(32) THEN GOTO185
186 IF DO$=CHR$(32)THEN RETURN
187 REM *** SCORE ****
188 POKEEN,0
189 TS=(S/XX)*100
190 PRINTCHR$(147)
191 FORNW=1TO6:PRINT:NEXTNW
192 PRINT"      YOUR SCORE IS ";TS;"%"
193 PRINT"      FOR";XX;"QUESTIONS ASKED."
194 PRINT"      PLEASE TURN DISK DRIVE ON."
195 PRINT:PRINT:PRINT:PRINT"      SPACE BAR FOR MAIN MENU."
196 GET MN$:IF MN$<>CHR$(32)THEN GOTO196
197 IF MN$=CHR$(32)THENGOTO219
198 REM *** DATA FOR PROBLEMS ***

```

Fig. E-10. Dc analysis program. (Continued from page 321.)

```

199 DATAWHAT IS THE VALUE OF RT,4,3600,1K OHMS,200 OHMS
200 DATAWHAT IS THE VALUE OF RT,3,660,2.2K OHMS,3.3K OHMS
201 DATAWHAT IS THE VALUE OF RT,4,4410,470 OHMS,1K OHMS
202 DATAWHAT IS THE VALUE OF RT,3,3837,2,10K OHMS,33K OHMS
203 DATAWHAT IS THE VALUE OF RT,1,888.57,330 OHMS,150 OHMS
204 DATAWHAT IS THE VALUE OF RT,2,1136780,1M OHMS,47K OHMS
205 DATAWHAT IS THE VALUE OF RT,3,831.1,6.8K OHMS,2.2K OHMS
206 DATAWHAT IS THE VALUE OF RT,4,726000,220K OHMS,22K OHMS
207 DATAWHAT IS THE VALUE OF RT,2,370,100 OHMS,150 OHMS
208 DATAWHAT IS THE VALUE OF RT,4,31410,470 OHMS,10K OHMS
209 DATAWHAT IS THE VALUE OF RT,1,1100,330 OHMS,330 OHMS
210 DATAWHAT IS THE VALUE OF RT,3,5500,22K OHMS,22K OHMS
211 DATAWHAT IS THE VALUE OF RT,2,37000,15K OHMS,10K OHMS
212 DATAWHAT IS THE VALUE OF RT,4,10000,1.8K OHMS,1.8K OHMS
213 DATAWHAT IS THE VALUE OF RT,3,74.92,220 OHMS,470 OHMS
214 DATAWHAT IS THE VALUE OF RT,2,36181,27K OHMS,3.3K OHMS
215 DATAWHAT IS THE VALUE OF RT,4,3300000,1M OHMS,100K OHMS
216 DATAWHAT IS THE VALUE OF RT,1,124.76,10 OHMS,100 OHMS
217 DATAWHAT IS THE VALUE OF RT,3,9693,47K OHMS,33K OHMS
218 DATAWHAT IS THE VALUE OF RT,2,1695.19,270 OHMS,1K OHMS
219 REM *** MENU LOADER ***
220 PRINTCHR$(147)
221 PRINT"    "          LOADING MENU"
222 PRINTCHR$(6)
223 LOAD"MENU 301",8

```

READY.

Fig. E-11. Oscilloscope ac program.

```

1 REM OSCILLOSCOPE AC
2 PRINTCHR$(147)
3 PRINT"    THIS PROGRAM ALLOWS THE USER TO          PRACTICE READING AC";
4 PRINT"    VOLTAGES ON THE          OSCILLOSCOPE."
5 PRINT"    THE OSCILLOSCOPE SCREEN WILL BE          DISPLAYED WITH A TRACE";
6 PRINT"    REPRESENTING          AN AC VOLTAGE, THE USER WILL BE          ASKED TO ";
7 PRINT"    DETERMINE THE VOLTAGE USING          THE SCREEN, THE TIME/";
8 PRINT"    DIVISIONS, AND          THE VOLTS/";
9 PRINT"    DIVISION SETTING FOR          CHANNEL 1 (THIS IS THE ONLY)";
10 PRINT"    CHANNEL          USED IN THIS EXERCISE).";
11 PRINT"    GROUND REFERENCE IS SET TO BE          THE CENTER LINE."
12 PRINT"    THE USER IS EXPECTED TO BE WITHIN 5%          OF THE ACTUAL READING."
13 PRINT"    NOTE: UNITS ARE EXPECTED AS PART OF          THE ANSWER."
14 PRINT"    "          SPACE BAR TO CONTINUE"
15 GET RT$:IF RT$<>CHR$(32)THENGOTO15
16 PRINTCHR$(147)
17 PRINT"    "          PLEASE BE PATIENT "
18 REM SPRITE MAP LOC
19 POKE 2040,192:A=12287
20 POKE 2041,193:B=12351
21 POKE 2042,194:C=12415
22 POKE 2043,195:D=12479
23 POKE 2044,196:E=12543
24 POKE 2045,197:F=12607
25 POKE 2046,198:G=12671
26 POKE 2047,199:H=12735
27 REM SPRITE DATA
28 REM CLEAR

```

```

29 FORHH=0T063
30 POKER+HH,0:POKEB+HH,0:POKEC+HH,0:POKED+HH,0:POKEE+HH,0:POKEF+HH,0
31 NEXTHH
32 REM ***** SINEWAVE *****
33 POKER+1,128:POKER+3,1:POKER+4,128:POKER+6,1:POKER+7,64:POKER+9,2
34 POKER+10,64:POKER+12,2:POKER+13,32:POKER+15,4:POKER+16,32:POKER+18,4
35 POKER+19,16:POKER+21,8:POKER+22,16:POKER+24,8:POKER+25,8:POKER+27,16
36 POKER+28,8:POKER+30,16:POKER+31,4:POKER+33,32:POKER+34,4:POKER+36,32
37 POKER+37,2:POKER+39,64:POKER+40,2:POKER+42,64:POKER+43,1:POKER+45,128
38 POKER+47,129:POKER+50,66:POKER+53,36:POKER+56,24
39 POKEB+8,24:POKEB+11,36:POKEB+14,66:POKEB+17,129:POKEB+19,1:POKEB+21,128
40 POKEB+22,2:POKEB+24,64:POKEB+25,2:POKEB+27,64:POKEB+28,4:POKEB+30,32
41 POKEB+31,4:POKEB+33,32:POKEB+34,8:POKEB+36,16:POKEB+37,8:POKEB+39,16
42 POKEB+40,16:POKEB+42,8:POKEB+43,16:POKEB+45,8:POKEB+46,32:POKEB+48,4
43 POKEB+49,32:POKEB+51,4:POKEB+52,64:POKEB+54,2:POKEB+55,64:POKEB+57,2
44 POKEB+58,128:POKEB+60,1:POKEB+61,128:POKEB+63,1
45 REM ***** SQUAREWAVE *****
46 POKEC+01,255:POKEC+02,255 :POKEC+03,255:POKEC+04,128:POKEC+06,1
47 POKEC+07,128:POKEC+09,1 :POKEC+10,128:POKEC+12,1 :POKEC+13,128
48 POKEC+15,1 :POKEC+16,128 :POKEC+18,1 :POKEC+19,128:POKEC+21,1
49 POKEC+22,128:POKEC+24,1 :POKEC+25,128:POKEC+27,1 :POKEC+28,128
50 POKEC+30,1 :POKEC+31,128 :POKEC+33,1 :POKEC+34,128:POKEC+36,1
51 POKEC+37,128:POKEC+39,1 :POKEC+40,128:POKEC+42,1 :POKEC+43,128
52 POKEC+45,1 :POKEC+46,128 :POKEC+48,1 :POKEC+49,128:POKEC+51,1
53 POKEC+52,128:POKEC+54,1 :POKEC+55,128:POKEC+57,1 :POKEC+58,128
54 POKEC+60,1 :POKEC+61,128 :POKEC+63,1
55 POKED+01,128:POKED+03,1:POKED+04,128:POKED+06,1
56 POKED+07,128:POKED+09,1 :POKED+10,128:POKED+12,1 :POKED+13,128
57 POKED+15,1 :POKED+16,128 :POKED+18,1 :POKED+19,128:POKED+21,1
58 POKED+22,128:POKED+24,1 :POKED+25,128:POKED+27,1 :POKED+28,128
59 POKED+30,1 :POKED+31,128 :POKED+33,1 :POKED+34,128:POKED+36,1
60 POKED+37,128:POKED+39,1 :POKED+40,128:POKED+42,1 :POKED+43,128
61 POKED+45,1 :POKED+46,128 :POKED+48,1 :POKED+49,128:POKED+51,1
62 POKED+52,128:POKED+54,1 :POKED+55,128:POKED+57,1 :POKED+58,128
63 POKED+60,1 :POKED+61,255 :POKED+62,255:POKED+63,255
64 REM ***** SAWTOOTH *****
65 POKEE+03,12 :POKEE+06,20 :POKEE+09,36 :POKEE+12,68 :POKEE+15,132
66 POKEE+17,1 :POKEE+18,4 :POKEE+20,2 :POKEE+21,4 :POKEE+23,4
67 POKEE+24,4 :POKEE+26,8 :POKEE+27,4 :POKEE+29,16 :POKEE+30,4
68 POKEE+32,32 :POKEE+33,4 :POKEE+35,64 :POKEE+36,4 :POKEE+38,128
69 POKEE+39,4 :POKEE+40,1 :POKEE+42,4 :POKEE+43,2 :POKEE+45,4
70 POKEE+46,4 :POKEE+48,4 :POKEE+49,8 :POKEE+51,4 :POKEE+52,16
71 POKEE+54,4 :POKEE+55,32 :POKEE+57,4 :POKEE+58,64 :POKEE+60,4
72 POKEE+61,128:POKEE+63,4
73 POKEF+03,12 :POKEF+06,20 :POKEF+09,36 :POKEF+12,68 :POKEF+15,132
74 POKEF+17,1 :POKEF+18,4 :POKEF+20,2 :POKEF+21,4 :POKEF+23,4
75 POKEF+24,4 :POKEF+26,8 :POKEF+27,4 :POKEF+29,16 :POKEF+30,4
76 POKEF+32,32 :POKEF+33,4 :POKEF+35,64 :POKEF+36,4 :POKEF+38,128
77 POKEF+39,4 :POKEF+40,1 :POKEF+42,4 :POKEF+43,2 :POKEF+45,4
78 POKEF+46,4 :POKEF+48,4 :POKEF+49,8 :POKEF+51,4 :POKEF+52,16
79 POKEF+54,4 :POKEF+55,32 :POKEF+57,4 :POKEF+58,64 :POKEF+60,4
80 POKEF+61,128:POKEF+63,4
81 V=53248:REM STARTING VIDEO LOC
82 POKEV,120
83 POKEV+2,72
84 POKEV+4,73
85 POKEV+6,120
86 POKEV+8,78
87 POKEV+10,121
88 POKEV+16,0 :REM XMSB
89 POKEV+1,115
90 POKEV+3,76

```

Fig. E-11. Oscilloscope ac program. (Continued from page 323.)

```

91 POKEV+5,76
92 POKEV+7,115
93 POKEV+9,76
94 POKEV+11,76
95 L=V+1:LL=V+3
96 REM WAVE COLOR
97 CC=53287
98 FOR LC=0T05: POKECC+LC,0:NEXTLC
99 REM ENABLE
100 POKEV+29,255:POKEV+23,255
101 POKE53269,0:GOTO127
102 REM ***** DISPLAY SCREEN *****
103 PRINTCHR$(147)
104 PRINT"
105 PRINT"
106 PRINT"
107 PRINT"
108 PRINT"
109 PRINT"
110 PRINT"
111 PRINT"
112 PRINT"
113 PRINT"
114 PRINT"
115 PRINT"
116 PRINT"
117 PRINT"
118 PRINT"
119 PRINT"
120 PRINT"
121 PRINT"
122 RETURN
123 REM *** SCALE SETTINGS ***
124 PRINT"IIIIIIIIIIIIIIII";TAB(30)T$
125 PRINT"XXXXXXXX";TAB(30)V$;"XXXXXXXXXXXXXXXX"
126 RETURN
127 REM *** QUESTION LOOP ***
128 FOR K=1 TO20:AA=0
129 GOSUB102
130 READT$,V$,SX,SY,PC,EN,Q$,A$,SU$
131 A=VAL(A$):GOSUB226
132 GOSUB123
133 PRINTK;"||.";Q$;
134 INPUTAA$:CO=LEN(A$):CU=LEN(SU$)
135 AB$=LEFT$(AA$,CO)
136 AC$=RIGHT$(AA$,CU)
137 AA=VAL(AB$)
138 LU= A-(A*.20):HU=A+(A*.20)
139 IFA<0THENLU=A+(A*.20):HU=A-(A*.20)
140 IFAA>LUANDAA<HUANDAC$=SU$THENGOSUB145:REM** CORRECT*
141 IFA=LUORAA=HUANDAC$=SU$THENGOSUB145:REM*** CORRECT ***
142 IFAA<LUORAA>HUORAC$<>SU$THENGOSUB152:REM**WRONG**
143 IFK=20THEN GOTO161
144 NEXTK
145 REM *** CORRECT ***
146 PRINTTAB(14)"CORRECT!" :S=S+1
147 PRINT:PRINT"SPACE BAR = NEXT, N = NEW SELECTION."
148 GETRR$:IFRR$<>CHR$(32)ANDRR$<>CHR$(78)THEN148
149 IF RR$=CHR$(32)ANDK=20THENGOTO161

```


Fig. E-11. Oscilloscope ac program. (Continued from page 325.)

```

212 DATA20US,2V,255,255,1,48,THE PERIOD OF THE WAVE IS,50,US
213 DATA10US,2V,255,255,1,12,THE PERIOD OF THE WAVE IS,60,US
214 DATA50US,5V,255,255,3,48,WHAT IS THE VOLTAGE PP,5.2,V
215 DATA50US,5V,255,255,4,3 ,WHAT IS THE VOLTAGE PP,10,V
216 DATA50US,10V,255,255,4,3 ,WHAT IS THE VOLTAGE PP,20,V
217 DATA5MS,5V,255,255,4,12,THE PERIOD OF THE WAVE IS,30,MS
218 DATA20US,2V,255,255,1,12,THE FREQUENCY OF THE WAVE IS,8333,HZ
219 DATA50US,2V,255,255,1,12,THE FREQUENCY OF THE WAVE IS,3333,HZ
220 DATA10US,5V,255,255,2,3,THE PERIOD OF THE WAVE IS,27.5,US
221 DATA50US,20V,255,255,1,3,WHAT IS THE VOLTAGE PP,84,V
222 DATA.5US,5V,255,255,4,48,THE PERIOD OF THIS WAVE IS,1.5,US
223 DATA100US,2V,255,255,1,3,THE FREQUENCY OF THE WAVE IS,1666,HZ
224 DATA50US,5V,255,255,4,48,WHAT IS THE VOLTAGE PP,5,V
225 DATA50US,5V,255,255,1,3,CALCULATE THE RMS VOLTAGE,7.9,V
226 REM **** ENABLE & POS ****
227 IF PC=1 THEN POKEV+4,74:POKEV+8,78
228 IF PC=1 THEN POKEV,120:POKEV+2,72:POKEV+1,128:POKEV+3,88:POKEV+5,88
229 IF PC=1 THEN POKEV+7,128:POKEV+9,88:POKEV+11,88:POKEV+29,255:POKEV+23,255
230 IF PC=2 THEN POKEV,120:POKEV+2,72:POKEV+1,128:POKEV+3,88:POKEV+5,88
231 IF PC=2 THEN POKEV+7,128:POKEV+9,88:POKEV+11,88
232 IF PC=2 THEN POKEV+2,98:POKEV+4,96:POKEV+8,98:POKEV+29,0:POKEV+23,255
233 IF PC=3 THEN POKEV,120:POKEV+2,72:POKEV+1,128:POKEV+3,109:POKEV+5,109
234 IF PC=3 THEN POKEV+7,128:POKEV+9,109:POKEV+11,109
235 IF PC=3 THEN POKEV+2,98:POKEV+4,96:POKEV+8,98:POKEV+29,0:POKEV+23,0
236 IF PC=4 THEN POKEV,120:POKEV+2,72:POKEV+1,128:POKEV+3,109:POKEV+5,109
237 IF PC=4 THEN POKEV+7,128:POKEV+9,109:POKEV+11,109
238 IF PC=4 THEN POKEV+2,72:POKEV+4,74:POKEV+8,78:POKEV+29,255:POKEV+23,0
239 POKE53269,EN:RETURN

```

READY.

Fig. E-12. Phase angle program.

```

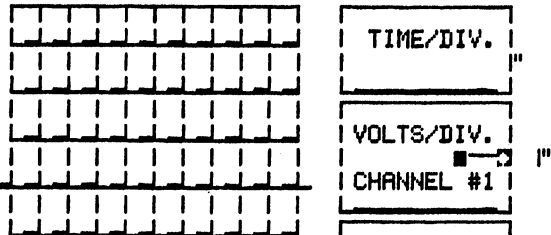
1 REM PHASE ANGLE
2 PRINTCHR$(147)
3 PRINT" THIS PROGRAM ALLOWS THE USER TO PRACTICE READING";
4 PRINT" PHASE DIFFERENCES ON THE OSCILLOSCOPE."
5 PRINT" THE OSCILLOSCOPE SCREEN WILL BE DISPLAYED WITH TWO";
6 PRINT" TRACES. THE USER WILL BE ASKED TO ";
7 PRINT"DETERMINE THE PHASE DIFFERENCE USING THE SCREEN, THE TIME/";
8 PRINT" DIVISIONS, AND THE VOLTS/";
9 PRINT" DIVISION SETTING FOR CHANNELS 1&2"
10 PRINT" QUESTIONS USE CHANNEL 1 (BLACK ";
11 PRINT" TRACE) AS THE REFERENCE WAVE."
12 PRINT" THE USER IS EXPECTED TO BE WITHIN 20% OF THE ACTUAL";
13 PRINT" READING."
14 PRINT" "
15 GET RT$: IF RT$<>CHR$(32)THENGOTO15
16 PRINTCHR$(147)
17 PRINT" PLEASE BE PATIENT "
18 REM SPRITE MAP LOC
19 POKE 2040,192:A=12287
20 POKE 2041,193:B=12351
21 POKE 2042,194:C=12415
22 POKE 2043,195:D=12479
23 POKE 2044,196:E=12543
24 POKE 2045,197:F=12607
25 POKE 2046,198:G=12671

```

```

26 POKE 2047,199:H=12735
27 REM SPRITE DATA
28 REM CLEAR
29 FORHH=0TO63
30 POKEA+HH,0:POKEB+HH,0:POKEC+HH,0:POKED+HH,0:POKEE+HH,0:POKEF+HH,0
31 NEXTHH
32 REM **** SINEWAVE ****
33 POKEA+1,128:POKEA+3,1:POKEA+4,128:POKEA+6,1:POKEA+7,64:POKEA+9,2
34 POKEA+10,64:POKEA+12,2:POKEA+13,32:POKEA+15,4:POKEA+16,32:POKEA+18,4
35 POKEA+19,16:POKEA+21,8:POKEA+22,16:POKEA+24,8:POKEA+25,8:POKEA+27,16
36 POKEA+28,8:POKEA+30,16:POKEA+31,4:POKEA+33,32:POKEA+34,4:POKEA+36,32
37 POKEA+37,2:POKEA+39,64:POKEA+40,2:POKEA+42,64:POKEA+43,1:POKEA+45,128
38 POKEA+47,129:POKEA+50,66:POKEA+53,36:POKEA+56,24
39 POKEB+8,24:POKEB+11,36:POKEB+14,66:POKEB+17,129:POKEB+19,1:POKEB+21,128
40 POKEB+22,2:POKEB+24,64:POKEB+25,2:POKEB+27,64:POKEB+28,4:POKEB+30,32
41 POKEB+31,4:POKEB+33,32:POKEB+34,8:POKEB+36,16:POKEB+37,8:POKEB+39,16
42 POKEB+40,16:POKEB+42,8:POKEB+43,16:POKEB+45,8:POKEB+46,32:POKEB+48,4
43 POKEB+49,32:POKEB+51,4:POKEB+52,64:POKEB+54,2:POKEB+55,64:POKEB+57,2
44 POKEB+58,128:POKEB+60,1:POKEB+61,128:POKEB+63,1
45 REM **** SINEWAVE 2 ****
46 POKEC+1,128:POKEC+3,1:POKEC+4,128:POKEC+6,1:POKEC+7,64:POKEC+9,2
47 POKEC+10,64:POKEC+12,2:POKEC+13,32:POKEC+15,4:POKEC+16,32:POKEC+18,4
48 POKEC+19,16:POKEC+21,8:POKEC+22,16:POKEC+24,8:POKEC+25,8:POKEC+27,16
49 POKEC+28,8:POKEC+30,16:POKEC+31,4:POKEC+33,32:POKEC+34,4:POKEC+36,32
50 POKEC+37,2:POKEC+39,64:POKEC+40,2:POKEC+42,64:POKEC+43,1:POKEC+45,128
51 POKEC+47,129:POKEC+50,66:POKEC+53,36:POKEC+56,24
52 POKED+8,24:POKED+11,36:POKED+14,66:POKED+17,129:POKED+19,1:POKED+21,128
53 POKED+22,2:POKED+24,64:POKED+25,2:POKED+27,64:POKED+28,4:POKED+30,32
54 POKED+31,4:POKED+33,32:POKED+34,8:POKED+36,16:POKED+37,8:POKED+39,16
55 POKED+40,16:POKED+42,8:POKED+43,16:POKED+45,8:POKED+46,32:POKED+48,4
56 POKED+49,32:POKED+51,4:POKED+52,64:POKED+54,2:POKED+55,64:POKED+57,2
57 POKED+58,128:POKED+60,1:POKED+61,128:POKED+63,1
58 V=53248:REM STARTING VIDEO LOC
59 POKEV,98
60 POKEV+2,40
61 POKEV+4,120
62 POKEV+6,72
63 POKEV+16,0:REM XMSB
64 POKEV+1,128
65 POKEV+3,88
66 POKEV+5,128
67 POKEV+7,88
68 L=V+1:LL=V+3
69 REM WAVE COLOR
70 CC=53287
71 POKECC,0:POKECC+1,0:POKECC+2,1:POKECC+3,1:POKECC+4,13:POKECC+5,13
72 REM ENABLE
73 POKEV+29,255:POKEV+23,255
74 POKE53269,0:GOTO101
75 REM ***** DISPLAY SCREEN *****
76 PRINTCHR$(147)
77 PRINT"
78 PRINT" | "
79 PRINT" | "
80 PRINT" | "
81 PRINT" | "
82 PRINT" | "
83 PRINT" | "
84 PRINT" | "
85 PRINT" | "
86 PRINT" | "
87 PRINT" | "

```




```

147 IF MM$=CHR$(32)THEN PRINTCHR$(147)
148 PRINT"    ";TAB(12)"LOADING MENU"
149 PRINTCHR$(6)
150 LOAD"MENU 301",8
151 REM *** HELP HINTS ***
152 PRINTCHR$(147):POKE53269,0:PRINT"    "
153 PRINT"    THIS EXERCISE IS CONCERNED WITH          PHASE RELATIONSHIPS."
154 PRINT"    WE NEED TO TAKE HORIZONTAL (TIME) ";
155 PRINT"    DIVISIONS INTO CONSIDERATION."
156 PRINT"    CHANNEL 1 REPRESENTS THE REFERENCE      WAVE. "
157 PRINT"    NOTE: COUNT TIME DIVISIONS AT        HORIZONTAL CENTER LINE."
158 PRINT"    1. COUNT THE NUMBER OF DIVISIONS FOR  ONE CYCLE OF WAVE 1."
159 PRINT"    2. DIVID 360 BY THE NUMBER OF        DIVISIONS";
160 PRINT"    (=DEGREES PER DIVISION)."
161 PRINT"    3. COUNT THE NUMBER OF DIVISIONS      BETWEEN THE TWO";
162 PRINT"    WAVEFORMS."
163 PRINT"    4. MULTIPLY THE NUMBER OF DIVISIONS   FROM STEP 3, BY THE";
164 PRINT"    (DEGREES PER          DIVISION) FROM STEP 2 (=DEGREES    OUT OF";
165 PRINT"    PHASE)."  

166 PRINT"    █SPACE BAR FOR MORE█ "
167 GET CC$:IF CC$<>CHR$(32)THEN167
168 IFCC$=CHR$(32)THENGOSUB75
169 PC=3:SS=1:GOSUB199
170 PRINT"TTTTTTTTTTTTTTTT";TAB(30)"50US"
171 PRINT"    ";TAB(30)"5V";"    "
172 PRINTTAB(30)"5V";"    "
173 PRINTTAB(16)"EXAMPLE"
174 PRINT"    DEGREES PER DIVISION = 360/6 = 60"
175 PRINT"    DEGREES OUT OF PHASE = 1.5 X 60 = 90"
176 PRINT:PRINT"    █SPACE BAR TO CONTINUE█"
177 GET RC$:IFRC$<>CHR$(32)THEN177
178 IFRC$=CHR$(32)THEN RETURN
179 DATA50US,5V,255,255,1,1,ARE THESE WAVES IN PHASE Y/N,Y
180 DATA50US,5V,255,255,1,1,HOW MANY DEGREES APART,0
181 DATA50US,5V,255,255,2,0,ARE THESE WAVES IN PHASE Y/N,N
182 DATA50US,5V,255,255,2,0,HOW MANY DEGREES APART,45
183 DATA50US,5V,255,255,3,0,ARE THESE WAVES IN PHASE Y/N,N
184 DATA50US,5V,255,255,3,0,HOW MANY DEGREES APART,90
185 DATA50US,5V,255,255,4,1,ARE THESE WAVES IN PHASE Y/N,N
186 DATA50US,5V,255,255,4,1,HOW MANY DEGREES APART,135
187 DATA50US,5V,255,255,5,1,ARE THESE WAVES IN PHASE Y/N,N
188 DATA50US,5V,255,255,5,1,HOW MANY DEGREES APART,180
189 DATA50US,5V,255,255,6,0,ARE THESE WAVES IN PHASE Y/N,N
190 DATA50US,5V,255,255,6,0,HOW MANY DEGREES APART,200
191 DATA50US,5V,255,255,7,0,ARE THESE WAVES IN PHASE Y/N,N
192 DATA50US,5V,255,255,7,0,HOW MANY DEGREES APART,225
193 DATA50US,5V,255,255,8,1,ARE THESE WAVES IN PHASE Y/N,N
194 DATA50US,5V,255,255,8,1,HOW MANY DEGREES APART,60
195 DATA50US,5V,255,255,9,0,ARE THESE WAVES IN PHASE Y/N,N
196 DATA50US,5V,255,255,9,0,HOW MANY DEGREES APART,120
197 DATA50US,5V,255,255,10,0,ARE THESE WAVES IN PHASE Y/N,N
198 DATA50US,5V,255,255,10,0,HOW MANY DEGREES APART,150
199 REM **** ENABLE & POS ****
200 REM ** SIZE OF WAVE 2 **
201 IFSS=1THEN POKEV+23,03:POKEV+7,109
202 IFSS=0THEN POKEV+23,255:POKEV+7,88
203 REM ** 0 DEGREE SHIFT **
204 IFPC=1THEN POKEV+4,88:POKEV+6,40
205 REM ** 45 DEGREE SHIFT **
206 IFPC=2THEN POKEV+4,100:POKEV+6,52
207 REM *** 90 PHASE ****
208 IFPC=3THEN POKEV+4,112:POKEV+6,64

```

Fig. E-12. Phase angle program. (Continued from page 329.)

```

209 REM *** 135 PHASE *****
210 IFPC=4THEN POKEY+4,124:POKEY+6,76
211 REM *** 180 PHASE *****
212 IFPC=5THEN POKEY+4,134:POKEY+6,88
213 REM *** 200 PHASE *****
214 IFPC=6THEN POKEY+4,142:POKEY+6,94
215 REM *** 225 PHASE *****
216 IFPC=7THEN POKEY+4,147:POKEY+6,99
217 REM *** 60 PHASE *****
218 IFPC=8THEN POKEY+4,104:POKEY+6,56
219 REM *** 120 PHASE *****
220 IFPC=9THEN POKEY+4,120:POKEY+6,72
221 REM *** 150 PHASE *****
222 IFPC=10THEN POKEY+4,128:POKEY+6,80
223 POKE53269,15:RETURN

```

READY.

Fig. E-13. Time constants program.

```

1 REM TIME CONSTANTS
2 PRINTCHR$(147):REM *** INTRODUCTION *****
3 PRINT" THIS PROGRAM IS AN EXERCISE"
4 PRINT" IN CALCULATING TIME CONSTANTS,"
5 PRINT" THE FORMULAS LEARNED IN"
6 PRINT" CHAPTER 13."
7 PRINT
8 PRINT" THE USER WILL BE GIVEN TWO"
9 PRINT" KNOWN, AND BE ASKED TO SOLVE"
10 PRINT" FOR THE UNKNOWN."
11 PRINT
12 PRINT" NOTE:POWER ON, AND POWER OFF"
13 PRINT" TIMES, ARE STATED FROM"
14 PRINT" TOTAL DISCHARGE, OR CHARGE,"
15 PRINT" RESPECTFULLY."
16 PRINT" YOUR ANSWERS ARE EXPECTED TO BE"
17 PRINT" WITH IN 5% OF THE COMPUTER'S"
18 PRINT" ANSWERS."
19 PRINT" PRESS SPACE BAR TO CONTINUE"
20 GET RT$:IF RT$<>CHR$(32)THENGOTO20
21 PRINTCHR$(147)
22 REM *** QUESTION LOOP ***
23 FOR K=1 TO20:AA=0
24 READTC$,CL$,CR$,Q$,A
25 PRINTCHR$(147)
26 PRINT" NOTE: UNITS ARE GIVEN, JUST GIVE THE NUMERIC VALUE."
27 PRINT" GIVEN:"
28 PRINT
29 PRINT TAB(10)TC$:PRINT
30 PRINT TAB(10)CL$:PRINT
31 PRINT TAB(10)CR$:PRINT
32 PRINT:PRINT
33 PRINTK;"|.";Q$;
34 INPUTAA:LU= A-(A*.05):HU=A+(A*.05)
35 IFA<0THENLU=A+(A*.05):HU=A-(A*.05)
36 IFAA>LUANDAA<HUTHENGOSUB41 :REM** CORRECT*
37 IFAA=LUORAA=HUTHENGOSUB41 :REM*** CORRECT ***
38 IFAA<LUORAA>HUTHENGOSUB48 :REM**WRONG**

```

```

39 IFK=20 THEN GOTO57
40 NEXTK
41 REM *** CORRECT ***
42 PRINT:PRINT:PRINTTAB(14)"CORRECT!":S=S+1
43 PRINT:PRINT"SPACE BAR = NEXT, N = NEW SELECTION."
44 GETRR$:IFRR$<>CHR$(32)ANDRR$<>CHR$(78)THEN44
45 IF RR$=CHR$(32)ANDK=20 THENGOTO57
46 IF RR$=CHR$(78)THEN RETURN
47 IF RR$=CHR$(32)THENGOTO57
48 REM *** WRONG ***
49 PRINT:PRINT:PRINTTAB(12)"WRONG ";A;" "
50 PRINT:PRINT"SPACE BAR = NEXT, F1 = HELP HINTS"
51 PRINT" N = NEW SELECTION"
52 GETWW$:IFWW$<>CHR$(32)ANDWW$<>CHR$(78)ANDWW$<>CHR$(133)THEN52
53 IFWW$=CHR$(32)ANDK=20 THENGOTO57
54 IFWW$=CHR$(133)THEN RETURN
55 IFWW$=CHR$(78)THENGOSUB70:RETURN:REM **HELP**
56 IFWW$=CHR$(32)THENGOTO57
57 REM *** SCORE ****
58 POKE53269,0
59 PRINTCHR$(147);"XXXXXXXX"
60 E=(S/K)*100
61 PRINT"YOUR SCORE IS ";E;"%":PRINT
62 PRINT"FOR";K;"QUESTIONS ASKED."
63 PRINT"PLEASE TURN DISK DRIVE ON."
64 PRINT"SPACE BAR FOR MAIN MENU."
65 GETMM$:IF MM$<>CHR$(32)THEN65
66 IF MM$=CHR$(32)THEN PRINTCHR$(147)
67 PRINT"LOADING MENU"
68 PRINTCHR$(6)
69 LOAD"MENU 301",8
70 REM *** HELP HINTS ***
71 PRINTCHR$(147)
72 PRINT"THIS EXERCISE NOT ONLY
73 PRINT" GIVES YOU PRACTICE AT THE
74 PRINT" FORMULAS, IT DOUBLES AS A
75 PRINT" PRACTICE IN TRANSPOSING
76 PRINT" NOTE:POWER ON, AND POWER OFF"
77 PRINT" TIMES, ARE STATED FROM"
78 PRINT" TOTAL DISCHARGE, OR CHARGE,"
79 PRINT" RESPECTFULLY."
80 PRINT
81 PRINT" THE LIST OF FORMULAS ON NEXT
82 PRINT" PAGE SHOULD HELP.
83 PRINT"SPACE BAR FOR LIST"
84 GET ZC$:IFZC$<>CHR$(32)THEN84
85 PRINTCHR$(147)
86 PRINT"INDUCTOR"," CAPACITOR"
87 PRINT" T= L/R"," T= R X C"
88 PRINT" L= T/R"," C= T/R"
89 PRINT" R= L X T"," R= T/C"
90 PRINT" WHERE T IS THE TIME CONSTANT."
91 PRINT
92 PRINT"SPACE BAR TO CONTINUE."
93 GET MC$:IFMC$<>CHR$(32)THEN93
94 PRINTCHR$(147)
95 PRINT" USE UNIVERSAL TIME CONSTANT CURVE"
96 PRINT" FOUND IN CHAPTER 13 FOR % OF CHARGE
97 PRINT" TO FIND THE TIME (ON OR OFF)"
98 PRINT" WHEN GIVEN THE TIME CONSTANT,"
99 PRINT" AND % OF CHARGE: FIND THE %"
100 PRINT" OF CHARGE ON THE CURVE AND LOOK"

```

FORMULAS."

QUESTIONS."

Fig. E-13. Time constants program. (Continued from page 331.)

```

101 PRINT"      STRAIGHT DOWN FROM THAT POINT"
102 PRINT"      TO THE NUMBER OF TIME CONSTANTS"
103 PRINT"      THEN MULTIPLY THE NUMBER OF"
104 PRINT"      TIME CONSTANTS BY THE TIME OF"
105 PRINT"      ONE TIME CONSTANT TO GET THE"
106 PRINT"      TIME (ON OR OFF) USE CHARGING"
107 PRINT"      CURVE, OR DISCHARGING CURVE"
108 PRINT"      RESPECTFULLY."
109 PRINT"XXXXXXXX      SPACE BAR TO CONTINUE.■"
110 GET LC$:IFLC$(<)CHR$(32)THEN110
111 PRINTCHR$(147)
112 PRINT"      TO FIND THE TIME CONSTANT WHEN"
113 PRINT"      GIVEN TIME (ON OR OFF), AND THE"
114 PRINT"      % OF CHARGE: FIND THE NUMBER"
115 PRINT"      OF TIME CONSTANTS AS BEFORE,"
116 PRINT"      ONLY DIVIDE THE TIME (ON OR OFF)"
117 PRINT"      BY THE NUMBER OF TIME CONSTANTS"
118 PRINT"      TO GET THE TIME OF ONE TIME"
119 PRINT"      CONSTANT."
120 PRINT
121 PRINT"      TO FIND THE % OF CHARGE WHEN"
122 PRINT"      GIVEN THE TIME CONSTANT AND"
123 PRINT"      THE TIME (ON OR OFF): DIVIDE"
124 PRINT"      THE TIME (ON OR OFF) BY ONE"
125 PRINT"      TIME CONSTANT, TO GET THE"
126 PRINT"      NUMBER OF TIME CONSTANTS, THEN"
127 PRINT"      GOTO THE CURVE AND LOCATE"
128 PRINT"      THE NUMBER OF TIME CONSTANTS"
129 PRINT"      WHERE IT INTERSECTS WITH THE CURVE"
130 PRINT"      AND THAT POINT ON THE CURVE"
131 PRINT"      REPRESENTS THE % OF CHARGE."
132 PRINT"XXXX      SPACE BAR TO CONTINUE.■"
133 GET RC$:IFRC$(<)CHR$(32)THEN133
134 IFRC$=CHR$(32)THEN RETURN
135 DATATIME CONSTANT = ? US,INDUCTOR = 2 MH,RESISTANCE = 1 KOHM
136 DATACALCULATE THE UNKNOWN,2
137 DATATIME CONSTANT = ? MS,CAPACITOR = 2 UF,RESISTANCE = 1 KOHM
138 DATACALCULATE THE UNKNOWN,2
139 DATATIME CONSTANT = 166 US,INDUCTOR = ? MH,RESISTANCE = 300 OHMS
140 DATACALCULATE THE UNKNOWN,50
141 DATATIME CONSTANT = 50 MS,CAPACITOR = ? UF,RESISTANCE = 500 OHMS
142 DATACALCULATE THE UNKNOWN,100
143 DATATIME CONSTANT = 2.5 MS,INDUCTOR = 5 H,RESISTANCE = ? KOHMS
144 DATACALCULATE THE UNKNOWN,2
145 DATATIME CONSTANT = 14 MS,CAPACITOR = 47 UF,RESISTANCE = ? OHMS
146 DATACALCULATE THE UNKNOWN,300
147 DATATIME CONSTANT = 100 US,CAPACITOR = ? UF,RESISTANCE = 10 OHMS
148 DATACALCULATE THE UNKNOWN,10
149 DATATIME CONSTANT = ? US,INDUCTOR = 25 MH,RESISTANCE = 100 OHMS
150 DATACALCULATE THE UNKNOWN,250
151 DATATIME CONSTANT = ? US,INDUCTOR = 90 MH,RESISTANCE = 10 KOHMS
152 DATACALCULATE THE UNKNOWN,9
153 DATATIME CONSTANT = 16.5 MS,CAPACITOR = ? UF,RESISTANCE = 500 OHMS
154 DATACALCULATE THE UNKNOWN,33
155 DATATIME CONSTANT = 2 US,TIME POWER ON = 2 US,PERCENT OF CHARGE = ? %
156 DATAFIND THE UNKNOWN,63
157 DATATIME CONSTANT = ? MS,TIME POWER OFF = 100 MS,PERCENT OF GHARGE = 14 %
158 DATAFIND THE UNKNOWN,50
159 DATATIME CONSTANT = 100 US,TIME POWER ON = ? US,PERCENT OF CHARGE = 95 %

```



```

160 DATAFIND THE UNKNOWN,300
161 DATETIME CONSTANT = 2.5 MS,TIME POWER ON = 3.75 MS,PERCENT OF CHARGE = ? %
162 DATAFIND THE UNKNOWN,76
163 DATETIME CONSTANT = 9 US,TIME POWER OFF = 36 US,PERCENT OF CHARGE = ? %
164 DATAFIND THE UNKNOWN,2
165 DATETIME CONSTANT = 125 US,TIME POWER OFF = ? US,PERCENT OF CHARGE = 1 %
166 DATAFIND THE UNKNOWN,625
167 DATETIME CONSTANT = ? US,TIME POWER OFF = 100 US,PERCENT OF CHARGE = 14 %
168 DATAFIND THE UNKNOWN,50
169 DATETIME CONSTANT = 25 US,TIME POWER ON = 50 US,PERCENT OF CHARGE = ? %
170 DATAFIND THE UNKNOWN,86
171 DATETIME CONSTANT = 10 US,TIME POWER ON = 50 US,PERCENT OF CHARGE = ? %
172 DATAFIND THE UNKNOWN,99
173 DATETIME CONSTANT = ? MS,TIME POWER ON = 5 MS,PERCENT OF CHARGE = 42%
174 DATAFIND THE UNKNOWN,10

```

READY.

Fig. E-14. Magnetism program.

```

1 REM MAGNETISM
2 PRINTCHR$(147):REM *** INTRODUCTION ****
3 PRINT"XXXXXXXX THIS PROGRAM IS A MULTIPLE"
4 PRINT" CHOICE QUIZ ON MAGNETISM."
5 PRINT
6 PRINT" THE USER WILL BE ASKED TO CHOOSE"
7 PRINT" THE BEST ANSWER FOR THE QUESTION"
8 PRINT" ASKED."
9 PRINT
10 PRINT"XXXXXXXX SPACE BAR TO CONTINUE"
11 GET RT$:IF RT$<>CHR$(32)THENGOTO11
12 PRINTCHR$(147)
13 REM *** QUESTION LOOP ****
14 FOR K=1 TO10:AA=0
15 READL$,F$,X$,CT$,Q$,A$
16 PRINTCHR$(147)
17 PRINT" CHOOSE THE MOST CORRECT ANSWER."
18 PRINT:PRINT
19 PRINTTAB(6)"A) ";L$:PRINT
20 PRINTTAB(6)"B) ";F$:PRINT
21 PRINTTAB(6)"C) ";X$:PRINT
22 PRINTTAB(6)"D) ";CT$:PRINT
23 PRINT
24 PRINTK;"■.";Q$:PRINT
25 INPUT" THE LETTER OF YOUR CHOICE IS";AA$
26 IFAA$=A$THENGOSUB30 :REM** CORRECT*
27 IFAA$<> A$THENGOSUB37 :REM**WRONG**
28 IFK=10THEN GOTO45
29 NEXTK
30 REM *** CORRECT ****
31 PRINT:PRINT:PRINT:PRINTTAB(14)"CORRECT!■":S=S+1
32 PRINT:PRINT" SPACE BAR = NEXT, N = NEW SELECTION."
33 GETRR$:IFRR$<>CHR$(32)ANDRR$<>CHR$(78)THEN33
34 IF RR$=CHR$(32)ANDK=10THENGOTO45
35 IF RR$=CHR$(32)THEN RETURN
36 IF RR$=CHR$(78)THENGOTO45
37 REM *** WRONG ***
38 PRINT:PRINT:PRINT:PRINTTAB(12)"WRONG ";A$;"■"
39 PRINT:PRINT" SPACE BAR = NEXT,";
40 PRINT" N = NEW SELECTION"
41 GETWW$:IFWW$<>CHR$(32)ANDWW$<>CHR$(78)THEN41

```

Fig. E-14. Magnetism program. (Continued from page 334.)

```

42 IFWW$=CHR$(32)ANDK=10THENGOTO45
43 IFWW$=CHR$(32)THEN RETURN
44 IFWW$=CHR$(78)THENGOTO45
45 REM *** SCORE ****
46 POKE53269,0
47 PRINTCHR$(147);"XXXXXXXX"
48 E=(S/K)*100
49 PRINT          YOUR SCORE IS ";E;"%:PRINT
50 PRINT"          FOR";K;"QUESTIONS ASKED."
51 PRINT"XXXX          PLEASE TURN DISK DRIVE ON."
52 PRINT"XXXX          SPACE BAR FOR MAIN MENU."
53 GETMM$:IF MM$<>CHR$(32)THEN53
54 IF MM$=CHR$(32)THEN PRINTCHR$(147)
55 PRINT"XXXX";TAB(12)"LOADING MENU"
56 PRINTCHR$(6)
57 LOAD"MENU 301",8
58 REM ***** SERIES *****
59 DATAREPEL,ATTRACT,MELT,DESTROY THE MAGNETS
60 DATAMAGNETS DO THIS WHEN LIKE POLES ARE      PLACED CLOSE TOGETHER.,A
61 DATA PERMANENT MAGNETS,NORTHS,MAGNETIC FLUX,COILS
62 DATATHE LINES OF FORCE AROUND A MAGNET      ARE ALSO CALLED?,C
63 DATA PERMANENT,MAGNETIC,NUCLEAR,PHASOR
64 DATAWHEN CURRENT FLOWS THROUGH A WIRE      IT CREATES A ----- FIELD.,B
65 DATA VOLTAGE,CURRENT,AIR,NONE OF THE ABOVE
66 DATA INDUCTORS RESIST A CHANGE IN -----.,B
67 DATA CHARGING,VOLTAGE,INDUCTANCE,NONE OF THE ABOVE
68 DATA AN INDUCTORS ABILITY TO RESIST A      CHANGE IN CURRENT IS CALLED?,C
69 DATA MAGNETIC,FORCE,AIR,NUCLEAR
70 DATAWHEN CURRENT DECREASES IN AN INDUCTOR  THIS FIELD COLAPSES.,A
71 DATA WATER,VOLTAGE,AIR,NONE OF THE ABOVE
72 DATA A CHANGING MAGNETIC FIELD INDUCES     WHAT IN THE INDUCTOR?,B
73 DATA A RESISTOR,A CAPACITOR,THE INDUCED VOLTAGE,NONE OF THE ABOVE
74 DATAWHAT CAUSES AN INDUCTOR TO RESIST     A CHAGE IN CURRENT?,C
75 DATA CONCENTRATE THE MAGNETIC FLUX,INCREASE THE INDUCTANCE,BOTH A AND B
76 DATA NONE OF THE ABOVE
77 DATA A MAGNETIC CORE IS PLACED INSIDE AN   INDUCTOR TO DO WHAT ?,C
78 DATA THE NUMBER OF TURNS OF WIRE,THE SPACE BETWEEN THE TURNS
79 DATA THE AREA OF THE TURNS,ALL OF THE ABOVE
80 DATA WHICH OF THE FOLLOWING WILL AFFECT     THE INDUCTANCE OF A COIL ?,D

```

READY.

Fig. E-15. Transformers program.

```

1 REM TRANSFORMERS
2 PRINTCHR$(147):REM *** INTRODUCTION ****
3 PRINT"XXXX          THIS PROGRAM IS A PRACTICE"
4 PRINT"          EXERCISE FOR THE TRANSFORMER"
5 PRINT"          FORMULAS LEARNED IN CHAPTER 12."
6 PRINT
7 PRINT"          IT WILL GIVE TWO KNOWN, AND"
8 PRINT"          ASK THE USER TO SOLVE FOR"
9 PRINT"          THE UNKNOWN."
10 PRINT
11 PRINT"          THE ANSWERS ARE EXPECTED TO"
12 PRINT"          BE WITH IN 5% OF THE COMPUTER'S"
13 PRINT"          ANSWERS."
14 PRINT"XXXX          SPACE BAR TO CONTINUE"

```

```

15 GET RT$:IF RT$<>CHR$(32)THENGOTO15
16 PRINTCHR$(147)
17 REM *** QUESTION LOOP ****
18 FOR K=1 TO20:AA=0
19 READL$,F$,X$,Q$,A
20 PRINTCHR$(147)
21 PRINT"    NOTE: UNITS ARE GIVEN, JUST GIVE          THE NUMERIC VALUE."
22 PRINT"X    GIVEN:"
23 PRINT
24 PRINTTAB(10)L$:PRINT
25 PRINTTAB(10)F$:PRINT
26 PRINTTAB(10)X$:PRINT
27 PRINT:PRINT
28 PRINTK;"|.";Q$:
29 INPUTAA:LU= A-(A*.05):HU=A+(A*.05)
30 IF A<0 THEN LU=A+(A*.05):HU=A-(A*.05)
31 IF A>LU AND A<HUTHENGOSUB36 :REM*** CORRECT*
32 IF A=LU OR A=HUTHENGOSUB36 :REM*** CORRECT ***
33 IF A<LU OR A>HUTHENGOSUB43 :REM***WRONG**
34 IF K=20 THEN GOT052
35 NEXTK
36 REM *** CORRECT ****
37 PRINT:PRINT:PRINT:PRINTTAB(14)"CORRECT!" :S=S+1
38 PRINT:PRINT"  SPACE BAR = NEXT, N = NEW SELECTION."
39 GETRR$:IFRR$<>CHR$(32)ANDRR$<>CHR$(78)THEN39
40 IF RR$=CHR$(32)ANDK=20THENGOTO52
41 IF RR$=CHR$(32)THEN RETURN
42 IF RR$=CHR$(78)THENGOTO52
43 REM *** WRONG ***
44 PRINT:PRINT:PRINT:PRINTTAB(12)"WRONG ";A;" "
45 PRINT:PRINT"  SPACE BAR = NEXT, F1 = HELP HINTS"
46 PRINT"  N = NEW SELECTION"
47 GETWW$:IFWW$<>CHR$(32)ANDWW$<>CHR$(78)ANDWW$<>CHR$(133)THEN47
48 IFWW$=CHR$(32)ANDK=20THENGOTO52
49 IFWW$=CHR$(32)THEN RETURN
50 IFWW$=CHR$(133)THENGOSUB65 :RETURN: REM **HELP*
51 IFWW$=CHR$(78)THENGOTO52
52 REM *** SCORE ****
53 POKES3269,0
54 PRINTCHR$(147);"XXXXXXXX"
55 E=(S/K)*100
56 PRINT"          YOUR SCORE IS ";E;"%":PRINT
57 PRINT"          FOR";K;"QUESTIONS ASKED."
58 PRINT"X    PLEASE TURN DISK DRIVE ON."
59 PRINT"X    SPACE BAR FOR MAIN MENU."
60 GETMM$:IF MM$<>CHR$(32)THEN60
61 IF MM$=CHR$(32)THEN PRINTCHR$(147)
62 PRINT"X";TAB(12)"LOADING MENU"
63 PRINTCHR$(6)
64 LOAD"MENU 301",0
65 REM *** HELP HINTS ****
66 PRINTCHR$(147)
67 PRINT"          THIS THREE PART LIST SHOULD          HELP YOU.XX"
68 PRINT"          TURNS RATIO: X"
69 PRINT"          VOLTAGE SEC          TURNS SEC"
70 PRINT"          _____ = _____"
71 PRINT"          VOLTAGE PRI          TURNS PRI"
72 PRINT"X    EFFICIENCY: X"
73 PRINT"          POWER OUT"
74 PRINT"          % EFFICIENCY = _____ X 100"
75 PRINT"          POWER IN "
76 PRINT"X    SPACE BAR FOR MORE"

```

Fig. E-15. Transformers program. (Continued from page 335.)

```

77 GET RC$:IFRC$<>CHR$(32)THEN77
78 PRINTCHR$(147):PRINT"          TURNS RATIO VOLTAGE:"
79 PRINT"      VS/VP = NS/NP"
80 PRINT"      VS = (NS/NP) X VP"
81 PRINT"      VP = (NP/NS) X VS"
82 PRINT"      NS = (VS/VP) X NP"
83 PRINT"      NP = (VP/VS) X NS"
84 PRINT"          SPACE BAR FOR MORE"
85 GET ZC$:IFZC$<>CHR$(32)THEN85
86 PRINTCHR$(147)
87 PRINT"          TURNS RATIO CURRENT:"
88 PRINT"      IP/IS = NS/NP"
89 PRINT"      IP = (NS/NP) X IS"
90 PRINT"      IS = (NP/NS) X IP"
91 PRINT"      NS = (IP/IS) X NP"
92 PRINT"      NP = (IS/IP) X NS"
93 PRINT"          EFFICIENCY FORMULAS:"
94 PRINT"      % EFFICIENCY = (P OUT/ P IN) X 100"
95 PRINT"      P OUT = (% EFF/100) X P IN"
96 PRINT"      P IN = P OUT / (% EFF/ 100)"
97 PRINT"          SPACE BAR TO CONTINUE"
98 GET YC$:IFYC$<>CHR$(32)THEN98
99 IFYC$=CHR$(32)THEN RETURN
100 DATATURNS RATIO = 10 TO 1,PRIMARY VOLTAGE = 120 V
101 DATASECONDARY VOLTAGE = ? V,FIND THE UNKNOWN,12
102 DATATURNS RATIO = ? TO 10,PRIMARY VOLTAGE = 100 V
103 DATASECONDARY VOLTAGE = 1000 V,FIND THE UNKNOWN,1
104 DATATURNS RATIO = 6 TO 1,PRIMARY VOLTAGE = ? V
105 DATASECONDARY VOLTAGE = 18 V,FIND THE UNKNOWN,108
106 DATATURNS RATIO = 1 TO 5,PRIMARY VOLTAGE = 12 V
107 DATASECONDARY VOLTAGE = ? V,FIND THE UNKNOWN,60
108 DATATURNS RATIO = 8 TO ?,PRIMARY VOLTAGE = 160 V
109 DATASECONDARY VOLTAGE = 20 V,FIND THE UNKNOWN,1
110 DATATURNS RATIO = 1 TO 1,PRIMARY VOLTAGE = 100 V
111 DATASECONDARY VOLTAGE = ? V,FIND THE UNKNOWN,100
112 DATATURNS RATIO = 1 TO 5,PRIMARY VOLTAGE = 60 V
113 DATASECONDARY VOLTAGE = ? V,FIND THE UNKNOWN,300
114 DATATURNS RATIO = 8 TO 1,PRIMARY VOLTAGE = ? V
115 DATASECONDARY VOLTAGE = 24 V,FIND THE UNKNOWN,192
116 DATATURNS RATIO = 3 TO 1,PRIMARY CURRENT = 2 AMP
117 DATASECONDARY CURRENT = ? AMPS,FIND THE UNKNOWN,6
118 DATATURNS RATIO = ? TO 1,PRIMARY CURRENT = .3 AMPS
119 DATASECONDARY CURRENT = 3 AMPS,FIND THE UNKNOWN,10
120 DATAEFFICIENCY = 85 %,PRIMARY POWER = 6 WATTS,SECONDARY POWER = ? WATTS
121 DATAFIND THE UNKNOWN,5.1
122 DATAEFFICIENCY = ? %,PRIMARY POWER = 3 WATTS,SECONDARY POWER = 2.8 WATTS
123 DATAFIND THE UNKNOWN,93
124 DATAEFFICIENCY = 70 %,PRIMARY POWER = 20 WATTS,SECONDARY POWER = ? WATTS
125 DATAFIND THE UNKNOWN,14
126 DATAEFFICIENCY = 75 %,PRIMARY POWER = ? WATTS,SECONDARY POWER = 7.5 WATTS
127 DATAFIND THE UNKNOWN,10
128 DATAEFFICIENCY = 95 %,PRIMARY POWER = 8 WATTS,SECONDARY POWER = ? WATTS
129 DATAFIND THE UNKNOWN,7.6
130 DATAEFFICIENCY = ? %,PRIMARY POWER = 6 WATTS,SECONDARY POWER = 4.8 WATTS
131 DATAFIND THE UNKNOWN,80
132 DATAEFFICIENCY = ? %,PRIMARY POWER = 10 WATTS,SECONDARY POWER = 9 WATTS
133 DATAFIND THE UNKNOWN,90
134 DATAEFFICIENCY = 90 %,PRIMARY POWER = 7 WATTS,SECONDARY POWER = ? WATTS
135 DATAFIND THE UNKNOWN,6.3

```

```

136 DATAEFFICIENCY = 95 %,PRIMARY POWER = ? WATTS,SECONDARY POWER = 10 WATTS
137 DATAFIND THE UNKNOWN,10.53
138 DATAEFFICIENCY = 75 %,PRIMARY POWER = ? WATTS,SECONDARY POWER = 5 WATTS
139 DATAFIND THE UNKNOWN,6.6

```

READY.

Fig. E-16. Reactance program.

```

1 REM REACTANCE
2 PRINTCHR$(147):REM *** INTRODUCTION ****
3 PRINT"XXXXXXXX THIS PROGRAM IS A PRACTICE"
4 PRINT" EXERCISE FOR THE REACTANCE"
5 PRINT" FORMULAS LEARNED IN CHAPTER 14."
6 PRINT
7 PRINT" IT WILL GIVE TWO KNOWNS, AND"
8 PRINT" ASK THE USER TO SOLVE FOR"
9 PRINT" THE UNKNOWN."
10 PRINT
11 PRINT" THE ANSWERS ARE EXPECTED TO"
12 PRINT" BE WITH IN 5% OF THE COMPUTER'S"
13 PRINT" ANSWERS."
14 PRINT"XXXXXXXX SPACE BAR TO CONTINUE"
15 GET RT$:IF RT$<>CHR$(32)THENGOTO15
16 PRINTCHR$(147)
17 REM *** QUESTION LOOP ****
18 FOR K=1 TO20:AA=0
19 READL$,F$,X$,Q$,A
20 PRINTCHR$(147)
21 PRINT" NOTE: UNITS ARE GIVEN, JUST GIVE THE NUMERIC VALUE."
22 PRINT"X GIVEN:"
23 PRINT
24 PRINTTAB(10)L$:PRINT
25 PRINTTAB(10)F$:PRINT
26 PRINTTAB(10)X$:PRINT
27 PRINT:PRINT
28 PRINTK;"||.";Q$;
29 INPUTAA:LU= A-(A*.05):HU=A+(A*.05)
30 IFA<0THENLU=A+(A*.05):HU=A-(A*.05)
31 IFAA>LUANDAA<HUTHENGOSUB36 :REM*** CORRECT*
32 IFAA<LUORAA>HUTHENGOSUB36 :REM*** CORRECT ***
33 IFAA<LUORAA>HUTHENGOSUB43 :REM***WRONG**
34 IFK=20THEN GOT052
35 NEXTK
36 REM *** CORRECT ****
37 PRINT:PRINT:PRINT:PRINTTAB(14)"CORRECT!":S=S+1
38 PRINT:PRINT" SPACE BAR = NEXT, N = NEW SELECTION."
39 GETRR$:IFRR$<>CHR$(32)ANDRR$<>CHR$(78)THEN39
40 IF RR$=CHR$(32)ANDK=20THENGOTO52
41 IF RR$=CHR$(32)THEN RETURN
42 IF RR$=CHR$(78)THENGOTO52
43 REM *** WRONG ***
44 PRINT:PRINT:PRINT:PRINTTAB(12)"WRONG ";A;" "
45 PRINT:PRINT" SPACE BAR = NEXT, F1 = HELP HINTS"
46 PRINT" N = NEW SELECTION"
47 GETWW$:IFWW$<>CHR$(32)ANDWW$<>CHR$(78)ANDWW$<>CHR$(133)THEN47
48 IFWW$=CHR$(32)ANDK=20THENGOTO52
49 IFWW$=CHR$(32)THEN RETURN
50 IFWW$=CHR$(133)THENGOSUB65 :RETURN: REM **HELP*
51 IFWW$=CHR$(78)THENGOTO52

```

Fig. E-16. Reactance program. (Continued from page 337.)

```

52 REM *** SCORE *****
53 POKE53269,0
54 PRINTCHR$(147);"XXXXXXXX"
55 E=(S/K)*100
56 PRINT"          YOUR SCORE IS ";E;"%":PRINT
57 PRINT"          FOR";K;"QUESTIONS ASKED."
58 PRINT"XXXXXXXX PLEASE TURN DISK DRIVE ON."
59 PRINT"XXXXXXXX SPACE BAR FOR MAIN MENU."
60 GETMM$:IF MM$<>CHR$(32)THEN60
61 IF MM$=CHR$(32)THEN PRINTCHR$(147)
62 PRINT"XXXXXXXX";TAB(12)"LOADING MENU"
63 PRINTCHR$(6)
64 LOAD"MENU 301",8
65 REM *** HELP HINTS ****
66 PRINTCHR$(147):PRINT"XXXXXXXX"
67 PRINT
68 PRINT"      MOST PEOPLE GET CONFUSED WHEN"
69 PRINT"      FIRST TRANSPOSING THESE"
70 PRINT"      FORMULAS."
71 PRINT
72 PRINT"      THIS LIST SHOULD HELP TILL YOU"
73 PRINT"      MEMORIZE THEM."
74 PRINT"XXXXXXXX SPACE BAR FOR LIST"
75 GET ZC$:IFZC$<>CHR$(32)THEN75
76 PRINTCHR$(147)
77 PRINT"      INDUCTORX"
78 PRINT"      XL= 2 (PI) F LX"
79 PRINT"      L= XL/(2 (PI) F)X"
80 PRINT"      F= XL/(2 (PI) L)X"
81 PRINT"      CAPACITORX"
82 PRINT"      XC= 1/(2 (PI) F C)X"
83 PRINT"      C= 1/(2 (PI) F XC)X"
84 PRINT"      F= 1/(2 (PI) XC C)X"
85 PRINT"      NOTE: (2 (PI)) CAN BE REPLACED"
86 PRINT"      BY (6.28) IN THE FORMULAS.X"
87 PRINT"XXXXXXXX SPACE BAR TO CONTINUE"
88 GET RC$:IFRC$<>CHR$(32)THEN88
89 IFRC$=CHR$(32)THEN RETURN
90 DATAINDUCTOR = 3 MH,FREQUENCY = 600 HZ
91 DATAREACTANCE = ? OHMS,FIND THE UNKNOWN,11.3
92 DATAINDUCTOR = 3 MH,FREQUENCY = 10 KHZ
93 DATAREACTANCE = ? OHMS,FIND THE UNKNOWN,188
94 DATACAPACITOR = 2 UF,FREQUENCY = 600 HZ
95 DATAREACTANCE = ? OHMS,FIND THE UNKNOWN,132
96 DATACAPACITOR = 2 UF,FREQUENCY = 10 KHZ
97 DATAREACTANCE = ? OHMS,FIND THE UNKNOWN,7.9
98 DATACAPACITOR = 1.5 UF,FREQUENCY = ? HZ
99 DATAREACTANCE = 1769 OHMS,FIND THE UNKNOWN,60
100 DATAINDUCTOR = 300 MH,FREQUENCY = ? HZ
101 DATAREACTANCE = 37.6 OHMS,FIND THE UNKNOWN,20
102 DATAINDUCTOR = ? H,FREQUENCY = 60 HZ
103 DATAREACTANCE = 753 OHMS,FIND THE UNKNOWN,2
104 DATACAPACITOR = ? UF,FREQUENCY = 60 HZ
105 DATAREACTANCE = 26.5 OHMS,FIND THE UNKNOWN,100
106 DATAINDUCTOR = 50 MH,FREQUENCY = 1 KHZ
107 DATAREACTANCE = ? OHMS,FIND THE UNKNOWN,314
108 DATACAPACITOR = 50 NF,FREQUENCY = 50 KHZ
109 DATAREACTANCE = ? OHMS,FIND THE UNKNOWN,63
110 DATACAPACITOR = 50 NF,FREQUENCY = 4 KHZ

```

```

111 DATA REACTANCE = ? OHMS, FIND THE UNKNOWN, 796
112 DATA INDUCTOR = 10 H, FREQUENCY = ? HZ
113 DATA REACTANCE = 628 OHMS, FIND THE UNKNOWN, 10
114 DATA INDUCTOR = ? MH, FREQUENCY = 100 HZ
115 DATA REACTANCE = 125.6 OHMS, FIND THE UNKNOWN, 200
116 DATA CAPACITOR = ? PF, FREQUENCY = 1 MHZ
117 DATA REACTANCE = 13269 OHMS, FIND THE UNKNOWN, 12
118 DATA CAPACITOR = 10 UF, FREQUENCY = ? HZ
119 DATA REACTANCE = 530 OHMS, FIND THE UNKNOWN, 30
120 DATA INDUCTOR = 25 MH, FREQUENCY = ? HZ
121 DATA REACTANCE = 12.5 OHMS, FIND THE UNKNOWN, 80
122 DATA INDUCTOR = 100 MH, FREQUENCY = 100 HZ
123 DATA REACTANCE = ? OHMS, FIND THE UNKNOWN, 62.8
124 DATA CAPACITOR = 47 UF, FREQUENCY = ? HZ
125 DATA REACTANCE = 1.6 OHMS, FIND THE UNKNOWN, 2117
126 DATA CAPACITOR = ? UF, FREQUENCY = 40 HZ
127 DATA REACTANCE = 120 OHMS, FIND THE UNKNOWN, 33
128 DATA INDUCTOR = 1 MH, FREQUENCY = ? HZ
129 DATA REACTANCE = 37.7 OHMS, FIND THE UNKNOWN, 6000
130 DATA REACTANCE = ? OHMS, FIND THE UNKNOWN, 18.8

```

READY.

Fig. E-17. Resonance program.

```

1 REM RESONANCE
2 PRINT CHR$(147):REM *** INTRODUCTION ****
3 PRINT "THIS PROGRAM IS A PRACTICE"
4 PRINT "EXERCISE FOR THE RESONANCE"
5 PRINT "FORMULAS LEARNED IN CHAPTER 15."
6 PRINT
7 PRINT "IT WILL GIVE THE INFORMATION NEEDED,"
8 PRINT "]" AND ASK THE USER TO SOLVE FOR"
9 PRINT "A PARTICULAR UNKNOWN."
10 PRINT
11 PRINT "THE ANSWERS ARE EXPECTED TO"
12 PRINT "BE WITH IN 5% OF THE COMPUTER'S"
13 PRINT "ANSWERS."
14 PRINT "SPACE BAR TO CONTINUE"
15 GET RT$:IF RT$<>CHR$(32)THEN GOTO 15
16 PRINT CHR$(147)
17 REM *** QUESTION LOOP ****
18 FOR K=1 TO 20:AA=0
19 READ L$,F$,X$,Q$,A,CT$
20 PRINT CHR$(147)
21 PRINT "NOTE: UNITS ARE GIVEN, JUST GIVE THE NUMERIC VALUE."
22 PRINT "GIVEN:"
23 PRINT
24 IF CT$<>" " THEN PRINT TAB(10)CT$:PRINT
25 PRINT TAB(10)L$:PRINT
26 PRINT TAB(10)F$:PRINT
27 PRINT TAB(10)X$:PRINT
28 PRINT:PRINT
29 PRINTK;"I.";Q$;
30 INPUT AA
31 LU= A-(A*.05):HU=A+(A*.05)
32 IF A<0 THEN LU=A+(A*.05):HU=A-(A*.05)
33 IF AA>LU AND AA<HU THEN GOSUB 38:REM *** CORRECT *
34 IF AA=LU OR AA=HU THEN GOSUB 38:REM *** CORRECT ***
35 IF AA<LU OR AA>HU THEN GOSUB 45:REM *** WRONG ***
36 IF K=20 THEN GOTO 54

```

Fig. E-17. Resonance program. (Continued from page 339.)

```

37 NEXTK
38 REM *** CORRECT ***
39 PRINT:PRINT:PRINT:PRINTTAB(14)"CORRECT!":S=S+1
40 PRINT:PRINT"  SPACE BAR = NEXT, N = NEW SELECTION."
41 GETRR$:IFRR$<>CHR$(32)ANDRR$<>CHR$(78)THEN41
42 IF RR$=CHR$(32)ANDK=20THENGOTO54
43 IF RR$=CHR$(32)THEN RETURN
44 IF RR$=CHR$(78)THENGOTO54
45 REM *** WRONG ***
46 PRINT:PRINT:PRINT:PRINTTAB(12)"WRONG ";A;" "
47 PRINT:PRINT"  SPACE BAR = NEXT, F1 = HELP HINTS"
48 PRINT"  N = NEW SELECTION"
49 GETWW$:IFWW$<>CHR$(32)ANDWW$<>CHR$(78)ANDWW$<>CHR$(133)THEN49
50 IFWW$=CHR$(32)ANDK=20THENGOTO54
51 IFWW$=CHR$(32)THEN RETURN
52 IFWW$=CHR$(133)THENGOSUB68:RETURN:REM **HELP*
53 IFWW$=CHR$(78)THENGOTO54
54 REM *** SCORE ****
55 POKE53269,0
56 PRINTCHR$(147);"*****"
57 IF K=21 THEN K=20
58 E=(S/K)*100
59 PRINT"          YOUR SCORE IS ";E;"%":PRINT
60 PRINT"          FOR";K;"QUESTIONS ASKED."
61 PRINT"***** PLEASE TURN DISK DRIVE ON.*****"
62 PRINT"***** SPACE BAR FOR MAIN MENU.*****"
63 GETMM$:IF MM$<>CHR$(32)THEN63
64 IF MM$=CHR$(32)THEN PRINTCHR$(147)
65 PRINT"*****";TAB(12)"LOADING MENU"
66 PRINTCHR$(6)
67 LOAD"MENU 301",0
68 REM *** HELP HINTS ***
69 PRINTCHR$(147)
70 PRINT"***** SERIES NET REACTANCE:"
71 PRINT"***** (GREATER X) - (LESSER X) = (NET X)"
72 PRINT"***** (NET X) WILL BE THE TYPE OF X THAT
73 PRINT"***** HAS THE GREATER VALUE.
74 PRINT"***** PARALLEL NET REACTANCE:"
75 PRINT"***** (GREATER I) - (LESSER I) = (NET I)"
76 PRINT"***** (NET X) = (V APPLIED) / (NET I)"
77 PRINT"***** (NET X) WILL BE THE TYPE OF X THAT
78 PRINT"***** HAD THE GREATER VALUE OF CURRENT."
79 PRINT"***** SPACE BAR FOR MORE*****"
80 GET ZC$:IFZC$<>CHR$(32)THEN80
81 PRINTCHR$(147)
82 PRINT"***** SERIES CURRENT:"
83 PRINT"***** I = V APPLIED / NET X"
84 PRINT"***** PARALLEL NET CURRENT:"
85 PRINT"***** NET I = GREATER IX - LESSER IX"
86 PRINT"***** SERIES VOLTAGE DROPS:"
87 PRINT"***** VD = NET I X REACTANCE"
88 PRINT"***** PARALLEL BRANCH CURRENT:"
89 PRINT"***** IC = V APPLIED / REACTANCE"
90 PRINT"***** SPACE BAR FOR MORE*****"
91 GET TC$:IFTC$<>CHR$(32)THEN91
92 PRINTCHR$(147)
93 PRINT"***** RESONANT FREQUENCY (FR)*****"
94 PRINT"***** 1*****"
95 PRINT"***** FR = -----*****"

```



```

96 PRINT"          2 (PI) X (SQR (L X C))"
97 PRINT"XXXXXXXXX  SQR = SQUARE ROOT"
98 PRINT"XXXXXXXXX  SPACE BAR TO CONTINUE"
99 GET RC$:IFRC$<>CHR$(32)THEN99
100 IFRC$=CHR$(32)THEN RETURN
101 REM ***** SERIES *****
102 DATA L = 100 OHMS,XC = 250 OHMS,V APPLIED = 10 VOLTS
103 DATA FIND TOTAL CURRENT IN AMPS,.066,SERIES CIRCUIT
104 DATA L = 75 OHMS,XC = 50 OHMS,V APPLIED = 25 VOLTS
105 DATA FIND NET REACTANCE IN OHMS,25,SERIES CIRCUIT
106 DATA L = 35 OHMS,XC = 50 OHMS,V APPLIED = 50 VOLTS
107 DATA FIND NET REACTANCE IN OHMS,15,SERIES CIRCUIT
108 DATA L = 200 OHMS,XC = 175 OHMS,V APPLIED = 25 VOLTS
109 DATA FIND VL IN VOLTS,200,SERIES CIRCUIT
110 DATA L = 150 OHMS,XC = 140 OHMS,V APPLIED = 100 VOLTS
111 DATA FIND VC IN VOLTS,1400,SERIES CIRCUIT
112 REM ***** PARALLEL *****
113 DATA L = 40 OHMS,XC = 30 OHMS,V APPLIED = 10 VOLTS
114 DATA FIND IL IN AMPS,.25,PARALLEL CIRCUIT
115 DATA L = 35 OHMS,XC = 50 OHMS,V APPLIED = 10 VOLTS
116 DATA FIND IC IN AMPS,.2,PARALLEL CIRCUIT
117 DATA L = 25 OHMS,XC = 30 OHMS,V APPLIED = 15 VOLTS
118 DATA FIND NET CURRENT IN AMPS,.1,PARALLEL CIRCUIT
119 DATA L = 25 OHMS,XC = 30 OHMS,V APPLIED = 15 VOLTS
120 DATA FIND NET REACTANCE IN OHMS,150,PARALLEL CIRCUIT
121 DATA L = 50 OHMS,XC = 75 OHMS,V APPLIED = 20 VOLTS
122 DATA FIND NET REACTANCE IN OHMS,142,PARALLEL CIRCUIT
123 REM ***** RESONANT FREQUENCY *****
124 DATA INDUCTOR = 25 MH,CAPACITOR = 10 UF,RESONANT FREQUENCY = ?
125 DATA RESONANT FREQUENCY IN HZ = ,318,
126 DATA INDUCTOR = 200 MH,CAPACITOR = 1 UF,RESONANT FREQUENCY = ?
127 DATA RESONANT FREQUENCY IN HZ = ,356,
128 DATA INDUCTOR = 10 MH,CAPACITOR = 30 PF,RESONANT FREQUENCY = ?
129 DATA RESONANT FREQUENCY IN HZ = ,290723,
130 DATA INDUCTOR = 10 UH,CAPACITOR = .47 UF,RESONANT FREQUENCY = ?
131 DATA RESONANT FREQUENCY IN HZ = ,73449,
132 DATA INDUCTOR = 10 MH,CAPACITOR = 5 UF,RESONANT FREQUENCY = ?
133 DATA RESONANT FREQUENCY IN HZ = ,712,
134 DATA INDUCTOR = 2 H,CAPACITOR = 3 UF,RESONANT FREQUENCY = ?
135 DATA RESONANT FREQUENCY IN HZ = ,65,
136 DATA INDUCTOR = 3 MH,CAPACITOR = 10 UF,RESONANT FREQUENCY = ?
137 DATA RESONANT FREQUENCY IN HZ = ,919,
138 DATA INDUCTOR = 150 MH,CAPACITOR = 5 UF,RESONANT FREQUENCY = ?
139 DATA RESONANT FREQUENCY IN HZ = ,184,
140 DATA INDUCTOR = 33 MH,CAPACITOR = 220 NF,RESONANT FREQUENCY = ?
141 DATA RESONANT FREQUENCY IN HZ = ,1868,
142 DATA INDUCTOR = 10 H,CAPACITOR = 100 UF,RESONANT FREQUENCY = ?
143 DATA RESONANT FREQUENCY IN HZ = ,5,

```

READY.

Index

- A**
ac circuits, 223-248, 261
ac power in, 233
circuit values for, 241
competency test for, 244
final examination for, 259-261
phasor analysis of, 225
program listing for, 243
ac power, 233
ac voltmeter, 171
alternating current, 84
dc vs., 159
line voltage for, 160
three-wire system for, 160
ammeter, 92-93
accuracy of, 96
program listing for, 314-316
schematic diagram of, 95
schematic symbol for, 272
ampere-hour rating (see batteries), 48
amplitude
conversion of, 167
units of, 164, 168
answers, 275-293
apparent power, 233, 270
applied power, series circuit, 113
associate degree, 2
astigmatism (see oscilloscopes), 105
attraction, law of, 150
autotransformer, 192
- B**
bachelor's degree, 2
back-EMF, 153
bandwidth, 256, 257
batteries, 48
ampere-hour rating for, 48
- C**
capacitance, 197-203
formation of, 198
unit of, 198
capacitive reactance, 31, 224, 225, 244, 269
parallel, 231, 232, 247
series, 230, 245
capacitors, 197-203, 261, 269
charging/discharging of, 199
competency test for, 218-222
high current from short of, 209
parallel, 201, 219
schematic symbols for, 198, 273
series, 201, 219
voltage dividers with, 202
center-tap transformer, 192
charge curve (see time constants), 204
instantaneous values in, 205
charging voltage, 269
circuit analysis theory, 139
circuit breakers, 52
ratings for, 52
schematic symbols for, 52, 272
circuits
calculating parameters of, 88
wiring of, 88
coefficients, 26
common denominator, 17
commons, schematic symbols for, 58, 272
complex circuits, 130-138
computer assisted instruction, 5-6
conductor, 2
magnetic fields and, 150
materials and sizes of, 49
constants, 26
continuity, using ohmmeter to measure, 74
core, losses in (see transformers), 184
crescent wrench, 10
current, 2, 82, 268
calculation for, 89
complex circuit, 133
direct vs. alternating, 84
maximum, resonance and, 254
minimum, resonance and, 255
Ohm's law for, 84
parallel circuit, 122, 123

series circuits, 112
current ratio (see transformers), 187, 268
cycle, 163, 169
calculating and plotting, 164

D

dc circuits, 47-62 144, 260
analysis of, 111-142
analysis test for, 139
circuit wiring for, 59
competency test for, 60-62, 98
examination for, 143-148
faults in, 52
incorrect wiring for, 60
resetting, 52
program listing for, 96-97, 139, 318-322
relationships, formulas, measurements with, 81-102
dc voltage source, 47
practice with, 108
symbol for, 58
schematic symbols for, 48
transformer and, 193
using oscilloscope to measure, 107
waveform of, 161
decimals
addition and subtraction with, 21
arithmetic with, 32
fraction conversion of, 22
multiplication and division with, 22
percent tolerance to, 23
degrees (educational), 2-3
degrees (see time, units of), 169
denominator, 16
differentiation, 211
digital ohmmeter, 68
direct current, 84
ac vs., 159
using oscilloscope to measure voltage in, 107
direct relationship, 85
discharge curve (see time constants), 205
instantaneous values in, 206
discharge voltage, 269
dual trace oscilloscope, 104

E

educational opportunities, 2-3
efficiency, 189, 190, 195
electrical energy, relationships in, 81, 83
electrical shock, 4
electricity, 2
electro-magnets, 151
electromotive force (EMF)
back-, 153
electronic terms, 1
engineering, 3

engineering notation, 35-46, 144, 259
competency test for, 45
conversion to, 40, 79
conversions with, 40
program listing for, 43-45, 301-304
writing numbers in, 40
equations, solving for, 15, 26-28, 34
exponential notation, 37

F

final examination, 259-261
fixed resistors, 53, 55
flux, 150
focus (see oscilloscopes), 105
formulas, 267-270
solving for, 15, 28, 31, 34
fractions, 13-14, 16-21, 32
arithmetic with, 19-21, 32
decimal conversion and, 14, 22
equivalent, 16, 17
improper, 16, 17
mixed number, 17
reducing, 16, 17
frequency, 170, 268
oscilloscope measurement of, 171
resonance of, 253
fuse, 52
ratings for, 52
schematic symbols for, 52, 272
symbol for, 58

G

ground
ac systems, 160
schematic symbols for, 58, 272

H

hand tools, 9
safety with, 3
Henrys (see inductance, units of), 153

I

impedance, 261
maximum, resonance and, 255
minimum, resonance and, 254
impedance ratio (see transformers), 187, 188, 268
inductance, 153-156
competency test for, 156
mutual, 154, 155
program listing for, 156
units of (see Henrys), 153
inductive circuit, 249
inductive reactance, 30, 224, 225, 244, 269
parallel, 228, 245
series, 227, 244
inductors, 261, 268
parallel, 155, 156
schematic diagrams for, 154

schematic symbols for, 273
series, 154, 155
instantaneous voltage, 164
integration, 211
introductory topics, 1-8
inverse relationships, 85
IR drop, 267
series circuit, 113
isolation transformer, 191

J

job market, 2

L

L/R time constant, 206-208, 269
charge and discharge resistances in, 207
high voltage from, 208
lamp, schematic symbol for, 58, 272
line voltage, ac, 160
lines of force (see magnetism), 150
long time constant, 214-216

M

magnetic cores, 151
magnetic fields, 149
conductor in, 150
magnetic lines of force, 150
magnetic shield, 150
magnetism, 149-153
competency test for, 156
electro-magnets in, 151
inducing voltage with, 150
program listing for, 156, 333-334
terms used in, 150
main menu program, 295
mathematical relationships, 85
medium time constant, 213, 214
meters
construction and operations of, 93
reading scales on, 98-101
schematic symbol for, 94, 272
mixed number, 16
moving coil meter, 93
multi-tap primary transformer, 192
multi-tap secondary transformer, 192
multimeter, 144, 145, 146
analog type, 64, 65
digital type, 66
multiplier names, 39
mutual inductance, 154, 155
parallel, 156

N

negative numbers, 14
net reactance
parallel, 251, 257
series, 249, 250
nominal voltage, 160
nonisolated transformer, 191
nonlinear scale (see ohmmeter), 69

numbers

- finding unknown values of, 15
 - positive and negative, 14
 - arithmetic with, 24-26, 33
 - rounding of, 35, 36
- numerator, 16

O

- Ohm's law, 30, 84, 86, 144, 259, 267, 268
 - program listing for, 310-314
- Ohmic value, 53
- ohmmeter, 63-80, 144, 145
 - adjustments to, 69
 - competency test for, 75
 - construction of, 63
 - measuring continuity with, 74
 - measuring potentiometers with, 72
 - measuring resistance with, 71
 - program listing for, 75, 307-310
 - range switch in, 66, 68
 - transformer testing with, 193
 - scales for, 69, 70, 80
 - schematic symbol for, 63, 67, 272
- ohms per volt rating (see voltmeters), 95
- open circuit, 52, 60
- oscilloscopes, 103-110, 144, 270
 - ac program listing for, 322-326
 - controls for, 105, 171
 - dc voltage measurement with, 107
 - frequency measurement with, 171
 - horizontal controls for, 106
 - measuring voltage with, 104
 - phase angle measurement with, 234
 - program listing for, 109-110, 316-318
 - schematic symbol for, 272
 - screen display of, 104
 - sine wave measurement of, 171
 - trace, focus, and astigmatism controls on, 105
 - trigger for, 106
 - vertical controls and adjustments for, 105

P

- parallel circuits, 122-129
 - analysis of, 139
- peak, 165, 268
- peak-to-peak, 166
- percent tolerance, 15, 23, 33
 - decimal conversion to, 23
- perimeter, rectangle, 29
- period, 169
- permanent magnet, 150
- permeability, 150
- phase angle, 226, 235-241, 247, 269, 270
 - program listing for, 326-330

- using oscilloscope to measure, 234

- phasor analysis (see ac circuits), 225
 - drawing phasor triangle in, 226
- photo-voltaic cells, 48
- place values, 37
- pliers, 9, 10
- positive numbers, 14
- post-secondary technical schools, 2
- potentiometer, 54, 55
 - schematic symbol for, 272
 - using ohmmeter to measure, 72
- power, 2, 30, 82, 84, 189
 - calculation for, 89
 - parallel circuit, 125
- power factor, 233
- power formulas, 86, 87, 144, 259, 267
 - Ohm's law and, 86
- power supplies, 47
- power tools, safety with, 3
- powers, 15
- powers of ten numbers, 38
 - arithmetic with, 41-43
- program listings, 295-341
 - how to use, 6

R

- R/C time constant, 208-210, 269
 - high current from short of capacitor and, 209
- range switch, 66, 68
- RC waveshaping, 211-218
- reactance, 223, 261
 - capacitive and inductive, 224
 - net, 249
 - program listing for, 337-339
- reactive circuits, 227-233
- reactive power, 233, 269
- reciprocal formula
 - inductors, 155
 - resistance, parallel circuit, 124
- relays, 152
 - schematic symbols for, 273
- reluctance, 150
- repulsion, law of, 150
- resetting circuit, 52
- residual magnetism, 150
- resistance, 2, 30, 81, 84, 267, 268
 - complex circuit, 133, 134
 - Ohm's law for, 85
 - parallel circuit, 123-125, 128
 - series circuits, 112
 - using ohmmeter to measure, 71
- resistors, 52
 - color coding for, 55-58, 61, 144, 304-307
 - fixed, 53
 - Ohmic value of, 53
 - schematic symbols for, 55, 58, 272
 - series, 117

- tolerance in, 78
- variable, 54
- wattage rating of, 53
- resonance, 249-258, 261
 - bandwidth and, 256
 - competency test for, 257
 - effect of, 253
 - maximum current at, 254
 - maximum impedance at, 255
 - minimum current and, 255
 - minimum impedance at, 254
 - parallel, 255
 - program listing for, 257, 339-341
 - Q of circuit in, 257
 - series, 254
- resonant frequency, 253, 258, 270
 - effect above and below, 255
- retentivity, 150
- rheostat, 54, 55
 - schematic symbol for, 272
- RMS, 167
- rocker switch, 50
- rounding numbers, 35, 36

S

- safety, 3, 4, 143
 - test for, 6-8
- sawtooth wave, 161
- schematic diagrams, 58-60
- schematic symbols, 58-60, 79, 144, 271-273
- scientific notation, 37, 38
- selectivity, 257
- self-induced voltage, 153
- series circuit, 111-122
 - analysis of, 139
 - applied power in, 113
 - current in, 112
 - IR drop in, 113
 - resistance in, 112
 - solving of, 114
 - voltage drops in, 113
- series-parallel circuits, 129-138
- shop math, 13-34
 - competency test for, 32
 - program listing for, 31, 296-301
- short circuit, 52, 60
- short time constant, 211, 212
- signal generator, 171
- significant figures, 35, 36
- sine wave, 159-182, 260
 - average of, 167
 - competency test for, 175-181
 - cycle of, 163
 - instantaneous voltage and, 268
 - oscilloscope measurement of, 171
 - plotting of, 164
 - practice with, 173-174
 - production of, 162
 - program listing for, 175
 - same amplitude/different frequency, 166

time in, 169
sine wave generator, 162
 rotating wire in, 162
single-load circuits, connection of,
 88
slide switch, 50
slip-joint pliers, 10
slope (see oscilloscopes), 107
soldering, 10, 11
solenoids, 151
SPDT switch, 51
 symbol for, 58
SPST switch
 symbol for, 58
square roots, 15
square wave, 161
step-up/step-down ratio, 186
student projects, 6
substitute values, 29
switches, 50
 schematic symbols for, 50, 51,
 272

T

technical schools, 3
technicians, 3
temperature conversion, 28
temporary magnet, 150
three-wire ac systems, 160
time, 30, 170
 units of, 169
time constants, 203-219, 261, 269
 competency test for, 218-222
 L/R, 206
 long, 214-216

medium, 213, 214
plotting charge curve of, 204
 program listing for, 218, 330-333
 R/C, 208
 short, 211
 universal curve for, 203
 waveshaping and, 214
toggle switches, 50
tools, 9-12
trace (see oscilloscopes), 105
transformers, 183-185, 260
 core of, 184
 dc voltage with, 193
 loaded and unloaded, 190
 ohmmeter testing of, 193
 power and efficiency of, 189, 195
 primary and secondary windings
 of, 184
 program listing for, 194, 334-337
 ratios of, 184, 195
 schematic symbols for, 185, 273
 variations of, 191
transposing formulas, 28
triangles, 269
 determining phase angles with,
 226
trigger (see oscilloscopes), 106, 235
true power, 233, 269
turns ratio, 184, 186, 188, 268

V

variable resistors, 54, 55
variables, 26
voltage, 2, 82
 ac line, 160
 ac nominal, 160

instantaneous, 164
magnetically induced, 150
Ohm's law for, 84
parallel circuit, 122
self-induced, 153
transformer test for, 193
 using oscilloscope to measure,
 104
voltage dividers, capacitive, 202,
 219
voltage drop, 267
 complex circuit, 132
 series circuit, 113
voltage ratio (see transformers), 186
voltage sources, schematic symbols
 for, 271
voltage-current relationships, 86
voltmeter, 89-92
 ac, 171
 accuracy of, 95
 ohms per volt rating of, 95
 program listing for, 314-316, 314
 schematic diagram of, 94, 272

W

wall socket, 162
waveforms, 160, 161
 time measurement of, 169
wavelength, 170
waveshaping, 221
 circuits for, 211
 time constants and, 214
whole number, 16
windings (see transformers), 184
wire strippers, 10
work, 30

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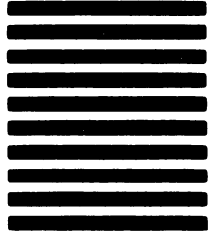


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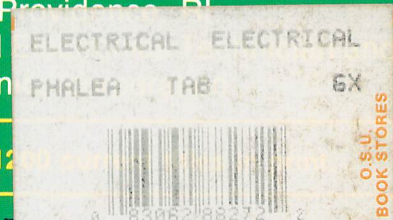
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