HOW TO UNDERSTAND AND USE YOUR...

OSCILLOSCOPE

technical application series

HEATHKIT

MODEL EF-2

PRICE $5.00

RESISTOR AND CAPACITOR COLOR CODES

RESISTORS

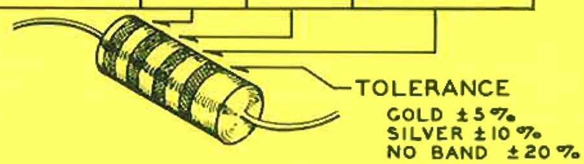
The colored bands around the body of a color coded resistor represent its value in ohms. These colored bands are grouped toward one end of the resistor body. Starting with this end of the resistor, the first band represents the first digit of the resistance value; the second band represents the second digit; the third band represents the number by which the first two digits are multiplied. A fourth band of gold or silver represents a tolerance of ±5% or ±10% respectively. The absence of a fourth band indicates a tolerance of ±20%.

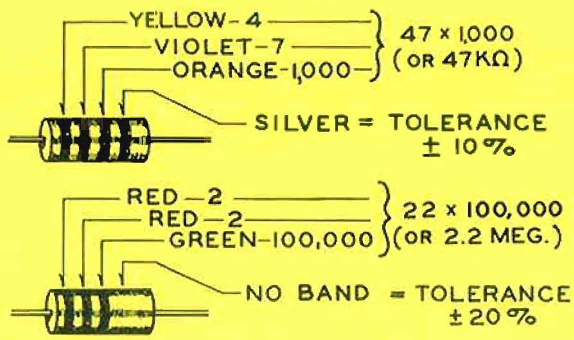
The physical size of a composition resistor is related to its wattage rating. Size increases progressively as the wattage rating is increased. The diameters of 1/2 watt, 1 watt and 2 watt resistors are approximately 1/8", 1/4" and 5/16", respectively.

The color code chart and examples which follow provide the information required to identify color coded resistors.

CODE

COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER
BLACK	0	0	1
BROWN	1	1	10
RED	2	2	100
ORANGE	3	3	1,000
YELLOW	4	4	10,000
GREEN	5	5	100,000
BLUE	6	6	1,000,000
VIOLET	7	7	10,000,000
GRAY	8	8	100,000,000
WHITE	9	9	1,000,000,000
GOLD	-	-	.1
SILVER	-	-	.01





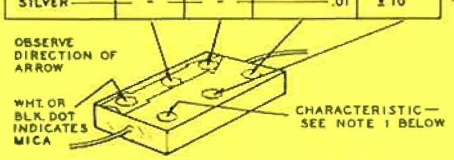
CAPACITORS

Generally, only mica and tubular ceramic capacitors, used in modern equipment, are color coded. The color codes differ somewhat among capacitor manufacturers, however the codes shown below apply to practically all of the mica and tubular ceramic capacitors that are in common use. These codes comply with EIA (Electronics Industries Association) Standards.

MICA

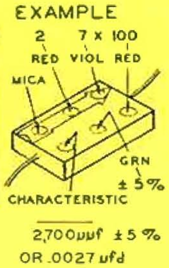
CODE

COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLER.%
BLACK	0	0	1	±20
BROWN	1	1	10	—
RED	2	2	100	± 2
ORANGE	3	3	1000	± 3
YELLOW	4	4	10,000	—
GREEN	5	5	—	± 5
BLUE	6	6	—	—
VIOLET	7	7	—	—
GRAY	8	8	—	—
WHITE	9	9	—	—
GOLD	-	-	.1	—
SILVER	-	-	.01	± 10



(VALUE IN μμf—SEE NOTE 3 BELOW)

EXAMPLE

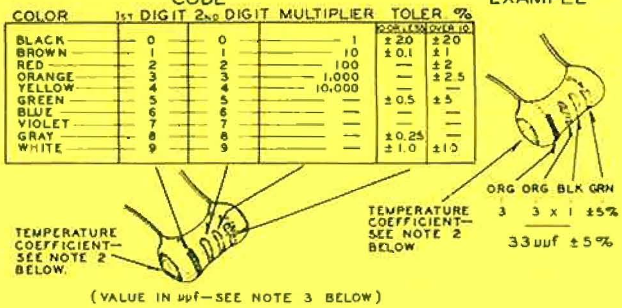


TUBULAR CERAMIC

Place the group of rings or dots to the left and read from left to right.

CODE

COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLER. % 10 OR LESS	TOLER. % OVER 10
BLACK	0	0	1	± 20	± 20
BROWN	1	1	10	± 0.1	± 1
RED	2	2	100	—	± 2
ORANGE	3	3	1,000	—	± 2.5
YELLOW	4	4	10,000	—	—
GREEN	5	5	—	± 0.5	± 5
BLUE	6	6	—	—	—
VIOLET	7	7	—	—	—
GRAY	8	8	—	± 0.25	—
WHITE	9	9	—	± 1.0	± 10



(VALUE IN μμf—SEE NOTE 3 BELOW)

NOTES:

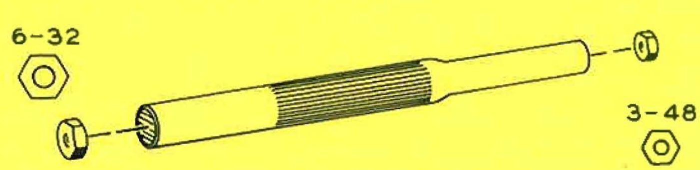
1. The characteristic of a mica capacitor is the temperature coefficient, drift capacitance and insulation resistance. This information is not usually needed to identify a capacitor but, if desired, it can be obtained by referring to EIA Standard, RS-153 (a Standard of Electronic Industries Association.)

2. The temperature coefficient of a capacitor is the predictable change in capacitance with temperature change and is expressed in parts per million per degree centigrade. Refer to EIA Standard, RS-198 (a Standard of Electronic Industries Association.)

3. The farad is the basic unit of capacitance, however capacitor values are generally expressed in terms of μfd (microfarad, .000001 farad) and μμf (micro-micro-farad, .000001 μfd); therefore, 1,000 μμf = .001 μfd, 1,000,000 μμf = 1μfd.

USING A PLASTIC NUT STARTER

A plastic nut starter offers a convenient method of starting the most used sizes: 3/16" and 1/4" (3-48 and 6-32). When the correct end is pushed down over a nut, the pliable tool conforms to the shape of the nut and the nut is gently held while it is being picked up and started on the screw. The tool should only be used to start the nut.



UNDERSTANDING AND USING YOUR

OSCILLOSCOPE

★ ★

One of a series of Learn-by-Doing
TECHNICAL APPLICATION KITS
prepared especially for
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TABLE OF CONTENTS

PREFACE

This kit has been prepared to help you reach a thorough understanding of one of the primary tools of electronics, the oscilloscope. Although the text assumes no previous electrical knowledge on your part, it was written to furnish you with a great deal of useful information, regardless of whether you are experienced in electronics, or just a beginner.

If you are just starting in electronics, this kit should be quite helpful, not only in understanding the oscilloscope, which is important enough to itself, but also in understanding basic electronic circuits. To understand basic electronic circuits is to understand the building blocks of the age of electronics.

If you are already in the electronics field, either as a professional or as an amateur, much of the material presented will be familiar to you, especially in Parts I and III. Even so, it would be well to read these parts to refresh your memory on some of the basic concepts of electronics and oscilloscope theory that you may have forgotten.

Part I of this book offers an introduction to the nature of and the need for oscilloscopes; it also gives oscilloscope operating instructions. Part II gives the complete assembly instructions for the test chassis and the special quick-connect test parts of this kit.

Part III of this book explains the basic theory of electricity The text in each chapter has been prepared to make learning the basic principles of electricity as easy and interesting as possible. To give you practical demonstrations of the concepts involved, Part IV of the book makes use of the basic principles learned in Part III to explain the theory of oscilloscope operation.

Part V of this book gives instructions for maintenance and repairs your oscilloscope might need. Part V should be used with, not in place of the information furnished with your oscilloscope by its manufacturer.

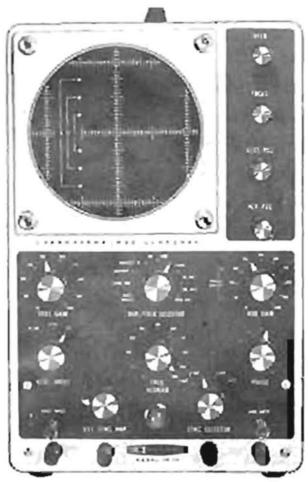
Part VI describes special types of oscilloscopes and oscilloscope applications. After Part VI a Bibliography lists a number of publications where additional information about oscilloscopes can be obtained. A Glossary of Terms provides you with a handy list where you can quickly look up the definitions of common electronic and oscilloscope terms.

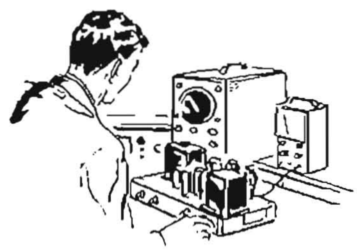
Do not become concerned if your grasp of the ideas in Parts III and IV is vague after the first reading. Unfamiliar concepts have a way of coming into focus after a second reading. During the second reading, however, to be sure that you do have a solid grasp of each idea before proceeding to the next. Do not feel above reading the material a second time, since a thorough knowledge of basic principles is essential to getting the most from your oscilloscope.

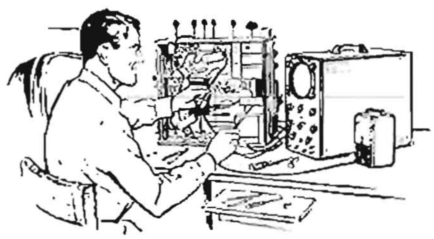
The knowledge gained from this Technical Application Kit should enable you to pursue a hobby in electronics and it may even enable you to do some professional repair work. Since your main purpose in following this text and carrying out the experiments will be to learn, we trust that you will find it a rewarding and satisfying experience.

PART I

An Introduction to the Oscilloscope







CHAPTER 1

The term "oscillation" means the act of fluctuating, or swinging back and forth. The pendulum of a clock is oscillating when it swings to and fro to keep the clock operating. Other oscillations occur all around us in many places. One of the most common examples of an oscillation is shown in the waves that show up when a stone is thrown into a pool of water. These waves, which flow in all directions from where the stone entered the water, are actually oscillations of the water.

Oscillations can also be found in almost all electrical circuits. These electrical oscillations look much like the waves of water when they are seen on an oscilloscope; they increase and decrease in size (amplitude) at a regular rate. Electrical oscillations may occur at almost any rate from less than 10 times per second up to many millions of times per second. The rate at which these electrical oscillations occur is called the "frequency;" it is expressed in cycles per second (cps), thousands of cycles per second (kilocycles, or kc), or millions of cycles per second (megacycles, or mc).

What is an Oscilloscope?

An oscilloscope is an electrical test instrument used to view electrical oscillations on a fluorescent screen. It can also be used to view mechanical and acoustical oscillations if they are first converted into electrical voltages.

The oscillations seen on an oscilloscope are used much like X-rays are used by doctors. X-rays allow a doctor to analyze the inner workings of the human body. The oscilloscope makes it possible for the operator to analyze electronic circuits by looking at the oscillations in the circuit.

Oscilloscopes are used extensively in all places where electrical and electronic circuits are found; in radio and TV service shops, in engineering, in scientific research and development laboratories, and in the production of electronic equipment. Their use is also gradually becoming rather widespread in science classrooms. It is hard to imagine any electronic device being developed today without an oscilloscope being used in the design and development process.

Basic Oscilloscope Principles

The purpose of introducing these basic principles to you at this time is to give you some familiarity with the oscilloscope to enable you to operate the controls more efficiently. Oscilloscope theory will be presented in detail in Part IV.

An oscilloscope has many similarities to your television set; both show you pictures on a fluorescent screen. The fluorescent screen on the picture tube of the television set shows scenes from the television studio. The fluorescent screen on the oscilloscope, instead of showing a scene, shows an electrical waveform. This waveform will be from the circuit being tested by the oscilloscope.

The fluorescent screen is contained on the face of a special tube called a cathode ray tube (Figure 1-2). A stream of electrons from the base of the tube is directed against the fluorescent coating, causing a spot of light to appear on the face of the tube. The spot of light is then moved vertically and horizontally on the tube by the horizontal and vertical circuits of the oscilloscope to make a line.

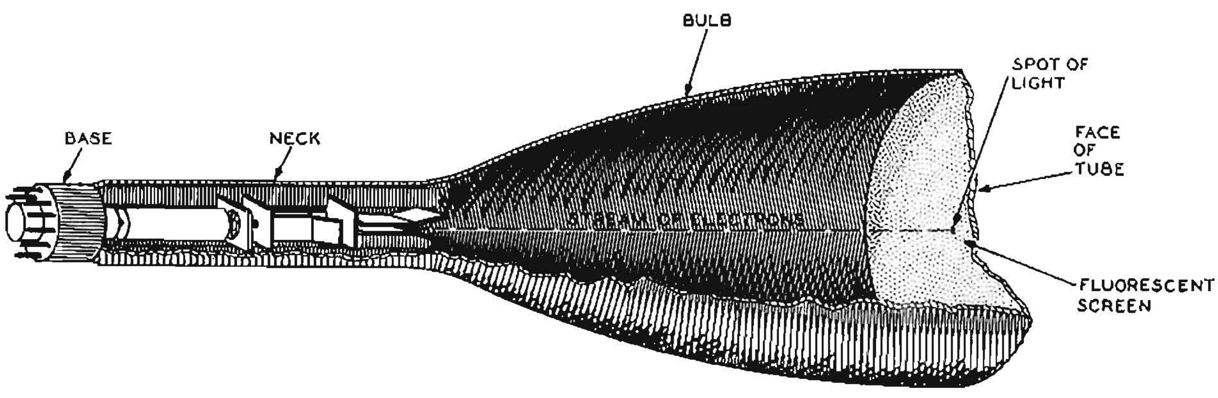


Figure 1-2

An easy way to think of this spot of light would be to compare it to the spot of light made by the beam from a flashlight on a wall. By moving the flashlight beam horizontally and vertically, different wave patterns could be traced on the wall. If the wall were of a fluorescent material, these waveforms would stay visible for a while after the light had been removed. The line, or waveform, on a cathode ray tube stays visible in this same manner, while the spot sweeps back and forth.

Figure 1-3 shows that the horizontal circuits cause the spot of light to move back and forth across the tube horizontally. The vertical circuits cause the spot to move vertically on the face of the tube.

Suppose a circuit is to be tested by the oscilloscope to see if it contains the correct waveform. First, test leads would be connected from the vertical input of the oscilloscope to the circuit. If the waveform in the circuit had a "frequency" of 500 times per second (500 cps), you would adjust the controls so the horizontal circuits would move the spot back and forth 500 times per second. The spot would then be moving across the fluorescent coating at the same rate as the waveform being tested. The oscilloscope vertical amplifier would then amplify (enlarge) the test waveform, and cause the spot to move up and down to match the waves in the test waveform. Thus, the test waveform would appear to be standing still on the face of the cathode ray tube.

The vertical and horizontal circuits of an oscilloscope control the spot on the cathode ray tube just as you might do with a flashlight if you followed the motion of a fly across a wall. The illuminated spot would have to be moved across the wall horizontally, at the same speed as the fly, to keep the fly in the beam of the flashlight. The spot would also have to be moved vertically when the fly moved vertically. This type of vertical and horizontal motion is controlled in the oscilloscope by the horizontal and vertical circuits.

NOTE: If your oscilloscope is in kit form, it should be assembled now, before proceeding with the following chapter.

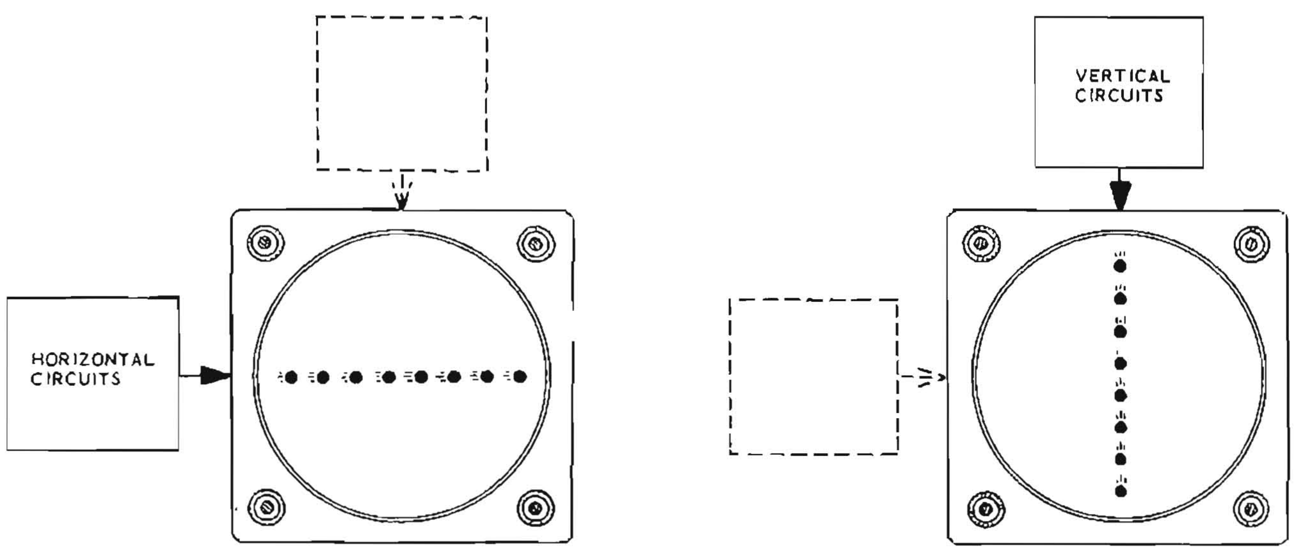


Figure 1-3

CHAPTER 2

Oscilloscope Operation

This book uses the Heathkit Model IO-12 Oscilloscope in all drawings as an example of a typical oscilloscope. No matter what make or model oscilloscope you have, you will find that it has most of the same controls, but they may be in different locations.

Figure 1-4 shows the front panel of a typical oscilloscope. Note that the controls are divided into groups, or sections. At the upper right is a group of controls that adjusts the spot and its position. At the left is a group of controls that adjusts the vertical size; at the right is a group that changes the horizontal width and frequency. At the bottom of the panel is a group called the synchronization controls. Now look at your own oscilloscope; if it is different from this model, establish the location of each of the controls. Some oscilloscopes do not have all of these controls and some may have additional controls. Also, some oscilloscopes have some of their controls on the chassis and not on the front panel.

Spot Controls

INTENSITY. The Intensity control is used to adjust the brightness of the spot on the screen.

FOCUS. The Focus control is adjusted to define the spot sharply on the fluorescent screen. The overall result of a sharply focused spot is a sharp clear image of a waveform.

VERTICAL POSITION. The Vertical Position control (often called the Vertical Centering control) adjusts the position of the spot vertically on the fluorescent screen.

HORIZONTAL POSITION. The Horizontal Position control (also called the Horizontal Centering control) adjusts the position of the spot horizontally on the fluorescent screen.

Each of these position controls moves the whole waveform on the oscilloscope screen.

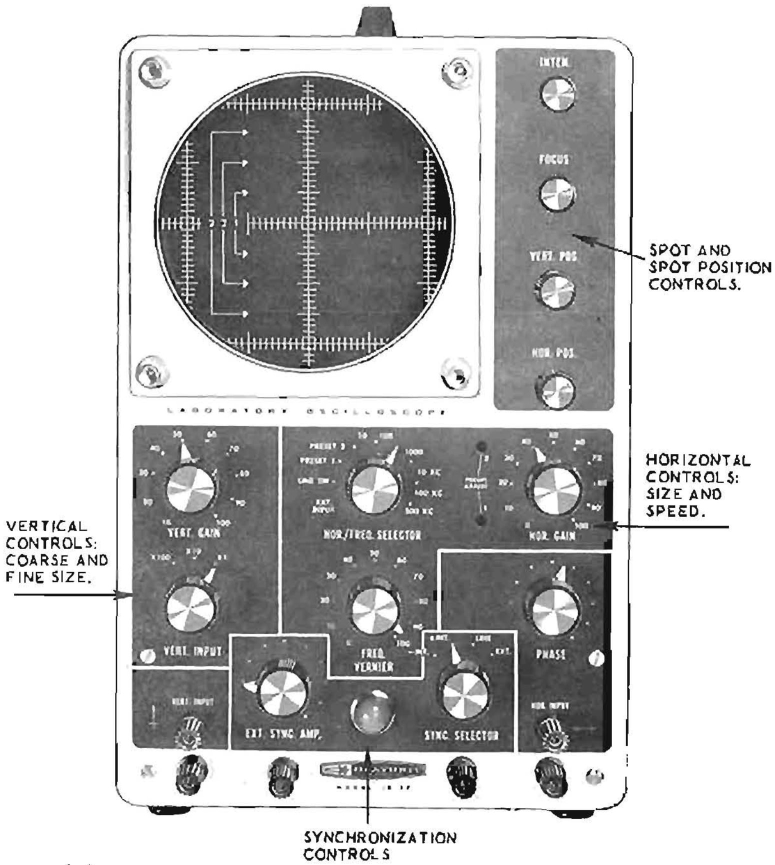


Figure 1-4

The Vertical Controls

VERTICAL INPUT. The Vertical Input switch is a coarse adjustment for the vertical size of any waveform that appears on the oscilloscope. The signal will appear largest when the switch is in the "X1" position. The signal will appear smallest when the switch is in the "X100" position.

VERTICAL GAIN. The Vertical Gain control is a fine adjustment of the vertical size of any waveform that appears on the oscilloscope.

Horizontal Controls

HORIZONTAL FREQUENCY. The Horizontal Frequency selector is a coarse adjustment of how many times per second the spot will be swept across the face of the scope. The slowest horizontal speed is at the position shown by the dot near the number 10. The highest horizontal speed is shown by the dot at the position near 500 kc. The terms preset 1, preset 2, line sweep and external sweep are for special applications and will be discussed in Part IV.

FREQUENCY VERNIER. The Frequency Vernier control is a fine adjustment of the horizontal speed (frequency) of the spot.

HORIZONTAL GAIN. The Horizontal Gain control adjusts the width of the waveform or the line on the oscilloscope.

Synchronization Controls

The simplest way of explaining synchronization at this point would be with an anology. The frequency of the spot on the face of the tube and the frequency of the waveform to be tested could be compared to two cars driving beside each other on the highway. To stay exactly side by side, the two cars would have to drive at exactly the same speed. One of these cars could represent the speed of the spot and the other car could represent the speed of the signal being tested. A very slight adjustment in speed would make one car pull in front of or fall behind the other car.

Synchronizing the spot and test frequencies would lock them together, just like placing a bar between the two cars would lock them at exactly the same speed. First, the horizontal controls would adjust the frequency of the spot to be exactly the same as the frequency of the test signal; then the synchronization controls would be adjusted to lock the two frequencies together.

SYNC SELECTOR. The Sync Selector selects different ways in which synchronization can be accomplished. Normally, either "+ internal" or "- internal" positions are used. The operation of this control will be explained in detail in Part IV of the manual.

EXTERNAL SYNC AMPLITUDE. Operation of this control will also be explained in detail in Part IV.

Other Controls

PHASE. This control is only used for special applications; its uses will be explained in Parts IV and VI.

The following are some of the additional types of controls that are often found on oscilloscopes.

ASTIGMATISM. An Astigmatism control operates much like the Focus control of an oscilloscope. Where the focus control adjusts the spot for a good sharp image on the face of the tube, the astigmatism control adjusts the spot to make sure it is round. This helps to give greater clarity to waveforms viewed on the oscilloscope.

TRIGGERING. Triggering controls operate much like synchronization controls in that they lock the frequency of the spot to the frequency of the signal being tested. Generally the manual received with the oscilloscope must be studied for proper operation of triggering controls, since there are many different methods of using these controls.

Safety

Safety is an important consideration in any electrical work, especially when high voltages are involved. Though the human body may be a wondrous mechanism, it was not designed to be a conductor of electric current. Always bear in mind that high voltages may appear in unpredictable places when you are testing defective equipment.

A foolproof rule to follow is to never touch two parts of a live circuit or any part of a live circuit and a ground connection (such as metal workbench, water pipe, or the ground connection in the circuit itself) at the same time. If you do, you become part of the circuit.

Always make the common (ground) test lead connection first. When making connections with alligator clips or when positioning probes, it is best to keep one hand in your pocket. A rubber mat on the floor around your workbench will prevent you from becoming a ground connection in this way, but this is only an additional precaution and does not insure your safety. Thorough knowledge of the circuit in which you are working will make you aware and wary of especially dangerous points.

When examining or repairing a piece of electronic equipment, do not make the mistake of assuming that you are safe from an electrical shock simply because the equipment is turned off or unplugged. This is not always the case. Many pieces of electronic equipment contain capacitors as part of their circuitry. As you will learn in Part III, the capacitor is a device that stores electrical energy. Thus, capacitors often stay charged, especially in faulty equipment, even after the equipment has been unplugged. If your body should complete a circuit between two ends of a capacitor, a high voltage discharge will pass through you. It is a good idea to use a piece of hookup wire or a screwdriver blade to discharge any capacitors in the circuit in which you are working.

EXPERIMENT 1-1

Turn on your oscilloscope in order to familiarize yourself with the controls by operating them. Usually, oscilloscopes are turned on by turning the Intensity control clockwise; after warmup, turn the intensity up until a spot or line is visible on the cathode ray tube.

CAUTION: If a spot is left for a long time at the same place on a tube, it will cause a burned spot to develop. If only a spot is visible, turn the Horizontal Gain control until a line shows that is about as wide as the face of the tube. Do not have the Horizontal Frequency selector in the External position, or a line will not appear.

Normally, the first thing to do after the oscilloscope is turned on is to adjust the spot controls for a sharp clear line. Next, adjust the position controls so the line is centered on the cathode ray tube. Connect a signal to the Vertical Input binding post. This signal may be of any frequency from a RF or AF generator (if one is available) or it may be a 60 cps signal from one of the following other sources.

Often, oscilloscopes will have a test voltage binding post on the front panel, marked "1 volt P-P" or "6 Volt test." If your oscilloscope has such a post, connect a wire from it to the Vert Input binding post.

If there is no other signal available, touch the Vert Input binding post with your finger (normally there is no shock danger anywhere on the front panel); this will introduce a 60 cps stray pickup signal into the oscilloscope.

Turn the vertical controls until you see the waveform about half as high as the face of the cathode ray tube.

Adjust the Horizontal Frequency and Frequency Vernier controls until two or three complete waveforms appear.

Turn the Sync Selector to the "+ Internal" position. If your oscilloscope has a sync amplitude control (not marked external sync amplitude; these are for special applications only), it should be turned up from the zero position just until the signal on your cathode ray tube is locked in place, and stops moving.

The signal is now being displayed on your oscilloscope. A stray pickup signal of course, will not be very stable in size, but it will still help you to learn the uses of the controls. Practice "tuning in" waveforms in the above manner until the different control functions become familiar.

PART II

Test Chassis and Parts Assembly

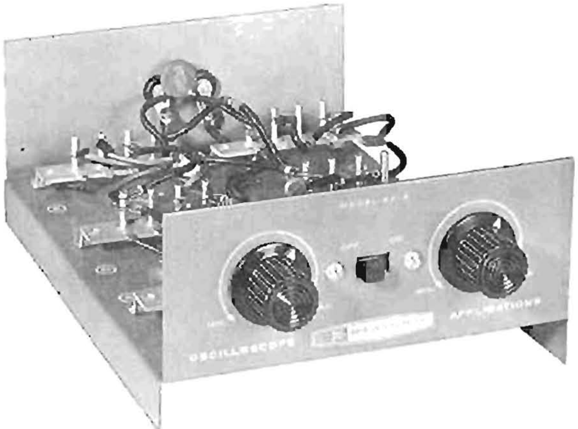


Figure 2-1

The Test Chassis and parts that you assemble in this section will be used to conduct the experiments in Parts III and IV. The quick-connect parts and terminals allow many different circuits to be connected on the chassis. This system allows circuits to be constructed quickly. It also helps to take away the drudgery of repeatedly soldering and unsoldering parts from solder terminals.

SPECIFICATIONS

Test Chassis.	Terminal strips, controls, coil, switch, and output terminals are permanently installed on the Test Chassis.
Clip-on Parts.	3 transistors, 17 resistors, 9 capacitors; extra clips, wire and sleeving also furnished.
Controls.	1 - 100 KΩ control. 1 - 20 KΩ control. 1 - OFF-ON switch.
Power Supply.	2-size AA 1.5 volt penlight batteries mounted in a holder on the Test Chassis.
Overall Dimensions.	6-1/8" wide x 9" deep x 3" high.
Net Weight.	1-1/2 lbs.

AUDIO OSCILLATOR SCHEMATIC

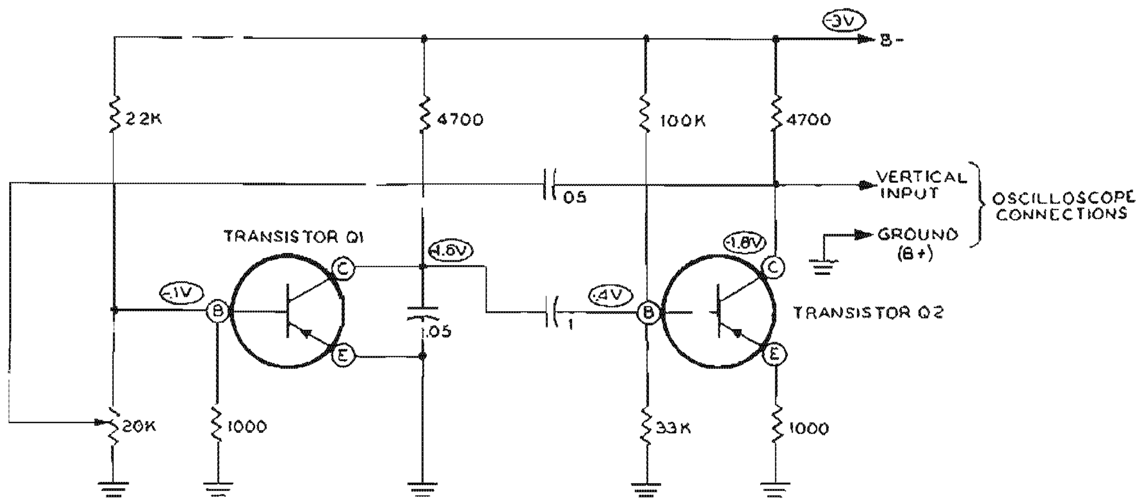


Figure 2-2

The schematic shown above is for the audio oscillator circuit that will be assembled on the Test Chassis in this section. A thorough description of this circuit is included in Chapter 8 of Part III.

CONSTRUCTION NOTES

UNPACK THE KIT CAREFULLY AND CHECK EACH PART AGAINST THE PARTS LIST. In doing this you will become acquainted with the parts. Refer to the information on the inside covers of the manual to help you identify the components. If some shortage or parts damage is found in checking the Parts List, please read the Replacements section and supply the information called for therein. Include all inspection slips in your letter to us.

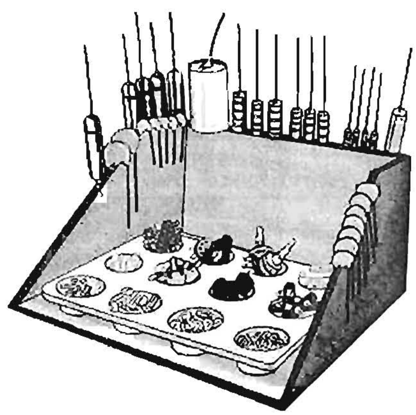
Resistors generally have a tolerance rating of 10% unless otherwise stated in the Parts List. Tolerances on capacitors are generally even greater.

We suggest that you do the following before work is started:

1. Lay out all parts so that they are readily available.

2. Provide yourself with good quality tools. Basic tool requirements consist of a screwdriver with a 1/4" blade; a small screwdriver with a 1/8" blade; long-nose pliers; wire cutters, preferably separate diagonal cutters; a penknife or a tool for stripping insulation from wires; a soldering iron (or gun) and rosin core solder.

Many kit builders find it helpful to separate the various parts into convenient categories. Muffin tins or molded egg cartons make convenient trays for small parts. Resistors and capacitors may be placed with their lead ends inserted in the edge of a piece of corrugated cardboard until they are needed. Values can be written on the cardboard next to each component. The illustration shows one method that may be used.



PARTS LIST

The numbers in parentheses in the Parts List are keyed to the numbers on the Parts Pictorial to aid in parts identification. The values of resistors are given in ohms (Ω), K mean to multiply by 1000: the values of capacitors are given in microfarads (μfd) or micro-microfarads (μμf).

PART No.	PARTS Per Kit	DESCRIPTION
Resistors		
(1) 1-66	2	150 Ω (brown-green-brown)
1-9	2	1000 Ω (brown-black-red)
1-44	1	2200 Ω (red-red-red)
1-16	2	4700 Ω (yellow-violet-red)
1-19	1	6800 Ω (blue-gray-red)
1-22	4	22 KΩ (red-red-orange)
1-24	1	33 KΩ (orange-orange-orange)
1-25	3	47 KΩ (yellow-violet-orange)
1-26	2	100 KΩ (brown-black-yellow)
1-31	1	330 KΩ (orange-orange-yellow)
Capacitors		
21-56	1	470 μμf disc
21-14	1	.001 μfd disc
21-47	2	.01 μfd disc
21-48	3	.05 μfd disc
21-95	2	.1 μfd disc
Hardware		
(3) 250-56	20	6-32 screw
(4) 252-3	20	6-32 nut
(5) 252-7	2	Control nut
(6) 253-1	4	Flat fiber washer
(7) 253-2	4	Fiber shoulder washer
(8) 253-10	2	Control flat washer
(9) 254-1	14	#6 lockwasher
(10) 254-4	2	Control lockwasher
(11) 258-33	1	Battery retaining spring
(12) 259-1	6	#6 solder lug
(13) 260-37	82	Spring clip

PART No.	PARTS Per Kit	DESCRIPTION
Wire-sleeving		
340-2	1	Length bare wire
344-21	1	Length hookup wire
(14) 346-1	1	Length black sleeving, fiberglas lining
(15) 346-19	1	Length black sleeving, pure plastic (no lining)
(16) 346-4	1	Length black sleeving, fiber type
Miscellaneous		
(17) 10-10	1	20 KΩ control
10-40	1	100 KΩ control
(18) 40-383	1	Oscillator coil
(19) 60-1	1	Slide switch
(20) 1401-36	1	Earphone
(21) 417-35	3	Transistor
474-5	1	Magnet
(22) 73-4	2	Grommet
(23) 75-17	4	Binding post insulator
(24) 427-2	2	Binding post base
(25) 100-M16B	1	Black binding post cap
100-M16R	1	Red binding post cap
200-M368F848-849-851	1	Chassis
(26) 214-M15	1	Battery bracket
331-6		Solder
390-120	1	Battery label
(27) 431-65	6	Terminal strip
462-52	2	Knob
(28) 490-1	1	Alignment tool
595-604	1	Manual

NOTE: Two size AA 1.5 volt penlight batteries will also be needed before your test chassis can be put in operation. By purchasing them now, you will be able to use your Test Chassis as soon as assembly is completed.

PROPER SOLDERING TECHNIQUES

Only a small percentage of customers find it necessary to return equipment for factory service. By far the largest portion of malfunctions in this equipment are due to poor or improper soldering.

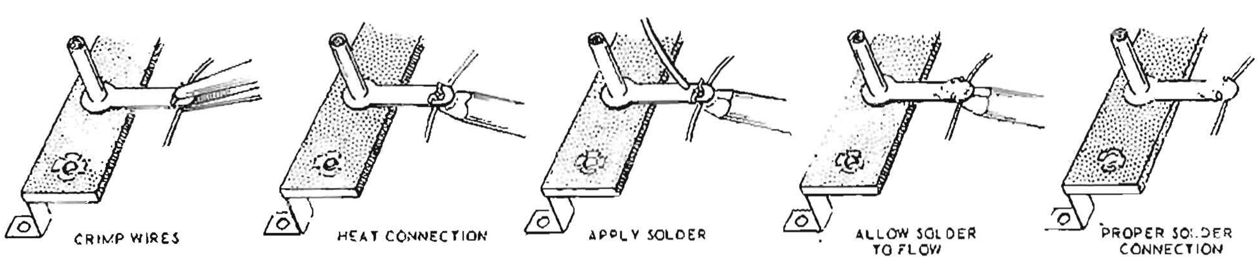
If terminals are bright and clean and free of wax, frayed insulation and other foreign substances, no difficulty will be experienced in soldering. Correctly soldered connections are essential if the performance engineered into a kit is to be fully realized. If you are a beginner with no experience in soldering, a half hour's practice with some odd lengths of wire may be a worthwhile investment.

For most wiring, a 25 to 100 watt iron or its equivalent in a soldering gun is very satisfactory. A lower wattage iron than this may not heat the connection enough to flow the solder smoothly. Keep the iron tip clean by wiping it from time to time with a cloth.

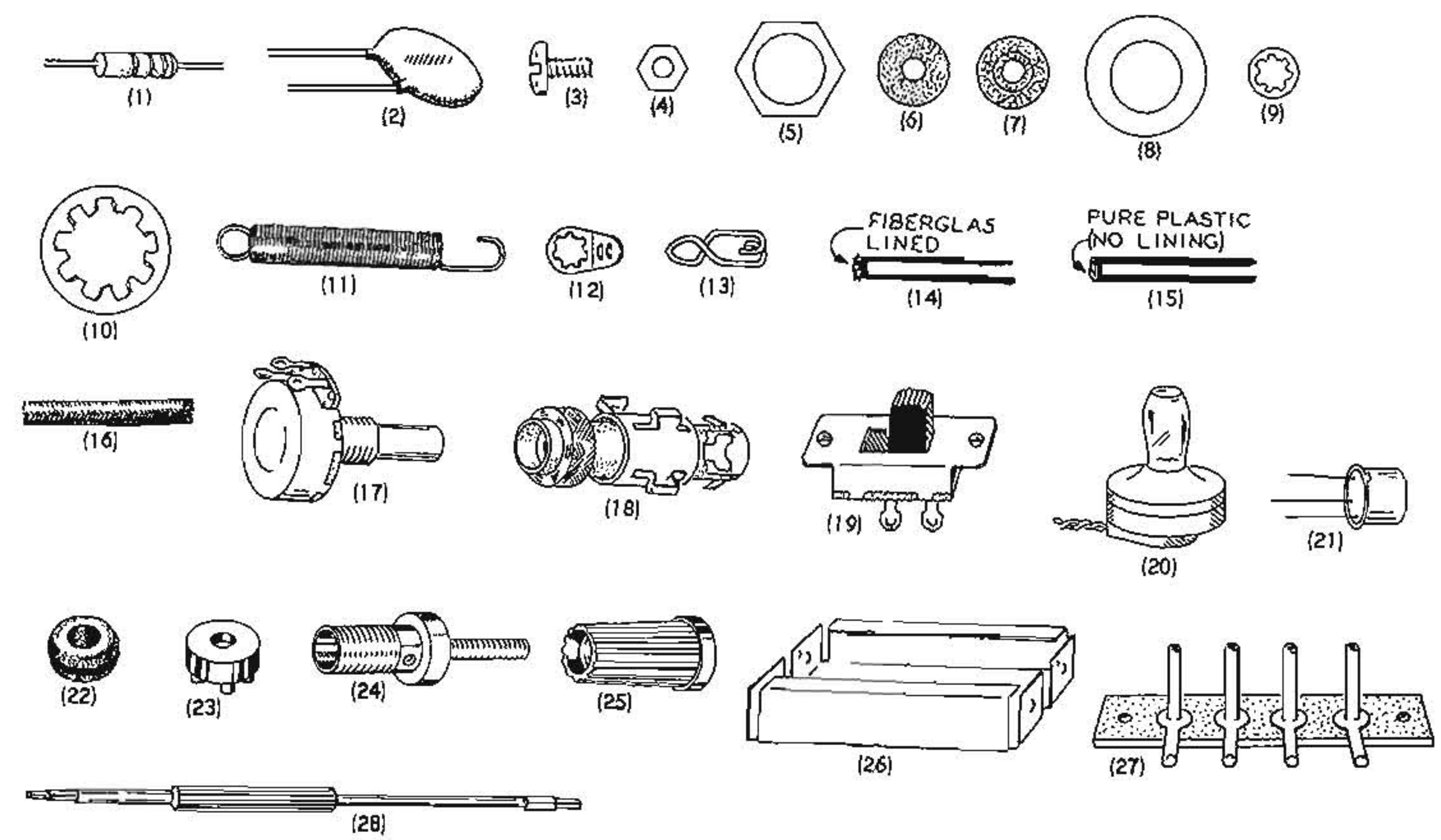
Chassis Wiring and Soldering

1. Unless otherwise indicated, all wire used is the type with colored insulation (hookup wire). In preparing a length of hookup wire, 1/4" of insulation should be removed from each end unless directed otherwise in the assembly step.
2. Crimp or bend the lead (or leads) around the terminal to form a good joint without relying on solder for physical strength. If the lead is too large to allow bending or if the step states that it is not to be crimped, position it so that a good solder connection can still be made.
3. Position the work, if possible, so that gravity will help to keep the solder where you want it.
4. Place a flat side of the soldering iron tip against the joint to be soldered until it is heated sufficiently to melt the solder.
5. Then place the solder against the terminal and it will immediately flow over the joint; use only enough solder to thoroughly wet the junction. It is usually not necessary to fill the entire hole in the terminal with solder.
6. Remove the solder and then the iron from the completed joint. Use care not to move the leads until the solder is solidified.

A poor or cold solder joint will usually look crystalline and have a grainy texture, or the solder will stand up in a blob and will not have adhered to the joint. Such joints should be reheated until the solder flows smoothly. In some cases, it may be necessary to add a little more solder to achieve a smooth, bright appearance.



PARTS PICTORIAL



ROSIN CORE SOLDER HAS BEEN SUPPLIED WITH THIS KIT. THIS TYPE OF SOLDER MUST BE USED FOR ALL SOLDERING IN THIS KIT. ALL GUARANTEES ARE VOIDED AND WE WILL NOT REPAIR OR SERVICE EQUIPMENT IN WHICH ACID CORE SOLDER OR PASTE FLUXES HAVE BEEN USED. IF ADDITIONAL SOLDER IS NEEDED, BE SURE TO PURCHASE ROSIN CORE (60:40 or 50:50 TIN-LEAD CONTENT) RADIO TYPE SOLDER.

STEP-BY-STEP PROCEDURE

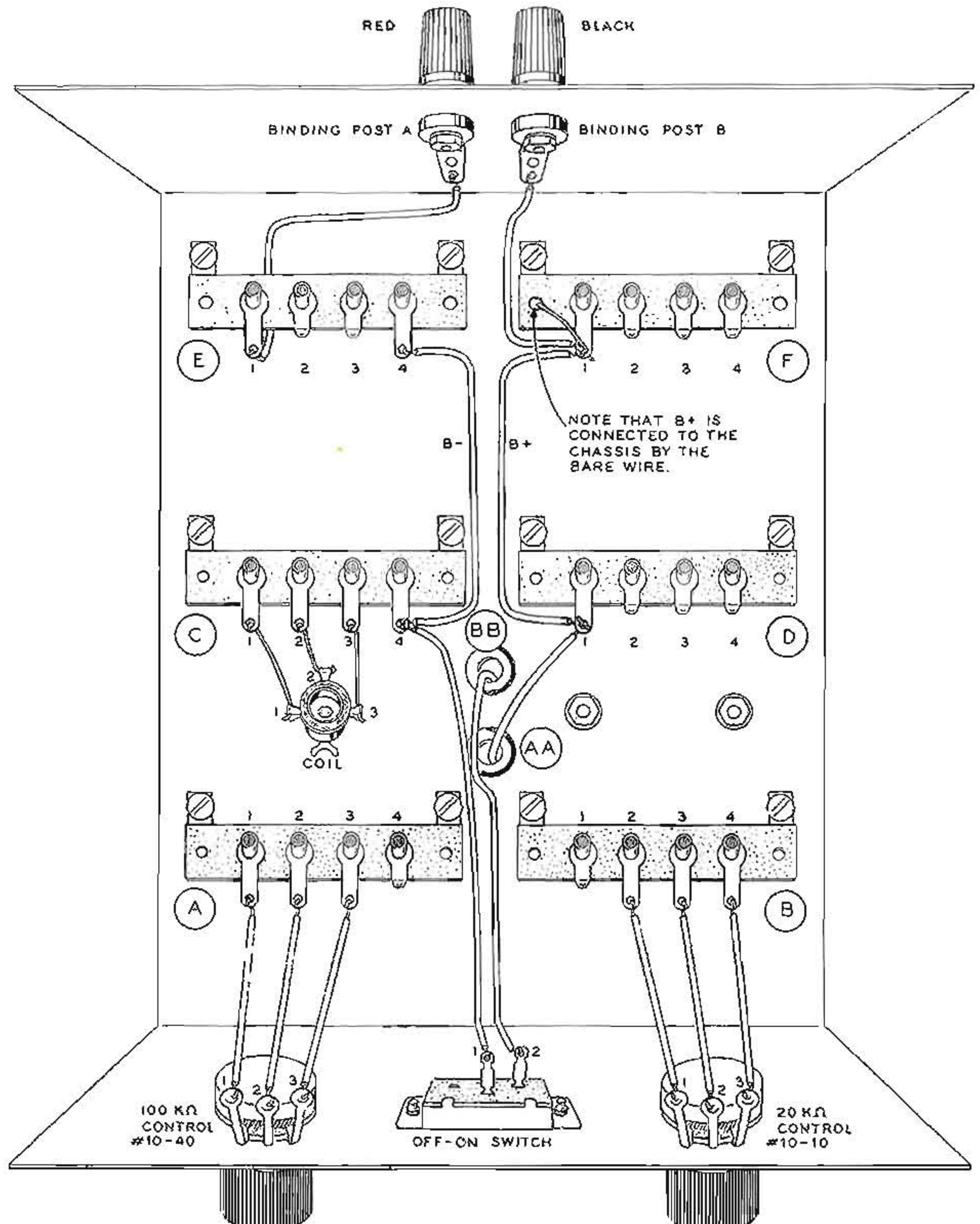
The following instructions are presented in a logical step-by-step sequence to enable you to complete your kit with the least possible confusion. Be sure to read each step all the way through before beginning the specified operation. Also read several steps ahead of the actual step being performed. This will familiarize you with the relationship of the subsequent operations. When the step is completed, check it off in the space provided. This is particularly important as it may prevent errors or omissions, especially if your work is interrupted. Some kit builders have also found it helpful to mark each wire and part in colored pencil on the Pictorial as it is added.

Illustrations

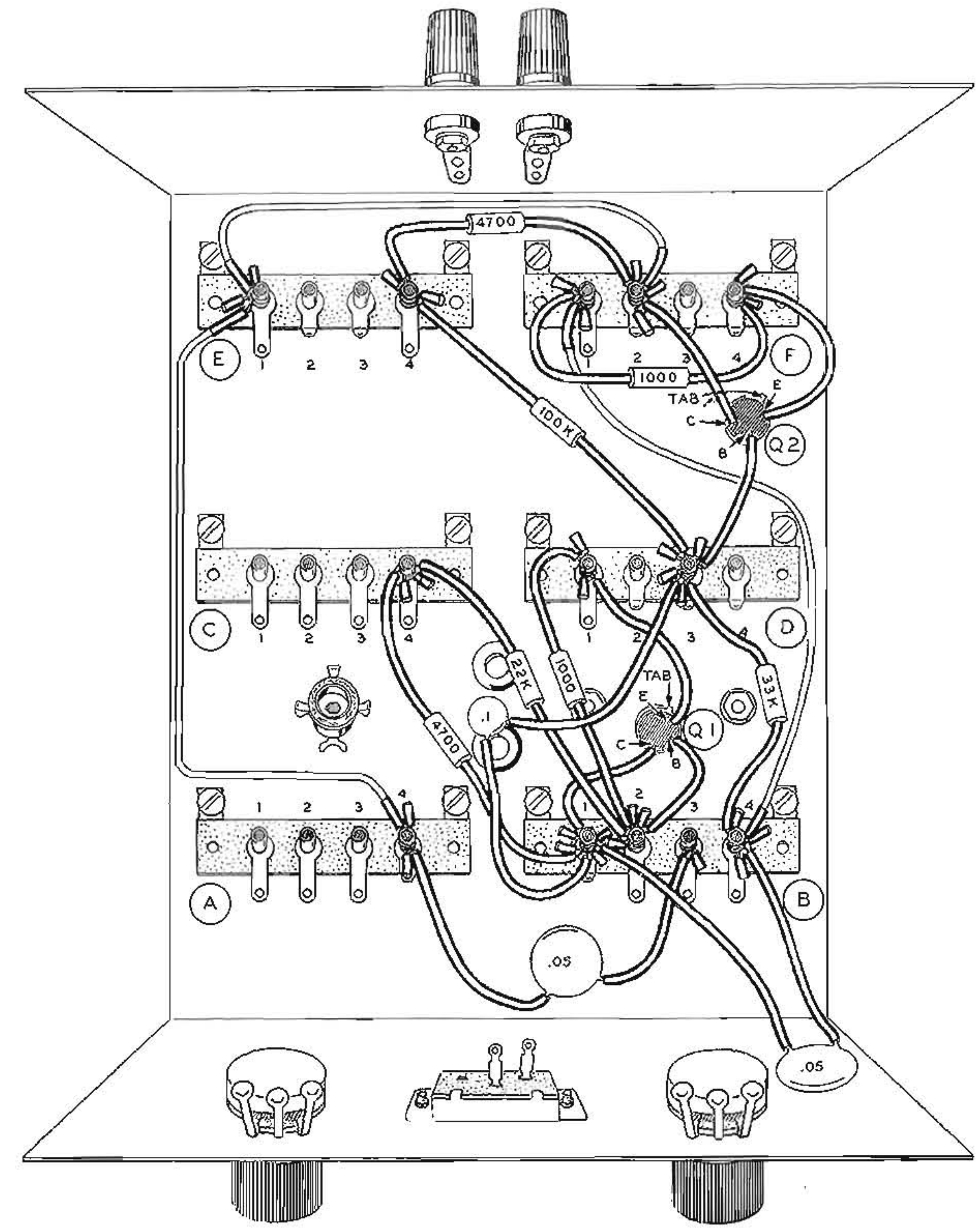
The fold-out diagrams in this manual may be removed and attached to the wall above your working area; but because they are an integral part of the instructions, they should be returned to the manual after the kit is completed. In general, the illustrations in this manual correspond to the actual configuration of the kit; however, in some instances the illustrations may be slightly distorted to facilitate clearly showing all of the parts.

Soldering

The abbreviation "NS" indicates that a connection should not be soldered yet as other wires will be added. When the last wire is installed, the terminal should be soldered and the abbreviation "S" is used to indicate this. Note that a number will appear after each solder instruction. This number indicates the number of leads that are supposed to be connected to the terminal before it is soldered. For example, if the instruction reads, "Connect a wire to lug 1 (S-2)," it will be understood that there will be two wires connected to the terminal at the time it is soldered. The steps directing the installation of resistors include color codes to help identify the parts.



Pictorial 2-1



Pictorial 2-3

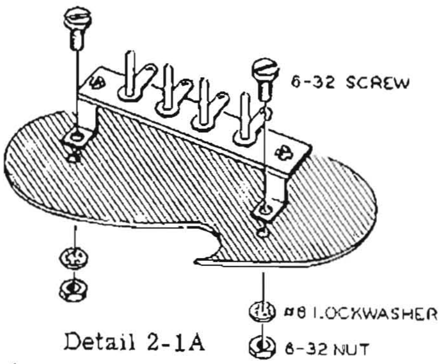
STEP-BY-STEP ASSEMBLY

Mechanical Assembly

Refer to Pictorial 2-1 for the following steps.

( ) Install grommets at AA and BB.

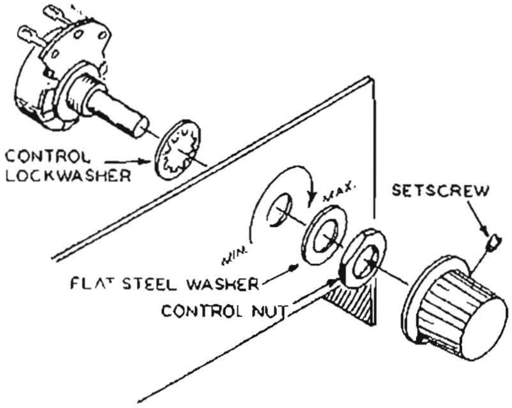
( ) Install the six terminal strips as shown in Detail 2-1A, with 6-32 screws, #6 lock-washers, and 6-32 nuts.



Detail 2-1A

( ) Mount the 20 KΩ control (#10-10) and the 100 KΩ control (#10-40) on the front panel as shown in Detail 2-1B, with control lock-washers, control flat washers, and control nuts. Turn the shafts of the controls to their full counterclockwise positions.

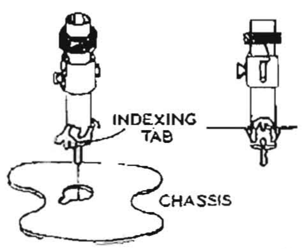
( ) Install a knob on each control shaft. Position each knob so its pointer points toward the word MIN, and then tighten the setscrew.



Detail 2-1B

( ) Mount the slide switch on the front panel by installing two 6-32 screws through the front panel holes, into the tapped holes on the switch. Be sure the lugs are in the position shown.

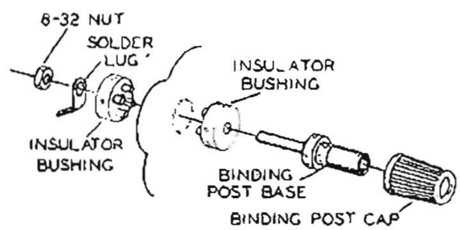
( ) Install the coil as shown in Detail 2-1C. Be sure the indexing tab has been installed in the slot, then move the coil back and forth sideways until the side tabs snap into place.



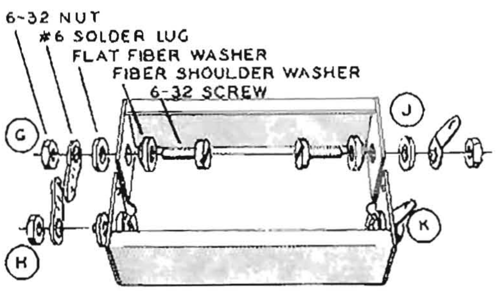
Detail 2-1C

( ) Install the binding post bases on the rear panel as shown in Detail 2-1D. Place the solder lugs as shown.

( ) Install red and black binding post caps on the binding post bases as shown.



Detail 2-1D



Detail 2-1E

( ) Locate the battery bracket and position it as shown in Detail 2-1E.

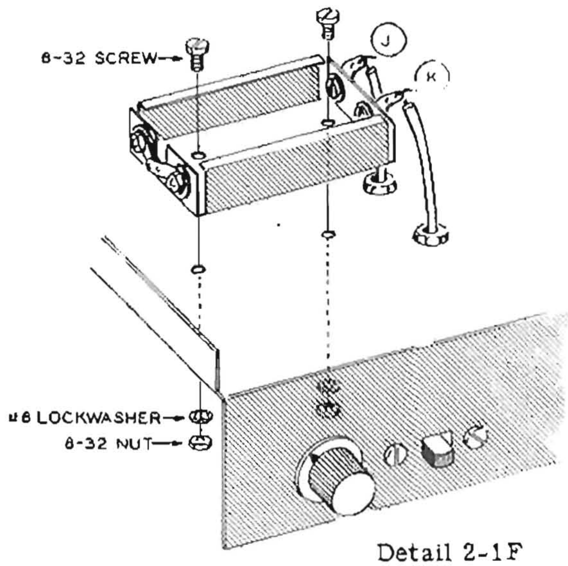
( ) Mount two #6 solder lugs on each end of the battery bracket. Use a 6-32 screw, a fiber shoulder washer with the shoulder centered in the hole, a fiber flat washer, a #6 solder lug, and a 6-32 nut for each mounting. Before tightening, bend solder lugs G and H until they overlap. Now solder them together. Be sure the soldered connection does not touch the battery bracket.

( ) Install the battery bracket on the bottom of the chassis as shown in Detail 2-1F. Fasten it in place with 6-32 screws, #6 lockwashers and 6-32 nuts. Be sure to bend lugs J and K over as they are shown.

( ) Remove the paper backing from the battery label and place the label in the bottom of the battery housing.

In each of the following steps using hookup wire, cut the hookup wire to the length indicated in the step and then remove 1/4" of insulation from each end.

( ) Insert one end of a 2-1/4" hookup wire down through grommet AA and connect it to lug K of the battery bracket (S-1). Connect the other end of this wire to the solder tab on lug 1 of terminal strip D (NS).



Detail 2-1F

( ) Insert one end of a 4-1/4" hookup wire down through grommet BB and connect it to lug J of the battery bracket (S-1). Connect the other end of this wire to lug 2 of the OFF-ON switch (S-1).

NOTE: In the following steps, connections should be made to the solder tabs as shown, not to the terminal pins. Refer to Pictorial 2-1.

( ) Connect a 4-1/2" hookup wire from lug 1 of terminal strip D (S-2) to lug 1 of terminal strip F (NS).

( ) Connect a 3-1/2" hookup wire from lug 1 of terminal strip F (NS) to binding post B (S-1).

( ) Connect a 1-1/2" bare wire from lug 1 (S-3) to the eyelet at the end of terminal strip F (S-1).

( ) Connect a 4-1/2" hookup wire from lug 1 of terminal strip E (S-1) to the lug of binding post A (S-1).

( ) Connect a 4-1/2" hookup wire from lug 4 of terminal strip E (S-1) to lug 4 of terminal strip C (NS).

( ) Connect a 5-1/2" hookup wire from lug 4 of terminal strip C (S-2) to lug 1 of the OFF-ON switch (S-1).

( ) Insert one end of a bare wire through lug 2 of terminal strip C (NS) to lug 2 of the coil (S-1). Now solder the wire to lug 2 of the terminal strip (S-1) and clip off the excess wire.

( ) Insert one end of a bare wire through lug 1 of terminal strip C (NS) to lug 1 of the coil (S-1). Now solder the wire to lug 1 of the terminal strip (S-1) and cut off the excess wire.

( ) Insert one end of a bare wire through lug 3 of terminal strip C (NS) to lug 3 of the coil (S-1). Now solder the wire to lug 3 of the terminal strip (S-1) and cut off the excess wire.

( ) Connect a 2-1/4" hookup wire from lug 1 of terminal strip A (S-1) to lug 1 of the 100 KΩ control (S-1).

( ) Connect a 2-1/4" hookup wire from lug 2 of terminal strip A (S-1) to lug 2 of the 100 KΩ control (S-1).

( ) Connect a 2-1/4" hookup wire from lug 3 of terminal strip A (S-1) to lug 3 of the 100 KΩ control (S-1).

( ) Connect a 2-1/4" hookup wire, from lug 2 of terminal strip B (S-1) to lug 1 of the 20 KΩ control (S-1).

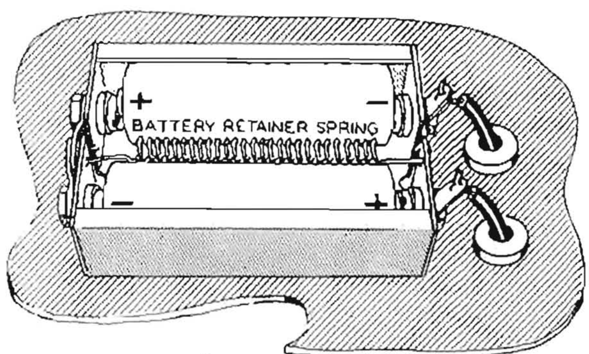
( ) Connect a 2-1/4" hookup wire from lug 3 of terminal strip B (S-1) to lug 2 of the 20 KΩ control (S-1).

( ) Connect a 2-1/2" hookup wire from lug 4 of terminal strip B (S-1) to lug 3 of the 20 KΩ control (S-1).

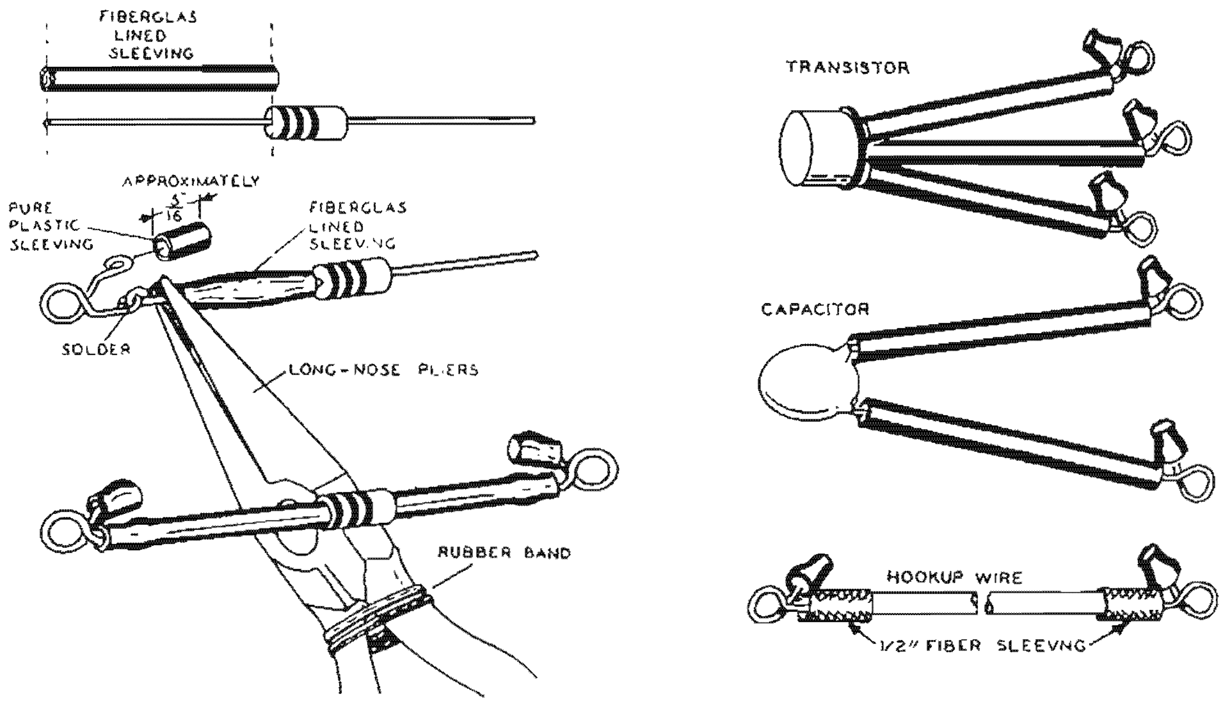
( ) Bend all of the unused solder tabs down as they are shown in the Pictorial. Be sure these tabs do not touch the metal of the chassis.

This completes the permanent wiring on your Test Chassis.

( ) Install two penlight batteries in the battery housing as shown in Detail 2-1G. Install the battery retainer spring as shown. If the batteries do not make good contact against the terminal screws, bend the ends of the battery housing inward a small amount.



Detail 2-1G



Pictorial 2-2

Quick-connect Parts Assembly

Refer to Pictorial 2-2 for the following steps.

Install clips and sleeving on the leads of each resistor and capacitor as directed in the following four steps.

1. Cut some fiberglas lined sleeving to the same length as the lead and put this sleeving over the lead.

2. Press the sleeving back toward the body of the resistor or capacitor, and fasten the end of the lead to one of the eyes in the clip.

3. Holding the lead with pliers with a rubber band placed around the handle, solder the clip and lead together.

4. Slide the sleeving over the solder connection. Place a 5/16" length (approximately) of pure plastic sleeving over the other eye of the clip.

( ) Install clips and sleeving on each lead of each transistor in the same manner.

( ) Prepare three 3-1/4" and three 6" connecting wires as shown. Place 1/2" length fiber sleeving over the ends of the lead before attaching and soldering the clips. After the clips are soldered, slide the lengths of fiber sleeving over the solder joints. Install short lengths of pure plastic sleeving over the other eye of each clip.

( ) Install clips on the earphone leads, using 1/2" lengths of fiber sleeving and 5/16" lengths of pure plastic sleeving.

Audio Oscillator Assembly

NOTE: Make sure the slide switch is in the OFF position.

Refer to Pictorial 2-3 (fold-out from Page 12) for the following steps.

( ) Clip a 6" wire from lug 1 of terminal strip E to lug 2 of terminal strip F.

( ) Clip a 6" wire from lug 1 of terminal strip E to lug 4 of terminal strip A.

( ) Clip a 6" wire from lug 1 of terminal strip F to lug 4 of terminal strip B.

( ) Clip a 4700 Ω (yellow-violet-red) resistor between lug 4 of terminal strip E and lug 2 of terminal strip F. The yellow color will be near the wire lead at one end of the resistor. The fourth color band refers to tolerance. Refer to the front cover of your manual.

( ) Clip a 1000 Ω (brown-black-red) resistor between lugs 1 and 4 of terminal strip F.

( ) Clip a 100 KΩ (brown-black-yellow) resistor between lug 4 of terminal strip E and lug 3 of terminal strip D.

( ) Clip a 4700 Ω (yellow-violet-red) resistor between lug 4 of terminal strip C and lug 1 of terminal strip B.

( ) Clip a 22 KΩ (red-red-orange) resistor between lug 4 of terminal strip C and lug 2 of terminal strip B.

( ) Clip a 1000 Ω (brown-black-red) resistor between lug 1 of terminal strip D and lug 2 of terminal strip B.

( ) Clip a 33 KΩ (orange-orange-orange) resistor between lug 3 of terminal strip D and lug 4 of terminal strip B.

( ) Clip a .1 μfd capacitor between lug 3 of terminal strip D and lug 1 of terminal strip B.

( ) Clip a .05 μfd capacitor between lug 4 of terminal strip A and lug 3 of terminal strip B.

( ) Clip a .05 μfd capacitor between lugs 1 and 4 of terminal strip B.

In this book the transistors are identified by the symbols Q1 and Q2; the transistor leads are referred to by the letters E (emitter), B (base), and C (collector). These letters are not actually marked on the transistors, but the leads can be identified by looking at Pictorial 2-3 and counting the leads from the small tab on the transistors.

( ) Install transistor Q2. Clip lead C to lug 2 and lead E to lug 4 of terminal strip F. Clip lead B to lug 3 of terminal strip D.

( ) Install transistor Q1. Clip lead C to lug 1 and lead B to lug 2 of terminal strip B. Clip lead E to lug 1 of terminal strip D.

This completes the assembly of the audio oscillator circuit on your test chassis.

ADJUSTMENTS

( ) Connect leads from the output terminals of the test chassis to the vertical input and ground terminals of your oscilloscope.

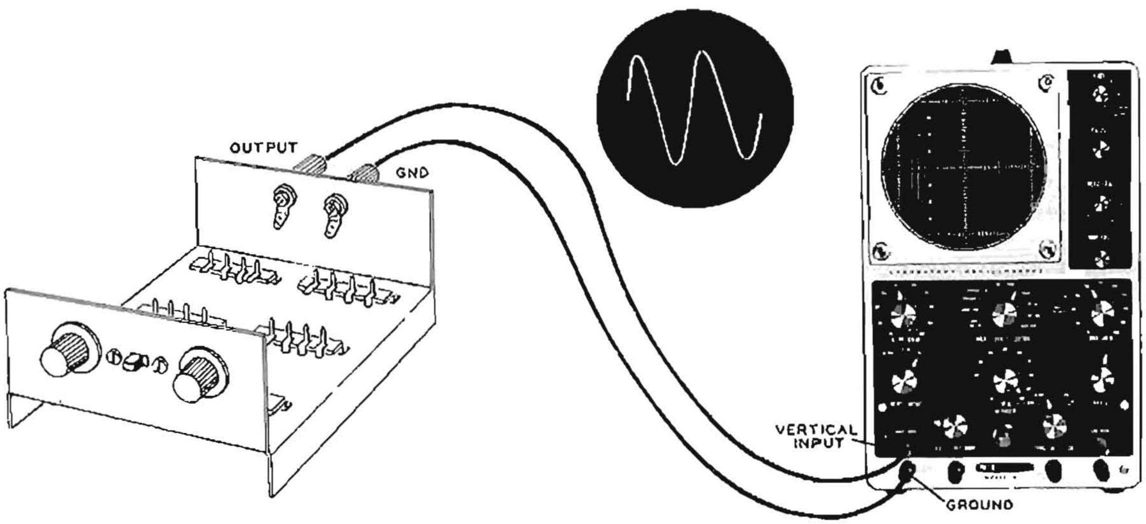
( ) Turn on your oscilloscope and adjust it to obtain a line on the cathode ray tube. Turn the vertical input switch to its X1 (most sensitive) position, and turn the vertical gain control to approximately the center of its range. The horizontal frequency selector should be set to the dot between 100 and 1000.

( ) Turn on the OFF-ON switch of the test chassis. Turn the 20 KΩ control to its full clockwise position and then to its full counterclockwise position. At the counterclockwise position (MIN), a straight line should appear on the tube; at the clockwise position (MAX), a signal should appear on the oscilloscope. If a signal did not appear, refer to the In Case Of Difficulty section.

( ) Set the 20 KΩ control back to near that point where the waveform first began to appear on the oscilloscope.

( ) Adjust the frequency vernier of your oscilloscope to obtain two complete cycles, this waveform should now look like the audio oscillator waveform shown in Pictorial 2-4.

The adjustments are now completed and if the circuit has responded correctly in these steps, you may proceed on to Part III of the manual.



Pictorial 2-4

IN CASE OF DIFFICULTY

1. Recheck the wiring. Trace each lead in colored pencil on the Pictorial. It is frequently helpful to have friends check your work, someone not familiar with the unit may notice something overlooked by the person who built the kit.

2. While only a few Heathkits are returned for repair at the factory, about 90% of the returned kits do not operate properly because of poor connections and soldering. Therefore, many of these problems can be eliminated by reheating all connections with a soldering iron.

3. Check the value of the resistors and capacitors to make sure they are in their proper positions.

4. Check the batteries. Check the control settings to make sure that they are properly adjusted.

5. Check the transistors with a transistor tester or by substitution of transistors of the same type known to be good.

6. If, after careful checks, the trouble is still not located and a voltmeter is available, check voltage readings against those found on the Schematic Diagram on Page 8. Voltages may vary ±10% from the voltages shown.

SERVICE INFORMATION

Service

If, after applying the information in this manual and your best efforts, you are still unable to obtain proper performance, it is suggested that you take advantage of the technical facilities which the Heath Company makes available to its customers.

The Technical Consultation Department is maintained for your benefit. This service is available to you at no charge. Its primary purpose is to provide assistance for those who encounter difficulty in the construction, operation or maintenance of HEATHKIT equipment. It is not intended, and is not equipped to function as a general source of technical information involving kit modifications nor anything other than the normal and specified performance of HEATHKIT equipment.

Although the Technical Consultants are familiar with all details of this kit, the effectiveness of their advice will depend entirely upon the amount and the accuracy of the information furnished by you. In a sense, YOU MUST QUALIFY for GOOD technical advice by helping the consultants to help you. Please use this outline:

1. Before writing, fully investigate each of the hints and suggestions listed in this manual under In Case Of Difficulty. Possibly it will not be necessary to write.

2. When writing, clearly describe the nature of the trouble and mention all associated equipment. Specifically report operating procedures, switch positions, connections to other units, and anything else that might help to isolate the cause of trouble.

3. Report fully on the results obtained when testing the unit initially and when following the suggestions under In Case Of Difficulty. Be as specific as possible and include voltage readings if test equipment is available.

4. Identify the kit model number and date of purchase, if available. Also mention the date of the manual. (Date at bottom of Page 1.)

5. Print or type your name and address, preferably in two places on the letter.

With the preceding information, the consultant will know exactly what kit you have, what you would like it to do for you and the difficulty you wish to correct. The date of purchase tells him whether or not engineering changes have been made since it was shipped to you. He will know what you have done in an effort to locate the cause of trouble and, thereby, avoid repetitious suggestions. In short, he will devote full time to the problem at hand, and through his familiarity with the kit, plus your accurate report, he will be able to give you a complete and helpful answer. If replacement parts are required, they will be shipped to you, subject to the terms of the Warranty.

The Factory Service facilities are also available to you, in case you are not familiar enough with electronics to provide our consultants with sufficient information on which to base a diagnosis of your difficulty, or in the event that you prefer to have the difficulty corrected in this manner. You may return the completed equipment to the Heath Company for inspection and necessary repairs and adjustments. You will be charged a minimal service fee, plus the price of any additional parts or material required. However, if the completed kit is returned within the Warranty period, parts charges will be governed by the terms of the Warranty. State the date of purchase, if possible.

Local Service by Authorized HEATHKIT Service Centers is also available in some areas and often will be your fastest, most efficient method of obtaining service for your HEATHKIT equipment. Although charges for local service are generally somewhat higher than for factory service, the amount of increase is usually offset by the transportation charge you would pay if you elected to return your kit to the Heath Company.

HEATHKIT Service Centers will honor the regular 90 day HEATHKIT Parts Warranty on all kits, whether purchased through a dealer or directly from Heath Company; however, it will be necessary that you verify the purchase date of your kit.

Under the conditions specified in the Warranty, replacement parts are supplied without charge; however, if the Service Center assists you in locating a defective part (or parts) in your kit, or installs a replacement part for you, you may be charged for this service.

HEATHKIT equipment purchased locally and returned to Heath Company for service must be accompanied by your copy of the dated sales receipt from your authorized HEATHKIT dealer in order to be eligible for parts replacement under the terms of the Warranty.

THIS SERVICE POLICY APPLIES ONLY TO COMPLETED EQUIPMENT CONSTRUCTED IN ACCORDANCE WITH THE INSTRUCTIONS AS STATED IN THE MANUAL. Equipment that has been modified in design will not be accepted for repair. If there is evidence of acid core solder or paste fluxes, the equipment will be returned NOT repaired.

For information regarding modification of HEATHKIT equipment for special applications, it is suggested that you refer to any one or more of the many publications that are available on all phases of electronics. They can be obtained at or through your local library, as well as at most electronic equipment stores. Although the Heath Company sincerely welcomes all comments and suggestions, it would be impossible to design, test, evaluate and assume responsibility for proposed circuit changes for special purposes. Therefore, such modifications must be made at the discretion of the kit builder, using information available from sources other than the Heath Company.

Replacements

Material supplied with HEATHKIT products has been carefully selected to meet design requirements and ordinarily will fulfill its function without difficulty. Occasionally, improper operation can be traced to a faulty component. Should inspection reveal the necessity for replacement, write to the Heath Company and supply all of the following information.

A. Thoroughly identify the part in question by using the part number and description found in the manual Parts List.

B. Identify the type and model number of kit in which it is used.

C. Mention date of purchase.

D. Describe the nature of defect or reason for requesting replacement.

The Heath Company will promptly supply the necessary replacement. PLEASE DO NOT RETURN THE ORIGINAL COMPONENT UNTIL SPECIFICALLY REQUESTED TO DO SO. Do not dismantle the component in question as this will void the guarantee. This replacement policy does not cover the free replacement of parts that may have been broken or damaged through carelessness on the part of the kit builder.

Shipping Instructions

In the event that your instrument must be returned for service, these instructions should be carefully followed.

Wrap the equipment in heavy paper, exercising care to prevent damage. Place the wrapped equipment in a stout carton of such size that at least three inches of shredded paper, excelsior, or other resilient packing material can be placed between all sides of the wrapped equipment and the carton. Close and seal the carton with gummed paper tape, or alternately, tie securely with stout cord. Clearly print the address on the carton as follows:

To: HEATH COMPANY
Benton Harbor, Michigan

ATTACH A LETTER TO THE OUTSIDE OF THE CARTON BEARING YOUR NAME, COMPLETE ADDRESS, DATE OF PURCHASE, AND A BRIEF DESCRIPTION OF THE DIFFICULTY ENCOUNTERED. Also, include your name and return address on the outside of the carton. Preferably affix one or more "Fragile" or "Handle With Care" labels to the carton, or otherwise so mark with a crayon of bright color. Ship by insured parcel post or prepaid express; note that a carrier cannot be held responsible for damage in transit if, in HIS OPINION, the article is inadequately packed for shipment.

WARRANTY

Heath Company warrants that for a period of three months from the date of shipment, all Heathkit parts shall be free of defects in materials and workmanship under normal use and service and that in fulfillment of any breach of such warranty, Heath Company shall replace such defective parts upon the return of the same to its factory. The foregoing warranty shall apply only to the original buyer, and is and shall be in lieu of all other warranties, whether express or implied and of all other obligations or liabilities on the part of Heath Company and in no event shall Heath Company be liable for any anticipated profits, consequential damages, loss of time or other losses incurred by the buyer in connection with the purchase, assembly or operation of Heathkits or components thereof. No replacement shall be made of parts damaged by the buyer in the course of handling or assembling Heathkit equipment.

NOTE: The foregoing warranty is completely void and we will not replace, repair or service instruments or parts thereof in which acid core solder or paste fluxes have been used.

HEATH COMPANY

PART III

Basic Principles of Electronics

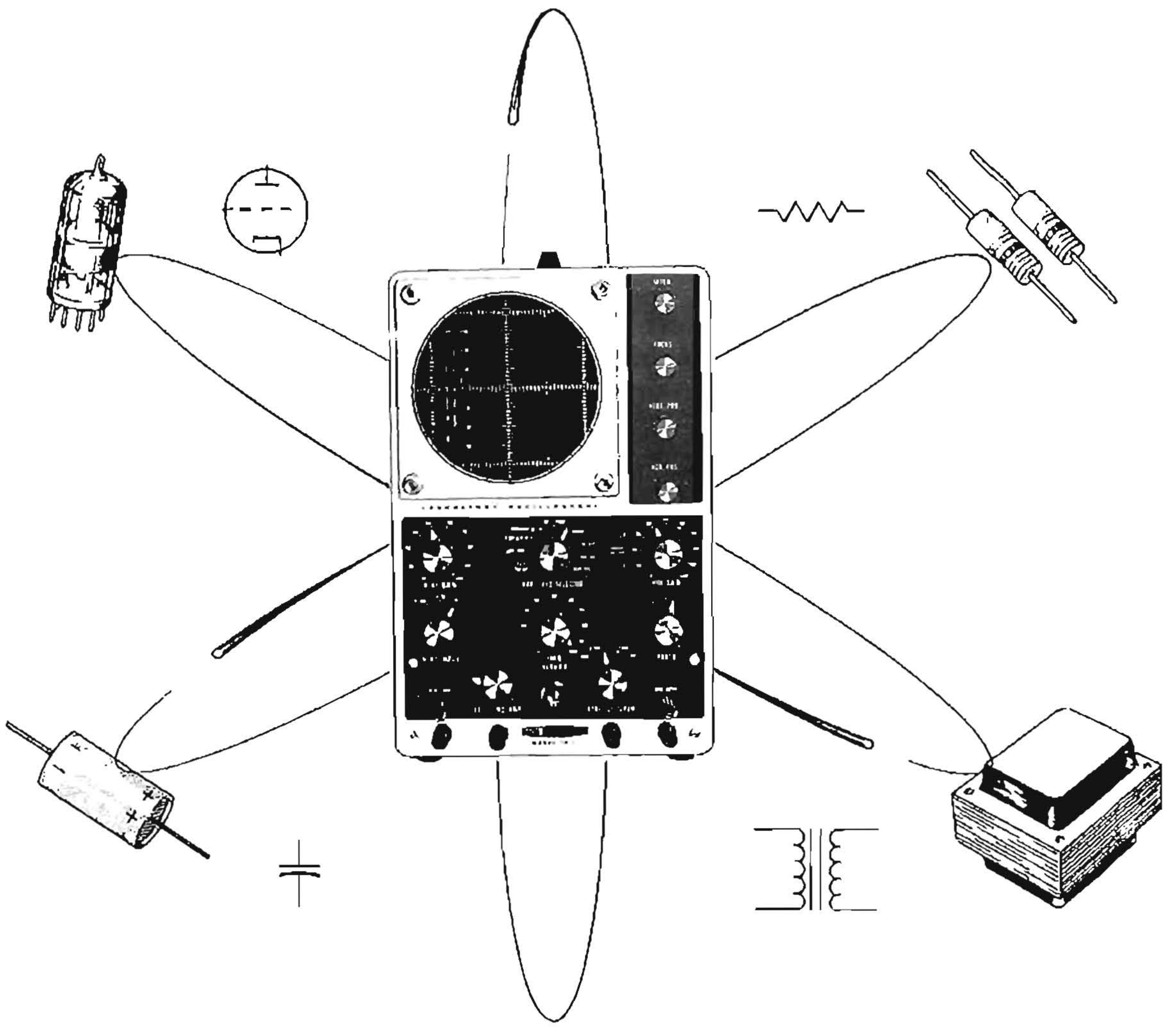


Figure 3-1

All electricity is based on the movement of tiny particles called electrons. Electrons, together with other tiny particles, make up the atom, the basic building block of all matter.

All substances are made up of one or more types of atoms. For example, copper has just one kind of atom, water has two kinds of atoms. This section of the manual will explain how electrons are fastened into atoms, and how and why electrons move about to create electricity. This section will also discuss how each type of part in electronic circuits reacts to the movement of electrons.

CHAPTER 1

Electricity - the Flow of Electrons

The seat of electricity is the atom. An atom is so small that if you were to enlarge it with the best electron microscope you would be unable to see it. Figure 3-2 shows what an atom might look like if it were possible to see one. It consists of a nucleus of protons and neutrons, surrounded by electrons in orbits.

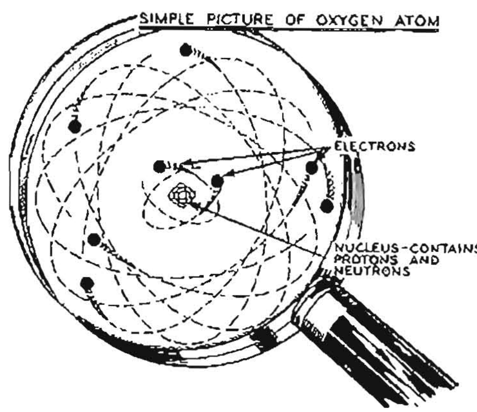


Figure 3-2

Each proton in the nucleus is matched by an electron in orbit. The number of protons, in the nucleus, identifies the type of atom. For example, a hydrogen atom has one proton, a helium atom has two protons, and a copper atom has 29 protons.

The atom is kept together by the forces that exist between the particles within the atom. Each atomic particle has a property called charge. The proton charge is called positive, or plus (+). The electron charge is called negative, or minus (-).The minus charge of one electron exactly balances the plus charge of one proton. The neutron, which actually consists of an electron and a proton bound tightly together, has a net charge of zero, and is electrically neutral because the minus charge of the electron exactly cancels the plus charge of the proton. Particles with opposite charges attract one another. Particles with like charges repel one another.

Atoms in their "natural" state are electrically neutral; that is, the number of electrons equals the number of protons. If there are less than the "natural" number of electrons, the atom has a plus charge. If there are more than the normal number of electrons, the atom has a minus charge. In either case, the atoms have a charge of static electricity. Ordinarily, only electrons can be added to or removed from an atom; the number of protons and neutrons stays the same.

Flowing Electrons and Holes

The electron, freed from its atom and set into motion, is electricity. However, not all electrons are easily removed from their atoms. To become free, electrons near the nucleus have to overcome both the attraction of the nucleus and the repulsion of electrons in outer orbits. Generally, only electrons in the outer orbits leave the atom.

The rate at which the electrons move, from atom to atom, is called current. The direction of current (movement of electrons) cannot be seen. Only the effect can be seen. Electrons will move from a negative region to a positive region. When a negative charge is placed at one end of a wire it will have an instant effect at the other end. This is comparable to the situation shown in Figure 3-3.

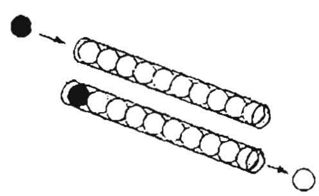


Figure 3-3

Ten billiard balls all touching one another are lined up in a tube. Another ball approaches the line from the left at a slow speed. When this ball strikes the ten, the impulse travels to the last ball in the line almost instantly, knocking the last ball in the line out of the tube. The last ball travels at about the same speed as the first entering ball. Only a very slight compression of the billiard balls prevents the impulse from traveling instantaneously to the last ball. The action of the billiard balls in a tube is much like the action of electrons in a wire. Though the speed of the individual electrons is small, the impulse travels at an almost infinite speed. Notice that although there is a flow of balls through the tube, at any time there are only ten balls in the tube. The same is true of electric current traveling through a wire. This interpretation of an electric current is called electron flow.

In electron flow theory, current was shown to flow from negative to positive. In some semiconductor devices, the flow of holes from positive to negative is a more useful interpretation. This is called "conventional current" or "hole current." Figure 3-4 shows the movement of a hole, or vacancy, from atom to atom. In Figure 3-4, the battery supplies the positive (+) and negative (-) charges, causing the movement of the hole. Notice that the hole moves from (+) to (-) and acts like a (+) charge. Current flow, either electron flow or hole current is measured in "amperes" just like the flow of water is measured in gallons per minute. One ampere is equal to the flow of a very great number of electrons or holes in a circuit past a point in one second. This great number of electrons is 6,250 with fifteen more zeros behind it.

Often, quite a bit less than one ampere of current flows in most electronic circuits. For this reason, the term milliampere (ma), which is 1/1000 of an ampere, is used extensively; for example, 1000 ma = 1 ampere, and .01 ampere = 10 milliamperes of current.

Voltage, the electrical pressure that drives electric current through a circuit, is measured in volts. A larger number of volts means more electrical pressure, and a smaller number of volts means less electrical pressure.

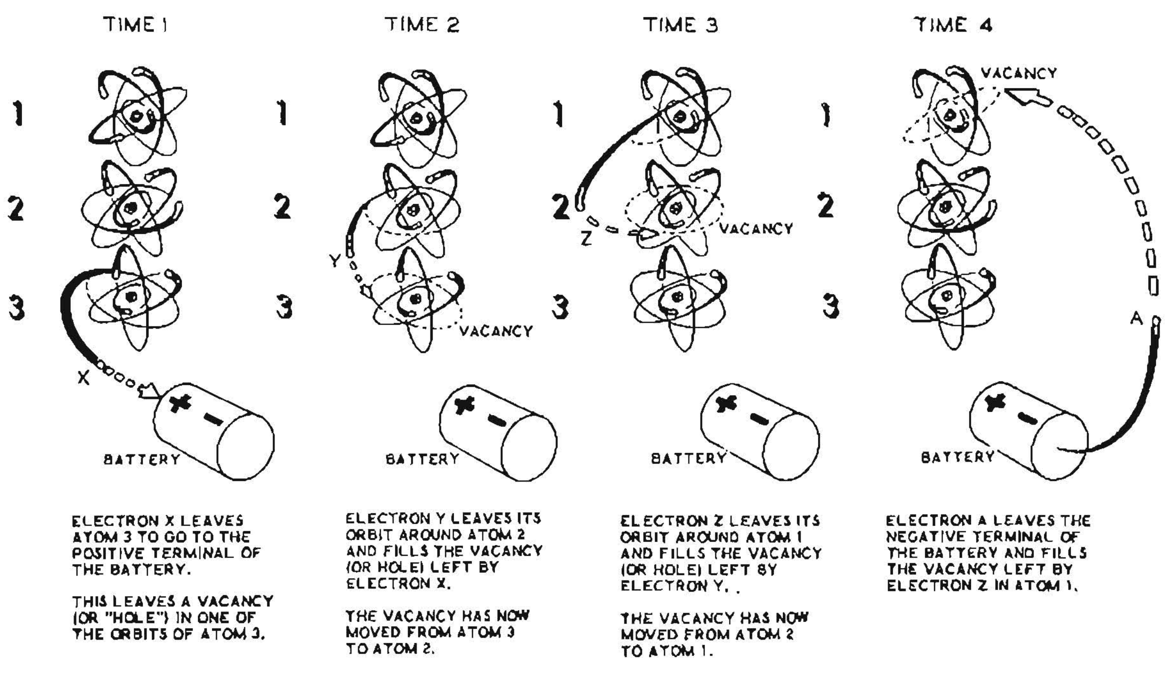


Figure 3-4

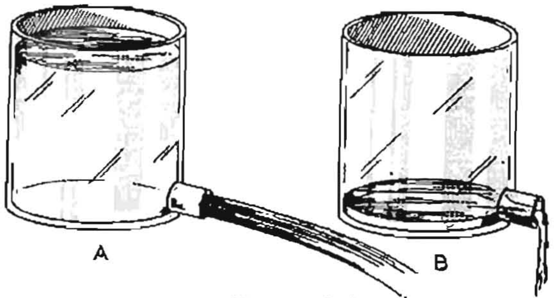


Figure 3-5

Electrical pressure works just like water pressure. Figure 3-5 demonstrates how voltage affects current flow. In part A of Figure 3-5, the greater water pressure causes a larger flow of water. As the water level goes down, the water pressure and flow decrease. As the electrical pressure (voltage) drops, the flow of current will drop. The battery in Figure 3-4 is used to maintain a constant voltage. This electrical pressure, a difference in charge between the ends of the battery, causes the holes to flow away from the plus (+) end, and the electrons to flow toward the plus (+) end of the battery. When the battery runs down, its voltage decreases and the current will also decrease.

Current Flow in Materials

The amount of current that can flow in a substance is determined by how tightly held or how free the electrons are in the outer orbits of the atoms. This property is used to classify materials. Conductors have many free electrons and conduct current easily. Insulators have very few free electrons and strongly resist the flow of current. Between conductors and insulators are semiconductors which only partially resist electric current. Figure 3-6 shows a chart of some of these materials.

EXPERIMENTS

Experiment 3-1

The purpose of this experiment is to illustrate the great differences in the ability of various materials to conduct current. The ability to conduct electric current is comparable to the ability of common liquids to evaporate. You will need the plastic coil alignment tool supplied with this kit, two paper facial tissues, a teaspoonful of rubbing alcohol, water, and cooking oil. See Figure 3-7. Place one sheet of facial tissue on a

Figure 3-7

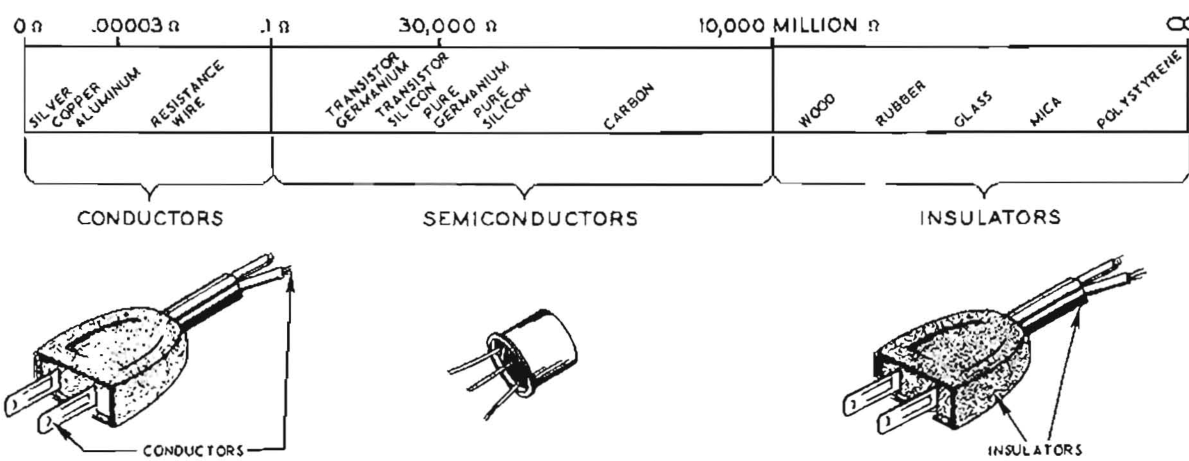


Figure 3-6

dark surface. With the alignment tool, quickly place three spots, one of each liquid, on the tissue. Wipe the alignment tool dry with the second tissue after each liquid is used. Make several trials.

Watch the order of disappearance of these three spots. The alcohol evaporates quickly. Water evaporates, but more slowly. The cooking oil will not disappear. The ability of conductors and semiconductors to conduct current varies as the rates of evaporation of alcohol and water. The inability of insulators to carry current is like the inability of cooking oil to evaporate.

Experiment 3-2

Water evaporates faster under certain conditions. Clothes dryers use heat and moving air to speed the drying rate. This experiment will show how temperature affects the current flowing in semiconductors, as heat affects the evaporation of water.

Connect the test chassis, with the audio oscillator still wired, to the oscilloscope with test leads. Get a small piece of ice and wrap it in absorbent paper, such as a paper towel. With the oscilloscope and audio oscillator turned on, adjust the trace as directed near the end of Part II, under Adjustments.

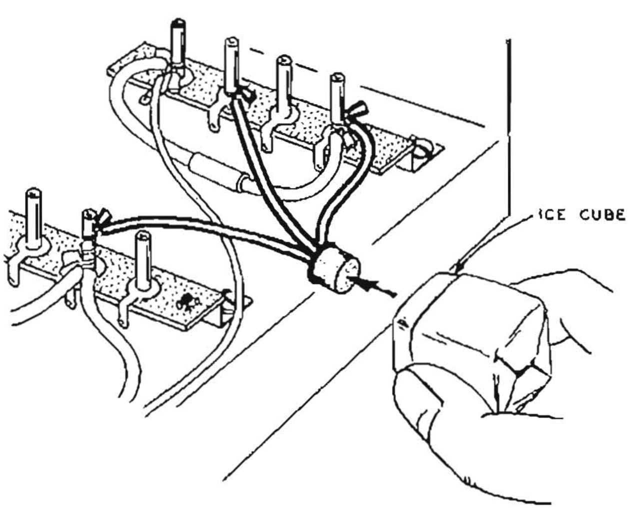


Figure 3-8

Place the ice on the metal covering of transistor Q2. You may have to move some of the components of the circuit aside and twist the transistor up to get to the metal cover. See Figure 3-8.

Watch the size of the trace. As the temperature of the transistor goes down, its ability to conduct current decreases. This will be seen as reduced height of the trace. Remove the ice and place your finger on the transistor. Observe how the size of the trace returns to its former height. Repeat this experiment with transistor Q1. Now turn the test chassis off.

This procedure might suggest increasing the temperature of the transistor. This is not advisable. High temperature will cause transistors to break down and conduct current like conductors. This would probably damage the transistor and prevent its further use in later experiments.

SUMMARY

The movement of electrons is electric current. These tiny particles, with neutrons and protrons, compose the atom. The electron (-) and proton (+) have opposite charges. Like charges repell; unlike charges attract. These forces keep the atom intact. Electrons, because of their position in the atom, can be added to or removed from the atom.

There are two interpretations of current, electron flow or hole current. Electron flow is from (-) to (+). Hole current is from (+) to (-). Current flow is measured in amperes or milliamperes (1 ma = 1/1000 ampere).

The driving force of electric current is voltage measured in volts.

Materials differ greatly in their ability to conduct electricity. Experiment 1 compared these differences to the evaporation of common liquids. Experiment 2 showed how changing temperature changed the ability of semiconductors to carry current.

CHAPTER 2

Ohm's Law

All materials offer some resistance to current flow. This property is used to control current flow and voltage distribution in a circuit. The relationship between current, voltage, and resistance is called Ohm's Law.

In electronics, some circuit components are made of carbon or certain metal alloys because they impede the flow of current. This is in contrast to house wiring where copper is used because it offers little opposition to current.

To save time, symbols are used to represent components in electronic circuit drawings. This chapter introduces schematics (circuit drawings) in the explanations of resistor circuitry. Ohm's Law is applied to both parallel and series resistor circuits.

Resistors

A resistor is a device that resists or impedes the flow of electric currents. The unit of resistance is the ohm (Ω). A resistor that offers a lot of resistance to current will have a large number of ohms, and a resistor that offers only a small amount of resistance to current will have a small number of ohms.

When resistances are much larger than the basic measuring unit, multiple units are used. The units KΩ (K-ohms) and MΩ or MegΩ (megohms) are commonly used for units of 1,000 and 1,000,000 ohms, respectively. The very same resistance may then be given as 6,200,000 Ω, 6,200 KΩ or 6.2 MΩ. (K = 1000 and M or Meg = 1,000,000.)

Generally, resistors are made of either a carbon compound or resistance wire made from metal alloys. Figure 3-9 shows how typical carbon resistors and typical wirewound resistors are constructed.

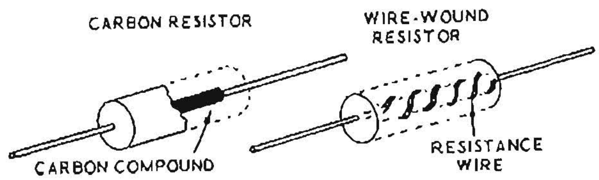
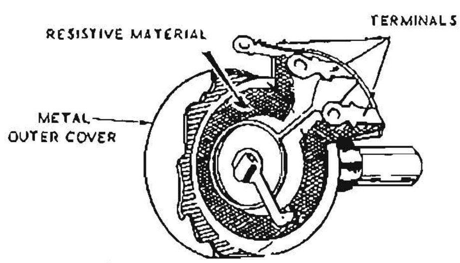


Figure 3-9

To control how much resistance (how many ohms) a carbon resistor will present to electric current, the carbon is mixed with a nonconducting material. By having more carbon and less of the other material, a small amount of resistance is created. By having a small amount of carbon and a large amount of the other substance, a large amount of resistance is created. The amount of resistance, or the number of ohms in a resistor, is determined by the mixture of the carbon compound and not by the physical size of the resistor.

The amount of resistance in a wire-wound resistor is determined by the length of the wire and by the types of metal from which the wire is made. This type of wire is called resistance wire and the longer the wire the greater the resistance.

A variable resistor, also called a potentiometer, or control, is a resistor whose electrical size (number of ohms) can be adjusted. Figure 3-10 shows how these variable resistors are generally constructed. A length of resistive material, such as carbon, or resistance wire, is connected in a horseshoe shape between two terminals. A metal tab, which is turned by the shaft, can contact any point along this resistive surface. This tab, called the "arm" of the control, is connected to the center terminal. When the shaft is turned, the resistance between the center lug and both outside lugs changes, one increasing as the other is decreasing.



CONSTRUCTION OF A POTENTIOMETER OR VARIABLE RESISTOR

Figure 3-10

The amount of current a resistor can pass depends on its physical and electrical size. Too much current would overheat a resistor and destroy its resistance element. The larger a resistor is physically, the more heat it will dissipate, allowing more current to pass through it safely. High-power resistors, therefore, are quite large and low-power resistors are rather small. This power rating is independent of the resistor value in ohms. For example, a 100 ohm resistor rated at 2 watts is usually much larger physically than a 500 ohm resistor rated at only 1/2 watt.

An Introduction to Schematics

Schematic diagrams are simplified drawings of an electronic circuit. Symbols instead of actual drawings are used for all the circuit elements and lines are used to depict wires. All the information about the circuit is presented in a manner which is more understandable than a detailed drawing of the circuit. Resistance values are written next to the resistor symbol, as are voltage values at points in the circuit. Some of the symbols used are shown in Figure 3-11.

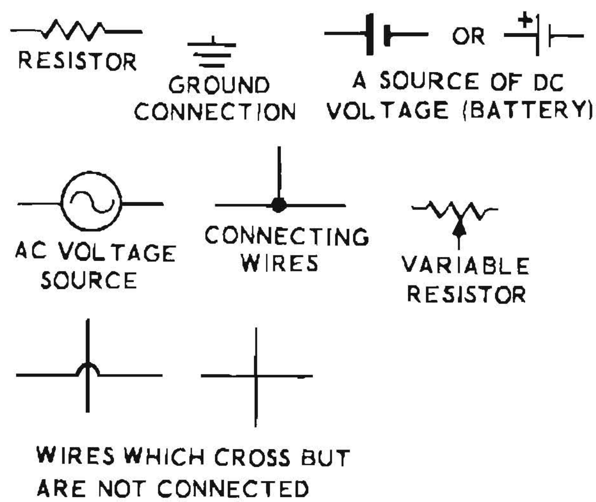


Figure 3-11

Ohm's Law

The total amount of current flowing in a circuit depends on two things: the resistance in the circuit, and the source voltage connected across the circuit. The amount of current can be calculated mathematically if the voltage and resistance are known by using Ohm's Law, which is:

$$I = \frac{E}{R}$$

I = current in "amperes"
E = voltage in "volts"
R = resistance in "ohms"

That is, the amount of current flowing in a circuit, I, is equal to the voltage across the circuit, E, divided by the resistance of the circuit, R. The abbreviation for voltage can be either E or V. Usually the letter E is used. (E is derived from electromotive force, E.M.F.)

The source voltage in a series circuit, as shown in Figure 3-12, is divided among the series resistors according to the amount of resistance in each resistor. In a series circuit, a large resistor will have a large voltage drop across it and a small resistor will have a small voltage drop across it. The sum of the voltages across the resistors is equal to the source voltage.

Part A of Figure 3-12 shows only one resistor connected across a battery. In this case all of the battery voltage is applied across this one resistor.

Part B of Figure 3-12 shows two resistors of equal value connected across a battery. Note that since these resistors are of equal value, the battery voltage divides evenly between the two resistors.

Part C of Figure 3-12 shows two resistors of different values connected across a battery. Resistor R2 is twice as large as resistor R1, for this reason resistor R2 has twice as much voltage across it as resistor R1. When three volts are applied from the battery, one volt appears across resistor R1 and two volts appear across resistor R2. The sum of the two voltages equals the source voltage, 3 volts.

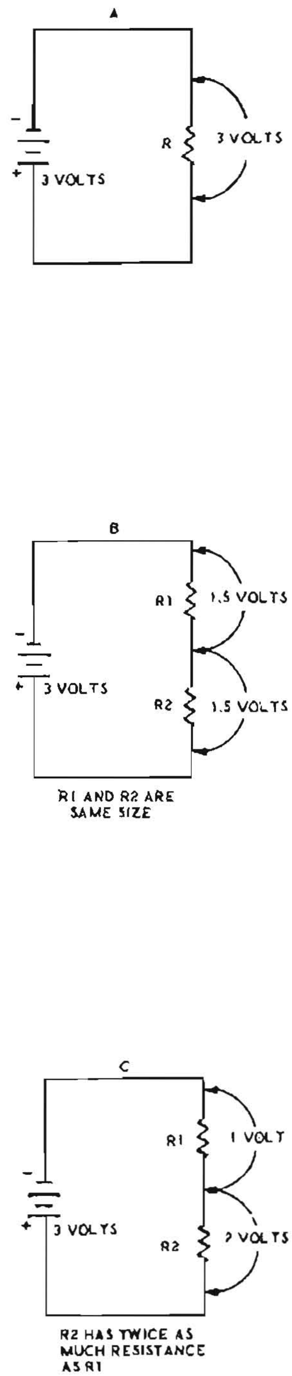


Figure 3-12

The currents in the circuits of Figure 3-12 could be calculated by using Ohm's Law. For example, if R = 1000 Ω in part A of Figure 3-12, then the current is:

$$I = \frac{E}{R}$$

$$= \frac{3 \text{ volts}}{1000 \text{ ohms}}$$

$$= .003 \text{ ampere}$$

$$= 3 \text{ milliampers (ma)}$$

To determine the current for parts B and C of Figure 3-12, the total value of resistance in the circuit must be known. The equivalent, or total, resistance of series and parallel circuits is given next.

Resistors in Series and Parallel

Resistors are connected in series when they lie in a line, end to end. For any number of resistors connected in series, the equivalent resistance is equal to the sum of all the resistances. See Figure 3-13.

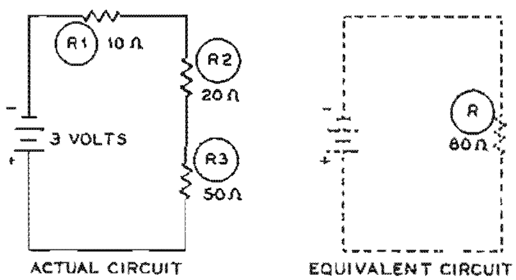


Figure 3-13

$$\text{Total } R = R_1 + R_2 + R_3$$

$$= 10\Omega + 20\Omega + 50\Omega$$

$$= 80\Omega$$

After you know the total resistance, you can calculate the total current, I, as follows:

$$I = \frac{E}{R}$$

$$= \frac{3V}{80\Omega}$$

$$- .0375 \text{ ampere}$$

$$- 37.5 \text{ ma}$$

In a series circuit, the current in each of the resistors is the same; that is:

$$I = I_1 = I_2 - I_3$$

Resistors are connected in parallel when each end of each resistor is connected to an end of every other resistor. For resistors in parallel, the total resistance or equivalent resistance is actually less than the resistance of any one of the individual resistors. The general formula for computing the equivalent resistance of odd values of resistors connected in parallel, such as shown in Figure 3-14, is:

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

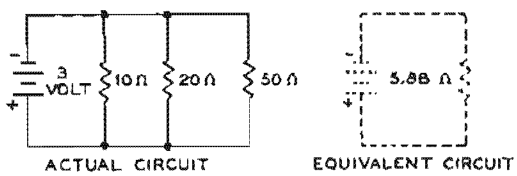


Figure 3-14

$$\frac{1}{R} = \frac{1}{10} + \frac{1}{20} + \frac{1}{50}$$

$$\frac{1}{R} = \frac{10}{100} + \frac{5}{100} + \frac{2}{100}$$

$$\frac{1}{R} - \frac{17}{100}$$

$$17R - 100$$

$$R = 5.88\Omega$$

The total current in this circuit is:

$$I = \frac{E}{R} = \frac{3V}{5.88\Omega} = .51 \text{ ampere} = 510 \text{ ma}$$

The current through each resistor can also be determined. The voltage across each resistor is 3 volts.

$$I_1 = \frac{3\,V}{10\Omega} = .30 \text{ ampere}$$

$$I_2 = \frac{3\,V}{20\Omega} = .15 \text{ ampere}$$

$$I_3 = \frac{3V}{50} = .06 \text{ ampere}$$

$$\text{Total I} \quad I_1 + I_2 + I_3$$

$$= .30 + .15 + .06$$

$$= .51 \text{ ampere}$$

EXPERIMENTS

In the following three experiments you will use the oscilloscope to compare various voltages. The height (H) of a waveform on an oscilloscope is proportional to the voltage (V) applied at the vertical input. Two voltages can be compared on an oscilloscope by using this relationship: $\frac{V_1}{V_2} = \frac{H_1}{H_2}$ This means, that if H_1 is twice H_2, then V_1 is twice V_2.

Experiment 3-3

The purpose of this experiment is to compare the voltages across two equal resistors in series. This is similar to Figure 3-12, part B. The circuit used for this experiment is shown in Figure 3-15. If R1 = R2, then the voltage should divide equally between R1 and R2. The sum, $V_1 + V_2$, should be equal to the total voltage across both resistors.

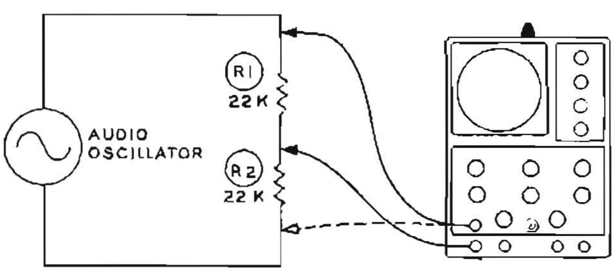


Figure 3-15

Refer to Pictorial 2-3 for the following steps.

( ) Connect a 22 KΩ (red-red-orange) resistor from lug 1 of terminal strip E to lug 2 of terminal strip E.

( ) Connect a second 22 KΩ resistor from lug 2 of terminal strip E to lug 1 of terminal strip D.

( ) Remove the test leads from the output terminals of the test chassis, then connect one test lead to lug 1 of terminal strip E and the other to lug 1 of terminal strip D. This will apply the voltage across both resistors to the vertical input of the oscilloscope.

The next series of steps can be used each time you wish to compare voltages. Since only the height of the waveform is needed for comparison, the waveform in the horizontal direction, is compressed so that only a vertical line appears.

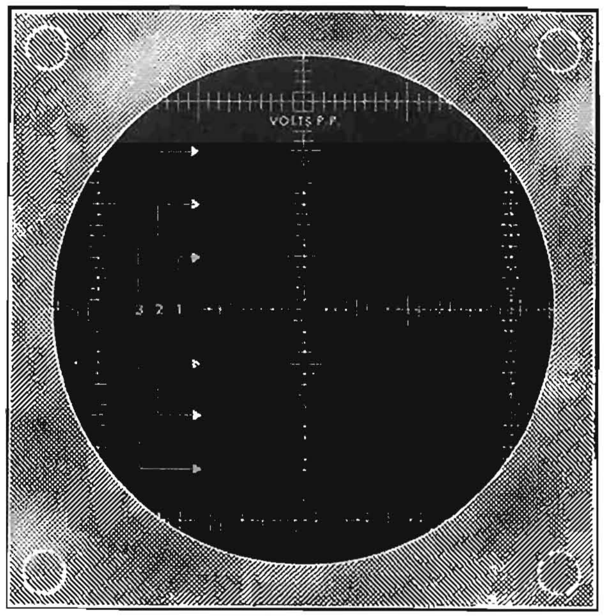


Figure 3-16

Most oscilloscopes have a grid screen as shown in Figure 3-16. The vertical line in the center is called the vertical axis. The horizontal line in the center is called the horizontal axis.

If your screen does not have a scale, as in Figure 3-16, one should be added for the following experiments. Using a pointed crayon or grease pencil and a plastic ruler, draw two central lines at right angles on the screen of the CRT. Rule inch, 1/2 inch, and 1/4 inch markers on the central lines.

( ) Turn on the oscilloscope and test chassis. Adjust the oscilloscope and test chassis for the signal used previously in Part II.

( ) Turn the horizontal gain to the minimum position. This should result in a vertical line.

( ) Adjust the height of the vertical line to six major units on the screen of the oscilloscope, about 2/3 of the height of the screen. This can be done with the vertical gain control of the oscilloscope or with the 20 KΩ control of the test chassis. Do not change either control for the rest of the experiment.

( ) Change the test lead from lug 1 of terminal strip D to lug 2 of terminal strip E. This will measure the voltage across R1. Record this value:____units.

( ) Change the test lead from lug 1 of terminal strip E to lug 1 of terminal strip D. This will measure the voltage across R2. Record this value:____units.

( ) $V_1 + V_2 =$ ______units. The two measured values should be approximately the same. The sum of the voltages across each resistor should be equal to the voltage across both resistors, about six units.

( ) Turn off the test chassis.

Experiment 3-4

The purpose of this experiment is to compare the voltages across two unequal resistors in series. This is similar to Part C of Figure 3-12. The circuit for this experiment is shown in Figure 3-17.

( ) Disconnect the 22 KΩ (red-red-orange) resistor from lug 2 of terminal strip E and lug 1 of terminal strip D and replace it with a 2200 Ω (red-red-red) resistor.

( ) Connect one test lead from the oscilloscope to lug 1 of terminal strip E and the other to lug 2 of terminal strip E. This will measure the voltage across the larger resistor, 22 KΩ (R2).

( ) Turn the test chassis on.

( ) Adjust the oscilloscope for a vertical line. Adjust the height to six major units, about 2/3 of the total height of the screen.

( ) Change the test lead from lug 1 of terminal strip E to lug 1 of terminal strip D. This measures the voltage across the smaller resistor, 2200 Ω (R1). Record this value: that is, V_1 = ____units.

$R_1 = \frac{1}{10} R_2$, and the voltages should divide proportionally; $V_1 = \frac{1}{10} V_2$.

( ) Disconnect the test leads and increase the horizontal gain control until a line appears.

( ) Turn off the test chassis.

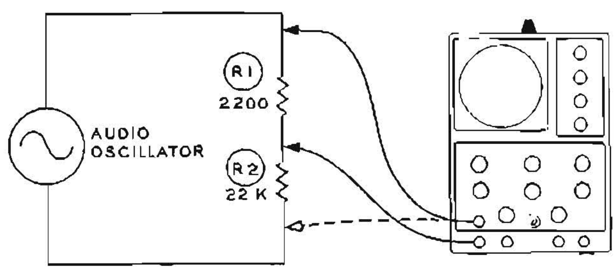


Figure 3-17

Experiment 3-5

The purpose of this experiment is to compare the voltages across three resistors, two in parallel connected to a third in series. The circuit is shown in Figure 3-18.

$R_1 = R_2 \quad R_3 = 22K\Omega$

For the two resistors in parallel:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R} = \frac{1}{22K\Omega} + \frac{1}{22K\Omega}$$

$$R = 11K\Omega$$

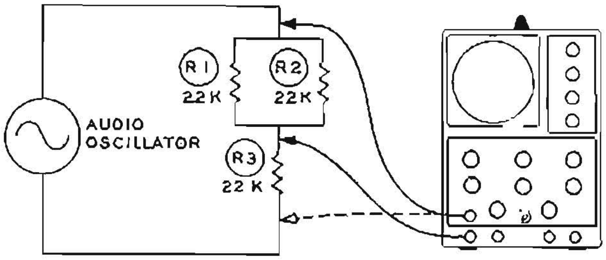


Figure 3-18

The resistors in parallel, R1 and R2, have 1/2 the total resistance of R3. The voltage across the parallel resistors should be 1/2 the voltage across the series resistor.

( ) Disconnect the 2200 Ω (red-red-red) resistor from lug 2 of terminal strip E to lug 1 of terminal strip D and replace it with a 22 KΩ (red-red-orange) resistor.

( ) Connect a second 22 KΩ resistor from lug 1 of terminal strip E to lug 2 of terminal strip E.

( ) Connect one test lead to lug 2 of terminal strip E and the other to lug 1 of terminal strip D. This will measure the voltage across the single series resistor, R3.

( ) Turn the test chassis on.

( ) Adjust the oscilloscope for a vertical line. Adjust the height to six major units.

( ) Change the test lead from lug 1 of terminal strip D to lug 1 of terminal strip E. This will measure the voltage across the two parallel resistors, R1 and R2. Record this value:____units.

The voltage across the two parallel resistors should be approximately 1/2 the voltage across the single series resistor.

( ) Turn off the test chassis.

( ) Remove the three 22 KΩ (red-red-orange) resistors used in this experiment from the test chassis.

SUMMARY

The amount of current that flows through a resistor depends on how much resistance (how many ohms) the resistor has, and how much voltage or electrical pressure is applied across the resistor. The current that flows in the resistor can be calculated with the formula

$$I = \frac{E}{R} \qquad \text{current} = \frac{\text{voltage}}{\text{resistance}}.$$

I : current in "amperes"

E = voltage in "volts"

R : resistance in "ohms"

A series circuit is a circuit where the current has only one path to follow around the circuit. The voltage in a series circuit is divided between the different resistors proportionally, according to how much resistance there is in each resistor.

A parallel circuit is a circuit in which there are two or more paths for current to flow through the circuit. The amount of current in each path depends on the amount of resistance in that path. The same voltage appears across each of the resistances (each current path) in a parallel circuit.

CHAPTER 3

DC and AC

Up to this time you have been concerned with only direct current or "DC" in your reading. You have used an "AC" current from the test chassis in your experiments. This AC current is called alternating current because the polarity or the sign (+ or -) of the current is continually changing. Consequently, the current flows first in one direction, then in the other.

These changes occur in a time sequence, thus they can best be interpreted by comparing them in a time versus current graph. The patterns that result when such graphs are made are called waveforms.

Many important waveforms occur in electronics. The most common of these is the sine wave. Other important waveforms are square waves, pulsating direct current waves (PDC), clipped sine waves, and sawtooth waves.

Understanding DC, AC, and PDC Current

The electric current in a wire is not easy to visualize. There is just no way to "see" the current because, of course, it is invisible. Yet these currents can be understood better if they are somehow translated into a form that can be put down on paper and analyzed. This may be done by the use of a graph. Here are some things to keep in mind so that the following graphs of DC, AC, and PDC current will be most meaningful to you.

1. Current will be called plus when it flows in one direction within a wire. Current will be called minus when it flows in the opposite direction within a wire. (Refer to Figure 3-19). These plus and minus symbols are assigned merely as a way of telling one direction of current flow from another.

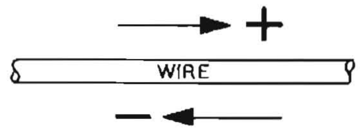
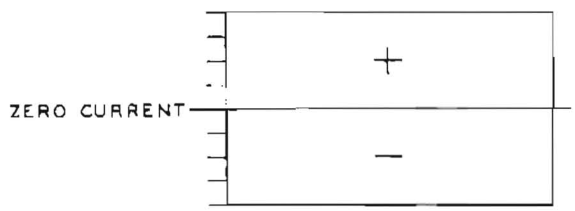


Figure 3-19

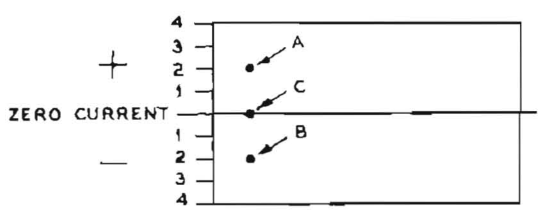
2. The zero-current line (Figure 3-20) is used as a base line for the following graphs. So far as these graphs are concerned, current flow in a plus direction will be shown above the zero-current line, and current flow in a minus direction will be shown below the zero-current line.



DIRECTION OF CURRENT FLOW IS SHOWN BY POSITION ABOVE OR BELOW ZERO-CURRENT LINE.

Figure 3-20

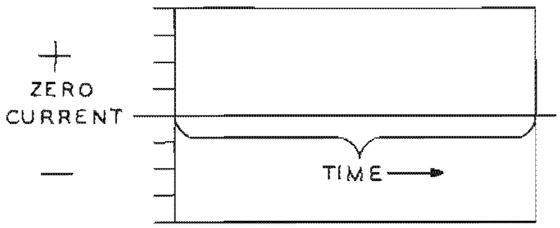
3. The amount of current flowing in the wire (Figure 3-21) will be shown by the distance above or below the zero-current line. For example, plus 2 amperes is at point A in Figure 3-21; minus 2 amperes is at point B; zero current is at point C.



DISTANCE ABOVE OR BELOW ZERO-CURRENT LINE SHOWS AMOUNT OF CURRENT.

Figure 3-21

4. Time elapsed (Figure 3-22) is shown by the distance along the zero-current line. Any convenient time value can be assigned to this distance, depending on how rapidly the current alternates and what the graph is designed to show.



TIME IS SHOWN BY DISTANCE ALONG THE ZERO-CURRENT LINE.

Figure 3-22

5. When current reverses its direction of flow (as alternating current does) this alternation usually takes place at a very rapid rate. Because of this fact, you may view a graph as being an ultra-slow-motion-picture of what is taking place.

DC Current

DC, or direct current, flows in only one direction. DC current maintains a steady value (constant amplitude), and shows up on a graph as a simple straight line. (See Figure 3-23.) The DC current line could have been graphed below the zero-current line (note dotted line) if it flowed in the opposite (minus) direction.

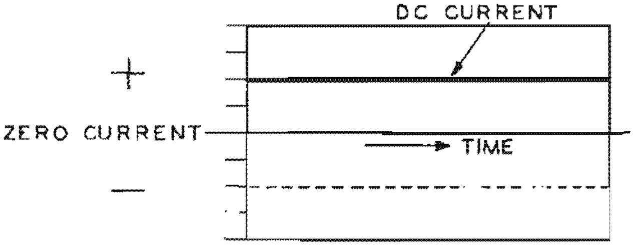


Figure 3-23

AC Current

AC, or alternating current, flows first in one direction and then in the other, while at the same time rising from zero up to a peak value and then returning to zero again. Following the graphed curve in Figure 3-24 will help you see

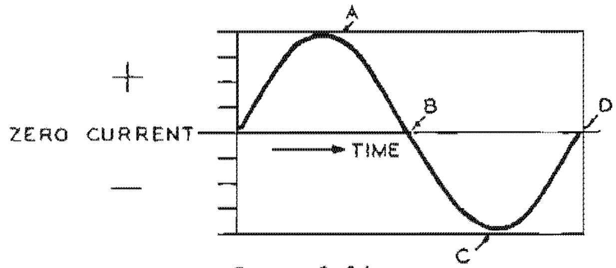


Figure 3-24

how the current starts from zero and rises rather steeply to a peak amount of current flow in the plus direction at A, and then decreases back to zero again at B. This much of the current flow has been in one direction only, since this action all took place on the plus side of the zero-current line. Then the current reverses and starts to flow in the opposite (minus) direction. From point B (zero) the current builds up to a peak at point C, and then falls back to zero again at point D. Notice that this latter rise and fall all took place on the minus side of the zero-current line. AC current, then, is doing two things; it is periodically changing in its direction of flow, and each time it changes direction, the amount of current builds up to a peak and falls back again. One complete cycle of this action is shown in Figure 3-24. Notice that one cycle consists of a rise and fall of current in one direction, then a rise and fall of current in the other direction.

PDC Current

PDC or pulsating direct current is direct current that varies periodically in amplitude. (See Figure 3-25.) To put it another way, PDC always flows in the same direction, just like DC current, but is changing in amount, just like AC current. PDC operates in cycles, and has a frequency, but this frequency refers only to how

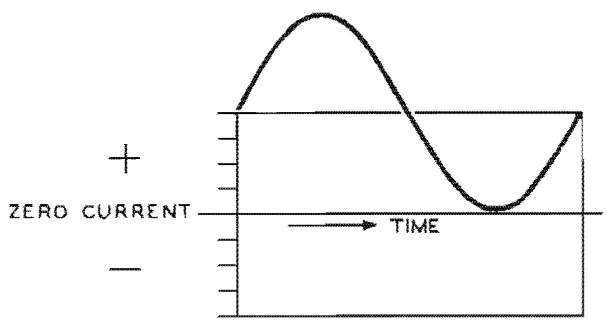


Figure 3-25

often the current changes in amount, and has nothing to do with any change in the direction of current flow. Notice that although the PDC current of Figure 3-25 rises and declines in amount, it stays above the zero-current line, showing that the current always flows in only one direction.

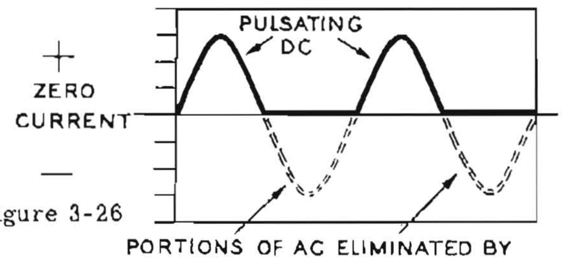


Figure 3-26

The most common example of PDC current looks somewhat different than that shown in the graph of Figure 3-25. This is because the PDC normally encountered in electronics is the one-way current left after AC current has been rectified. Rectification is the process of passing current through a device that will conduct current in only one direction. You will learn more about this process later. It is enough at this time to say that if a two-way current (AC) is fed to a one-way current device, half of the current will be blocked. The PDC that remains after rectifying an AC current is graphed in Figure 3-26. A rectifier will pass current in only one direction, so one half, or the other (plus or minus) of the AC current is blocked, and a pulsating DC current remains. When more cycles are involved the result would appear as in Figure 3-27.

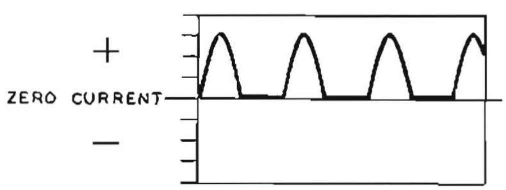


Figure 3-27

Frequency

The three basic forms that electric current can take have now been covered under the headings of DC current, AC current, and pulsating DC current. Since AC current occurs in "cycles," and has "frequency," a further discussion of these subjects is in order to see how this alternating and pulsating current is related to audio and radio frequency signals.

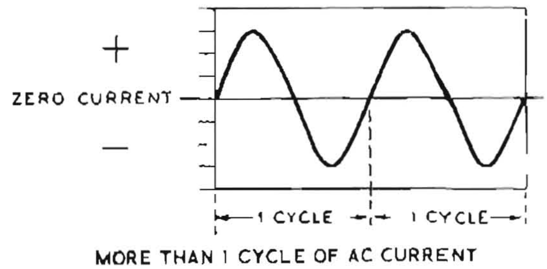


Figure 3-28

A plus swing followed by a minus swing, constitutes one cycle of AC current (see Figure 3-28). The frequency of an AC current is determined by the number of cycles that take place in one second. Your 60 cycle AC house current, for example, completes 60 full cycles of direction change combined with amount change, every second! Since 60 cycles take place every second, the time required for one cycle would be 1/60 of a second, and this may be seen on the graph in Figure 3-29, where the time line has been given a definite value. This graph shows one cycle of 60 cps (cycles per second) house current, AC current at a frequency of 60 cps is usually used for house current in the United States.

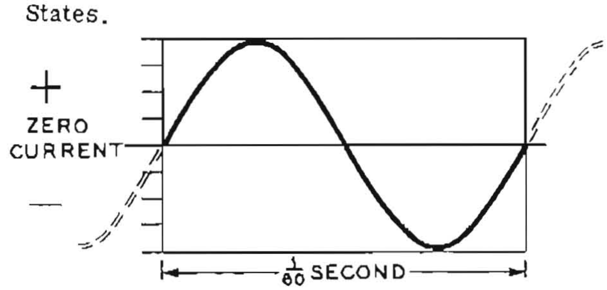


Figure 3-29

AC current that ranges in frequency from about 20 cps to 20,000 cps may be heard when connected to a speaker or earphone, and therefore is considered as "sound in electrical form." Electric current with its frequency in this range is called audio. The term audio simply refers to the fact that these electrical impulses could be heard if connected to a sound reproducing device, even though not everyone's hearing range extends to these extreme limits. Below 20 cps or above 20,000 cps, the human ear would not detect the sound, even if it were fed to a sound reproducing device that was able to move the air in vibrations at these frequencies.

AC current will cause radiation through space over long distances, if provided in sufficient power and connected to an antenna tower or other radiating device. The range of frequencies above the audio limit are referred to as radio frequency currents. The broadcast band, for example, takes in frequencies between approximately 550 kc and 1600 kc (550,000 cps to 1,600,000 cps). The only difference then, between ordinary AC power line current, audio current, and radio current, is the frequency of the AC alternations and the power of the generating source. As the frequency gets higher and higher, the behavior of the current changes.

While it would be impossible to graph accurately so many cycles taking place in one second, you can still draw radio frequency waves in graph form by merely showing a great number of cycles occuring along the graph in a very short period of time. A radio frequency AC current is shown in Figure 3-30. Again note that the only difference between this radio frequency AC current and your AC house current is in the greater number of cycles taking place in a short length of time.

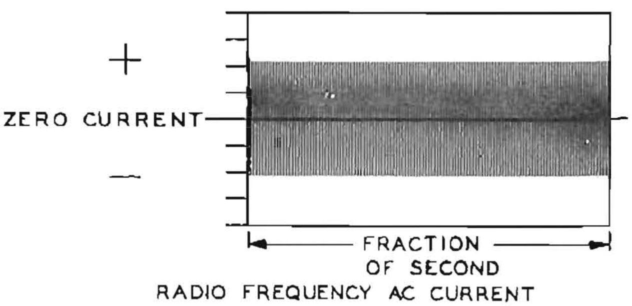


Figure 3-30

AC and DC Voltage

AC and DC voltages have much the same waveforms as AC and DC currents. AC voltages will be discussed now to explain "peak-to-peak" voltages and "sine" waves.

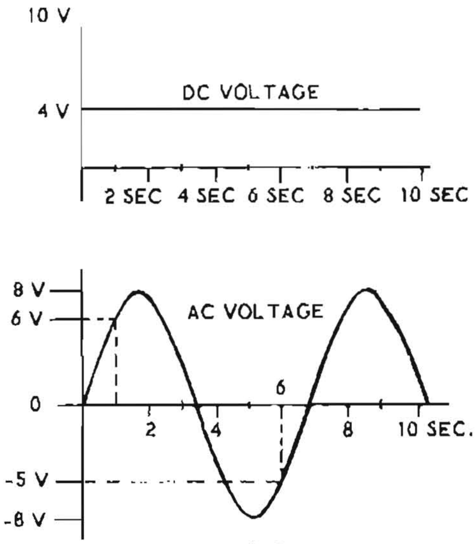


Figure 3-31

The variation of AC voltage as compared to DC voltage is shown in Figure 3-31. To use such a graph, pick a point on the horizontal scale, where time is marked in seconds. From the height of the curve above or below the line at this point, read off the value of the voltage at that time from the vertical scale on which volts are marked. For the curve shown in Figure 3-31, the voltage is +6 volts at one second and -5 volts at six seconds. The maximum voltage is +8 volts and the minimum voltage is -8 volts. The "peak" voltage is 8 volts and the "peak-to-peak" voltage is 16 volts. The DC voltage is constant at 4 volts.

The beginning time of such a graph is not really important, but the zero mark is usually taken when the voltage is either maximum, minimum, or zero.

The waves shown in Figure 3-32 are sine waves, the most common waveform encountered. Ordinary household current is sine wave AC.

Not just any random up and down variation of voltage is a sine wave. There is a precise relationship between the time and the voltage in a sine wave, once the frequency and the peak or maximum voltage are set. Although there is such an exact relationship, the appearance of a sine wave depends on the scale

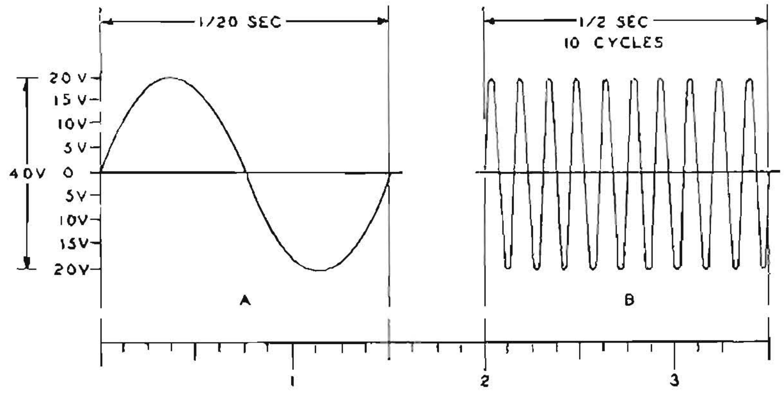


Figure 3-32

factor used to draw the sine wave. The scale factor simply determines how many inches on the graph represent how many volts or seconds. For example: Figure 3-32A shows a voltage sine wave which has a maximum or peak voltage of 20 volts and a frequency of 20 cps. This graph is drawn with 40 volts equal to one inch on the vertical scale and one and one-half inches equal to 1/20 of a second on the horizontal scale.

Exactly the same 20 cycle sine wave is shown in Figure 3-32B but the time scaling has been changed so that one and one-half inches now equals 1/2 second. Although the appearance of the graph is radically changed, the same information about exactly the same wave is presented. Any sine wave, regardless of frequency or peak voltage, could be "fitted" to the curve of Figure 3-32B by using the right scale factor.

Although the sine wave is very common, many other waveforms are encountered in electronics. We have already looked at one form of PDC, pulsating direct current, that which is left after AC current has been rectified. Also, a type of PDC may be formed by the addition of DC current to an AC current. This and other waveforms are shown in Figure 3-33.

The great value of the oscilloscope is its ability to trace out the exact waveform at a point in the circuit under test. Information about the circuit in this graphic form is very helpful in drawing conclusions. This information may not be obtainable in any other way.

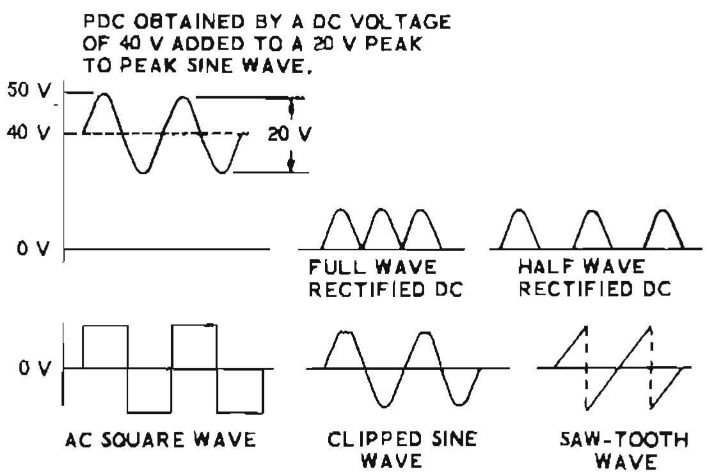


Figure 3-33

EXPERIMENTS

Experiment 3-6

The purpose of this experiment is to show how some of the controls of the oscilloscope can be used to change the appearance of the graph of a sine wave. Proper adjustment of the various controls allows the operator of the oscilloscope to pick the waveform that gives the most useful information.

( ) Connect the test leads from the vertical input and ground terminals of the oscilloscope to the output terminals of the test chassis.

( ) Turn on the oscilloscope and test chassis. Adjust the oscilloscope for a waveform as directed in Part II. You will start your adjustments with two cycles on the screen. Be sure that the 20 KΩ control on the test chassis is adjusted so that a sine wave appears such as in Figure 3-34.

( ) Increase and decrease the vertical gain (vertical amplitude) and notice the effect. Finally, adjust the height to fill 2/3 of the screen.

( ) Increase and decrease the horizontal gain (horizontal amplitude) and notice the effect. Finally adjust for minimum gain so that you see a vertical line.

( ) Adjust the horizontal position (horizontal centering) control so that the line coincides with the vertical axis as in Figure 3-35.

( ) Adjust the vertical position so that as much of the line extends below as above the horizontal axis.

( ) Now adjust the horizontal gain to fill 1/2 to 2/3 of the screen in the horizontal direction.

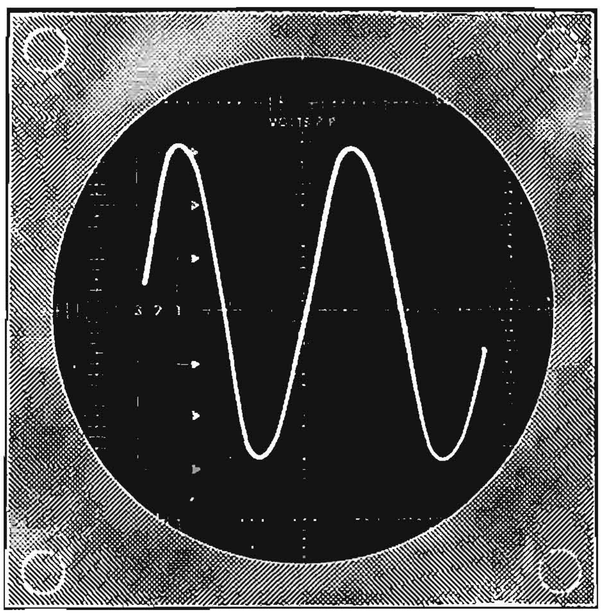


Figure 3-34

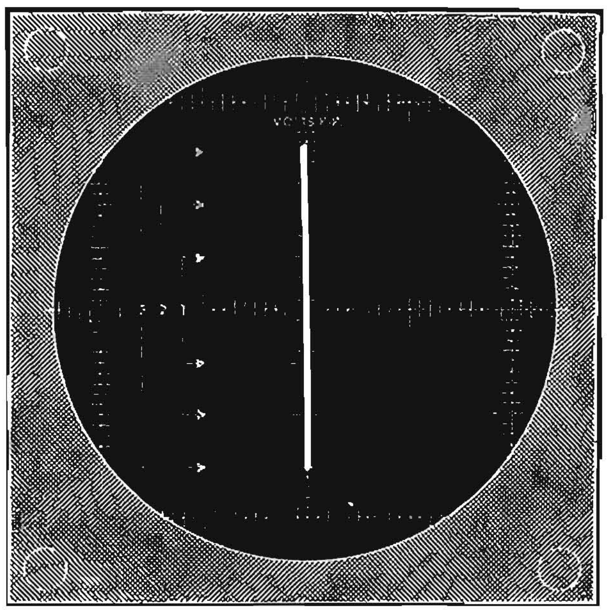


Figure 3-35

( ) Increase the frequency vernier slowly until one cycle appears. Further increase will give only a fraction of a cycle. The time base, the length of time for one horizontal sweep, is now 1/2 of that for two cycles.

The approximate frequency of the audio oscillation from the test chassis is 800 cycles per second. Notice the horizontal frequency selector position is such that it covers this frequency. (On the Heathkit IO-12 Oscilloscope, the horizontal frequency selector is set to a dot between 100 and 1000.) These values are only approximate for example, a 900 cycle per second sweep can be obtained at this setting; it may also be obtained at the setting between 1000 cps and 10 kc. This overlap is generally true of all oscilloscopes.

( ) Decrease the frequency vernier slowly. You should see two cycles again. Continue to decrease the frequency vernier until three cycles appear, then four, etc.

( ) Change the horizontal frequency selector to a lower frequency range and adjust the frequency vernier to obtain different examples of several cycles of the waveform. Select one example and count the number of cycles. For example if you count 10, then the time base is 10 times longer than that for one cycle.

( ) Change the horizontal frequency selector to a higher frequency range and adjust the frequency vernier through its total range. In this position, little useful information about the waveform is gained. Return to the original horizontal frequency setting and adjust for two cycles.

( ) Vary the focus control and notice the effect. Reset the focus control for the sharpest, most distinct trace.

( ) Vary the intensity control and notice the effect. Reset this control to a point just bright enough to see the trace easily.

These control settings will give a useful waveform for most applications. Additional controls such as external sync amplitude, sync selector, and phase controls will be discussed later, as they are needed.

Experiment 3-7

This experiment will compare audio frequencies visually on the oscilloscope screen and audibly in the earphone.

( ) Connect one lead of the earphone to lug 1 of terminal strip E and the other lead to lug 1 of terminal strip F.

( ) Adjust the oscilloscope and test chassis for the proper two-cycle waveform as in Experiment 3-6.

( ) Decrease the 20 KΩ control of the test chassis until the waveform disappears.

( ) Slowly advance the 20 KΩ control while listening with the earphone. Watch the screen for the first waveform to appear. You should see and hear the audio frequency waveform at the same time. Adjustment of the vertical gain control may be necessary to accomplish this.

( ) Continue to advance the 20 KΩ control of the test chassis and note the change in waveform.

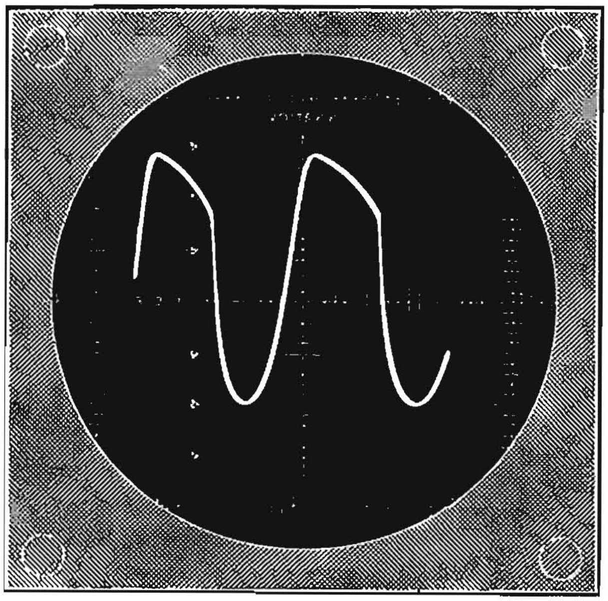


Figure 3-36

You should observe the following: (1) As the intensity of the sound increases, the amplitude increases on the screen. (2) As the sound changes, there will be a corresponding change in the shape of the curve such as in Figure 3-36. This is a distorted sound wave. You may also note a slight change in frequency in doing this part of the experiment.

( ) Decrease the 20 KΩ control until the simple two-cycle sine wave appears.

( ) Turn off the test chassis. Blow or whistle into the earphone. Note the complicated waveforms that appear on the screen of the oscilloscope. You may have to adjust the vertical gain control to obtain enough amplitude on the screen. Other sound sources can also be tried.

( ) Remove the earphone connections from the test chassis and turn off the oscilloscope.

SUMMARY

Current that flows only in one direction is called DC. Current that flows first in one direction, then in the other is called AC.

Graphs are useful in interpreting different AC currents. Time is shown by a distance along a horizontal line and current is shown as a distance in the vertical direction. AC voltages are interpreted in the same manner. Graphs help compare frequency, amplitude, and waveforms of different AC currents.

The most common waveform is the sine wave. Household current is a 60 cycle sine wave; that is, it makes 60 alternations in one second.

Other waveforms that occur in electronics are the pulsating direct current (PDC) wave, the square wave, the clipped sine wave, rectified DC and many more complex waveforms. The oscilloscopes great value is that it can graph electronically complex waveforms.

CHAPTER 4

Capacitors

The capacitor is made by placing two conductors of large surface area close to each other, separated by a thin insulating material. Capacitors are used in electronic circuits because they block DC current and pass AC current.

The amount of opposition a capacitor offers to AC current depends on the frequency of the AC current and the electrical size of the capacitor. This opposition is called capacitive reactance.

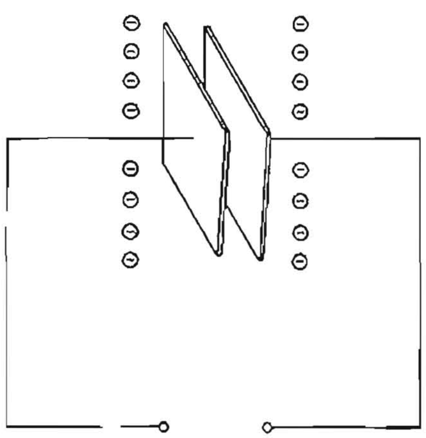
This chapter will show why capacitors will pass AC current and not DC current. It will show how capacitors can be combined and how capacitive reactance can be calculated. Special attention will be given to resistors and capacitors in combination.

Capacitors and Capacitance

A very simple capacitor can consist of two closely-spaced (but not touching) metal plates, as shown in Figure 3-37. Since the wires connected to these metal plates are not connected to any source of electrical energy, it may be assumed that the plates are "in balance" as far as electrical charge is concerned. Both metal plates contain normal numbers of electrons (symbolized by the minus signs next to each plate). Air acts as the insulation between the two plates.

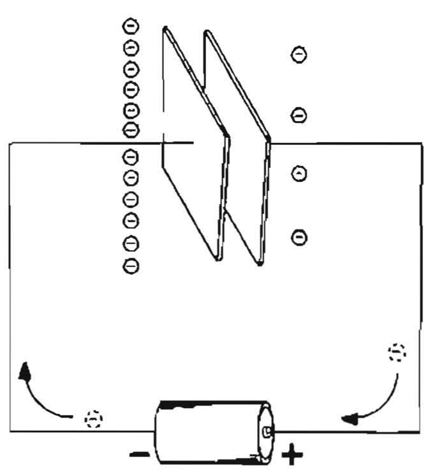
One of the unusual things about a capacitor is that when a source of electrical energy is connected to its plates (for example, the battery in Figure 3-38), the electrical pressure in the battery causes electrons to pile up on one plate, and move away from the other plate. The two plates are not in contact with each other, so the circuit is actually "open" as far as the battery is concerned...yet current does flow in the circuit for a short instant, as the electrical pressure in the battery attempts to force the current around the circuit in the direction indicated by the arrows. This short impulse of current "charges" the capacitor in the sense that extra electrons are accumulated on one plate and drawn away from the other plate. This "unbalanced" condition is shown in Figure 3-38 by the minus signs symbolizing negative charge.

As soon as the battery has exerted all the pressure it can in the circuit, and has moved as many electrons onto one capacitor plate and away from the other plate as it can, the "charged" condition is reached, and no further current flows.



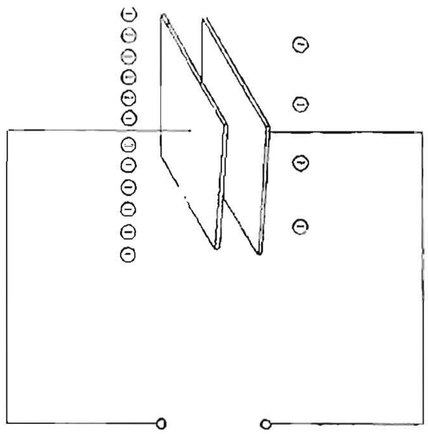
A SIMPLE CAPACITOR CONSISTING OF TWO METAL PLATES FACING EACH OTHER BUT NOT TOUCHING.

Figure 3-37



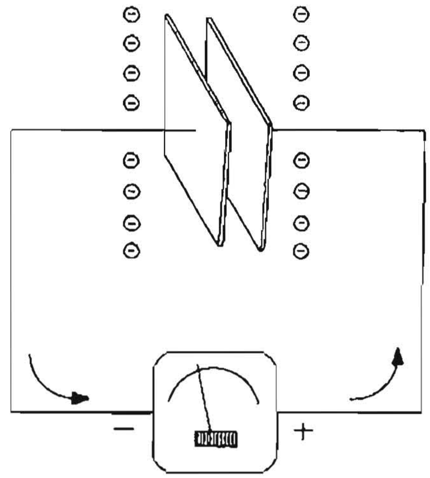
ELECTRICAL PRESSURE FROM BATTERY "CHARGES" CAPACITOR

Figure 3-38



A CAPACITOR HOLDS THE "CHARGE" PUT ON ITS PLATES.

Figure 3-39



A CAPACITOR DISCHARGES AND NEUTRALIZES ITS PLATES AS SOON AS A CIRCUIT IS PROVIDED.

Figure 3-40

If the battery is then removed from the circuit (Figure 3-39), the charge remains on the capacitor even though the source of energy has been taken away. The charge of the capacitor will remain (barring some leakage through the air) until a circuit is provided to connect the plates together and equalize them again. The capacitor will remain charged, in other words, until a circuit is provided through which current can flow to discharge it. In a sense, a charged capacitor is like a battery since it has energy of its own which it will dispense very quickly as soon as a circuit is provided through which it can discharge.

Figure 3-40 shows what happens when a discharge circuit is provided so the capacitor plates may return to "balance" again, with equal amounts of electrons. A meter, connected to complete the circuit from one capacitor plate to the other, would provide a path for the two plates to equalize their charge. Current would flow from the plate with an excess of electrons, around to the plate with a deficiency of electrons (indicated by the arrows) and the meter would actually register a pulse of current as this discharge action took place. The direction of discharge current flow (arrows in Figure 3-40) is just the opposite from the direction of current flow that took place in charging the capacitor (Figure 3-38).

A capacitor, therefore, reacts to circuit current by becoming charged, and then has the capacity to provide current of its own in the process of discharging back through the circuit. If a series of pulses were fed to a capacitor, and the circuit were closed between pulses to provide a path for the capacitor to discharge, the capacitor would "answer" current pulses by returning "kick-back" pulses of its own.

To put it another way, a quick surge of current applied to a capacitor causes electrons to pile up on one plate and move away from the other plate. The capacitor is thereby charged. When the surge of current stops, the capacitor can send its own surge of current back around the circuit to equalize its plates again. You should keep this important characteristic of capacitors in mind, since the action of a capacitor in a tuned circuit is related to its ability to answer current pulses with pulse reactions of its own.

Suppose we now connect, not a DC voltage, but an AC voltage source to the capacitor. This would create a continuous repetition of the pulse current obtained when the DC battery was switched in and out of the circuit; an AC current will apparently flow right through the capacitor.

Actually, the electrons do not flow across the space between the plates, since it is insulated. When an AC voltage source is used, however, the effect is the same as though the current were flowing right through the capacitor.

If a pulsating direct current (PDC) is used, the capacitor will block the constant part of the current but will pass the varying part, as indicated in Figure 3-41. This ability of a capacitor to block the constant portion of a PDC current is one reason why the capacitor is such an important circuit element.

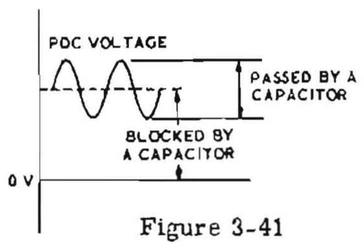
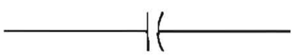


Figure 3-41

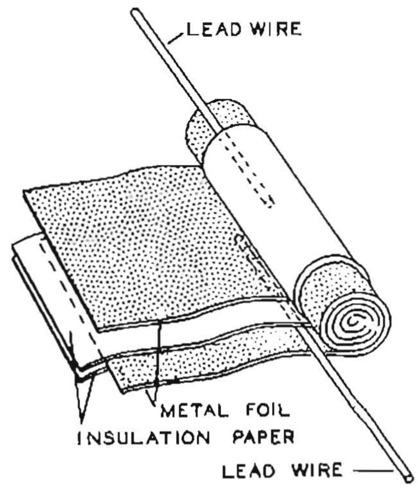
The schematic symbol for a fixed capacitor is shown in Figure 3-42.



SCHEMATIC SYMBOL FOR FIXED CAPACITOR.

Figure 3-42

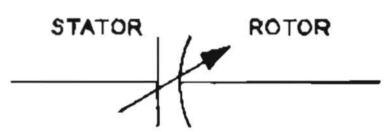
Figure 3-43 shows how the effect of large capacitor plates spaced closely together, but not touching, is achieved in some actual capacitors. A sandwich made of two sheets of metal foil, separated by insulating paper, is wound into a roll to give a large plate area. This keeps the physical size of the capacitor to manageable dimensions.



ACTUAL CAPACITORS ARE FREQUENTLY MADE OF METAL FOIL AND INSULATING PAPER, WOUND TOGETHER IN A ROLL.

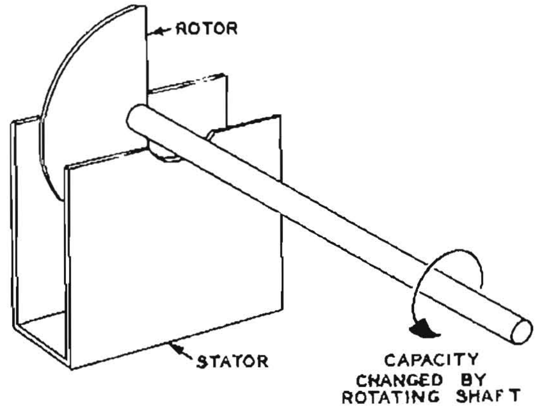
Figure 3-43

The schematic symbol for a variable capacitor is shown in Figure 3-44. You will observe a diagonal arrow across the plates. This symbolizes the fact that the size of the capacitor may be varied.



SCHEMATIC SYMBOL FOR VARIABLE CAPACITOR.

Figure 3-44



VARIABLE TUNING CAPACITOR.

Figure 3-45

The physical construction of a common type of variable capacitor is shown in Figure 3-45. Most variable capacitors of this type use air as the insulator between the two plates, and one plate is so arranged that it can be moved in and out of the space between the two opposing plates.

The amount of charge on each plate of a capacitor depends on the voltage applied. The greater the voltage applied, the greater the charge. However, if you divide the charge on each plate by the voltage applied across the plates, the number we get is always the same for any one capacitor. This number is called the capacitance, the symbol for which is "C."

$$C = \frac{\text{charge acquired on each plate}}{\text{voltage applied across the plate}}$$

Capacitors are rated in farads, which is a measure of the capacitor's ability to take a charge. The main factors in determining a capacitor's electrical size are the amount of effective plate area, and the distance between the two plates. The closer the plates are together (without touching), and the larger the plate area, the higher the capacity.

The actual capacitors used in electronics are only small fractions of a farad in size, so the terms microfarad (one millionth of a farad), and micromicrofarad (one millionth of a millionth of a farad) are commonly used. As an example of this relationship, note that 1000 micromicrofarads is equal to .001 microfarad, which is equal to .000,000,001 farads. Microfarad is abbreviated mfd, μf or μfd, and micromicrofarad is abbreviated mmf, mmfd, or $\mu\mu f$.

The term "picofarad" is now taking the place of micromicrofarad and is denoted pf. The term "nanofarad" (nf) is occasionally used for millimicrofarad.

Capacitors in Series and Parallel

Capacitors, like resistors, can be arranged in series and parallel connections, but the rules for determining an equivalent capacitance are not the same.

The rules for adding capacitances in series and parallel connections are just the opposite of those for adding resistors.

For any number of capacitors connected in parallel, the total capacitance is simply the sum of all the individual capacitances. Thus, total $C = C_1 + C_2 + C_3 + C_4 + C_5$, etc., when the capacitors are connected in parallel.

For any number of capacitors connected in series, the total or equivalent capacitance is

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} + \frac{1}{C_5}, \text{ etc.}$$

Capacitive Reactance

When a negative voltage is applied to one plate of the capacitor, the force of repulsion between the electrons forces electrons off the second plate. Naturally this same force of repulsion works both ways. That is, the electrons on the second plate hinder the build-up of negative charge on the first plate. The capacitor thus opposes the flow of current. The opposition of a capacitor to current is measured by its capacitive reactance. For a simple circuit consisting only of capacitors and an AC voltage source, the capacitor reactance (symbolized X_C) can be used in Ohm's Law in place of R.

Although similar to resistance, capacitive reactance differs from resistance because capacitive reactance depends on the frequency. As the frequency increases, the capacitive reactance decreases, less voltage occurs across the capacitor, and a greater current flows. As the frequency decreases, the capacitive reactance increases. The voltage across the capacitor then increases and the current flow decreases. When the frequency is zero, that is, when the current is a direct current, no current flows at all as you have already seen.

Ohm's Law for capacitors is the same as Ohm's Law for resistors, except that resistance (R) is replaced by capacitive reactance (X_C). Thus,

$$I = \frac{E}{X_C} \text{ or } E = I\,X_C \text{ or } X_C = \frac{E}{I}$$

The exact value of X_C for a capacitor when it is connected across an AC voltage source is given by the equation $X_C = \frac{1}{2\pi f C}$. In this equation,

π (pi) equals 3.14, f is the frequency in cycles per second, C is capacitance in farads, and X_C is in ohms. If C is in microfarads, X_C is in megohms.

When both capacitors and resistors are included in the same circuit, which is usually the case, the resistances and the capacitive reactances cannot be simply added together. Just how resistance and capacitive reactance may be added, along with a third type of opposition to the flow, called inductive reactance, to obtain the total opposition to the flow, called impedance, will be discussed in Chapter 5.

RC Circuits

If a voltage is applied to a small resistor and capacitor, the charge increases with time as shown in Figure 3-46. The rate of charging, which is current, is affected by resistance. When a large resistor is placed in series with the capacitor as in Figure 3-47, the slope of the graph changes. By Ohm's Law E = IR. As R increases, I decreases if the voltage stays the same.

The actual time required for a capacitor C to charge through a resistor R to about two-thirds of the supply voltage is equal to the product of C x R. If C is expressed in farads and R is expressed in ohms, then the time constant is in seconds. If C is expressed in microfarads and R is expressed in megohms, then time is also in seconds. This value is referred to as the "time constant."

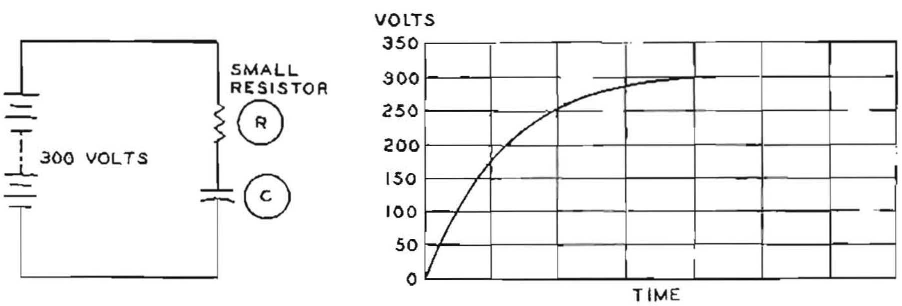


Figure 3-46

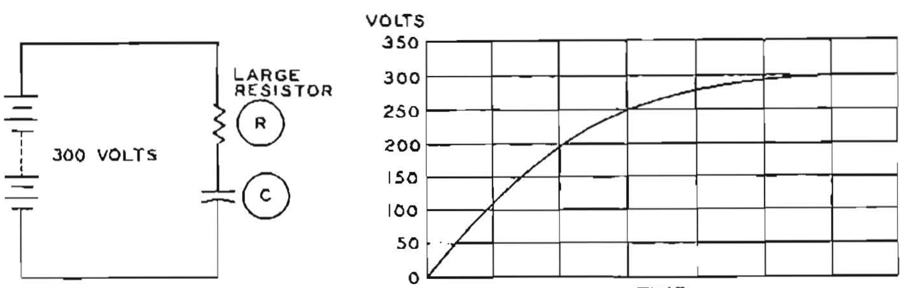


Figure 3-47

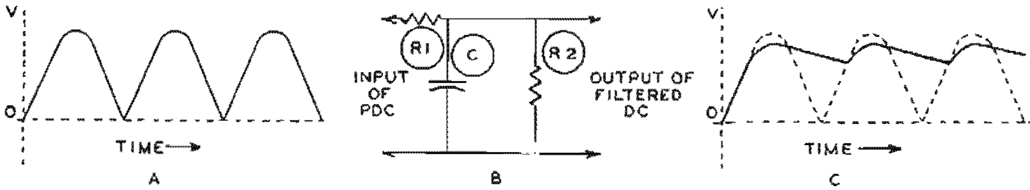


Figure 3-48

This characteristic is used in oscilloscope design to give the time reference needed in moving the spot across the face of the oscilloscope screen to be in step with the waveform being viewed.

Another type of RC circuit consists of resistance and capacitance placed in parallel. When PDC voltage is applied to such a circuit, the waveform is altered. Figure 3-48, Part A, shows such a circuit with PDC applied to it. The resistance of R2 is made large compared to the capacitive reactance of the capacitor C and the resistance of R1.

As the voltage increases in the network (the parallel circuit) the capacitor charges through R1. As the voltage starts to decrease below the voltage across the charged capacitor, the capacitor starts to discharge through the resistor, R2. This delays the drop in voltage across R2. The values of the capacitance and resistance determine how much the voltage is delayed in decreasing across R2.

As the capacitor continues to discharge through the resistor, a second increase in voltage starts. The increasing voltage will again charge the capacitor, repeating the cycle. This results in leveling out the PDC to make it look more like DC. This process is called filtering. Figure 3-48, Part B shows an example of this effect.

If the resistance between the capacitor and the ground is infinite (an open circuit), and if there is no leakage of the charge between the plates (that is, the plates are completely insulated) the capacitor will maintain its charge almost indefinitely. This situation is a source of serious danger to the unwary. The beginner in electronics is often startled to discover that some instruments are dangerous even when they are turned off. If your hand should complete a circuit from one plate to another of a charged capacitor, directly, or from one plate to the other through ground, the capacitor will discharge through you. Oscilloscopes are especially treacherous in this regard and the highest safety precautions should be used when working on this instrument with the cabinet removed.

EXPERIMENTS

In the following experiments you will see and hear how the presence of a capacitor effects the operation of your audio oscillator. You will also be able to see how the size of the capacitor will affect the characteristics of a circuit.

We have selected the "feedback" portion of the circuit to show these effects. This portion was chosen because it will function properly only if it passes AC current and blocks DC current. You will find the experience of working with the feedback circuit helpful when it is discussed in Chapter 8 in connection with oscillators.

Experiment 3-8

This experiment will show why it is sometimes desirable to pass an AC current while blocking DC current. This is shown by replacing a capacitor with a wire conductor, which will pass both AC and DC current.

( ) Adjust the oscilloscope and audio oscillator on the test chassis for a two-cycle waveform.

( ) Replace the .05 μfd capacitor that is connected from lug 4 of terminal strip A to lug 3 of terminal strip B with 3-1/4" wire.

( ) Connect one lead of the earphone to lug 1 of terminal strip E and the other lead to lug 1 of terminal strip F.

( ) Turn the 20 KΩ control through its full range. The audio frequency AC current is very low and may not be heard or seen.

( ) Remove the 3-1/4" wire and replace it with the .05 μfd capacitor.

( ) Adjust the 20 KΩ control for the proper two-cycle waveform.

Experiment 3-9

In this experiment you will see the effect of changing the size of capacitors in the circuit.

( ) Note the position of the frequency vernier. Record: ______.

( ) Replace the .05 μfd capacitor from lug 4 of terminal strip A to lug 3 of terminal strip B with a .01 μfd capacitor.

( ) Adjust the 20 KΩ control on the test chassis, if necessary, to obtain a waveform.

( ) Adjust the frequency vernier on the oscilloscope for a two-cycle waveform. Note the position and record: ___. Also notice any change in the frequency in the earphone.

( ) Replace the .01 μfd capacitor with a .1 μfd capacitor.

( ) Adjust the 20 KΩ control on the test chassis, if necessary, for a waveform.

( ) Adjust frequency vernier on the oscilloscope for a two-cycle waveform. Note the position and record: ____. Again note the change in frequency of the sound in the earphone.

Comparing the values you recorded for the three positions of the frequency vernier, you will see that as the size of the capacitance increases, the frequency decreases. In the next experiment we will use this information to show that capacitors in parallel have more capacitance, and in series they have less capacitance.

( ) Replace the .1 μfd capacitor with a .05 μfd capacitor and adjust for the standard two-cycle waveform.

Experiment 3-10

If two .05 μfd capacitors are placed in parallel, their total capacitance can be calculated as follows:

$$C = C_1 + C_2 = .05 + .05 = .10\ \mu fd$$

Therefore, if another .05 μfd capacitor is placed in parallel with the .05 μfd "feedback" capacitor, this increase in capacitance should decrease the frequency.

( ) Connect a second .05 μfd capacitor from lug 4 of terminal strip A to lug 3 of terminal strip B.

( ) Adjust the 20 KΩ control on the test chassis if necessary, and note the frequency change.

If the same two capacitors are placed in series, their total capacitance is:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{.05} + \frac{1}{.05}$$

$$\frac{1}{C} = \frac{2}{.05}$$

$$C = .025\ \mu fd$$

This decrease in capacitance should increase the frequency of the audio oscillator.

( ) Disconnect the 6" wire at lug 4 of terminal strip A and connect it to lug 2 of terminal strip D.

( ) Disconnect one of the two .05 μfd capacitors at lug 3 of terminal strip B and connect it to lug 2 of terminal strip D. This places two .05 capacitors in series.

( ) Adjust the 20 KΩ control of the test chassis if necessary, and note the frequency change.

( ) Remove the .05 μfd capacitor from lug 4 of terminal strip A to lug 2 of terminal strip D.

( ) Disconnect the 6" wire from lug 2 of terminal strip D and connect it to lug 4 of terminal strip A.

( ) Remove the earphones.

( ) Adjust for the two-cycle waveform and remove the earphone connections from the test chassis.

( ) Turn off the oscilloscope and test chassis.

SUMMARY

Capacitors are used in electronic circuits because they pass AC and block DC current.

The opposition to current flow called capacitive reactance, is decreased by increasing either the frequency or the capacitance.

Capacitors placed in series decrease the capacitance. Capacitors placed in parallel increase the capacitance.

Resistance placed in series with a capacitor changes the charging and discharging rate. RC circuits, among other things, are used to filter rectified DC and to provide a time base for oscilloscopes.

CHAPTER 5

Inductance and Impedance

An inductor is a coil of wire which opposes the flow of AC current. Coils have different electrical values, depending upon the size of wire, the diameter of the turns, the number of turns, the nature of the material used in the center of the coil, etc. The coil you installed on the test chassis is an iron core, center tapped, variable inductor. Two types of coils are shown in Figure 3-49.

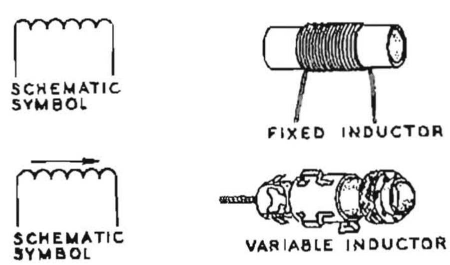


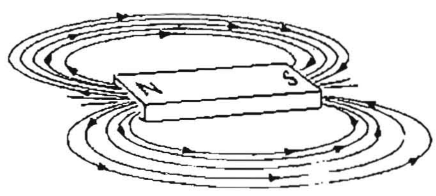
Figure 3-49

Transformers, antenna loops, and electric motor windings are familiar types of inductors. RF coils, IF coils, and speaker coils used in radios are examples of not-so-well known inductors. An inductor with a capacitor make up a very special circuit called the tuned circuit.

Inductors function because a wire carrying an electric current has a magnetic field around it. How this affects the current flowing in a coil of wire will be discussed in this chapter.

Magnetism and Current

Everyone is familiar with magnets. The magnetic field around the magnet is shown pictorially by drawing magnetic lines of force around it. See Figure 3-50.



MAGNETIC LINES OF FORCE AROUND A MAGNET

Figure 3-50

Although magnetism and electricity are not exactly the same thing, they are very closely related. A magnetic field is set up around any current-carrying wire. Also a current can be made to flow in a wire by moving the wire through a magnetic field. The magnetic lines of force around a current-carrying wire are shown in Figure 3-51. If AC current is used in the wire shown in Figure 3-51, the magnetic lines of force from the first part of the wire loop cut across the second part of the loop and induce a back current. This back current is smaller than the initial current and is in the opposite direction. The wire loop thus opposes the flow of alternating current. The induced current is in the direction opposite to the entering current, and therefore opposes the entering current. This opposition to the entering current is called "inductance." The symbol for inductance is L.

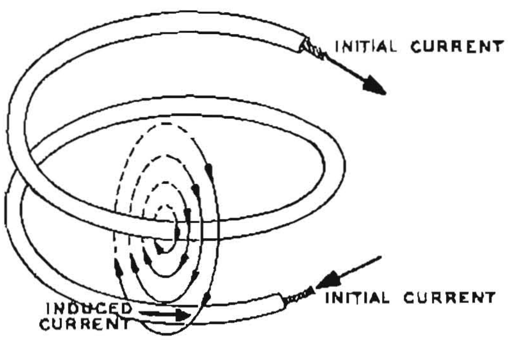


Figure 3-51

The inductance of the single loop is very small. Appreciable inductance is achieved by stacking the loops to form a coil so that the magnetic fields of each loop reinforce one another.

By Ohm's Law, the induced current must be accompanied by an induced voltage. Because this voltage can be measured more directly, we usually speak of an induced voltage rather than an induced current. The term back emf (electromotive force) is used more frequently than the term "induced voltage" to emphasize the fact that the induced voltage opposes the entering flow.

The inductance of a coil is measured in henrys. When a current is changing uniformly at one ampere per second and produces a back emf in the coil of 1 volt, the inductance of the coil is 1 henry.

Pure inductances in series and parallel add the same way resistors do. For inductors in series, $L = L_1 + L_2 + L_3 + L_4 + L_5$. For inductances in parallel, $\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \frac{1}{L_4} + \frac{1}{L_5}$.

However, it is almost impossible to get a pure inductance of any appreciable size, since any coil of wire also contains DC resistance.

Transformers

A transformer is a device used to change the voltage and current from an AC source. It is usually used to step up the voltage and step down the current. It makes use of the relation between magnetism and current discussed previously. The magnetic field around a coil produces a back emf (or induced current) in that same coil. If a second coil is placed very close to the first one, the magnetic lines of force from the first coil will also cut across the second coil and induce in it a current, provided that the current in the first coil is AC. The value of the current and voltage in the second coil depends on the number of turns in each coil and, of course, upon the current and voltage in the first coil. It also depends on the electrical properties of any material between the two coils. Power supplies use iron core transformers.

For an iron core transformer, if the number of turns in the secondary coil is twice the number of turns in the first coil, called the primary coil, the voltage will be doubled. If there are four times as many turns in the secondary coil as there are in the primary coil, the induced voltage (the voltage in the secondary coil) is four times as large as the input voltage (the voltage in the primary coil). The air core transformer is used at radio frequencies. The symbols for air core and iron core transformers are shown in Figure 3-52.

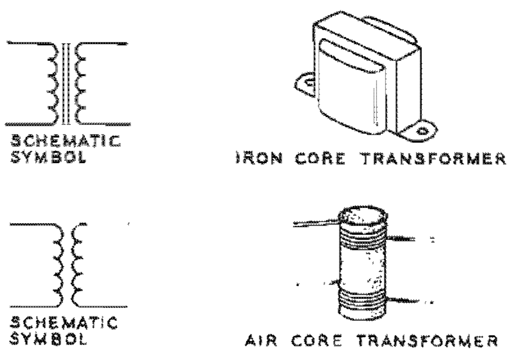


Figure 3-52

Inductive Reactance

Inductance opposes the flow of current as does resistance and capacitance. The opposition to current flow in a coil is called inductive reactance. Like capacitive reactance, inductive reactance depends on the frequency. Whereas capacitive reactance decreases with an increase in frequency, inductive reactance increases with an increase in frequency. When the frequency is zero (direct current) the inductive reactance is zero.

The formula for inductive reactance (symbolized X_L) is $X_L = 2\pi fL$; where π equals 3.14, f is the frequency in cycles per second, L is the inductance in henrys, and X_L is given in ohms.

Like R and X_C, X_L can be used in Ohm's Law only if inductance alone is present in the circuit.

To use Ohm's Law in a circuit containing inductance, resistance, and capacitance, the three quantities are combined in one called impedance.

Impedance

The total opposition of the circuit to current is called the impedance "Z" of the circuit. If the circuit contains only resistance, the impedance is equal to the resistance. If the circuit contains all three; inductive reactance, capacitive reactance, and resistance, the impedance is a combination of these but not simply the sum of all three.

This is true because X_L, X_C, and R all oppose the current flow in different ways. Resistance only dissipates the energy in the current; capacitance and inductance both store and release the energy. Capacitance and inductance differ because when capacitance is storing the energy, inductance is releasing it. When the capacitance is releasing energy, the inductance is storing it.

Inductive reactance and capacitive reactance are both called reactance, "X," but because they function in opposite ways they are considered of opposite nature. Because of this, the total reactance is equal to the difference between X_C and X_L. Reactance can be thought of as AC resistance. It is used in calculating the impedance of the circuit. If X_L is larger than X_C, then the reactance $X = X_L - X_C$. If X_C is larger than X_L, then the reactance $X = X_C - X_L$. The equation for the total impedance of the circuit is: $Z^2 = R^2 + X^2$ or $Z = \sqrt{R^2 + X^2}$.

R is the resistance of the circuit and X is the reactance of the circuit, equal to the difference between the capacitive reactance and the inductive reactance. Z, R, and X are all given in ohms.

Impedance can now be used directly in place of R in Ohm's Law for any AC or DC circuit. Ohm's Law, in its most general form, is $E = IZ$ or $I = \frac{E}{Z}$ or $Z = \frac{E}{I}$.

Resonant Circuits

A circuit composed of a resistor, a coil, and a capacitor, all connected in series with an AC voltage source is shown in Figure 3-53A. Such a circuit is called a series RLC circuit. Figure 3-53B shows a parallel tuned circuit such as will be constructed in Experiment 3-11. These circuits are resonant at one particular frequency; the impedance of the circuit changes with the frequency and is equal to R for a particular frequency, called the resonant frequency.

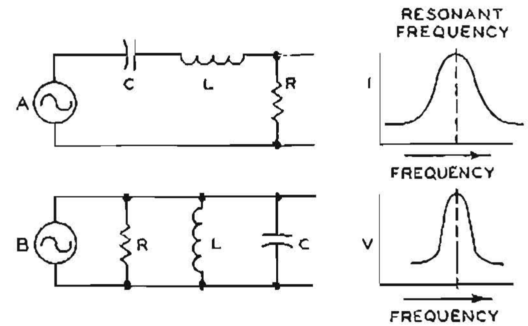


Figure 3-53

As you saw earlier, the impedance of an AC circuit can be broken down into the DC impedance (or resistance) and the AC impedance (or reactance). The reactance is equal to the difference between the inductive reactance and the capacitive reactance. Since inductive reactance increases with frequency and capacitive reactance decreases with frequency, there is one particular frequency at which the inductive reactance just equals the capacitive reactance.

When $X_L = X_C$, $X_L - X_C = 0$; that is, the reactance of the circuit is equal to zero. The total impedance of the circuit is then equal to just the DC impedance or the resistance, and this occurs when the frequency is the resonant frequency. At any frequency above or below resonance the total impedance will be greater.

When the total impedance is at a minimum (at the resonant frequency), the current passed through the RLC circuit will naturally be at a maximum. The general shape of the voltage frequency curve is shown in Figure 3-53B. The exact shape of the curve will depend on the particular values of R, L and C used. The sharper the peak on the current frequency graph, the greater is the selectivity or sharpness of the circuit.

The RLC circuit has many applications in such fields as radio, amplifier stages, radio frequency oscillators, and others. The tuning circuit of a radio consists of a fixed coil, some resistance, and a variable capacitor. A radio station broadcasts its signal at one particular frequency. The radio signal is picked up by the antenna, causing an RF (radio frequency) voltage to exist in the antenna. The antenna lead is connected to the tuning circuit. When the variable capacitor of the tuning circuit is adjusted so that the resonant frequency of the tuning circuit is the same as the frequency at which the radio station is broadcasting, this signal is passed by the tuning circuit, whereas the signals of all other radio stations which are broadcasting at different frequencies are rejected. The tuned ratio frequency is then passed through the rest of the radio and ultimately into the speaker of the radio. (The subject of amplification will be discussed in Part IV.)

EXPERIMENT 3-11

In the first part of this experiment you will build a radio frequency (RF) oscillator. An RF oscillator has three basic sections; an amplifier, feedback, and a tuned circuit. You will examine the tuned circuit variation as shown by the shaded area in Figure 3-54.

Amplifiers and feedback will be discussed in a later chapter. How an oscillator works will also be discussed later.

In the second part of the experiment you will look at an RF sine wave and observe the effect of changing the inductance in the circuit.

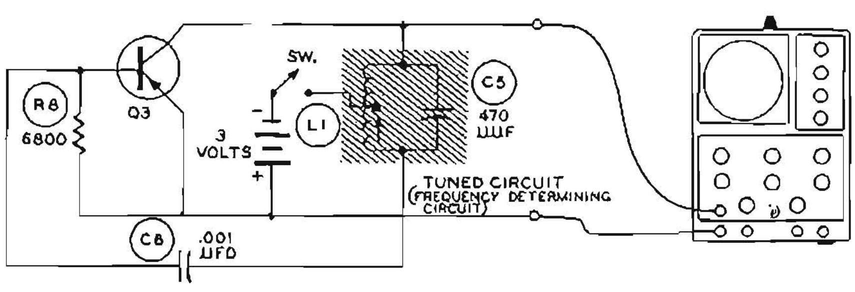


Figure 3-54

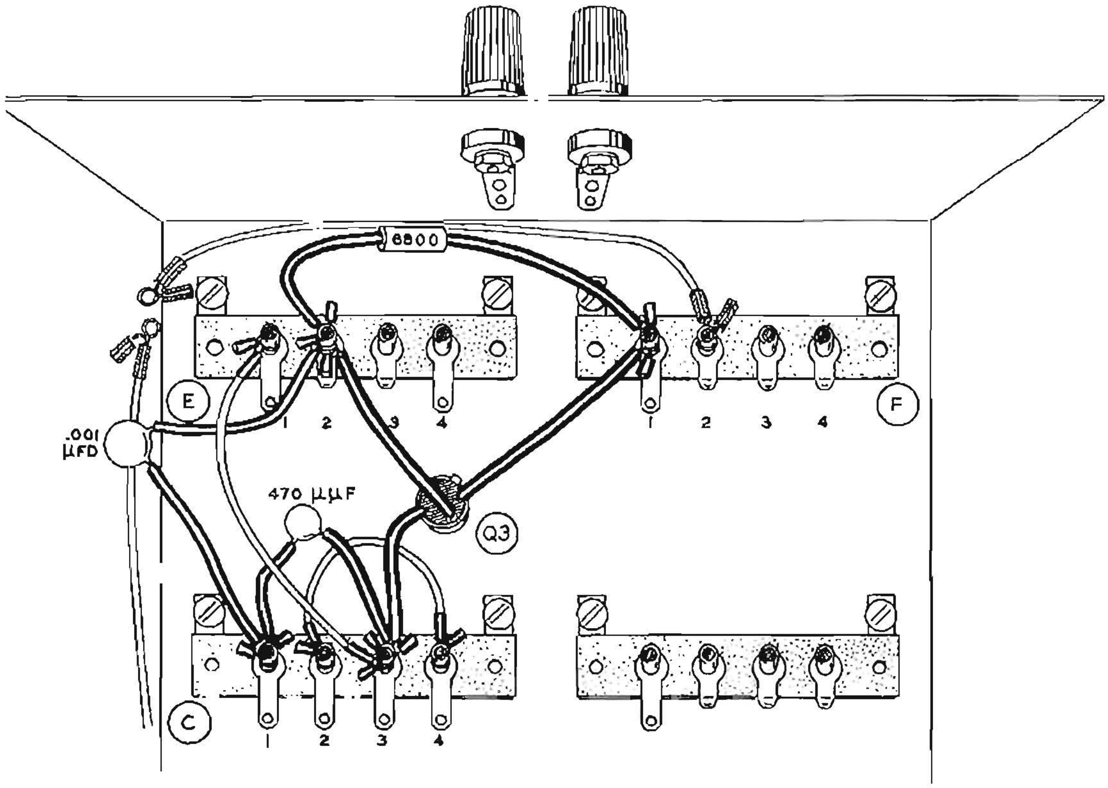


Figure 3-55

Do not remove any of the components on the test chassis. They will be needed in a later experiment.

Refer to Figure 3-55 for the following steps.

( ) Locate lug 1 of terminal strip E and disconnect the 6" wire that runs to lug 4 of terminal strip A.

( ) Disconnect the 6" wire that runs to lug 2 of terminal strip F.

( ) Connect a 6800 Ω (blue-gray-red) resistor from lug 2 of terminal strip E to lug 1 of terminal strip F.

( ) Connect a .001 μfd capacitor from lug 1 of terminal strip C to lug 2 of terminal strip E.

( ) Connect a 470 μμf capacitor from lug 1 to lug 3 of terminal strip C.

( ) Connect a 3-1/4" wire from lug 2 to lug 4 of terminal strip C.

( ) Connect a 3-1/4" wire from lug 3 of terminal strip C to lug 1 of terminal strip E.

( ) Install transistor Q3. Connect lead C to lug 3 of terminal strip C. Connect lead E to lug 1 of terminal strip F, and connect lead B to lug 2 of terminal strip E.

This completes the assembly of the RF oscillator circuit on your test chassis.

( ) Connect test leads from the test chassis output terminals to the vertical input of the oscilloscope. Turn on both units.

( ) Turn the horizontal frequency selector to cover the 100-500 kc range.

( ) If the oscillator does not oscillate, connect a 100 KΩ (brown-black-yellow) resistor from lug 2 of terminal strip E to lug 2 of terminal strip C.

( ) Adjust for a two-cycle waveform.

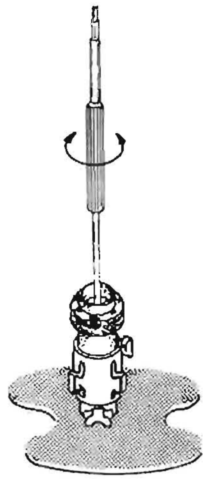


Figure 3-56

( ) Using the plastic alignment tool, turn the slug inside the coil slowly clockwise (as in Figure 3-56) and note the change in waveform.

Turning the slug, a molded, powdered-iron core, changes the inductance of the coil. Since the inductance has changed, X_L no longer equals X_C for that frequency. Small changes of L will result in small changes of frequency. However, if the slug is turned completely out of the coil, the circuit will stop oscillating. This happens because the inductive reactance becomes too small.

( ) Turn the slug counterclockwise until it reaches approximately its original position. If the oscillator does not start to oscillate, turn the test chassis off and back on.

( ) Turn the slug counterclockwise to repeat the above procedure.

( ) Turn off the chassis.

SUMMARY

A coil of wire offers resistance to the flow of AC current. This property of coils is called inductance, L. L is measured in henrys. The AC resistance of an inductor, called inductive reactance is measured in ohms.

A transformer is two or more windings with the same core. Transformers are used to change the current and voltage values of an AC source. Transformers are used in power supplies.

The total opposition to the flow of current in a circuit is called impedance and is a combination of R, X_C, and X_L. Since X equals the difference of X_L and X_C, then $Z = \sqrt{R^2 + X^2}$. Z is also measured in ohms.

In an RLC circuit the impedance changes with the frequency. At a particular frequency, the resonant frequency when $X_L = X_C$ and Z equals only R, the circuit can be made to oscillate easily. This is a tuned circuit.

CHAPTER 6

Semiconductors

Between conductors and insulators are semiconductors, which only partially resist electric current. Such materials as germanium and silicon, in special prepared forms, make up a long line of important semiconductor devices. Transistors, crystal diodes, thermistors, varistors, and solar cells are made of semiconductor material.

In this chapter the crystal diode and transistor will be discussed. The transistor as a circuit element is shown. And finally, in this chapter, the amplifier is discussed. You will then build a transistor amplifier in the experiments.

Semiconductor Materials

Semiconductors are a group of materials that are in the center of the resistance spectrum. These materials acquire special characteristics caused by altering their crystal structure.

Pure semiconductor materials have a rather high resistance to the flow of electric current. When impurities are added to the semiconductor material (amounts and types of these impurity materials are carefully controlled), the material has much less resistance to the flow of electric current. When one type of impurity is added, it causes a semiconductor material to have many excess (loosely held) electrons; this type of semiconductor crystal, shown in Figure 3-57, is called "N" type (negative).

When another type of impurity is added to the semiconductor material, it causes a shortage of electrons in a semiconductor material; this type of semiconductor crystal, also shown in Figure 3-57, is called "P" type (positive).

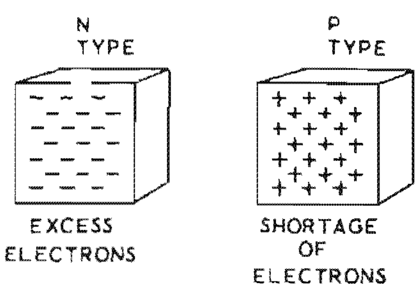


Figure 3-57

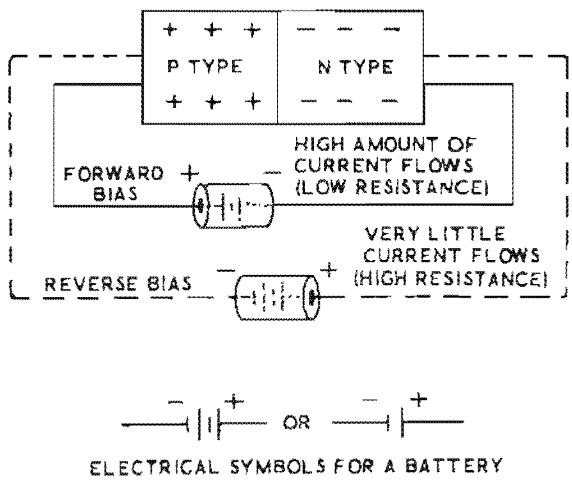


Figure 3-58

When N type and P type semiconductor crystals are joined together in a crystal diode, as shown in Figure 3-58, an unusual and very important phenomenon occurs at the "junction" where the two crystals are joined. When the positive terminal of the battery is connected to the N type crystal and the negative terminal of the battery is connected to the P type crystal, the junction appears like a very high resistance (almost like an insulator) and only the tiniest trickle of current is able to flow. A PN crystal, connected in this manner so that almost no current flows, is said to have reverse bias applied to it.

When the battery is reversed, with the negative terminal connected to the N type crystal and the positive terminal connected to the P type crystal, current flows easily and the PN crystal acts like a small resistor (almost like a conductor). A PN crystal, connected in this manner so that the current flows through it, is said to have forward bias applied to it.

A PN crystal junction, therefore, acts like a very large resistance when current tries to flow through it in one direction, and acts like a very small resistance when current flows through it in the other direction. This makes semiconducting material different from ordinary resistance materials.

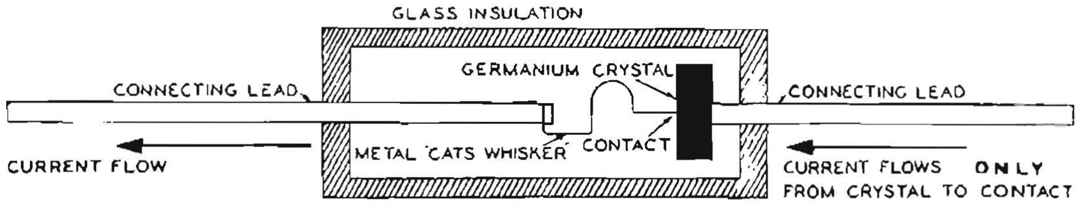


Figure 3-59

The same type of one-way current effect also occurs in a different type of crystal diode, called the "point contact" diode. The point contact diode is shown in Figure 3-59. The behavior of this point contact diode is essentially the same as the behavior of the PN junction diode; in one direction it presents a very high resistance to electric current and in the other direction, it presents a very low resistance to electric current.

Transistors

Transistors are made by placing the two different types of semiconductor crystals together in the form of a sandwich. Two crystals of one type are used for the "bread" parts of the sandwich, and one crystal of the other type is used in the "meat" position between the two others. A transistor is also like having two semiconductor diodes, made from only three pieces of crystal material.

Figure 3-60 shows how junction transistors are constructed, and their schematic symbols. At one end of the PNP transistor is a large "P" type semiconductor crystal called the Emitter. At the other end of the transistor is another large P type crystal called the Collector. In between these two P type crystals is a thin wafer of N type crystal material called the Base.

The NPN transistors are constructed in exactly the same manner, except that the types of crystal material are reversed; two N type crystals are separated by a thin wafer of P type crystal. The schematic symbol for the NPN type transistor is the same, except that the arrow that indicates the emitter points in the opposite direction, away from the base. The first type of transistor, the PNP type, is used in the circuits that are constructed in this kit and are the most common type.

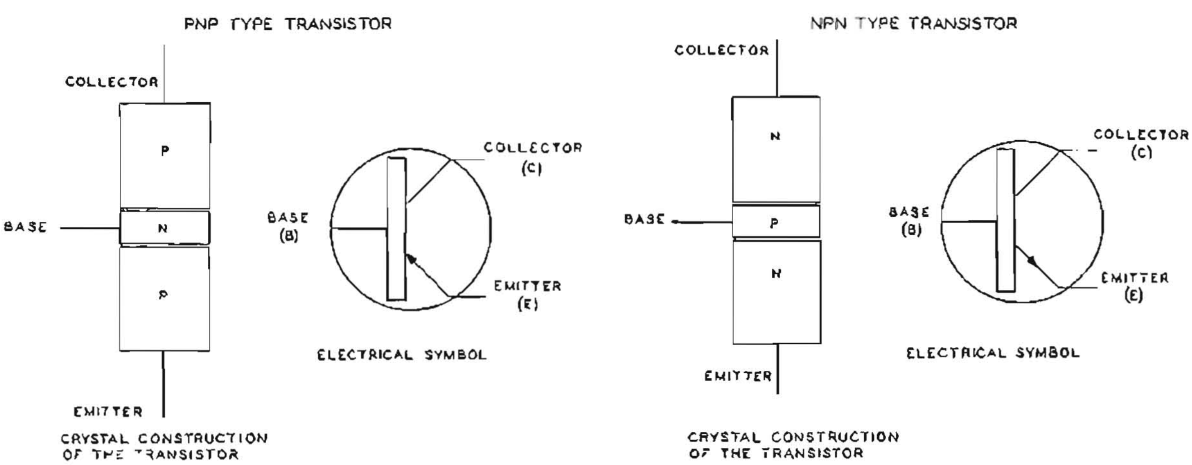
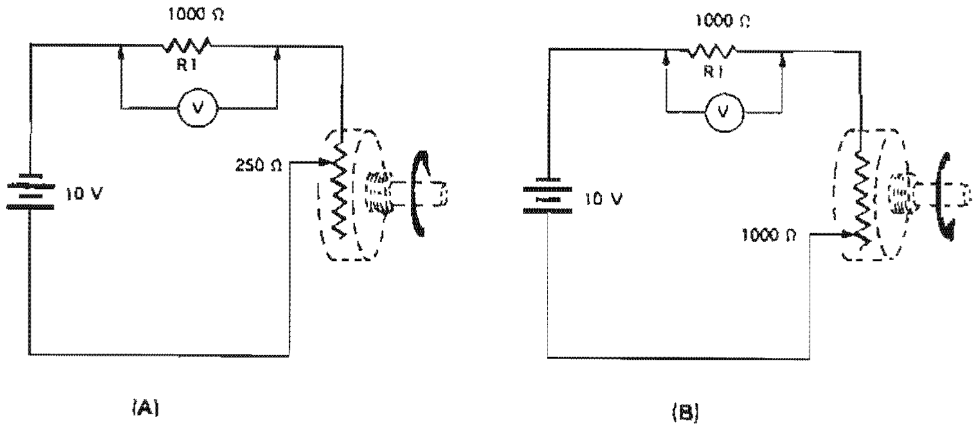


Figure 3-60



CIRCUIT CURRENT = $\frac{\text{TOTAL E}}{\text{TOTAL R}} = \frac{10}{1250}$ = 8 MA.

VOLTAGE ACROSS R1 E IR = 8V

CIRCUIT CURRENT = $\frac{\text{TOTAL E}}{\text{TOTAL R}} = \frac{10}{2000}$ 5 MA.

VOLTAGE ACROSS R1 E IR = 5V.

Figure 3-61

To make the operation of transistors easier to understand, think of the Emitter as emitting current into the transistor. Think of the Collector as collecting current and sending it back through the rest of the circuit to the battery.

The Transistor as a Circuit Element

A transistor acts like a resistor; a resistor that can be adjusted in electrical size to have either a larger or smaller number of ohms. By controlling the amount of resistance that this transistor presents to the circuit, the amount of current that flows through the circuit can be controlled.

In Figure 3-61 a 1000 ohm resistor, R1, has been connected in series with the variable resistor. In Part A of Figure 3-61 the variable resistor has been adjusted to a resistance of 250 ohms. The Ohm's Law calculation shows that .008 amperes, or 8 milliamperes of current is flowing through the circuit. The lower calculation shows that 8 milliamperes of current flowing through R1 causes 8 volts to be measured across resistor R1. The remaining 2 volts appear across the variable resistor.

In part B of Figure 3-61 the variable resistor has been adjusted to a resistance of 1000 ohms. Now, 5 milliamperes of current is flowing through the circuit. This 5 milliamperes of current flowing through resistor R1 causes a voltage of 5 volts to appear across R1. The remaining voltage, 5 volts, appears across the variable resistor.

Thus the voltage across the series resistor (R1) changed from 8 volts to 5 volts. This is demonstrated in the two schematics of Figure 3-61 which show that turning the shaft of the variable resistor controls the circuit current. Therefore, turning the shaft controls the voltage developed across series resistor R1. The amount that the voltage across R1 changes depends on how far the shaft is turned.

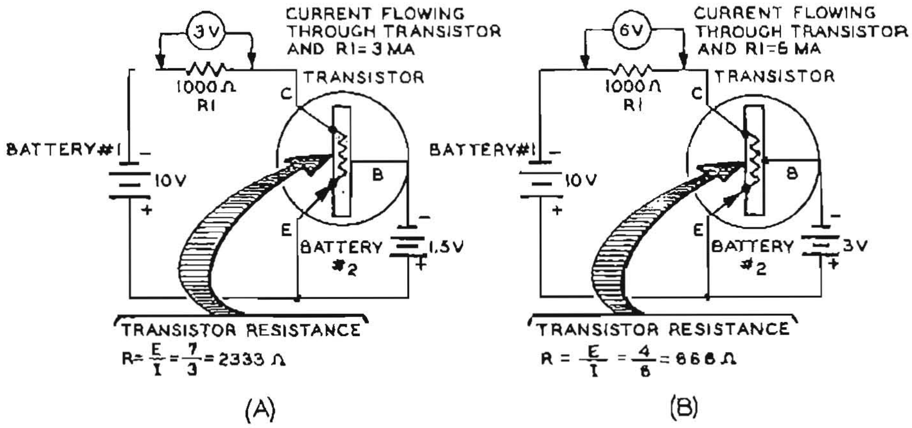


Figure 3-62

A transistor changes circuit voltages and current (see R1) electrically by changing the transistor control voltage of battery #2. Figure 3-62 shows a transistor replacing the variable resistor of Figure 3-61. The values for current and resistance given in Figure 3-62 were selected to make the circuit action as clear as possible, and are not necessarily the amounts of current or resistance that you might find in an actual circuit.

In both parts of Figure 3-62 the battery voltage connected to the Base of the transistor does the same job as the shaft of the variable resistor; it causes the resistance of the transistor in the series circuit to be changed.

In Part A of Figure 3-62, a 1.5 volt battery is connected between the Base and Emitter of the transistor, causing 3 milliamperes of current to flow in the circuit. The 3 milliamperes of current causes 3 volts to appear across 1000 ohm resistor R1. This leaves 7 volts appearing across the transistor. Calculating the resistance of the transistor with Ohm's Law shows that under these conditions the transistor acts like a 2333 ohm resistance would in the circuit.

In Part B of Figure 3-62; a 3 volt battery replaces the 1-1/2 volt battery that is connected between the Base and Emitter of the transistor. This voltage increase causes the resistance of the transistor to decrease, so that now 6 milliamperes of current flows in the circuit. With the larger current, 6 volts now appear across resistor R1. Using Ohm's Law to calculate the new resistance of the transistor in the circuit, shows that it has decreased to 666 ohms.

This change in resistance demonstrates that a transistor in a series circuit acts like a variable resistor. The change of resistance is performed mechanically in the variable resistor by turning the shaft, and it is performed electrically in the transistor by changing the voltage applied between the Base and the Emitter. The next section will explain how this electrically-controlled resistance change is put to use in circuits.

HOW TO CONTROL THE CURRENT FLOWING THROUGH A TRANSISTOR

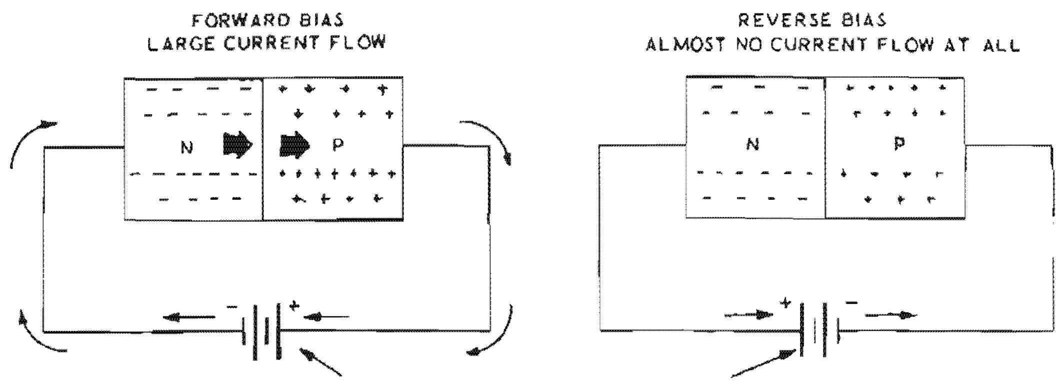


Figure 3-63

How to Control the Current Flowing Through a Transistor

You will now see how a small current flowing from the Emitter to the Base controls the amount of resistance in the transistor, and therefore determines whether a large or small current will flow through the transistor from Emitter to Collector. Earlier in this chapter you were introduced to P type and N type semiconductor crystals. Remember that a diode was made by joining N type and P type crystals together, and that a diode may be connected to a battery in two ways. The area where the two crystals come together is referred to as a junction.

Useful amounts of current will flow in only one direction through a junction. When the battery is connected to the crystal in such a direction that current flows, the diode (or junction) is said to have "forward bias" applied to it. When the battery is connected so that practically no current flows, the diode (or junction) is said to have "reverse bias" connected to it. Semiconductor diodes that have forward bias and reverse bias applied to them are shown in Figure 3-63.

Transistors usually contain two PN junctions. One of these junctions is between the Emitter crystal and the Base crystal, and the other is between the Base crystal and the Collector crystal. A NPN type transistor is shown in Figure 3-64.

To make the transistor operate properly, the batteries are connected so that the Emitter-to-Base junction has forward bias applied to it, and the Base-to-Collector junction has reverse bias applied to it. Because the Base crystal is actually constructed so that it is very thin (sometimes only about 1/1000 of an inch thick), most of the current leaves the Emitter, passes right through the thin Base region, and flows to the Collector. As a result, only a very small current flows from the emitter to the Base, and a comparatively large current flows from the

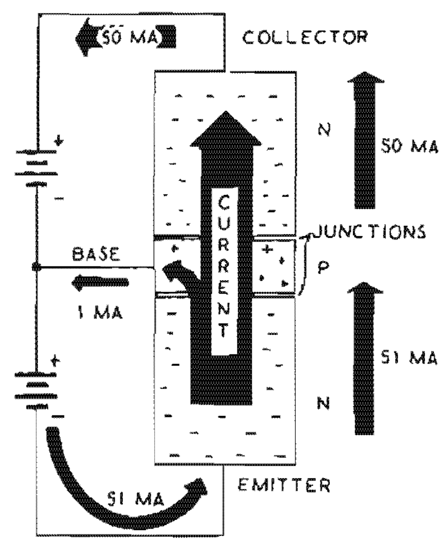


Figure 3-64

Emitter to the Collector. The currents shown in Figure 3-64 are representative of the relative sizes of currents in actual circuits. Notice that 50 milliamperes of current is flowing from the Emitter to the Collector and only 1 milliampere of current is flowing from the Emitter to the Base.

The small current that flows from the Emitter to the Base controls the large current that flows from the Emitter to the Collector. This smaller Emitter-to-Base current causes changes to take place in the PN junctions with the result that the transistor acts as if it were made up of the resistors shown in Figure 3-65.

The junction between the Emitter and the Base acts like a small fixed resistor, and the junction between the Base and the Collector acts like a large variable resistor. This large variable resistor usually stays large compared to the smaller resistor.

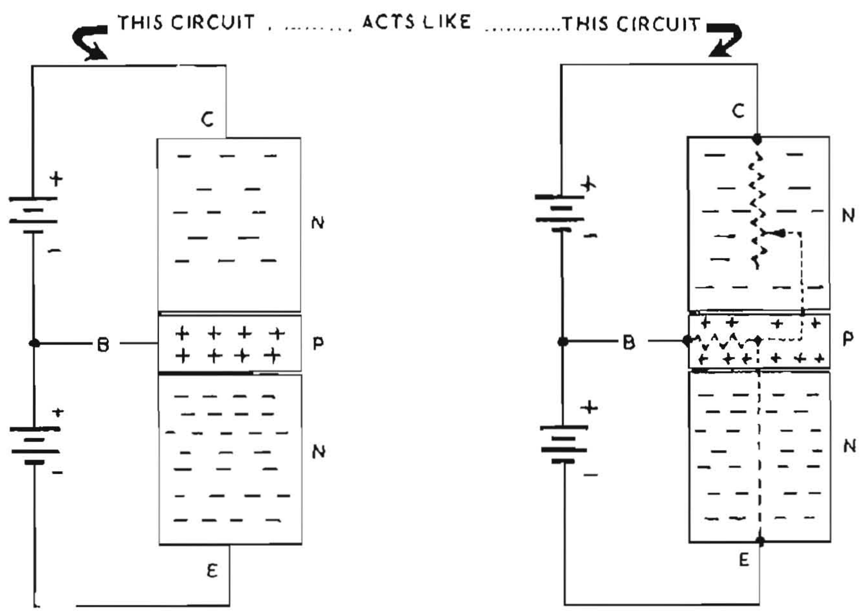


Figure 3-65

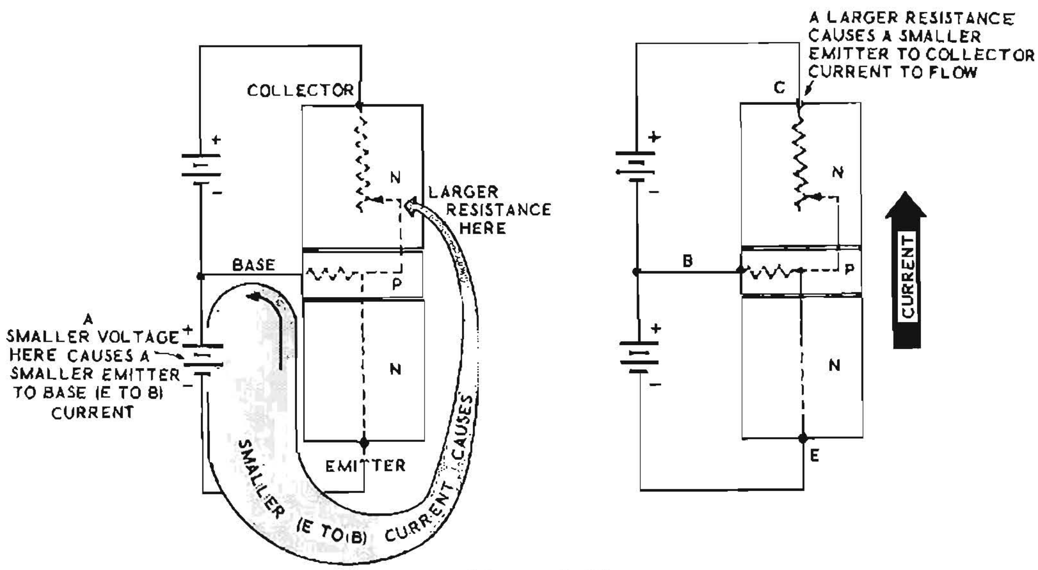


Figure 3-66

Figures 3-66 and 3-67 shows how the Emitter-to-Base current affects the larger variable resistance that appears between the Base and Collector of the transistor. In Figure 3-66 a small voltage is connected between the Base and Emitter with the minus and plus terminals connected as shown. The small voltage causes a small amount of current to flow from the Emitter to the Base. This small Emitter-to-Base current causes the variable Base-to-Collector resistance to be quite large, and as a result, a smaller current flows through the transistor from the Emitter to the Collector.

In Figure 3-67 a larger voltage has been connected between the Base and Emitter of the transistor, causing a larger current to flow. The larger Emitter-to-Base current causes the variable Base-to-Collector resistance to become smaller, thus allowing a larger current to flow from the Emitter to the Collector in the transistor. Remember then, that a small Emitter-to-Base current results in a small Emitter-to-Collector current and that a larger Emitter-to-Base current causes a large current to flow from the Emitter to the Collector.

A small voltage, therefore, applied between the Base and Emitter of a transistor, will control the current flowing in a transistor almost as if it were opening and closing a gate for the current to flow through. All practical transistor circuits work only because the current through the transistor can be controlled in this manner.

PNP Transistor

There are two types of transistors, the NPN type and the PNP type. In the explanations of previous paragraphs, NPN transistors have been used. In NPN transistors, the current emitted by the Emitter consists of a flow of electrons. These electrons are then collected by the Collector and sent back to the battery.

In the following paragraphs, all explanations will deal with PNP transistors, since transistors of this type, which are used more commonly, are supplied with this kit. PNP transistors work in exactly the same manner as the other type, except that the batteries are connected in the opposite direction. This means that all the electron streams will flow through PNP transistors in the opposite direction from the currents that were shown by the arrows in the circuits of the previous pages.

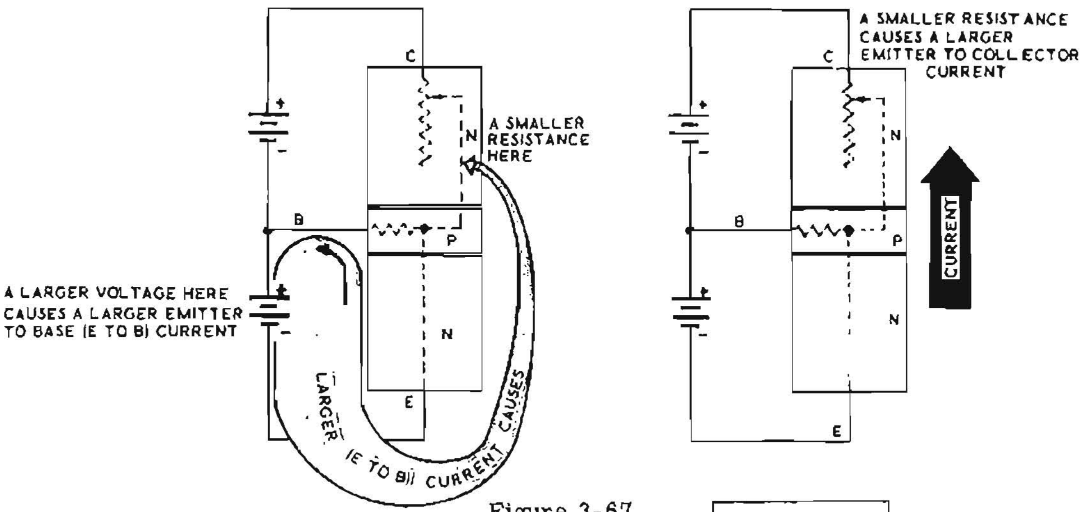


Figure 3-67

All the PNP circuits in the following pages could be explained by observing the flow of electrons as you have done in previous lessons. As you follow the flow of electrons from the Collector to the Emitter, it would seem as if the current were flowing backwards in the transistor. In the type of explanation that will be used, however, the Emitter is still emitting the current into the transistor and the Collector still collects current as before. The following paragraphs will explain how and why this is done.

Hole Current

Engineers and scientists explain the flow of current by either one of two theories; by the flow of electrons which flow from - to + in the circuit, or by the flow of holes (called "conventional current" or "hole current") which flow the other way, from + to -. These two types of currents were discussed in Chapter 1 of Part III. See Figure 3-68.

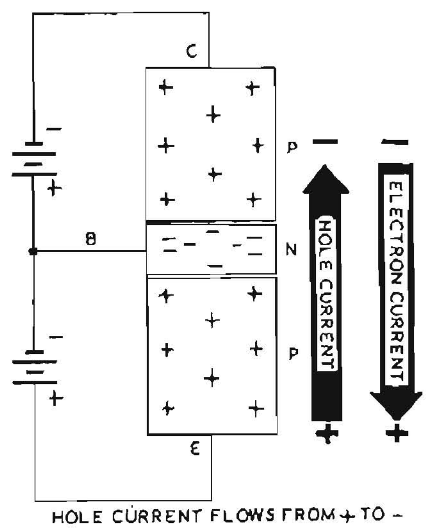


Figure 3-68

We will use this "hole current" to explain the PNP transistor circuits. The current emitted by the Emitter and collected by the Collector will be holes instead of electrons. The same + to - hole current will be used throughout all these circuits.

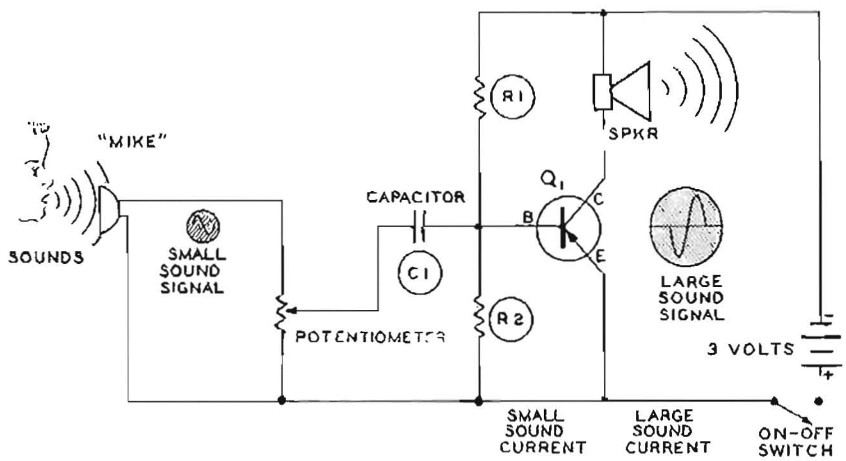


Figure 3-69

A Simple One-Transistor Amplifier

Amplifiers are necessary because the signal from a microphone (or other source of electrical signals, such as a phonograph pickup) is far too small and weak to be able to make a speaker operate. The amplifier takes the small signal from the microphone, or phonograph, and amplifies it until it is large and powerful enough to operate a speaker.

Figure 3-69 shows a complete one-transistor amplifier. The audio signal from the crystal microphone is connected across a potentiometer. The potentiometer selects a larger or smaller amount of this signal (depending on whether you wish the sounds to be louder or quieter) and connects it through the capacitor to the Base of the transistor. The capacitor is placed in the circuit so that the AC sound signal will travel from the potentiometer to the transistor, but the DC voltages at the Base of the transistor will be blocked, so it will affect neither the potentiometer nor the microphone.

As shown in Figure 3-70, resistors R1 and R2 form a voltage divider. This voltage divider causes a DC voltage to appear across resistor R2 that takes the place of the battery that was shown connected between the Emitter and Base in previous circuits. The main advantage of using resistor voltage dividers instead of batteries, are that they are smaller in size, and also that only one battery is needed for the whole amplifier.

The signal voltage from the potentiometer is connected across resistor R2 by means of the capacitor.

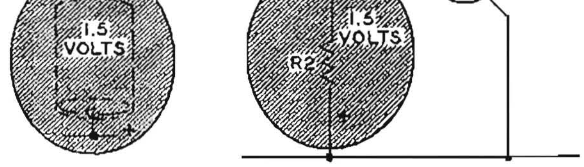


Figure 3-70

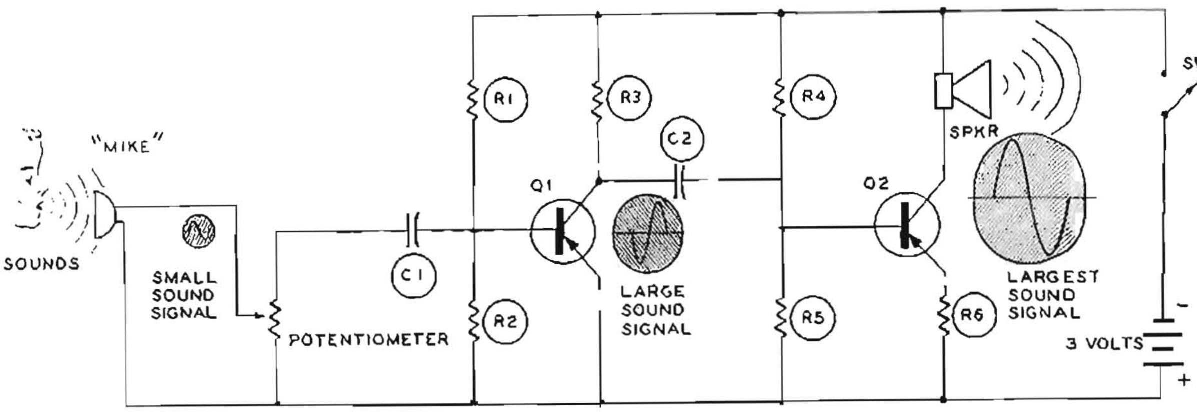


Figure 3-71

The small signal current flowing from the Emitter to the Base controls the large current flowing from the Emitter to the Collector; as a result the large current, since it is controlled by the smaller current, looks exactly like the small signal current. The larger signal current from the Collector then goes through the speaker where it is changed back into sound again.

A Two-Transistor Amplifier

Figure 3-71 shows a two-transistor amplifier. Actually, a one-transistor amplifier such as the amplifier of Figure 3-69 usually is not able, by itself, to create a large enough signal to drive a speaker.

In the two-transistor amplifier the sound signal is sent from the crystal microphone to the potentiometer, and from the potentiometer through C1 to resistor R2. The signal voltage across resistor R2 controls the Emitter-to-Base current of transistor Q1. Just as before, the smaller Emitter-to-Base (signal) current controls the larger Emitter-to-Collector (signal) current.

The amplified signal current from the Collector of transistor Q1, instead of flowing through the speaker as before, flows through load resistor R3. Since the signal current through R3 is changing like the input signal from the microphone, it creates a voltage across R3 (by Ohm's Law) that follows all the changes of the input audio signal.

The enlarged audio signal appearing across R3 then passes through capacitor C2 and is applied to the Base of transistor Q2. Capacitor C2 keeps the DC voltages of the two transistors from being mixed together but allows the AC signal voltages to pass from one transistor circuit to the other.

Now, at transistor Q2, the full cycle repeats itself once again. The audio signal increases and decreases the currents flowing from the Emitter to the Base of transistor Q2. This controls the larger current that flows from the Emitter to the Collector of transistor Q2, and the audio signal is enlarged a second time, just as it was in transistor Q1. The signal from the Collector of transistor Q2 is connected to the speaker, and the original signal from the microphone is changed back into a sound signal again, but greatly amplified in size. The purpose of resistor R6 is to provide the correct DC operating voltage at the Emitter of transistor Q2.

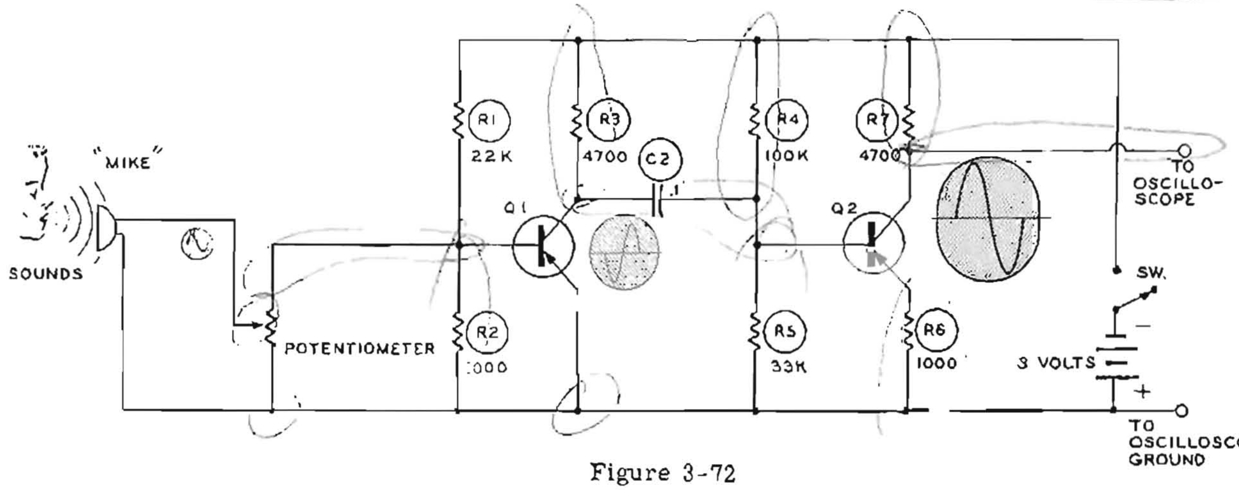


Figure 3-72

EXPERIMENT 3-12

The earphone supplied with this kit will also serve as a small microphone to convert sound waves to small AC currents. The two-transistor amplifier of Figure 3-72 will be used to amplify this small AC current so that it can be viewed on the oscilloscope. In Figure 3-72 the speaker discussed earlier is replaced with resistor R7, which serves as a load resistor for the collector of Q2. Figure 3-73 shows the test chassis wiring for the circuit shown in Figure 3-72.

( ) Take the earphone apart as shown in Figure 3-73A.

( ) Disconnect from lug 1 of terminal strip E the 3-1/4" wire that runs to lug 3 of terminal strip C.

( ) Reconnect to lug 1 of terminal strip E the 6" wire that runs to lug 2 of terminal strip F.

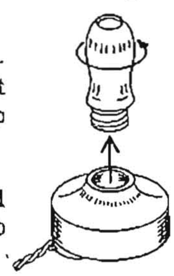


Figure 3-73A

( ) Remove the .05 μfd capacitor from lug 4 of terminal strip A to lug 3 of terminal strip B.

( ) Remove the .05 μfd capacitor from lug 1 to lug 4 of terminal strip B.

( ) Connect one lead of the earphone to lug 3 of terminal strip B and the other lead to lug 1 of terminal strip D.

( ) Connect one test lead of the oscilloscope to lug 2 of terminal strip F and the other to lug 1 of terminal strip D.

( ) Turn on the oscilloscope and adjust it for a straight line on the horizontal axis. Turn the vertical input to the X1 position (most sensitive position). Turn the horizontal frequency selector to the 100 to 1000 cps range.

( ) Turn on the test chassis. Talk into the microphone (earphone). Adjust the vertical gain until an easily visible waveform can be seen. Adjust the 20 KΩ control fully clockwise.

( ) Try several sources of sound such as whistling, singing, talking, etc. Note the difference of waveforms between "noise" and whistling.

( ) Using a steady amplitude (intensity) level of sound, change the oscilloscope lead from lug 2 of terminal strip F to lug 1 of terminal strip B.

Note the change in height of the waveform. This change of leads picks up the sound wave after only one stage of amplification, at the collector of Q1.

( ) Remove the earphone leads and turn off both the oscilloscope and the test chassis.

SUMMARY

Semiconductor materials are resistive materials that have special characteristics caused by their crystal structure. When impurities are added to these semiconductor materials it causes either excess electrons in the semiconductor material (N type) or causes a shortage of electrons in the semiconductor material (P type).

Combining an N type and a P type crystal results in a rather unusual effect across the junction where the two crystals join. When an electric current goes through this PN crystal in one direction, the crystal appears to have a very low resistance; when an electric current tries to go through this PN crystal in the other direction, the crystal appears to have a very high resistance. This unusual effect is put to practical use in both crystal diodes and transistors.

A transistor contains three semiconductor crystals. A very thin wafer of one type of crystal is placed between two larger segments of the other type of crystal. Current flows into this transistor from the crystal at one end called the Emitter, passes through the thin center crystal called the Base, and is collected by a third crystal called the Collector. Only a small amount of the total current from the Emitter of the transistor flows from the Emitter to the Base. Because the Base is so thin, most of the current passes through it to the Collector.

The small current that flows from the Emitter to the Base of the transistor controls the large current that flows from Emitter to Collector. When the Emitter-to-Base current is smaller it acts as if it were closing a gate between the Emitter and Collector, which allows less current to flow through. When there is a larger Emitter-to-Base current it acts as if it were opening a gate between the Emitter and Collector, allowing a larger current to flow through.

In an NPN transistor, a stream of electrons flows from the Emitter to the Collector. In a PNP transistor, a stream of holes (hole current) flows from the Emitter to the Collector.

In a two-transistor amplifier the electrical sound signal from the microphone is amplified two different times. One transistor amplifies this audio signal and the second transistor amplifies the signal more. If each of these transistors amplified the signal ten times, then the signal coming from the second transistor would be one hundred times larger than the signal that was going into the first transistor.

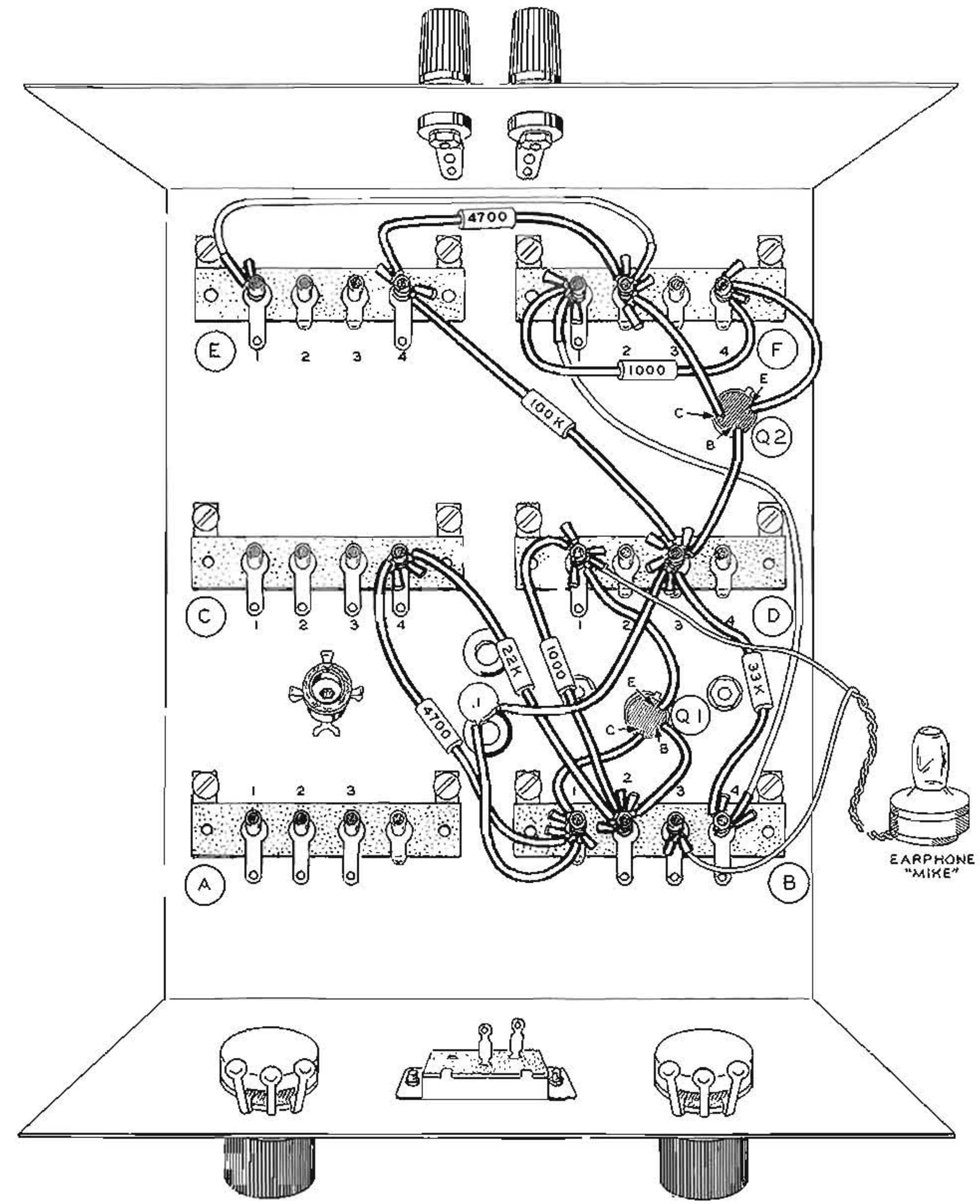


Figure 3-73

CHAPTER 7

Vacuum Tubes

If two metal plates, or electrodes, are enclosed in a vacuum by a glass tube, we have a simple vacuum tube called the diode. Adding another metal element results in another type of vacuum tube called the triode. Adding more elements yields the tetrode and pentode.

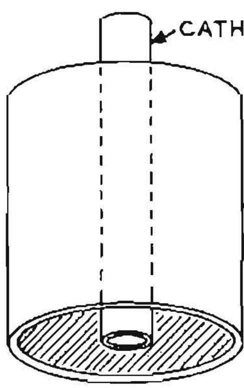
The vacuum tube is still the heart of most electronic devices such as radio, television, and radar. The oscilloscope contains several different types of tubes. For many applications in the oscilloscope, vacuum tubes as compared to transistors, handle high voltages and great power.

This chapter will explain how the vacuum tube works. The process of rectification is discussed and vacuum tube amplification is explained.

The Diode Tube

The term "diode" when applied to a vacuum tube means that the tube has just two elements; a cathode, and a plate. The "cathode" is a small-diameter metal tube located in the center of a larger-diameter metal tube called the "plate" or "anode." The cathode and plate elements of a diode vacuum tube are shown in Figure 3-74. Both metal cylinders may be open at each end, and are positioned in the tube so they do not touch each other at any point.

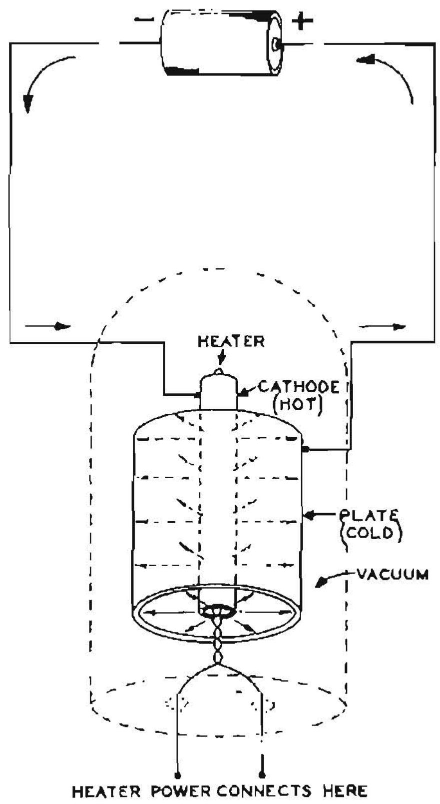
THE DIODE TUBE



THE TWO MAIN ELEMENTS OF A DIODE TUBE ARE THE CATHODE AND THE PLATE.

Figure 3-74

The operation of any vacuum tube depends on the emission of electrons from a material. Some materials, such as tungsten and several metallic oxides, will emit electrons from their surfaces when they are heated. The electron emission occurs in the same way that water boils off the surface of a hot frying pan. The cathode of a vacuum tube is made of an emitting material, and the cathode is heated by a heater filament just like the heating filaments in an electric toaster. For this discussion a diode is pictorially connected to a battery in Figure 3-75. The same picture is shown in schematic form in Figure 3-76.



CURRENT FLOWS IN THE CIRCUIT WHEN:

1. CATHODE IS HEATED.
2. BOTH ELEMENTS ARE ENCLOSED IN A VACUUM.
3. A POSITIVE PLATE-TO-CATHODE VOLTAGE IS APPLIED.

Figure 3-75

With no other elements present, a cloud of electrons would accumulate above the surface of the cathode, just as a fog of water vapor will appear at the spout of a tea kettle.

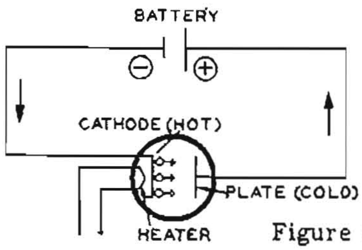


Figure 3-76

When the battery is connected as shown in Figure 3-76, a + charge appears on the plate (P). When the heater filament (H) is heated (by a separate voltage source not shown in Figure 3-76) the cathode (K) becomes hot enough to emit electrons. These electrons are then attracted to the plate (opposite charges attract) and travel the space between the cathode and the plate as shown by the small arrows in the tube in Figure 3-76. The tube is evacuated so that the electrons will not be slowed down by any air in the tube. (Hence the term "vacuum tube.") When the electrons reach the plate, they continue to flow to the + side of the battery. The electrons which have "boiled off" the cathode are replaced by the - side of the battery, so that electrons must flow from the - side of the battery to the cathode. In this way, a circuit is completed.

If the battery is reversed as shown in Figure 3-77, no current will flow. The cathode will still emit electrons, but these will be repulsed, not attracted, by the plate since the plate now has a minus charge. A small cloud of electrons will accumulate around the cathode, as shown by the minus signs near the cathode in Figure 3-77. Consequently no circuit is completed and no current flows.

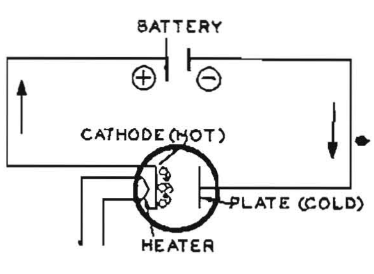


Figure 3-77

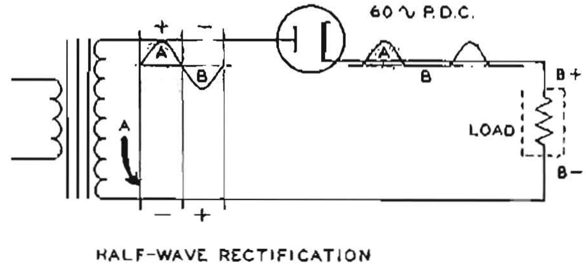


Figure 3-78

If an AC voltage is applied to the vacuum tube, the effect would be just like continually reversing the battery. The positive half of the cycle would cause a current to flow, but the negative half of the cycle would not. The current is thus rectified, and the resulting waveform is half-wave rectified DC. The circuit with one diode for rectifying AC current is shown in Figure 3-78. Two vacuum tube diodes can be arranged as in Figure 3-79 to produce full-wave rectified DC.

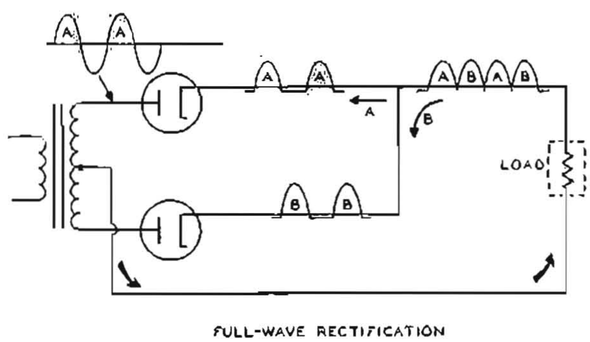


Figure 3-79

Amplification

The importance of amplification by a triode is not limited to just the operation of oscilloscopes. It is the heart of modern electronics. This "Age of Electronics" began when a third element, the grid, was added to the vacuum tube diode, resulting in a triode.

When it is said that a small "input" voltage is "amplified" by a triode to produce a large "output" current, this does not mean that the number of electrons in a wire is suddenly multiplied by some magic means. You do not get something for nothing. If a small input voltage is "amplified" to produce a large output current, the output current is supplied by a separate current source. The large output current is merely regulated or controlled by the small input voltage. The output current of an amplifier is proportional to the input voltage, but the output current does not come from the input voltage.

Another look at a similar water flow situation will serve to illustrate the idea of amplification. Figure 3-80 shows a water duct which is partially closed by a valve gate. How much of the pipe is open depends on the water pressure from the hose. When the hose is turned off, the gate will swing down and completely block the flow of water from the pipe. As the hose pressure is increased, the gate will swing away from the opening and allow more water to flow from the duct. With this sort of arrangement, the pressure from a simple garden hose could regulate the flow of millions of gallons of water.

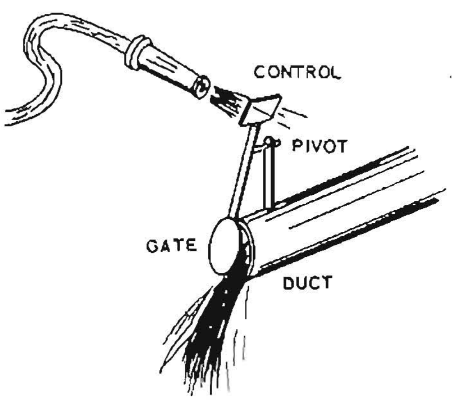


Figure 3-80

In a triode, the voltage to be amplified is just like the pressure in the hose. The large water duct is like a diode. The water in the large pipe is like the voltage supplied to a diode by a separate voltage source such as a battery. The valve gate is like the grid of a triode. The voltage to be amplified is applied to the grid to regulate the current through the diode in much the same way that the water pressure from the hose is applied to the valve gate to regulate the flow through the duct.

Triode

The construction of a triode is represented in Figure 3-81. The grid is simply a screen of fine wires, placed close to the cathode. (Like the plate, the grid is usually tubular and fits over the cathode between the cathode and the plate, as shown.)

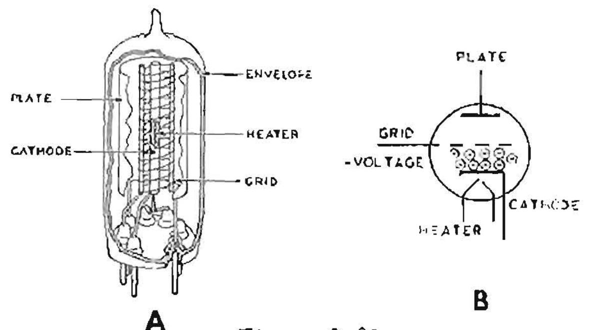


Figure 3-81

If no voltage is applied to the grid, the tube operates just like the diode already discussed. If now a small negative voltage, called a negative bias voltage, is applied to the grid, the force of repulsion between the negative charges on the grid and on the cathode opposes the flow of electrons from the negatively charged cathode to the positively charged plate. The important thing to understand is that the voltage between the grid and cathode affects the flow of electrons much more than the voltage on the plate does, because the grid is so much closer to the cathode than the plate. This is where amplification comes in. A small change in the grid voltage will greatly affect the electron flow from the cathode to the plate.

The voltage to be amplified is now applied to the grid along with the negative DC voltage. If the input voltage is positive, it tends to cancel out the opposing effect of the bias voltage, thus increasing the electron flow from the cathode to the plate. If the positive input voltage is just as large as the negative bias voltage, the two cancel each other completely, and the triode operates as a diode. The positive input voltage is usually not allowed to get larger than the negative bias voltage, for if the input voltage more than cancels the bias voltage, the output of the triode is no longer proportional to the input.

If a negative input voltage is applied to the grid along with the negative bias voltage, the flow from the cathode to the plate is reduced because of the increased repulsion between the grid and the cathode. If the total negative grid voltage (bias + input voltage) reaches a certain point called the cut-off voltage, the electron flow from the cathode to the plate will be entirely stopped. This is similar to a completely closed water pipe in Figure 3-80.

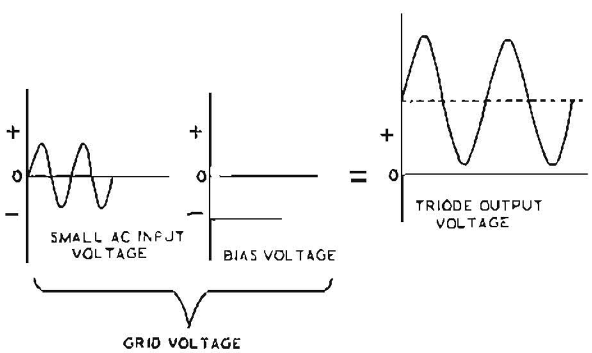


Figure 3-82

If a small AC voltage is used as the signal voltage, the output voltage will be amplified as shown in Figure 3-82. However, if the AC voltage is so large that the cut-off grid voltage is reached during the negative half of the AC cycle, the resulting output voltage would be clipped voltage, as shown in Figure 3-83. Since it is desirable that the output voltage waveform be an enlarged copy of the input voltage waveform instead of being clipped, this condition must be avoided by a careful choice of the triodes operating voltages.

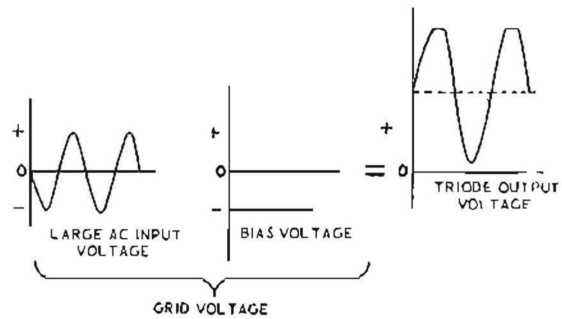
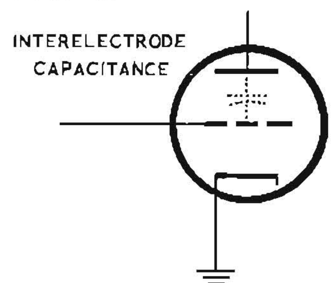


Figure 3-83

Tetrodes

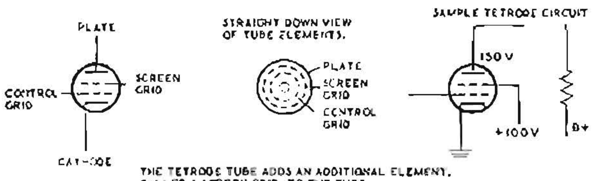
A disadvantage of the triode tube that tends to limit its operating range is the small amount of capacity that is created between the plate and the control grid of the tube. This small amount of capacity (called interelectrode capacitance) is developed because the plate and the grid of the triode act like the two plates of a capacitor. This capacitance, shown in Figure 3-84, is a very serious disadvantage in the operation of some circuits.



THE PLATE AND THE GRID OF THE TUBE ACT LIKE THE PLATES OF A CAPACITOR, AND A SMALL AMOUNT OF CAPACITANCE APPEARS BETWEEN THEM.

Figure 3-84

The tetrode tube decreases this interelectrode capacitance and makes the tube operate more efficiently by adding another grid between the control grid and the plate of the triode. This new grid that has been added to the tube is called the screen grid. The physical construction of the tetrode, along with its schematic symbol, is shown in Figure 3-85.

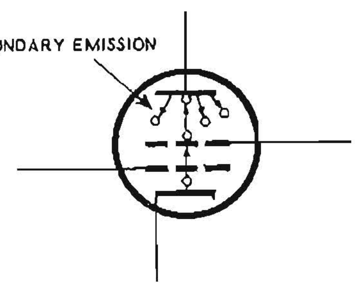


THE TETRODE TUBE ADDS AN ADDITIONAL ELEMENT, CALLED A SCREEN GRID TO THE TUBE.

Figure 3-85

A positive voltage, usually smaller than the voltage on the plate, is applied to the screen grid of this tube. This screen grid can be placed closer to the control grid than the plate. The large positive voltage on the screen grid pulls the electrons from the cathode, and since the screen grid is made of a fine wire, the great majority of these electrons flow through the screen grid to the plate of the tube. This allows much greater amplification to occur in the tube. Also, the screen grid shields the plate of the tube from the control grid, causing the interelectrode capacitance between these two elements to be much smaller. This improvement allows the tetrode to be used much more widely in circuits where interelectrode capacitance is such a serious problem.

The main disadvantage of the tetrode tube is the effect shown in Figure 3-86 called "secondary emission." When electrons from the cathode are accelerated by the screen grid, they hit the plate at a high rate of speed and tend to knock other electrons loose from the plate. Because the screen grid has a high positive voltage, many of these electrons that are knocked loose from the plate can be attracted to the screen grid. The number of these electrons that go to the screen grid, and the number that are returned to the plate, depends on the voltage on the plate compared to the voltage on the screen grid. If there is a higher voltage on the plate, then most of the electrons will return to the plate. If there is a higher voltage on the screen grid, then a great many of these electrons will go to the screen grid. The results of this "secondary emission" in the tetrode can be serious distortion or lower amplification than would otherwise be possible. The effect of secondary emission can be minimized by adding a third grid.

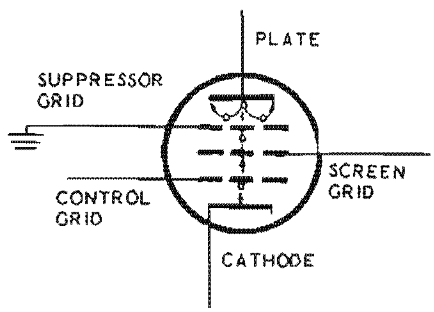


IN A TETRODE THE ELECTRONS KNOCKED FROM THE PLATE OF THE TUBE CAN BECOME A SERIOUS PROBLEM.

Figure 3-86

Pentodes

In the pentode tube the third grid, called the suppressor grid, is placed between the screen grid and the plate of the tube and is used to isolate the screen grid from the plate of the tube. It is generally connected to ground or to the cathode of the tube. The electrons that are knocked loose from the plate are now prevented by the more negative voltage at the suppressor grid from traveling to the screen grid. This forces them to return to the plate. See Figure 3-87.



ANOTHER GRID CALLED A SUPPRESSOR GRID, IS ADDED IN THE PENTODE TUBE.

Figure 3-87

Since the suppressor grid is made of fine wire mesh the electrons traveling from the cathode to the plate tend to pass right through it. Because it has a high negative voltage with respect to the plate, the suppressor repels the electrons that tend to bounce from the plate. The screen grid would now be isolated from the plate, therefore a much higher voltage can be placed on it. This causes the pentode to be much more efficient than either the tetrode or the triode.

Because the cathode of the tube is very close to ground potential, the suppressor grid is quite often connected to it instead of to ground. This is done mainly for convenience, since the cathode connection of the tube is often closer to the suppressor grid than a ground connection. In some pentodes, the suppressor is connected to the cathode inside the tube.

SUMMARY

The diode consists of a hot cathode, from which electrons are emitted, and a positive plate, which attracts electrons. The cathode is heated by a heater filament. The diode is a one way circuit element. One diode used for rectification results in half-wave rectification. Two diodes can be connected for full-wave rectification.

In a triode, a third element, the grid, acts like a valve and allows either more or less current to flow through the tube from the cathode to the plate. Because a small signal at the grid of the tube can control a large amount of current flowing through the tube, the grid signal is made much larger in the plate circuit of the tube. This is called amplification.

When the tetrode was developed it offered some advantages over the triode tubes. The tetrode has an additional grid, called a screen grid, which helps draw electrons to the plate. This grid also decreases the interelectrode capacitance between the control grid and the plate of the tube by isolating them from each other. The main disadvantage of the tetrode is the undesirable effects caused by secondary emission from the plate of the tube.

The pentode has a third grid called a suppressor grid. This grid minimizes the secondary emission previously mentioned. The pentode has higher amplification than the triode.

CHAPTER 8

Oscillators

An oscillator is a device that is used to generate an AC signal. This AC signal may be either an audio signal or a radio frequency signal. The RF signal used by the radio stations in their modulated broadcast signal, is created by an RF oscillator. Oscillators are also used widely in all types of radio transmitters, television, and in many other types of electronic equipment.

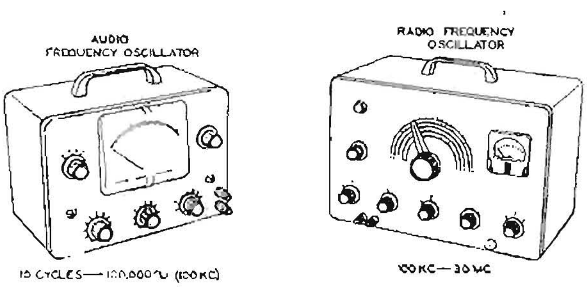


Figure 3-88

Figure 3-88 shows two test oscillators used to design and repair radio receivers, and other types of electronic equipment. The audio oscillator creates a signal that can be used in testing audio circuits. The RF oscillator creates signals that can be used to test RF circuits. The meter shows how large the signal is for each oscillator. The knobs for these oscillators are used to adjust the oscillator for a larger or smaller signal; they are also used to adjust the frequency of the signal.

This chapter will show you how the oscillator circuit creates a signal.

Oscillation

By definition, to oscillate means to swing back and forth. A common example of this would be a child on a swing as shown in Figure 3-89. The graph in the center of Figure 3-89 shows how many seconds it takes the swing to move in each part of the cycle, and how far it moves in feet.

Four seconds of time are shown horizontally on the clocks. Ten feet, five feet each side of center, are shown vertically on the graph. The swing starts at the center position, position Y, at 0 feet. At the end of one second, it has moved back five feet to position X. At the end of two seconds, it moves through the Y position (or 0). At the end of three seconds, the swing moves to position Z, 5 feet on the other side of 0 position. At the end of four seconds, the swing returns again to position Y, or 0 feet where the cycle begins all over again.

Notice, that when the motion of the swing is drawn in this manner, it takes the form of a sine wave. This is a mechanical oscillator. In an electrical oscillator circuit, the current must be made to oscillate back and forth in this same manner; the current must flow first in one direction and then in the other direction.

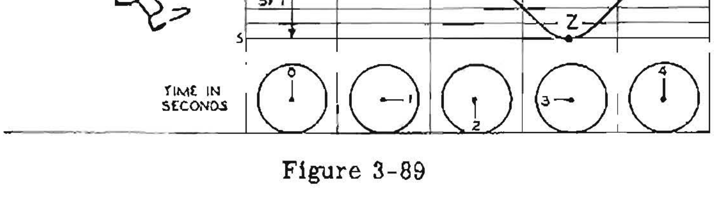


Figure 3-89

If you wanted to keep him swinging back and forth without gradually lessening the 10 foot distance you would have to give the boy a small push during each cycle. The same thing would be true in an electrical circuit, a little extra current (or push) would have to be added to the circuit from the power supply during each cycle, to sustain the oscillation at the same level (or voltage).

To generate an AC waveform, then, something is needed that will cause the current to reverse itself at a regular rate; first it must go one way and then it must go the other way, just like the motion of the swing. The circuits that generate these AC waveforms are "oscillator" circuits. AC waveforms may also be generated by using a large motor-generator, such as the one at the electric power station, when large amounts of power are desired. An example of a signal of this type is the AC current received in homes and factories from the power stations.

What Circuits Need to Oscillate

When some of the output signal of an amplifier is connected back to its own input, in such a way that it adds more voltage to its own input signal, the amplifier begins to "oscillate." As the output signal adds to the input signal, the currents in the amplifier increase and the circuit keeps amplifying. The circuit will continue to oscillate until the connection that sends the signal from the output to the input is removed. A common example of this type of oscillation is shown in Figure 3-90. When the gain of a public address amplifier is turned up too high, the signal from the speakers (output) is carried back to the microphone (input) through the air, and an oscillation in the form of a loud squeal is heard.

The term "feedback" is given to that part of the output signal that is connected back to the input of an amplifier. This name can easily be remembered by thinking of its meaning, that some of the output is fed back to the input of an amplifier.

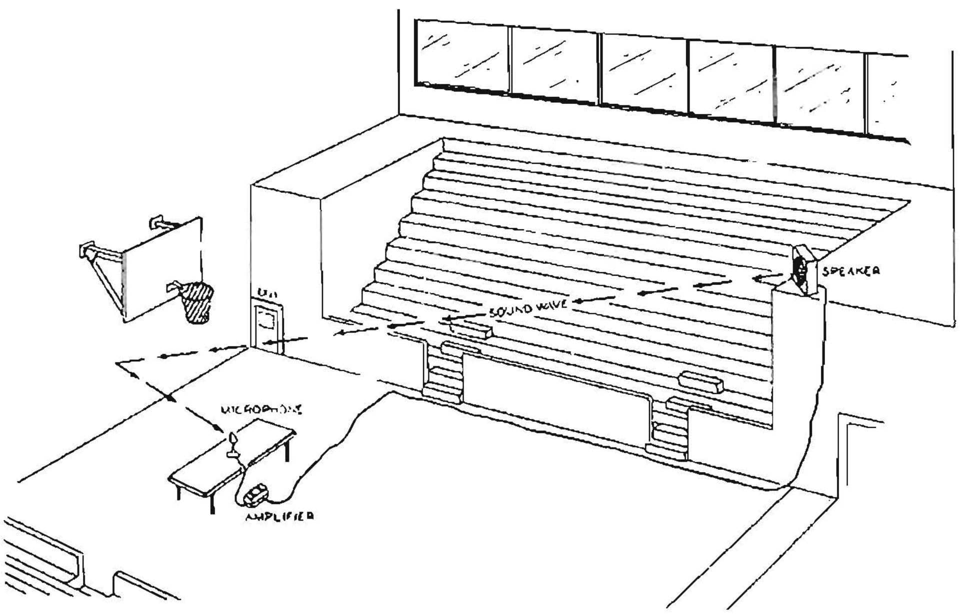


Figure 3-90

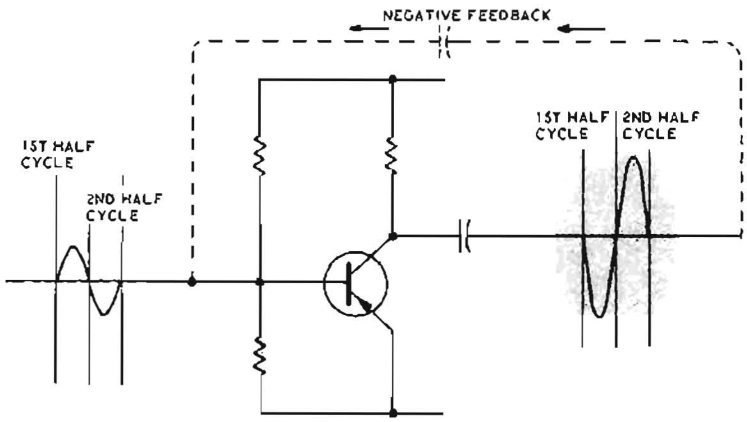


Figure 3-91

An oscillator circuit must be connected so that the feedback will ADD to its own signal at the input. How this feedback could either add or subtract from its own signal at the input is shown in Figure 3-91 and Figure 3-92.

One of the inherent properties of most amplifiers is that signals or sine waves are inverted every time they pass through each stage of an amplifier. This is shown in Figure 3-91. Note that the output signal is turned over, or inverted, from the way it was at the input. The first half-cycle was increasing at the input, and at the output of the amplifier it is shown decreasing. The second half-cycle is shown decreasing at the input and it is increasing at the output of the amplifier. If some of this output signal were connected back to the input by a capacitor, as shown, the two signals would be going in opposite directions. The output signal would try to cancel out, or decrease, some of the input signal. This is called negative feedback.

The amplifier of Figure 3-92 contains two amplifier stages, Q1 and Q2. In this case, the signal from the input of the amplifier has been inverted in transistor Q1 just as it was in the previous circuit. The inverted signal from transistor Q1 is inverted once again in transistor Q2. Now, when the signal at the input of the amplifier increases, the signal at the output of the amplifier also increases the same way at the same time. When the signal at the input of the amplifier goes in the negative direction, the signal at the output of the amplifier also goes in a negative direction. This is called positive feedback.

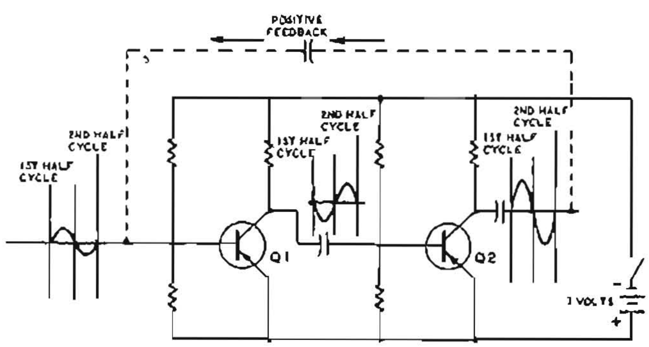


Figure 3-92

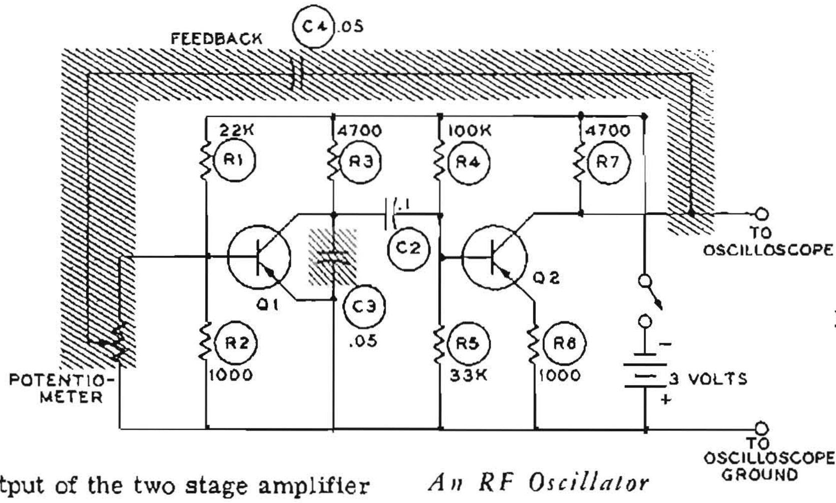


Figure 3-93

Now, when the output of the two stage amplifier is fed back to the input, it adds to the input signal instead of subtracting from it. This causes an oscillation to occur, and once this oscillation has been started, no input signal is needed. The circuit oscillates back and forth just like the swing did and only a little additional push from the power supply is needed to keep the oscillator going.

In actual circuits, just turning on the switch starts current increasing through the oscillator circuit, and this action, by itself, starts the oscillator.

An Audio Oscillator Circuit

Figure 3-93 shows the circuit diagram of the audio frequency oscillator supplied with this kit. The shaded areas point out where changes were made in the two-transistor amplifier of Experiment 3-12 in Chapter 6. Capacitor C4 prevents DC from passing through the feedback circuit. C4 also acts as the feedback path. The potentiometer adjusts the amount of feedback desired. Capacitor C3 acts as a filter to prevent unwanted frequencies from distorting the audio frequency of the oscillator.

An RF Oscillator

RF oscillators have the same requirements as audio oscillators; an amplifier, feedback, and a frequency determining circuit. In the RF oscillator circuit of Figure 3-94, these requirements are shown in their three separate (shaded) areas. The amplifier area includes transistor Q3 and bias resistor R1. The frequency determining circuit of the oscillator consists of capacitor C5 and the coil. The electrical size of the coil can be adjusted. Capacitor C6 at the lower part of the schematic provides a path to apply feedback to the input of amplifier transistor Q3.

THE AMPLIFIER: In Figure 3-94, this oscillator, like most RF oscillators, a way has been found so that a one-transistor amplifier can be used instead of a two-transistor amplifier. The input signal at the Base of the amplifier is inverted only one time in the amplifier instead of twice as in the previous (audio) circuits. The signal is inverted the second time in the tuned circuit because of the way the feedback capacitor is connected to it.

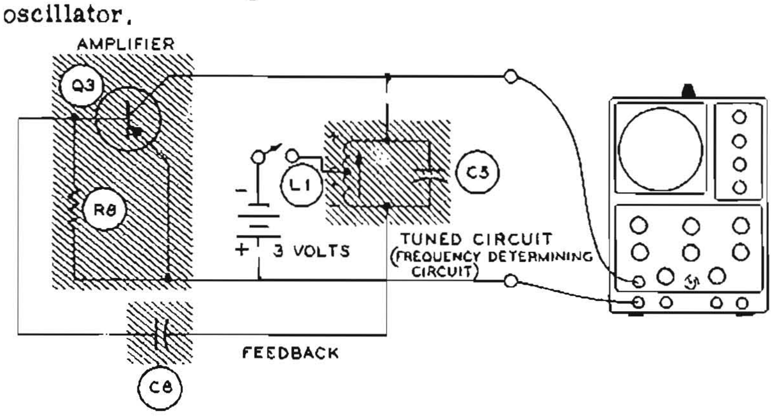


Figure 3-94

The output signal from the Collector of the amplifier is applied to the tuned circuit instead of to a resistor as it has been in the other circuits you have studied.

FEEDBACK: To provide feedback, some of the output signal from the tuned circuit is connected back through capacitor C6 to the input of the amplifier. Since this feedback signal has been inverted twice (once in the transistor and once in the tuned circuit), it adds to the signal at the input of the amplifier and the circuit begins to oscillate.

Actually, since no external input signal is connected to the oscillator, the oscillation starts by itself when the switch is turned on. Turning the switch causes the current in the circuit to start to flow. When the current starts to flow, it appears just like the first part of a signal to the circuit, causing an oscillation to start. From this point on, no external input signal is needed.

THE TUNED CIRCUIT: It is a property of a tuned circuit to contain electrical energy. In it, a current circulates back and forth, first one way and then the other way between the coil and capacitor. The current circulating back and forth in the tuned circuit is like the swing of the previous lesson. The swing contains mechanical energy as it moves back and forth, and the current in a tuned circuit contains electrical energy as it moves back and forth.

The current will circulate back and forth in the tuned circuit at only one frequency, and this frequency depends on the electrical size of the coil and capacitor. This frequency is called the "resonant frequency."

If the swing of the previous paragraphs did not get pushed during each cycle, it would gradually swing less and less, until it stopped. To keep it swinging back and forth for the same distance, it would need a small amount of push at one part of each cycle. The circulating currents in the tuned circuit act in the same manner; they also must have a small amount of push at one part of each cycle to keep them from gradually becoming smaller and smaller. It is the purpose of the amplifier part of the circuit along with the feedback circuit to supply this "push" to the tuned circuit.

When the electrical size of the coil or capacitor is changed, it causes the current to circulate back and forth either faster or slower. This changes the frequency of the RF oscillation in the tuned circuit, therefore it changes the operating frequency for the whole oscillator circuit.

Modulating the RF Oscillator

Figure 3-95 shows the AF oscillator and the RF oscillator combined into one circuit. The output of the RF oscillator is connected to the

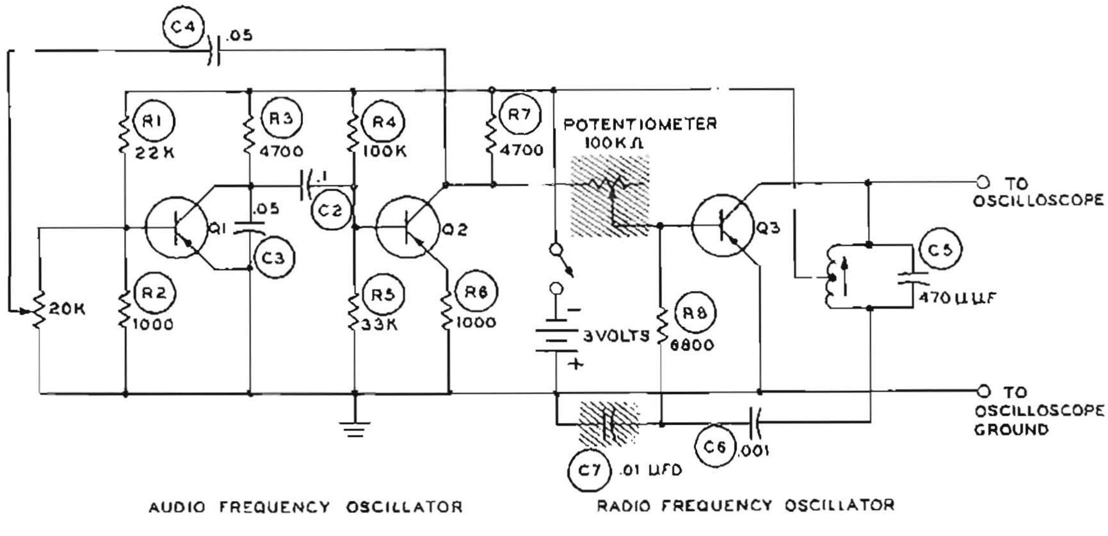


Figure 3-95

oscilloscope input. The shaded areas indicate the additional circuit elements necessary to connect the two oscillators together. The 100 KΩ potentiometer is used for adjusting the amount of AF imposed on the RF. The .01 μfd capacitor provides an AC path to ground but not a DC path to ground.

In Figure 3-95, both the feedback circuit of the RF oscillator and the output of the AF oscillator are connected to the Base, which controls the output of the RF amplifier.

Both oscillators supply an AC voltage, but of different frequencies. This means that there are times when they are both of the same sign, and other times when they are of opposite sign.

Figure 3-96 shows "hills and valleys" in the RF waveform. The more pronounced the valleys become, the greater is the percentage of audio frequency that is impressed on the radio frequency waveform. The impressing of the two different frequencies is called amplitude modulation. When the oscilloscope is set to view audio frequencies (about 1000 cycles per second) and one-half as much audio is impressed on the RF, almost 100% modulation results, as shown in Figure 3-96. When less than one-half is impressed on the RF Figure 3-97 shows less than 100% modulation. If more audio frequency is impressed on the RF over 100% modulation is shown in Figure 3-98, and distortion is seen on the oscilloscope and heard through the speaker or earphone.

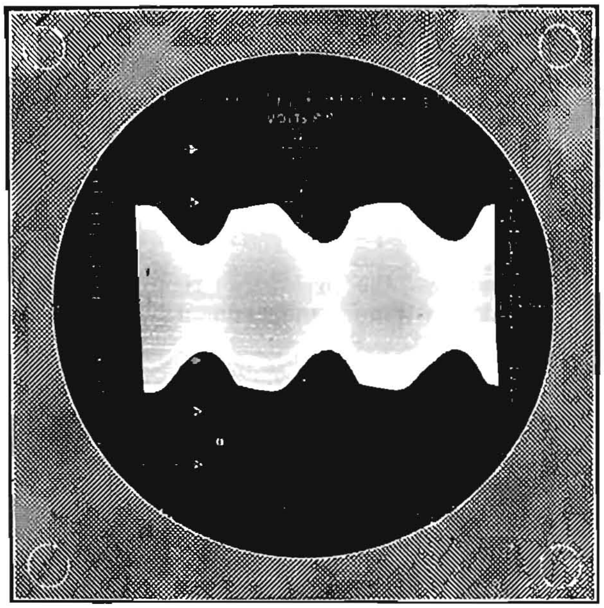


Figure 3-97

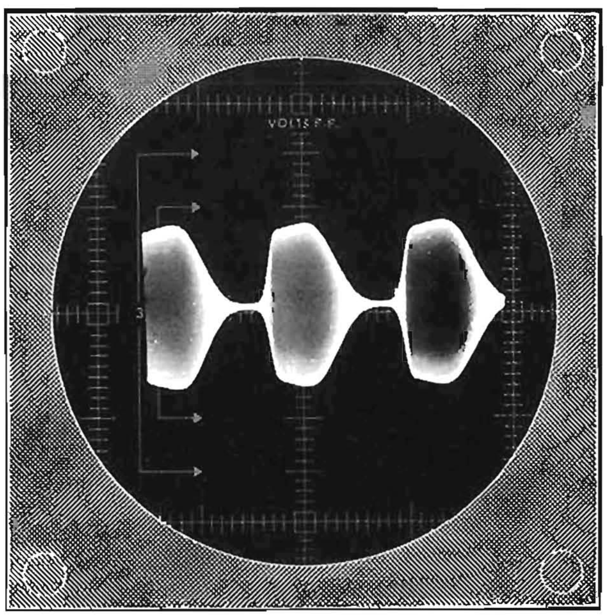


Figure 3-96

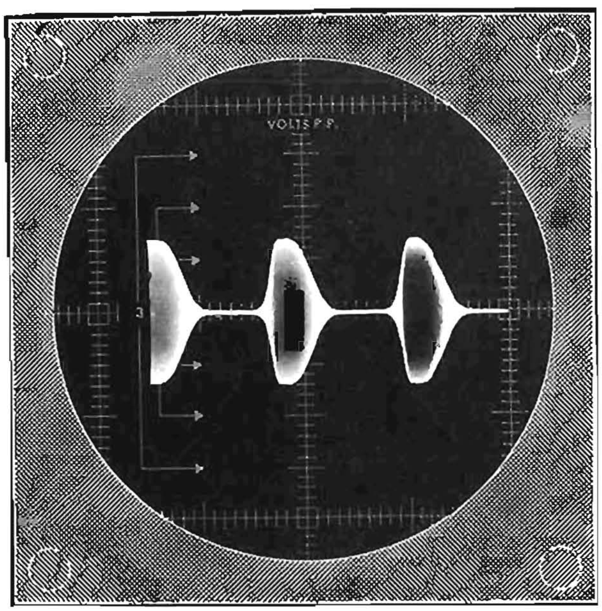


Figure 3-98

EXPERIMENTS

Experiment 3-13

In this experiment you will connect the RF and AF oscillators together to examine "modulated RF."

Refer to Figures 3-99 and 3-100 for the following steps.

( ) Disconnect the 6" wire from lug 1 of terminal strip E and connect it to lug 3 of terminal strip A.

( ) Connect the .05 μfd capacitor from lug 3 of terminal strip B to lug 3 of terminal strip A.

( ) Connect a 6" wire from lug 2 of terminal strip A to lug 2 of terminal strip E.

( ) Connect the 3-1/4" wire from lug 3 of terminal strip C to lug 1 of terminal strip E.

( ) Connect a .01 μfd capacitor from lug 2 of terminal strip E to lug 1 of terminal strip D.

( ) Turn on the oscilloscope and test chassis. Adjust the oscilloscope to view AF.

( ) Turn the 20 KΩ control on the test chassis to the minimum position. Adjust the 100 KΩ control until a RF waveform appears. Adjust the horizontal amplitude controls of the oscilloscope to fill 3/4 of the screen.

( ) Using the plastic alignment tool, turn the slug inside the coil slowly until you obtain the largest possible RF waveform. Do not adjust the 20 KΩ control during this adjustment.

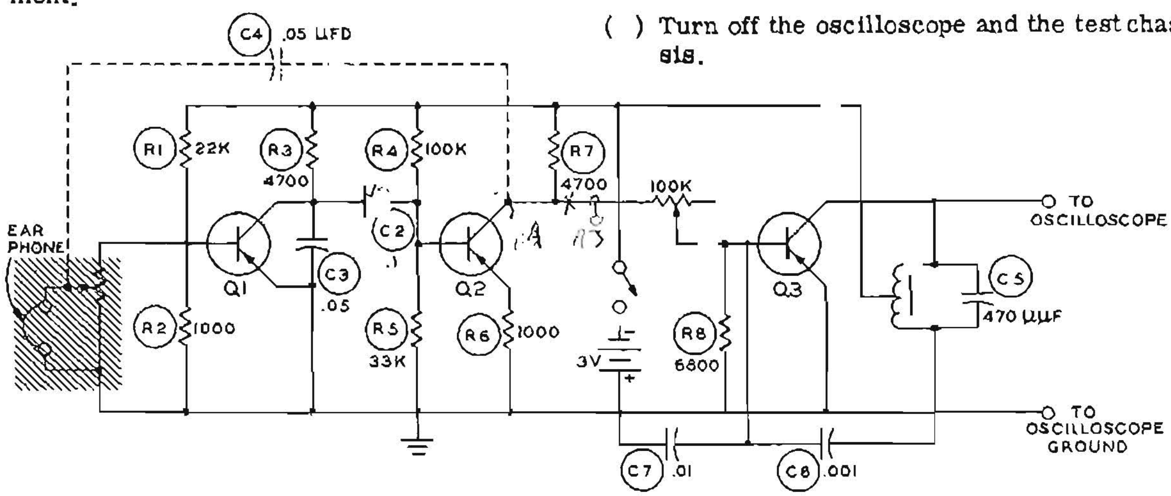


Figure 3-99

( ) Turn the 100 KΩ control until the waveform is one-half its maximum amplitude.

( ) Slowly turn the 20 KΩ control until a waveform such as in Figure 3-96 appears.

( ) Slowly turn the 20 KΩ control toward the maximum position and note the changing waveforms. You should observe all these waveforms, as in Figures 3-96, 3-97, and 3-98. The frequency vernier may have to be adjusted slightly as you do this procedure.

( ) Leave these adjustments set for the next experiment.

Experiment 3-14

In this experiment you will use the microphone (earphone) to modulate the RF signal. The earphone will act as the AF source and the audio oscillator will be converted to a two-transistor amplifier to obtain the necessary AF voltage to modulate the RF voltage.

( ) Remove the .05 μfd capacitor from lug 3 of terminal strip A and lug 3 of terminal strip B.

( ) Connect one lead of the earphone to lug 3 of terminal strip B and the other to lug 1 of terminal strip D. The circuit diagram is shown in Figure 3-99.

( ) Whistle different notes at various intensities into the microphone and note the effect on the RF waveform. The 20 KΩ control can be turned until the desired level of AF is imposed on the RF signal. Other sources of sound should also be tried.

( ) Turn off the oscilloscope and the test chassis.

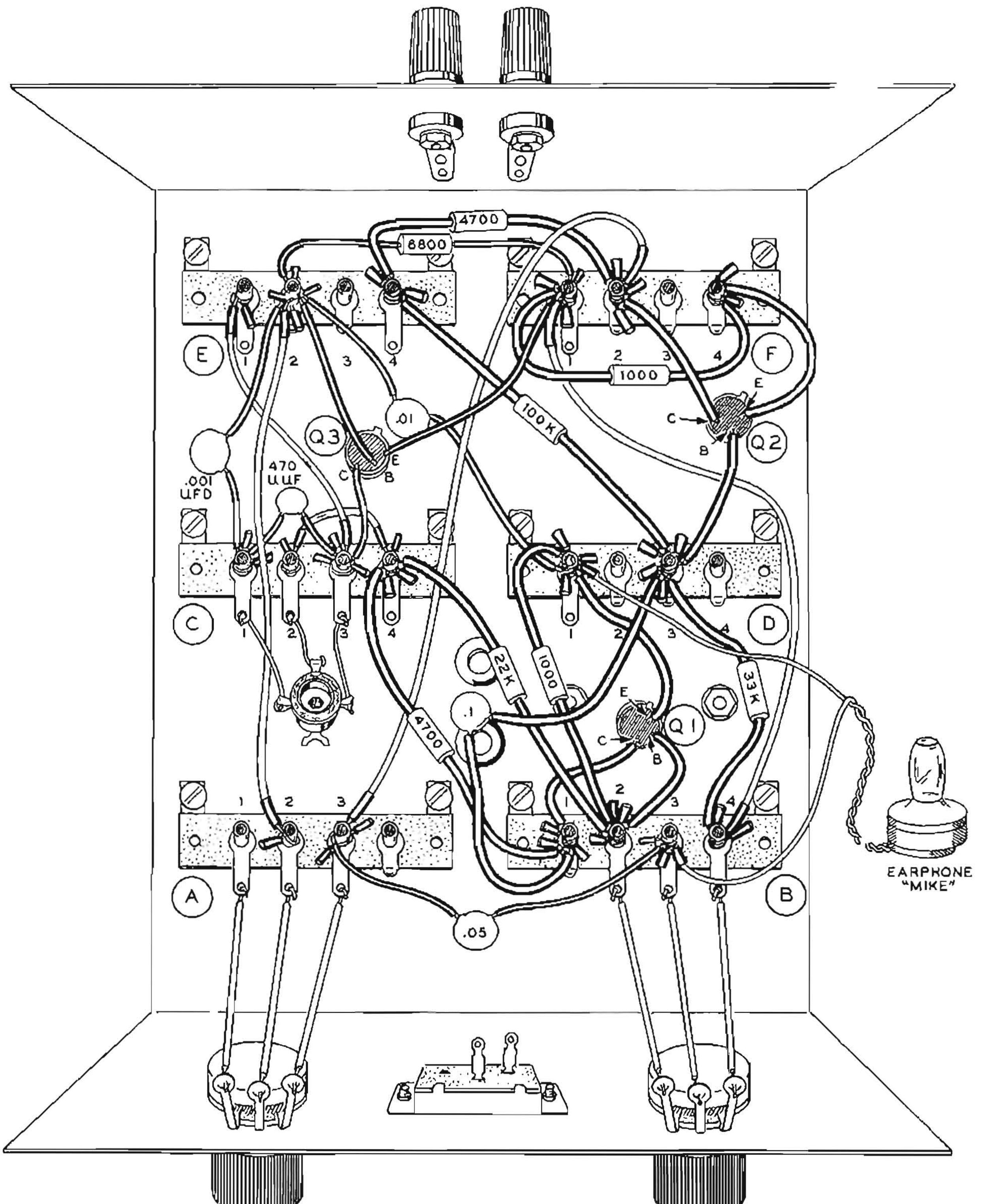

4700
6800
E
1
2
3
4
F
1000
.01
100 K
E
C
B
Q2
Q3
E
C
B
.001
U.FD
470
U.U.F
C
1
2
3
4
D
22K
1000
33K
E
Q1
C
B
.1
4700
A
1
2
3
B
.05
EARPHONE
"MIKE"

Figure 3-100

SUMMARY

An oscillator is the device that is used to generate an AC signal. This AC signal may be either at an audio rate or an RF rate.

To oscillate, some of the signal from an amplifier must be connected back to the input. This signal that is connected back is called "feedback," and it must be connected in such a way as to add more signal to the input signal. This causes the current in the amplifier to increase as far as it will go in one direction. The swinging back and forth of the current, first in one direction and then in the other direction, at a regular rate, is called oscillation.

The audio oscillator uses two transistor stages so the feedback signal will be in step with the input signal. When a signal passes through one transistor it is inverted and if then fedback it would oppose the input signal. Two inversions from two transistors prevent this. The value of the resistors and capacitors used in the circuit determines the frequency of an AF oscillator.

The RF oscillator also contains an amplifier and a feedback circuit. This differs from the AF oscillator in that its frequency is determined by a tuned circuit. The tuned circuit eliminates the need for the second transistor, as it will invert the signal for the second time before it is fed back to the input of the amplifier.

In a tuned circuit, current circulates back and forth between the coil and capacitor. The sizes of the coil and capacitor determine the frequency of the oscillation. The amplifier supplies a small amount of push to keep the current circulating.

The modulator circuit allows the audio signal to control the amount of RF signal that will flow in the RF oscillator. The AF voltage is supplied to the Base of the RF amplifier transistor which controls the output of the RF oscillator.

When one-half AF is impressed on RF, the RF signal is 100% amplitude modulated. If there is less than one-half AF than RF, the signal is less than 100% modulated. If there is more than one-half audio on the RF, the signal is over 100% modulated.

This completes Part III. Leave components and controls on the test chassis in their present positions. They will be referred to in experiments for Part IV in these positions.

PART IV

Oscilloscope Theory

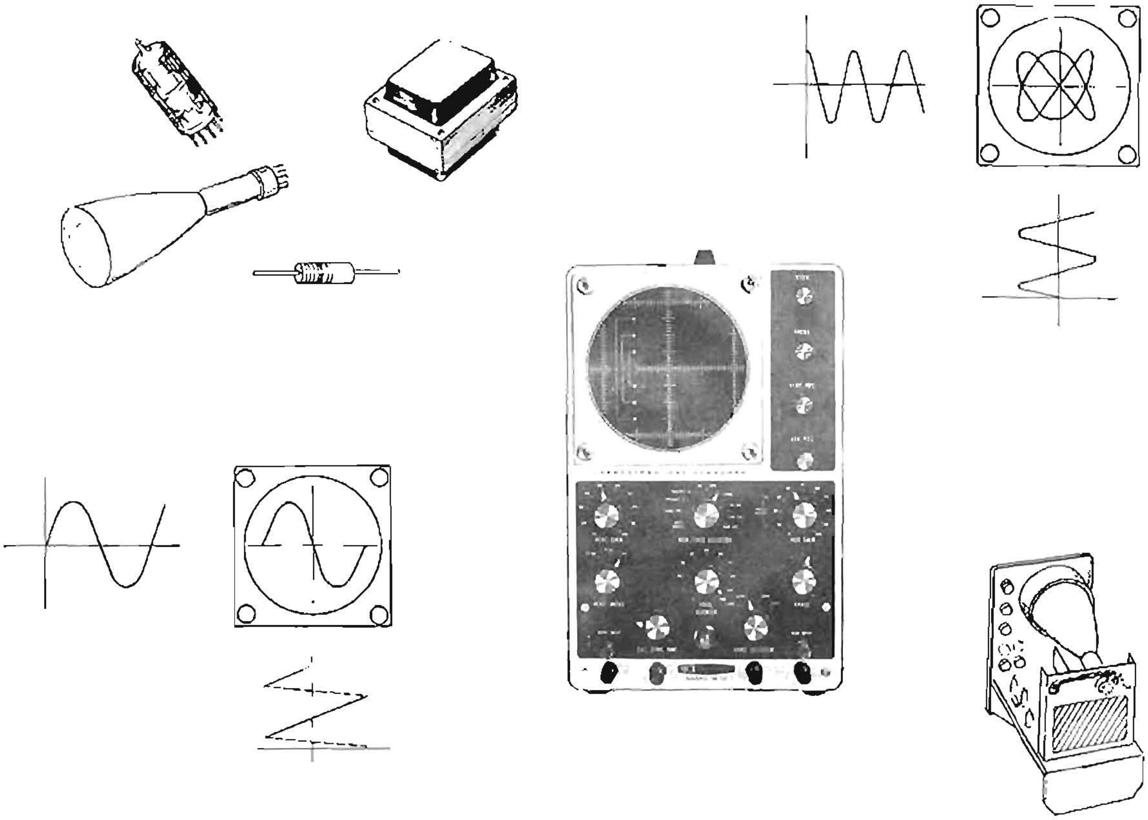


Figure 4-1

The oscilloscope has a wide range of abilities. It displays visually the quality as well as the quantity of voltage. Details such as amplitude, phase shift, frequency, waveform distortion, and pulse duration may be displayed on the screen of an oscilloscope.

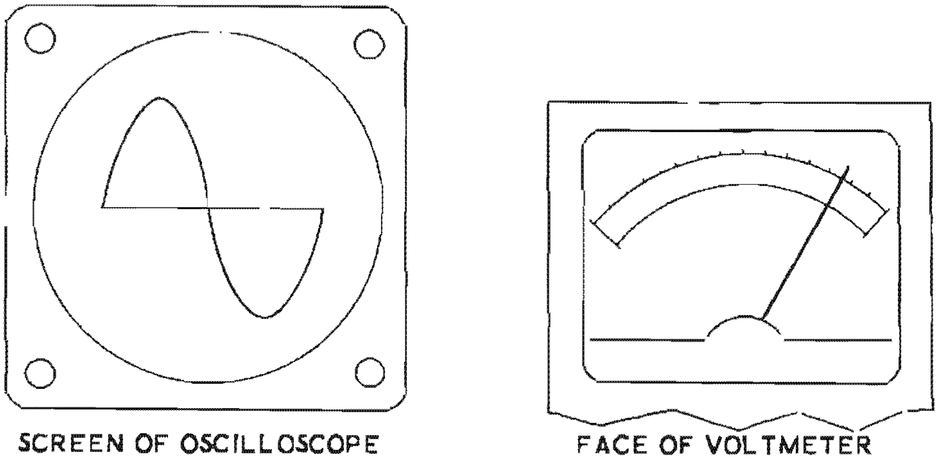


Figure 4-2

You can use the oscilloscope like a simple voltmeter to measure voltage quantities. But unlike the voltmeter, the oscilloscope can display additional useful information. Figure 4-2 compares these two instruments in measuring 115 volt, 60 cycle household AC. Other sine waves could be measured similarly. The voltmeter indicates a steady voltage value; the oscilloscope indicates the same voltage value as well as the waveform of the voltage. An oscilloscope is able to do this because its electron beam (in the CRT) is able to "follow" the voltage changes. The pointer of the voltmeter cannot move as rapidly and, therefore, indicates only the steady effective value of the voltage.

Most vibrations or oscillations that occur in our physical world, electrical or mechanical, can be be studied with the oscilloscope. If they can be converted to a changing voltage, the oscilloscope can display their waveforms. Transducers are used to convert mechanical oscillations into electrical oscillations. The cartridge in your phonograph and the photocell in your lightmeter are examples of common transducers; they convert physical energy, such as light or movement, into electrical energy.

Several types of oscilloscopes are designed for various applications. For example, there are DC oscilloscopes for voltage level comparisons, dual-trace oscilloscopes, limited-frequency oscilloscopes, and general purpose oscilloscopes.

Most oscilloscopes are basically similar, and the general purpose oscilloscope can be considered typical. Part IV will examine a general purpose oscilloscope. The circuits described in Part IV may differ in some details from those of your oscilloscope, but the results are similar.

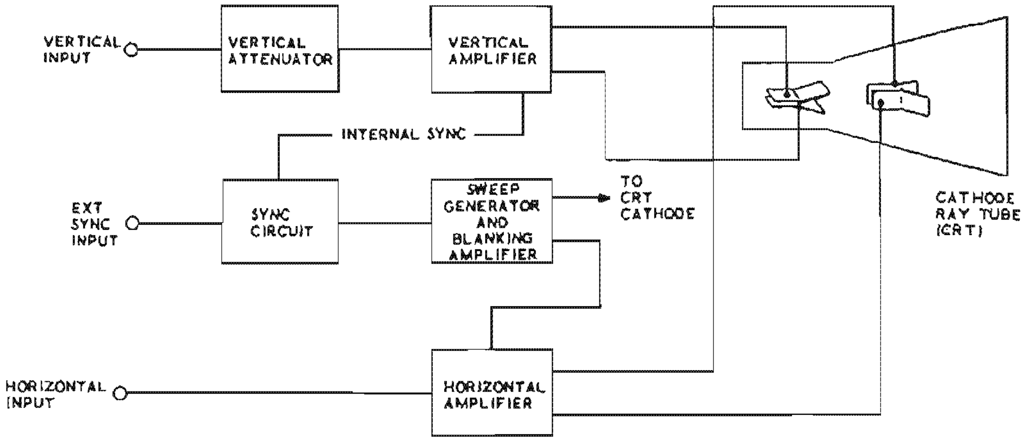


Figure 4-3

Part IV shows you how this instrument converts a changing electrical voltage into a visual picture. The material is arranged in five chapters; the cathode-ray tube, power supplies, sweep circuits, amplifiers, and synchronization circuits.

Figure 4-3 shows in block diagram form a general purpose oscilloscope. Referring to such a block diagram will help you to understand the descriptions of the various oscilloscope circuits.

CHAPTER 1

The Cathode Ray Tube

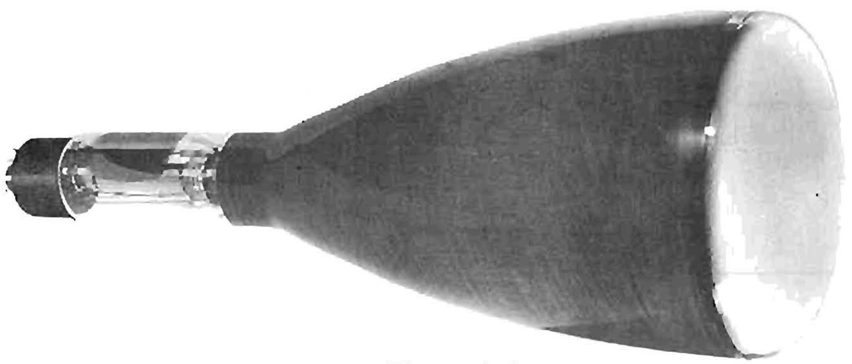


Figure 4-4

The CRT or Cathode Ray Tube is a special vacuum tube. The CRT consists of an electron gun, two sets of deflection plates, and a fluorescent screen. The fluorescent screen converts an impinging stream of electrons into visible light.

Other sections of the oscilloscope, the amplifiers, power supply, sweep circuit, and synchronization (sync) circuit are the aids necessary for the CRT to convert to a complex variety of electrical signals into visible waveforms.

The CRT

Figure 4-5 shows the physical construction of the CRT. Externally the tube can be divided into four parts: the base, neck, bulb and the face. Internally the tube can be divided into four different parts: the electron gun, deflection plates, aquadag coating, and the fluorescent screen on the inside of the face. The electron gun supplies electrons and shapes them into a beam. The deflection plates impress signals on the electron beam. The aquadag is a special conductive coating that may be used for accelerating the electron beam. The bombarding electron beam causes the fluorescent screen of the CRT to glow.

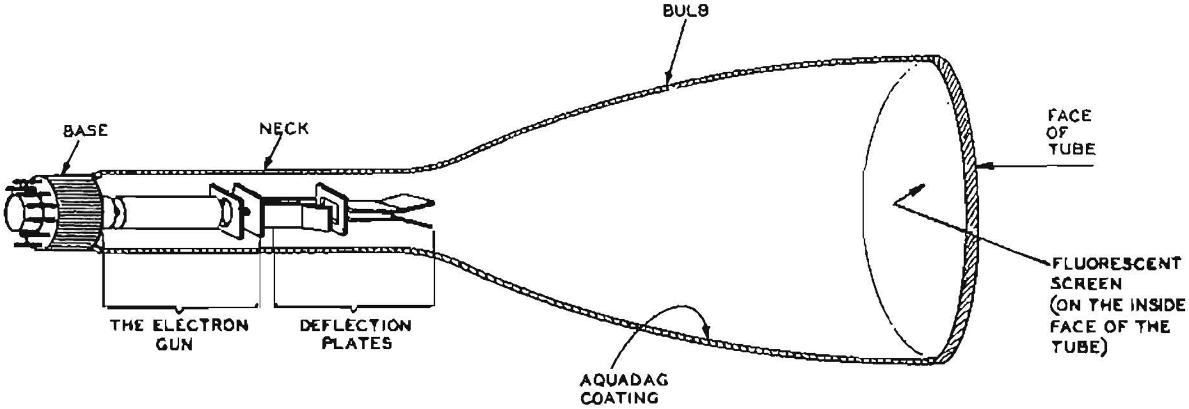


Figure 4-5

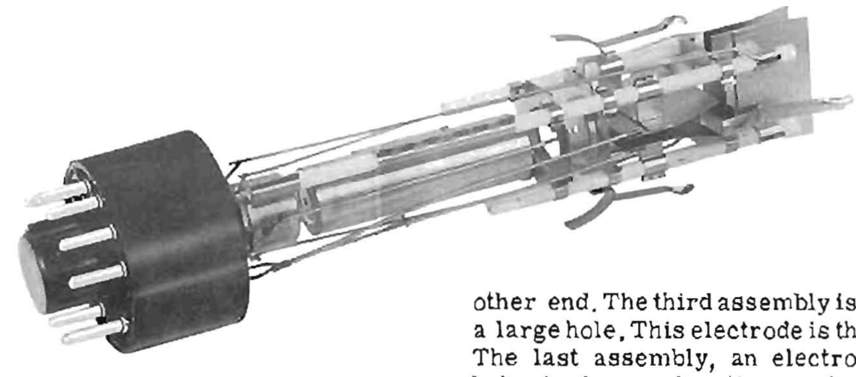


Figure 4-6

The Electron Gun

The electron gun is the most complex part of the CRT. It is divided into four assemblies joined by insulating supports. The deflection plates are also mounted on the insulating supports. The entire assembly is placed in the neck of the glass envelope.

Refer to Figure 4-7 for the following description.

The first section, beginning from the base of the tube, contains the heater and two electrodes; the cathode, and the control grid. The next assembly is the preaccelerating electrode; open at one end and closed but for a small hole at the other end. The third assembly is a small disc with a large hole. This electrode is the focusing anode. The last assembly, an electrode with a small hole, is the accelerating anode.

The accelerating anode is connected to the aquadag, a conductive coating on the inside of the tube. The particular gun used in these illustrations also contains an electrode between the deflection plates, as shown in Figure 4-7. This electrode is an electrostatic shield.

The two sets of deflection plates are also attached to the end of the gun structure. The deflection plates will be discussed in another section of this chapter.

Action of the gun is based on the principle of like electric charges repelling and unlike electric charges attracting. The heater causes the cathode to emit electrons in the general direction of the screen. The anodes, placed between the cathode and screen, are made very positive with respect to the cathode. The large positive charge of the anodes accelerate the electrons to high velocities. The small holes allow a needle-like beam of electrons to pass through the anodes toward the screen.

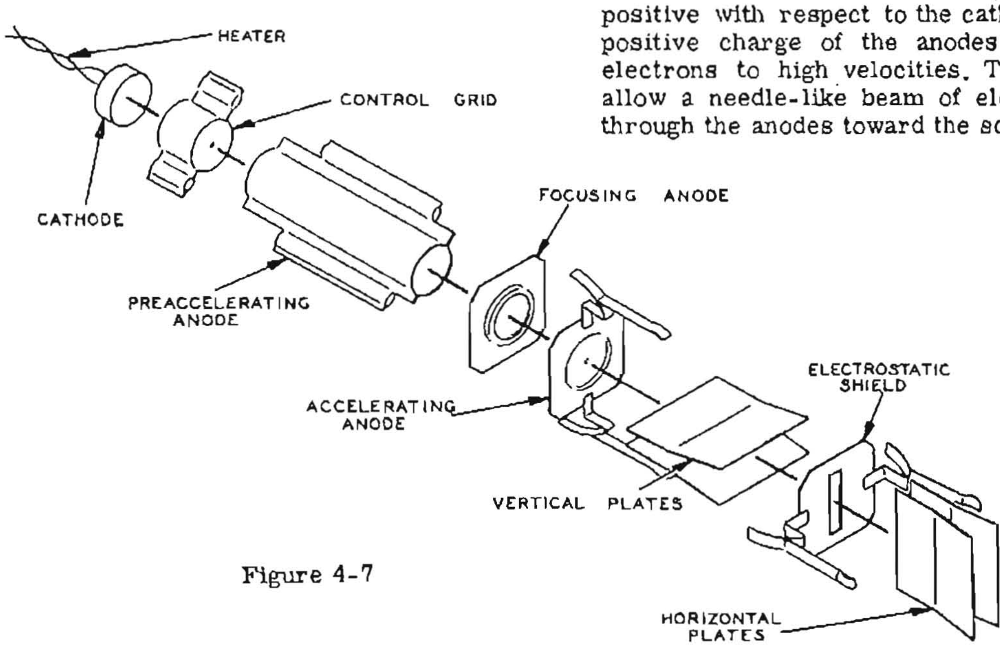


Figure 4-7

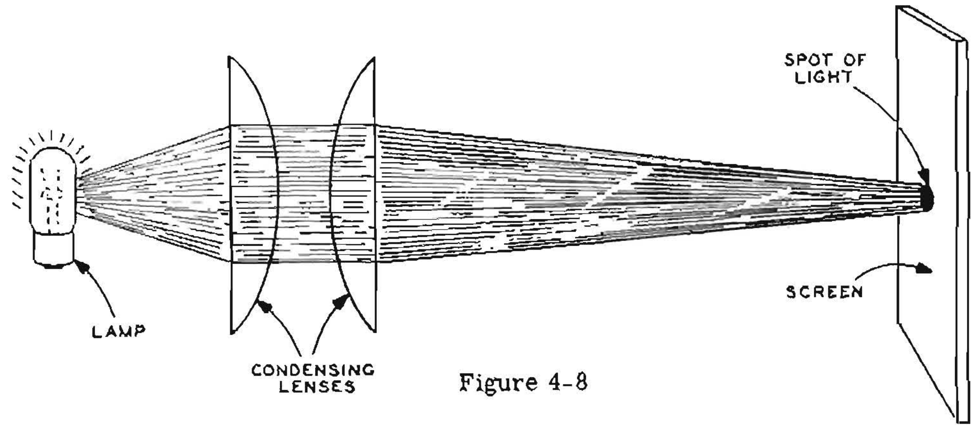


Figure 4-8

The focusing anode is made less positive with respect to the two adjacent anodes. The regions between the electrodes act on the electron beam in the same manner as a glass lens acts on a light beam. Figure 4-8 shows how light might pass through two glass lenses, as found in slide projectors.

Figure 4-9 shows the path of the electron beam through the electron gun. Changing the voltage on the focusing anode has the same effect as adjusting the focusing control of the slide projector.

The electron gun consists primarily of the electrodes just described. Two additional elements aid in accelerating the electron beam toward the phosphor screen. The first is the electrode between the two sets of deflection plates (see Figure 4-7); the second is the black conductive coating inside the tube, the aquadag (see Figure 4-5). These elements are at the same positive potential as the preacceleration anode and the first acceleration anode.

Another method used to accelerate the electrons involves the use of a post-deflection accelerating anode. This anode, since it is placed after the deflection plates, increases the velocity of the electrons without making it more difficult to deflect them. The higher velocity electron collisions on the screen result in a more brilliant trace. This brilliant trace is needed to observe very high speed phenomena, where the spot moves so fast it has only enough time to cause the screen to fluoresce dimly. This situation occurs quite frequently in observing transient (non-repetitive) waveforms, where the waveforms do not recur at a regular rate.

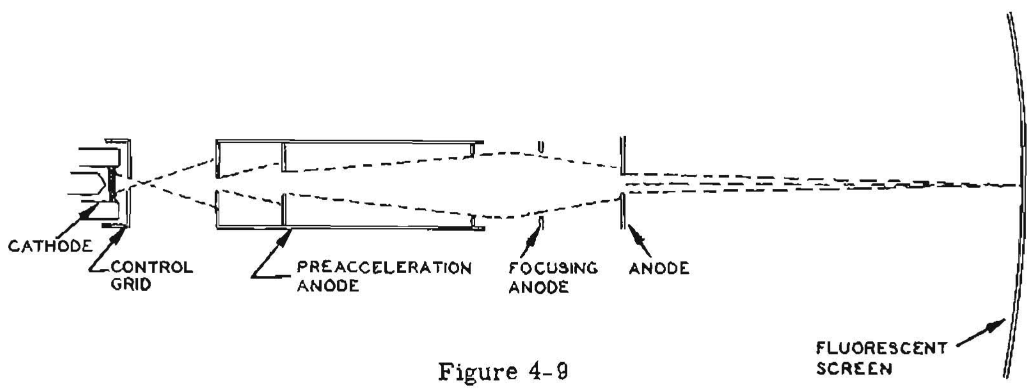


Figure 4-9

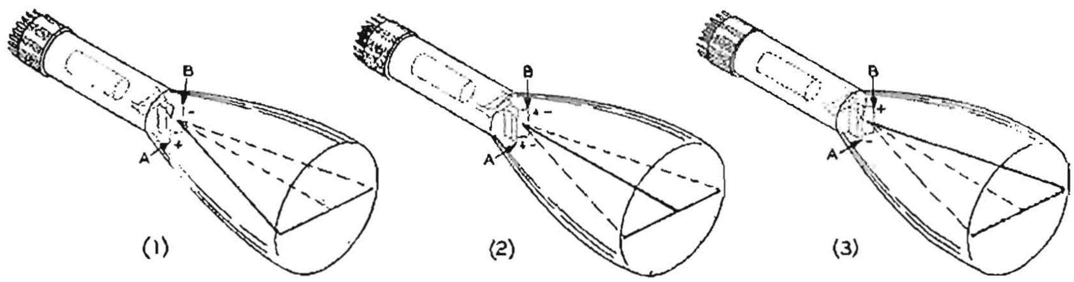


Figure 4-11

Beam Deflection

The electron beam formed by the electron gun will move in a straight line and form a small dot on the screen. The vertical and horizontal deflection system causes this beam to be moved up or down, left or right.

Attached to the end of the electron gun structure are the deflection plates, as seen in Figure 4-7. The plates are mounted in pairs at right angles to each other and parallel to the beam. If one plate is made positive and the other negative, the electron beam will be bent away from the negative plate toward the positive plate.

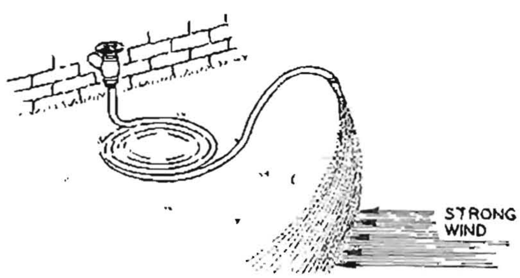


Figure 4-10

The bending action of the electron beam can be compared to a stream of water in a strong wind. Figure 4-10 shows a stream of water from a garden hose. The nozzle acts as the electron gun, forming the stream of water. Adjusting the nozzle has much the same effect as the focusing anode does on the electron beam. The wind blowing from the side will cause the stream to be deflected. The stronger the wind, the greater the deflection.

Figure 4-11 shows three effects of different voltages applied to one set of plates. In Part 1 plate A is positive with respect to plate B. In Part 2, plate A is the same as plate B, and in Part 3, plate A is negative with respect to plate B.

If the plates are the horizontal plates of the CRT and plate A is gradually changed from positive to negative, a horizontal line will be traced on the screen. If a special type of AC voltage is applied to the horizontal plates, this horizontal line can be repeatedly traced out. Such an AC voltage is called a sawtooth waveform, Figure 4-12 shows a type of sawtooth waveform. The section from A to B will move the spot from left to right across the screen. The section from B to C will move the spot back, from right to left.

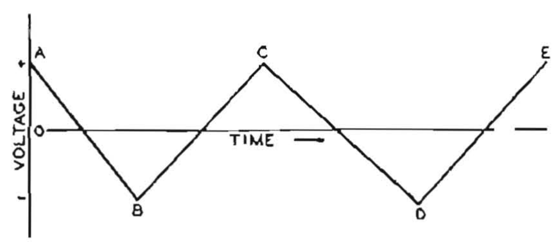


Figure 4-12

A more practical sawtooth waveform would be like the one displayed in Figure 4-13. Graphic information generally flows from left to right.

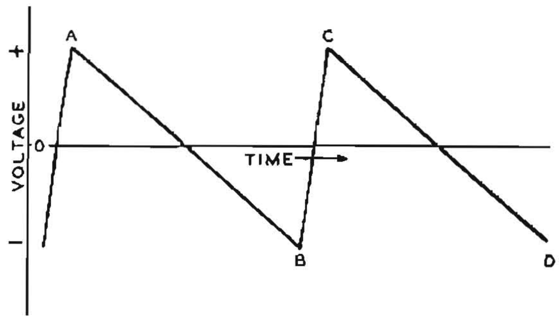
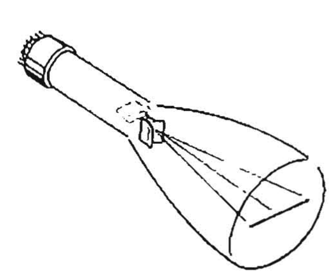


Figure 4-13

It is therefore desirable to display waveforms only when the beam swings from left to right, and not when its swings from right to left. Therefore, the flyback or retrace time, from right to left, is made as short as possible.

Figure 4-14 shows one segment of the sawtooth waveform applied to the horizontal plates of a CRT. When the voltage is maximum in the positive direction, the spot is over to the left side of the CRT. As the voltage decreases the spot moves toward the right. The dotted line connects corresponding points on the sawtooth and the line traced out on the CRT. The spot moves across the screen at an even rate.



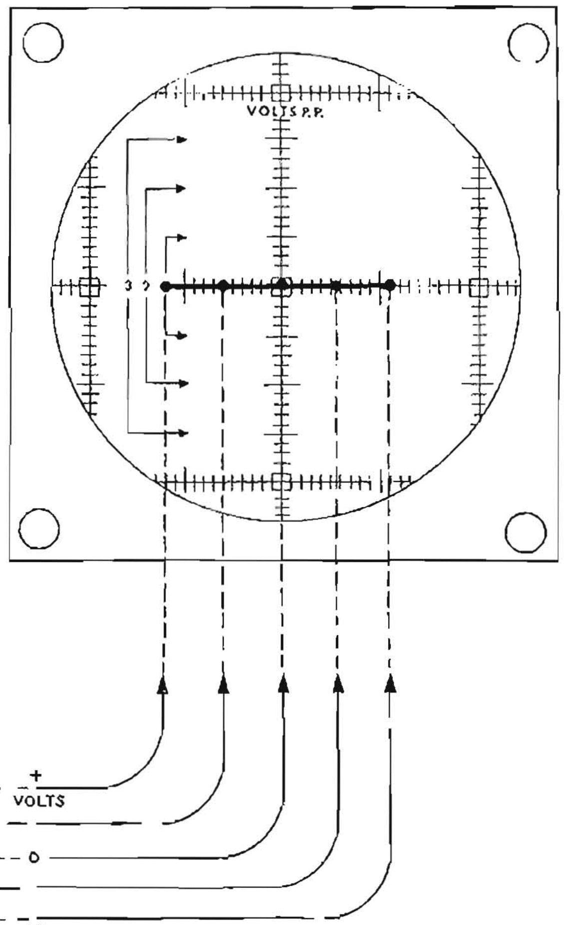
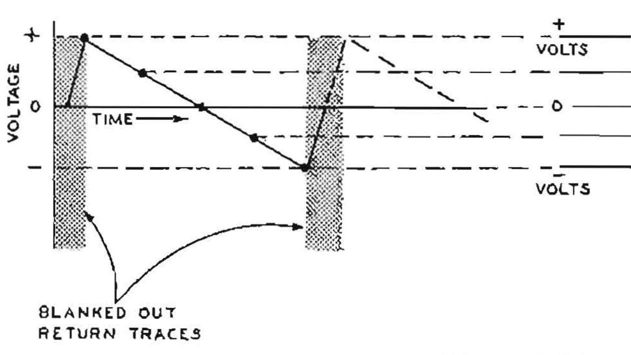



Figure 4-14

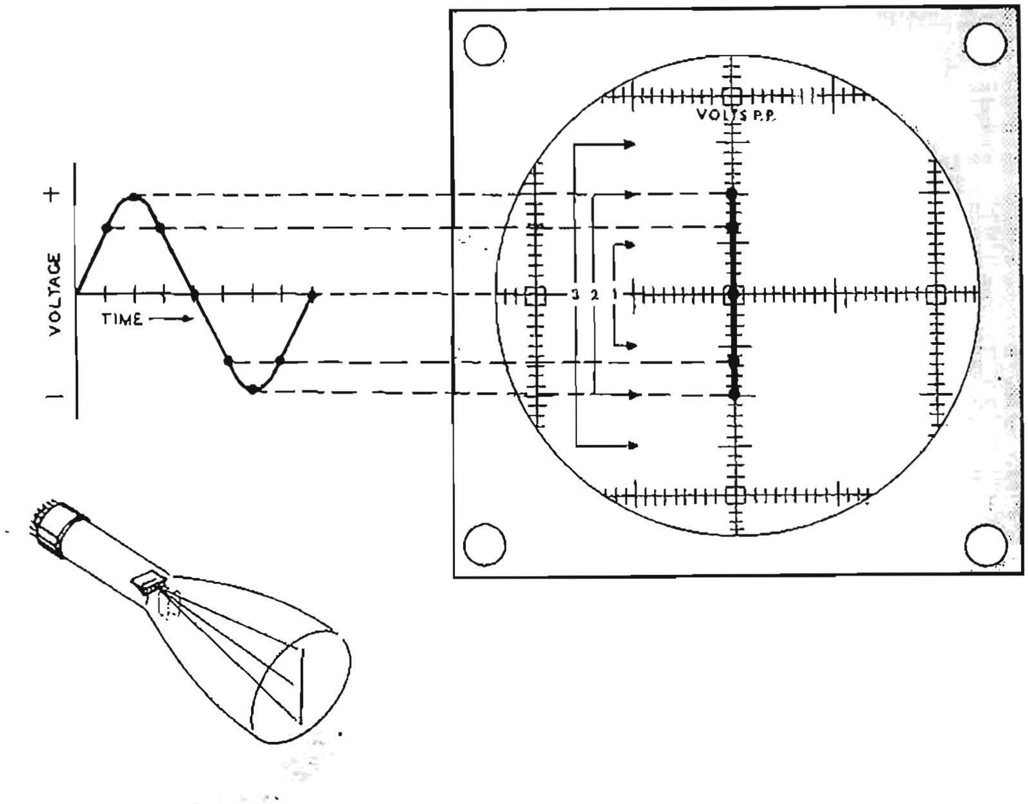


Figure 4-15

Figure 4-15 shows a sine wave applied to the vertical plates; that is, the plates that cause the beam to move up and down. Again the dotted line connects corresponding points on the sine curve and on the screen of the CRT. A vertical line is traced out, but it does not move up and down at an even rate.

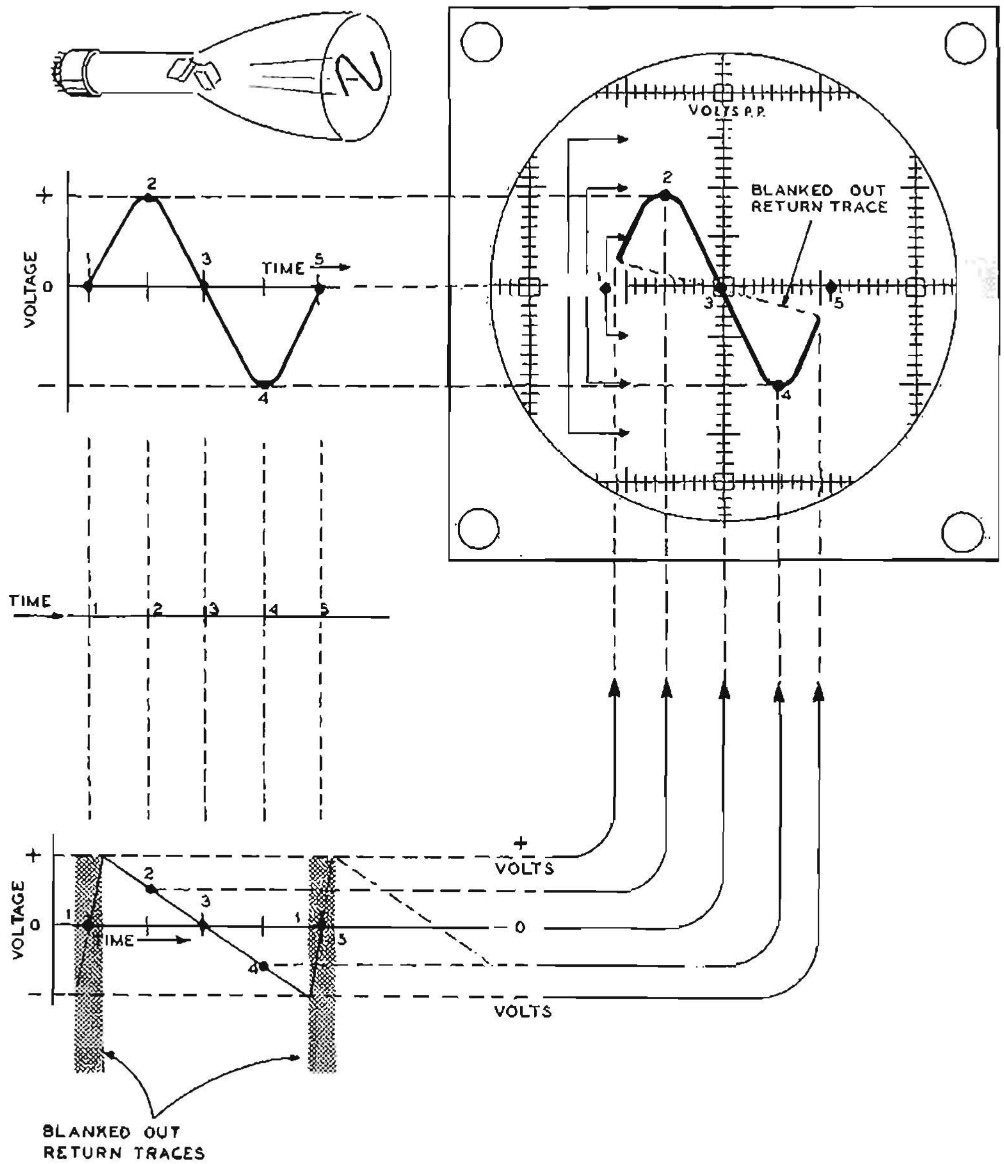


Figure 4-16

Each waveform, vertical and horizontal, when applied separately, resulted in a straight line. If, however, they are both applied simultaneously, a waveform is traced out on the screen. Figure 4-16 shows both waveforms applied. Again, dotted lines connect corresponding points of the applied waveforms to the waveform displayed on the screen.

In our example, the frequency of the sine wave and the sawtooth are the same and only one cycle of the sine wave appears. If the frequency of the sine wave is twice that of the sawtooth, two cycles of thè sine wave will be traced out. If the sawtooth is twice the frequency of the sine wave, only one-half the sine wave cycle will appear.

Deflection of the beam, as discussed in these paragraphs, is electrostatic deflection. Magnetic deflection of electrons is also possible. This method is used in television receivers. The limited frequency response of magnetic deflection, however prevent its use in popular oscilloscopes.

The Fluorescent Screen

The change of electrical energy into light is accomplished by the collision of electrons with certain materials in the fluorescent screen. The phosphor material used to coat the inside of the screen has two properties. The first is luminescence, the property of converting the impact of the electrons into light energy at relatively low temperatures. The second is phosphorescense, the property of continued glow after the impact is over. The persistence of glow varies with the material used. These phosphor coatings vary with the application intended for the CRT.

The tube number of the CRT identifies the type of phosphor used. For the type 5UP1: the "5" designates the diameter of the tube. The P1 identifies that a medium short persistence green phosphor was used. Television tubes have a medium white persistence and are identified by P4. Radar CRTs use a long persistence phosphor, P7, so that the trace can be seen for some time because of phosphorescence.

The Typical CRT

Figure 4-17 shows the 5UP1 as it is used in a typical oscilloscope. A few details have been left out for simplification. Other CRTs will vary in some details, but the basic principles are the same. This tube will serve as an example of other tubes.

Figure 4-18 shows the location of the pins as shown on the base of the tube. This method of numbering pins is common to all tubes.

Figure 4-18

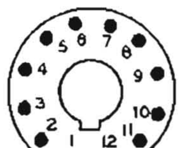


Figure 4-17 shows how these pins are connected internally to the various electrodes of the CRT. This is done by identifying the electrode connection with a pin number around the tube outline. Pins 1 and 12 are connected to the filament. Pin 3 is connected to the cathode. Pins 9 and 10 are connected to the vertical plates. Pins 6 and 7 are connected to the horizontal plates. Pin 8 is connected to the accelerating anodes.

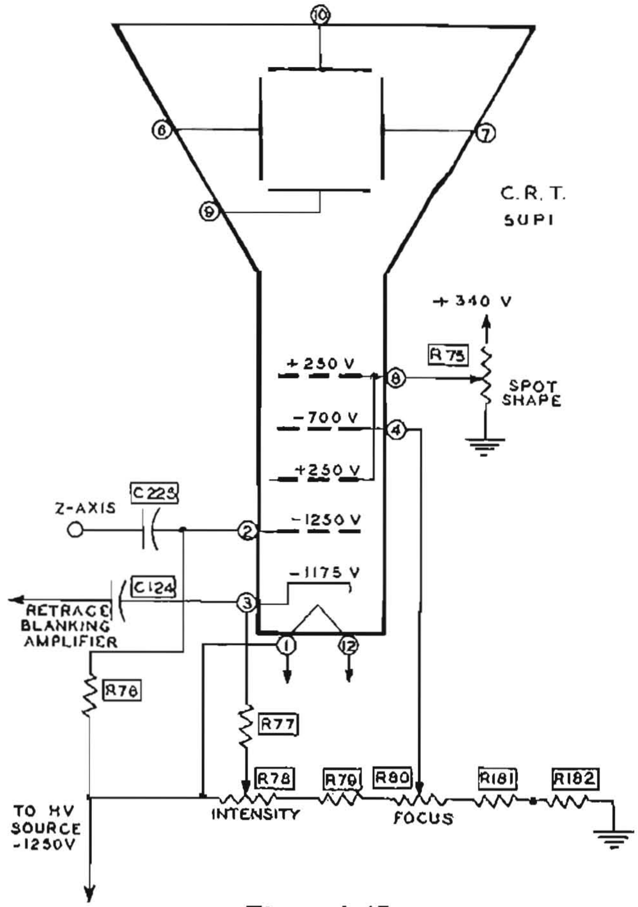


Figure 4-17

The accelerating voltage supplied is a negative 1250 volts. The negative high voltage is somewhat unusual in electronic test equipment. The high voltage causes the electrons to acquire enough speed to enable the screen to become fluorescent. It is made negative to avoid special design problems such as large coupling capacitors between some of the electrodes and other parts of the circuit.

The shaded area of Figure 4-17 shows a voltage dividing circuit. The electrodes of the 5UP1 obtain their operating voltages from this network.

Figure 4-17 also shows the approximate voltage at each electrode. The total voltage difference separating the cathode and the accelerating anode is about 1425 volts (250 + 1175). The control grid has a voltage that is about 75 volts more negative than the cathode.

The negative voltage on the control grid of the CRT, like other vacuum tubes, will greatly affect the amount of electrons allowed to leave the cathode. Adjusting R78 will change the voltage difference between the two electrodes. A small voltage difference results in a bright spot. A large voltage difference will cause a dim spot. R78, which is located on the front panel, is called the intensity control.

The voltage between the cathode and the control grid can also be controlled in another way. If a suitable AC signal is fed into the control grid, the intensity of the spot is varied in time with the signal.

In Figure 4-17, an input to the control grid is labeled Z-axis. The Z-axis input is generally located at the rear of the oscilloscope. Figure 4-19 shows the location behind a small removable panel. Many oscilloscopes have this input located in the same general area.

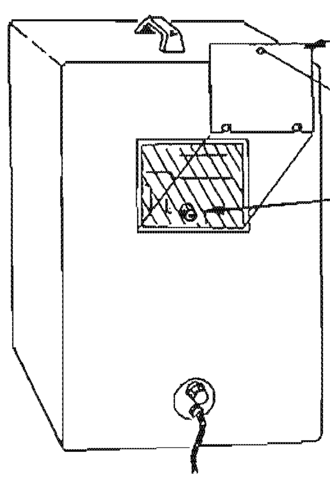


Figure 4-19

A signal could be fed directly to the deflection plates and, in some oscilloscopes, provisions are made for this purpose. About 80 volts of signal are needed to deflect the beam 1" on the screen. The small output of the test chassis AF oscillator would not deflect the beam by a noticeable amount. The plates are generally driven by voltage amplifiers in the oscilloscope. These amplifiers are discussed in Chapter 4.

Although the type 5UP1 CRT was discussed mainly in this chapter, it is typical of the CR tubes used in most general purpose oscilloscopes. An understanding of the 5UP1, should enable you to also understand other types of CR tubes.

EXPERIMENT 4-1

The general purpose CRT uses electrostatic deflection. Magnetic deflection is also possible; the television CRT uses this type of deflection. The purpose of this experiment is to illustrate that a small magnetic field can affect the path of the electron beam. You can see after doing this experiment why magnetic shielding is often used in oscilloscopes. Stray magnetic fields, often distort the true picture of the waveform. External fields can often be less annoying if the scope is moved or turned a little.

( ) Remove the test leads from the oscilloscope.

( ) Turn the scope on and adjust it for a horizontal line across the center of the screen.

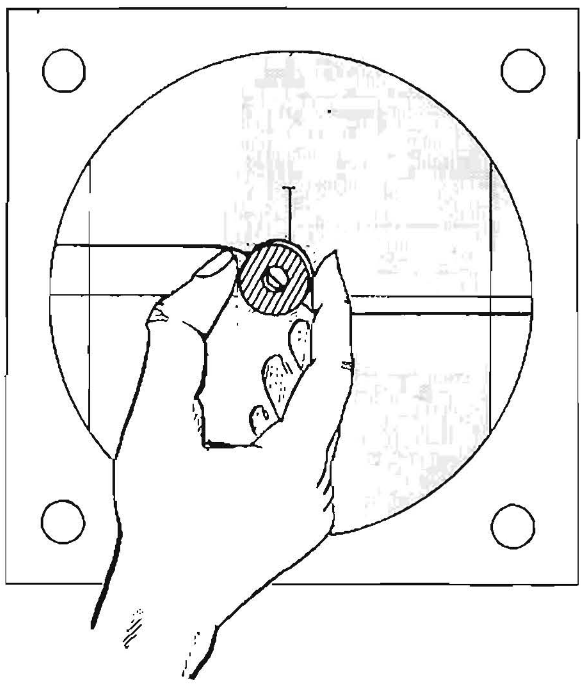


Figure 4-20

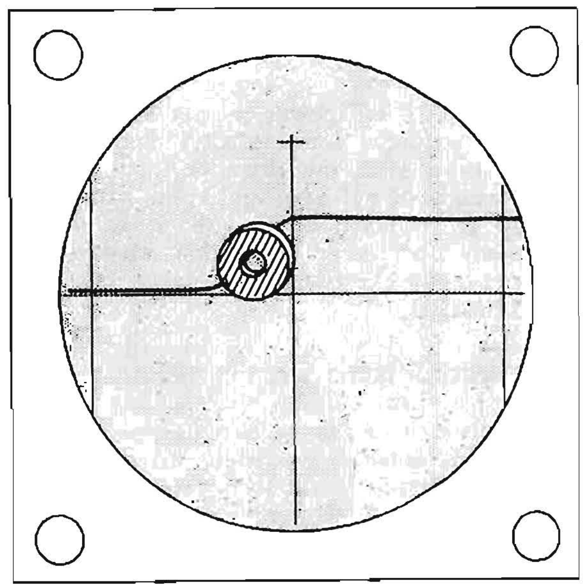


Figure 4-21

( ) A small magnet is supplied with your kit. Place it against the screen and in front of the line as shown in Figure 4-20. Note how the line bends (distorts) in back of the magnet.

( ) Turn the magnet over and note that the line now bends in the other direction. Move the magnet back and forth and note that the bent part of the trace stays behind (in the magnetic field of) the magnet.

SUMMARY

The CRT is a rather large special purpose vacuum tube. Internally it consists of an electron gun, two sets of deflection plates, and a fluorescent screen. These sections of the CRT function together to produce visible waveforms.

The electron gun, located in the neck of the tube generates and shapes an electron beam. The deflection plates impart the signal characteristics to the beam. Finally, the phosphor of the fluorescent screen converts the deflected beam pattern into a light pattern that corresponds to the signal.

The pattern takes on the signal characteristics when the signal voltage is applied to the vertical deflection plates of the CRT. These plates are at right angles to the linear sweep voltage applied to the horizontal deflection plates. A sawtooth waveform that is linear in time is used to produce this sweep voltage.

High voltages are needed to accelerate the electrons sufficiently to produce fluorescence. Generally these high voltages are negative to minimize design problems.

The 5UP1 CRT used as an example is a 5", medium persistence tube. Other tubes are also available, varying in details as determined by their intended application.

CHAPTER 2

Power Supply

The function of the power supply is to supply operating voltages for the CRT and for the other sections of the oscilloscope. It must supply a wide range of voltages and at the same time be free from undesirable voltage variations or surges. The power supply may also furnish signals for synchronization, retrace blanking, and calibration.

An oscilloscope power supply generally has two sections; a low voltage section and a high voltage section. Each section has four parts: power transformer, rectifier, filter, and a voltage dividing network. Very often one transformer serves both sections.

Each part of the power supply is discussed separately. At the end of the chapter, the power supply used in actual general purpose oscilloscopes will be analyzed.

The Power Transformer

The power transformer has special features not generally found in the transformers used for other test equipment. Better insulation and more windings are required for the high voltage section. Three or more separate filament windings are needed.

The separate filament winding for the CRT is connected on one side to high voltage. This requires extra insulation on these transformer leads. The filament winding for the high voltage rectifier is part of the high voltage winding and also needs heavier insulation.

Figure 4-22 shows a typical oscilloscope power transformer. The separate filament leads for the CRT and the high voltage rectifier are indicated. The high voltage winding and low voltage winding are on the same coil. The low voltage winding is center tapped; the high voltage winding is not center tapped. Center tapped windings are required with full-wave rectifiers. The untapped high voltage winding is used with a half-wave rectifier.

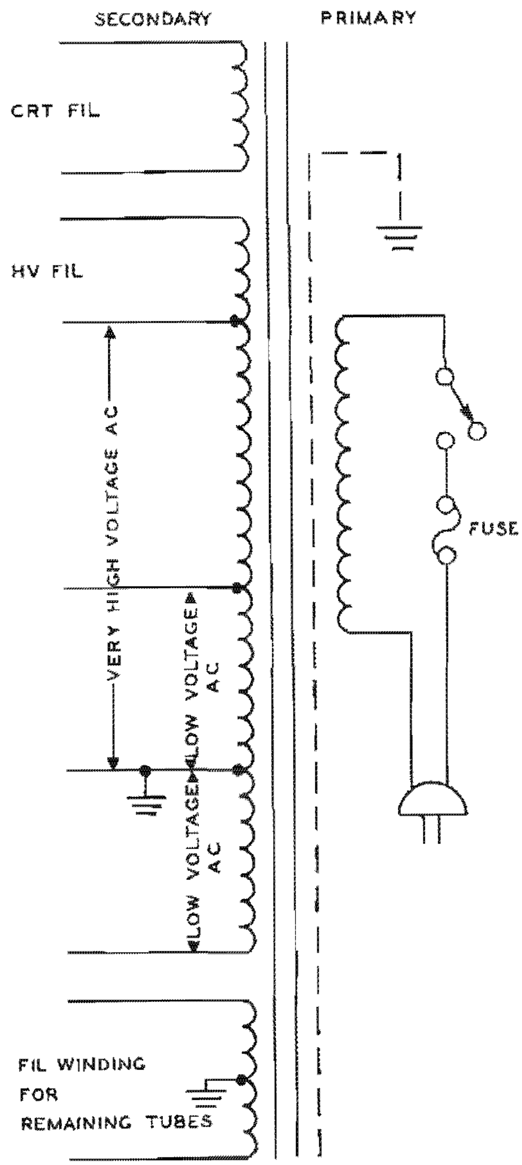


Figure 4-22

The primary circuit includes the protective fuse and the instrument on-off switch. The switch is usually ganged with one of the other front panel controls. In our example of a general purpose oscilloscope, it is combined with the intensity control. The fuse is generally a "slow-blow" fuse. This type of fuse will withstand a harmless short-duration surge of current. Longer surges of damaging current will melt the soft metal of the fuse. Figure 4-23 shows the construction of the fuse. The spring will absorb a small amount of heat to keep the short surge from melting the protective filament.

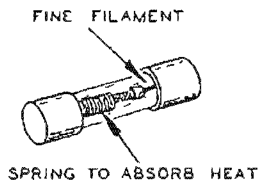


Figure 4-23

In Figure 4-22 you will notice some dotted lines in the schematic drawing of the power transformer. These indicate electrostatic shielding to prevent unwanted coupling in the transformer. For example, random voltages entering the primary from the line could affect the heater of the CRT. These unwanted voltages could cause false indications in the waveform being viewed.

High Voltage Power Supply

High voltage power supplies generally use half-wave rectifiers. Most rectifiers used for this purpose in oscilloscopes are tube type.

Figure 4-24 shows the basic outline of the circuit commonly used. If the electron current flow is traced, electrons are emitted from the filament-cathode toward the plate. The electron current passes through the filter network, through the voltage dividing network, through the secondary windings of the power transformer, and back to the filament-cathode. The electron current flows from point A to point B. This makes A negative with respect to B. If point B is made ground (the zero reference point) then A is negative.

The high voltage is derived from the large number of turns on the transformer secondary winding. The tube selected for the diode must be able to function properly at high voltage. The current flowing in this section of the power supply is low. The diode does not have to conduct a large current.

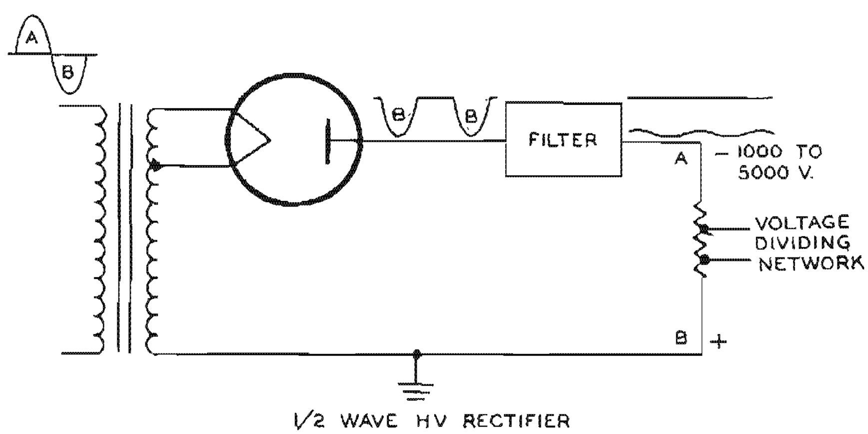


Figure 4-24

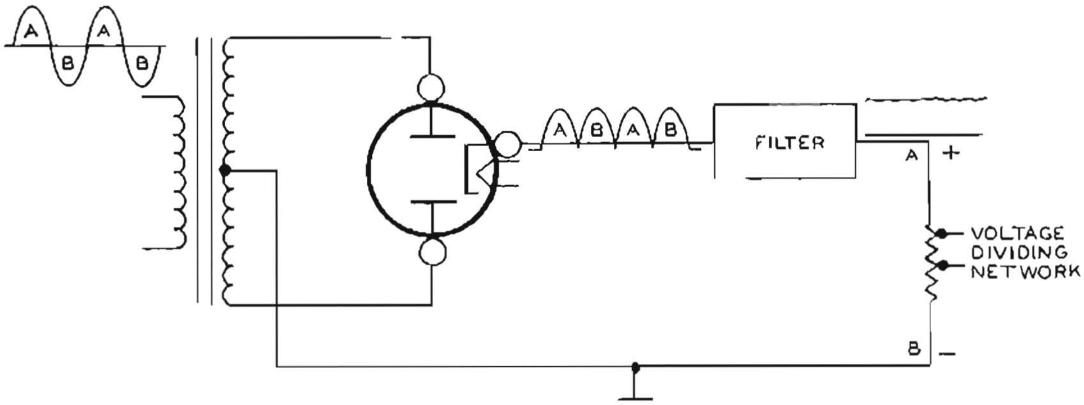


Figure 4-25

FULL WAVE LV RECTIFIER

Low Voltage Power Supply

Low voltage power supplies generally use full-wave rectifiers. These are either tube type or silicon diode circuits. Figure 4-25 shows the basic outline of a circuit commonly used.

The electron current flow can be traced out in the same manner as for the half-wave rectifier. One diode section conducts for one-half cycle of the AC input, the other diode conducts the other half cycle. In this power supply, the plate side of the diodes is connected to the common ground. Electron current flows from B to A, therefore, if B is made zero, then A is positive. Ripple in the DC voltage cannot be tolerated in the early stages of amplification because the signal to be amplified is so small. The full-wave rectification waveform is easier to convert to smooth, ripple-free DC.

Figure 4-26 shows a typical RC circuit commonly used for filtering.

The action of such a RC circuit was discussed in Chapter 4 of Part III. The values of C1, C2, and R1 vary from power supply to power supply, governed by the voltages used and the current requirements.

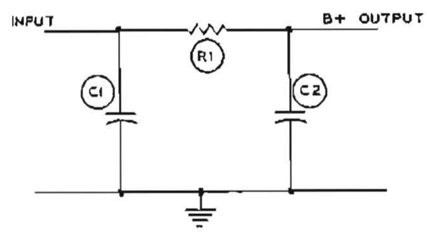


Figure 4-26

Additional RC circuits are provided for each separate application of voltage if the circuit is critical. This minimizes the signal leakage from one circuit to another circuit through common power supply connections.

Filter Networks

Figure 4-24 and Figure 4-25 show the rectified waveforms before and after passing through the filter sections. The filter network clips the peaks of the voltage surges and fills in the valleys.

The Voltage Divider

The voltage dividing circuit does exactly what its name indicates. Its purpose is to divide the voltages in accordance with the needs of the circuits connected to it. In addition to dividing

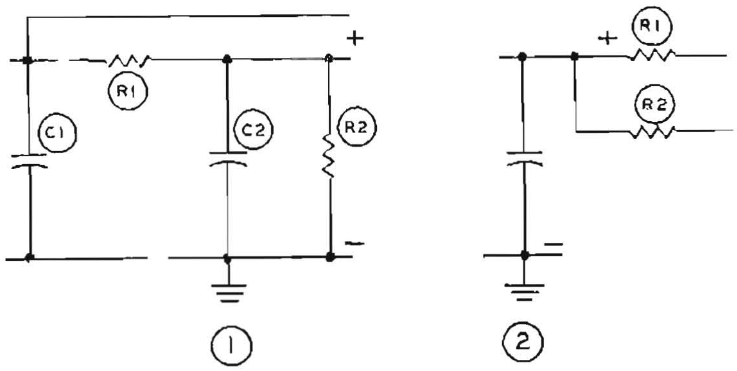


Figure 4-27

the voltages, the high voltage divider also acts as a bleeder which drains off accumulated charge on the filter capacitors after the circuit has been turned off. The low voltage supply serves circuits that use more current. When the circuit is shut off the tubes are still hot and continue to conduct for a short time dissipating the charge on the capacitors. For this reason, bleeder resistors are not always used in low voltage power supplies.

Figure 4-27 shows the types of circuits involved in voltage dividing networks. Parts 1 and 2 show typical circuits that appear in a low voltage dividing network. In Part 1, R1 and R2 act as bleeders as well as dividing the voltage. In Part 2 the resistors are in series with the remaining portion of the circuit. The voltage is changed, but the filter capacitors will not be able to discharge through R1 or R2 to ground.

Voltage Regulators

Filtering networks will even out the pulses caused by rectification, but cannot stabilize the voltage under all conditions. Changes in the line voltage or current drawn in various circuits will affect the voltage output of the power supply. However, in order for the oscilloscope to function consistently, fairly constant voltages are required.

Figure 4-28 shows an elementary voltage regulator. The voltage regulator works as a variable resistor. When the load current decreases, voltage rises. This causes the voltage regulator tube to increase in resistance. The increased voltage, therefore, will appear across the voltage regulator tube instead of the load.

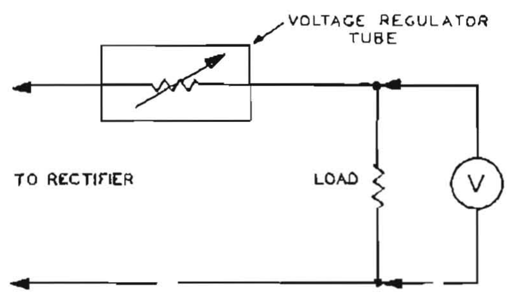


Figure 4-28

When the external load current increases, the variable resistance decreases, thus maintaining a constant voltage. However, this type of regulator has operating limits.

The most common voltage regulator is the glow discharge tube. The voltage drop across the tube remains relatively constant over a wide range of currents through it. Voltage regulators of a more complex nature can also be used, but basically they use the same principle.

The Complete Power Supply

Figure 4-29 shows an example of an actual power supply as used in a Heathkit general purpose oscilloscope. Most power supplies for oscilloscopes will have a circuit which produces the required voltages in much the same manner.

V9 is the high voltage half-wave rectifier. The filter network for the high voltage consists of capacitors C36 and C37 connected by resistor R71. The voltage dividing network R78, R79, R80, R181, and R182) was discussed in Chapter 1.

The low voltage power supply has a full-wave rectifier, V8. Since it must supply many different voltage values and many different circuits, it has many more elements. For example, in the "AA" voltage output circuit, capacitors C38 and C40 with resistor R68 act as a filter network. You will also notice that each individual output of the low voltage power supply has one capacitor in the circuit to ground. This capacitor, in addition to filtering, acts as a decoupling capacitor. Decoupling reduces the amount of AC signal leaking from one circuit to another through the power supply.

Tube V10 is a special type of voltage regulator. Its only function is to prevent very sudden voltage surges in the circuit. A gradual voltage change is not acted upon.

EXPERIMENT 4-2

The experiment for this chapter uses a special type of circuit found in oscilloscopes, called the multivibrator. The purpose of building a multivibrator at this time is to prepare for the principles of sweep circuitry in Chapter 3. The multivibrator built in this experiment will be used to explain the principle of the multivibrator.

Before assembly begins, two things should be done. First, all quick-connect circuit components should be removed from the test chassis. Second, fresh batteries should be installed.

POWER SUPPLY

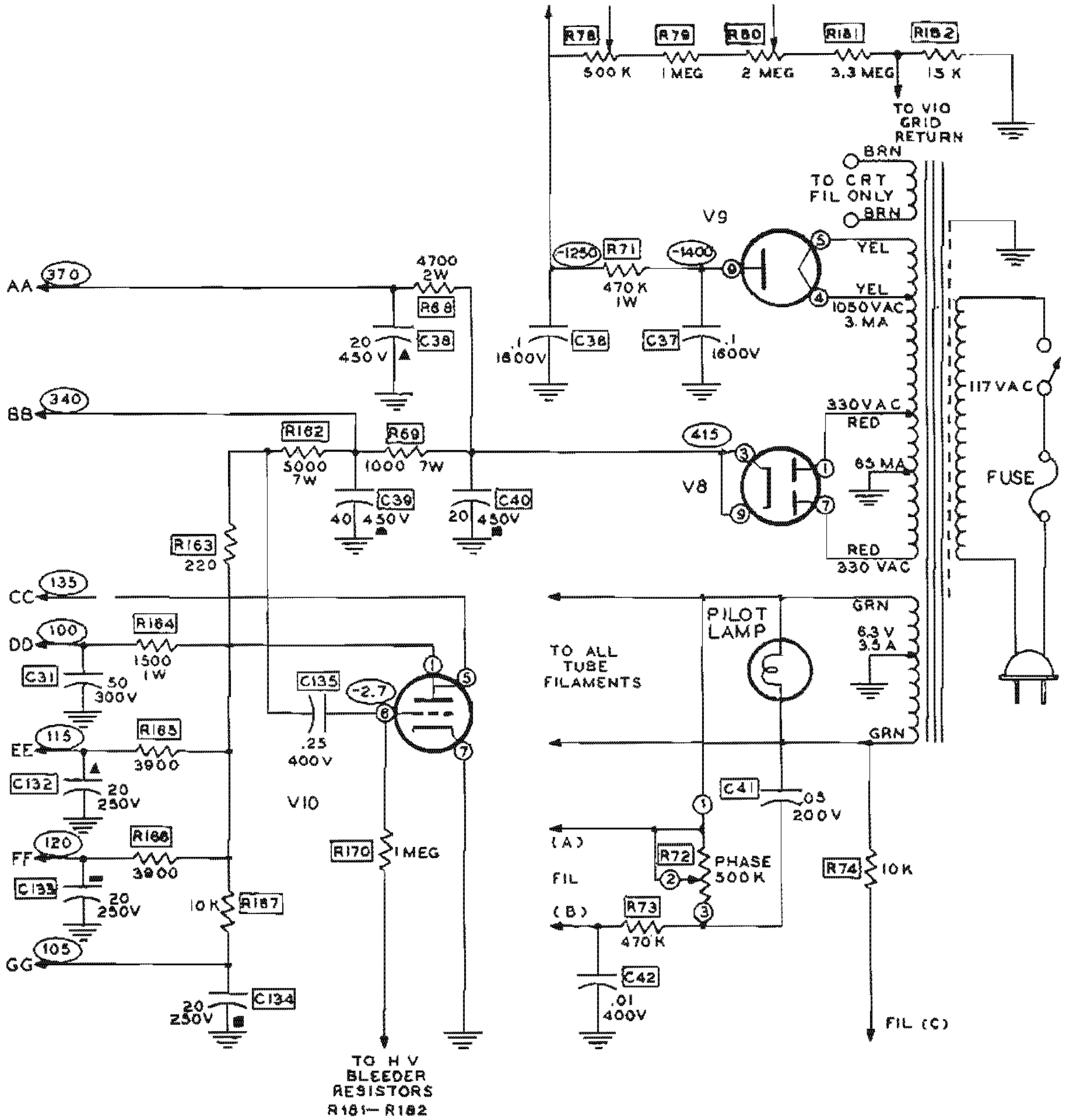


Figure 4-29

Refer to Figure 4-30 for the following assembly.

( ) Connect a 100 KΩ (brown-black-yellow) resistor from lug 1 of terminal strip F to lug 2 of terminal strip D. Connect a second 100 KΩ resistor from lug 1 of terminal strip F to lug 4 of terminal strip D.

( ) Connect a 150 Ω (brown-green-brown) resistor from lug 1 of terminal strip D to lug 4 of terminal strip A. Connect a second 150 Ω resistor from lug 1 to lug 4 of terminal strip F.

( ) Connect a 4700 Ω (yellow-violet-red) resistor from lug 2 of terminal strip F to lug 4 of terminal strip E. Connect a second 4700 Ω resistor from lug 2 of terminal strip B to lug 4 of terminal strip C.

( ) Connect a 47 KΩ (yellow-violet-orange) resistor from lug 2 of terminal strip F to lug 2 of terminal strip D. Connect a second 47 KΩ resistor from lug 4 of terminal strip D to lug 2 of terminal strip B. Connect a third 47 KΩ resistor from lug 3 of terminal strip C to lug 3 of terminal strip E.

( ) Connect a .05 μfd capacitor from lug 3 of terminal strip E to lug 1 of terminal strip F.

( ) Connect a 3-1/4" wire from lug 2 of terminal strip F to lug 3 of terminal strip C.

( ) Install transistor Q1. Connect lead B to lug 2 of terminal strip D. Connect lead E to lug 4 of terminal strip A. Connect lead C to lug 2 of terminal strip B.

( ) Install transistor Q2. Connect lead B to lug 4 of terminal strip D. Connect lead C to lug 2 of terminal strip F. Connect lead E to lug 4 of terminal strip F.

( ) Connect a .01 μfd capacitor from lug 3 of terminal strip C to lug 2 of terminal strip D.

( ) Connect a .01 μfd capacitor from lug 2 of terminal strip B to lug 4 of terminal strip D.

( ) Connect a 6" wire from lug 1 of terminal strip E to lug 3 of terminal strip C.

This completes the basic connections of this circuit. Connect the oscilloscope leads to the output terminals of the test chassis. Turn on the oscilloscope and test chassis. Adjust the oscilloscope and test chassis for two-cycle waveform. The waveform should appear approximately like the one in Figure 4-31. Turn off the test chassis.

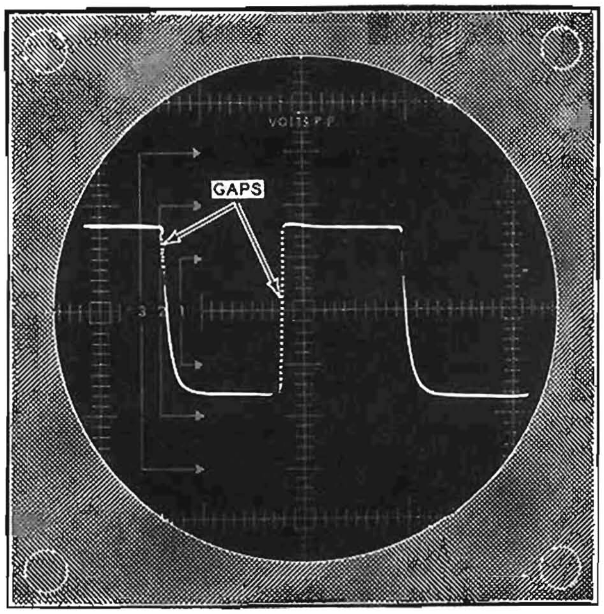


Figure 4-31

SUMMARY

The oscilloscope power supply furnishes a wide variety of different voltages for the many parts of the instrument. The power supply is divided into two parts, a high voltage section and a low voltage section.

The high voltage section produces high negative voltage, using a half-wave rectifier. The high voltage requires special insulation in the circuit wiring. The high voltage is used primarily for accelerating the electrons in the electron beam of the CRT.

The low voltage section supplies operating voltage for the remaining parts of the oscilloscope. Because of the high sensitivity of the amplifiers, the low voltage power supply generally uses a full-wave rectifier for more filtering, and a voltage regulator for smooth DC voltages.

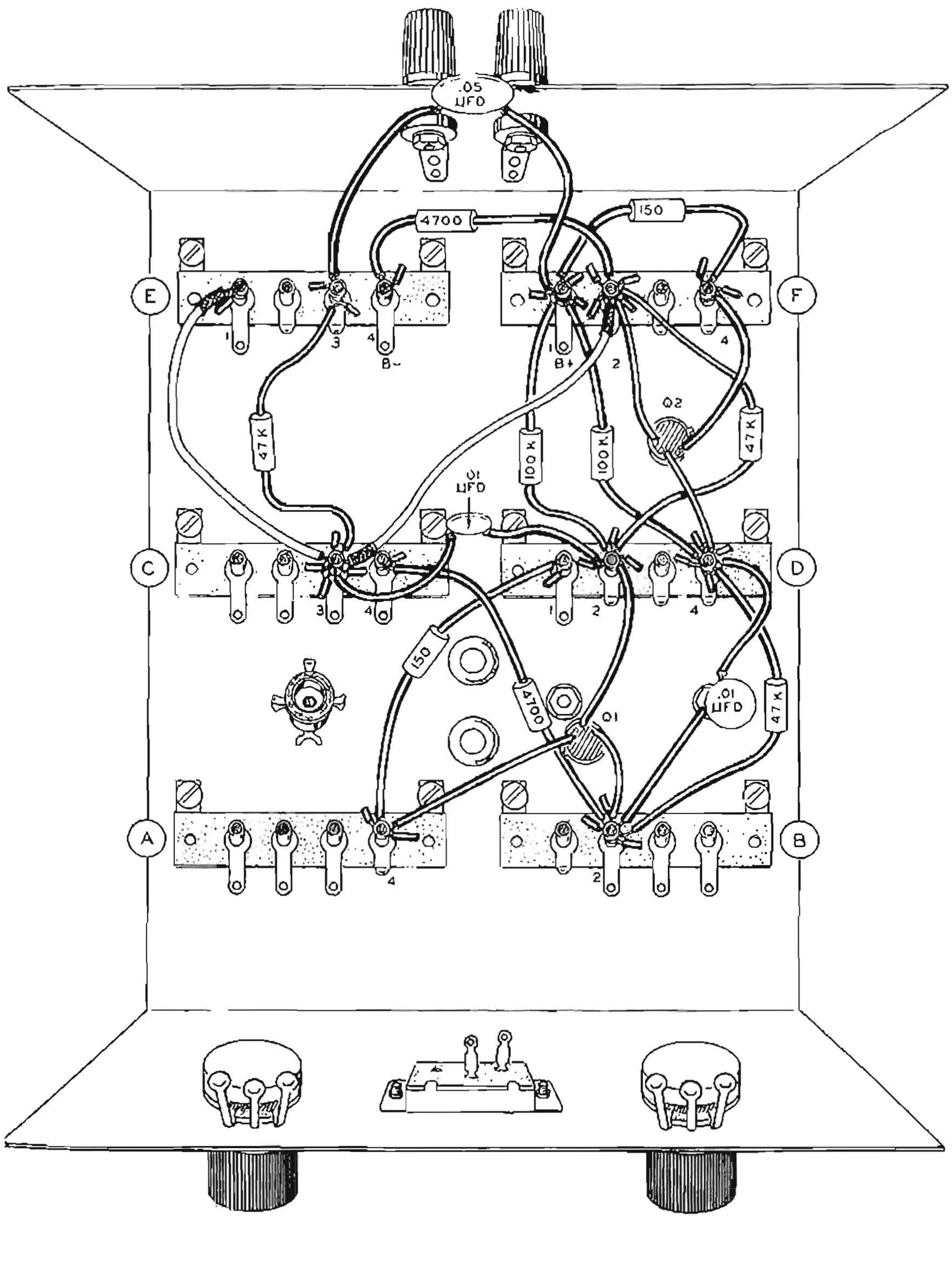

.05
UFD
4700
150
E
1
3
4
B-
F
1
B+
2
4
Q2
47K
100K
100K
47K
.01
UFD
C
3
4
D
1
2
4
150
4700
.01
UFD
47K
Q1
A
4
B
2

Figure 4-30

CHAPTER 3

Sweep Circuits

In Chapter 1, you saw how a sawtooth waveform was applied to the horizontal plates of the CRT to help in displaying a sine wave. The action of two waveforms at right angles is necessary for the proper formation of a two-dimensional figure on the CRT screen. Only one waveform applied to one set of deflection plates results in a straight line.

The sweep circuit in an oscilloscope provides the second waveform. The type of waveform needed depends on the reason for studying a test signal. Generally, the information needed is how the waveform changes as time passes. The sweep waveform, then, must have the characteristics of a clock. The time between 1:00 to 2:00 is the same as the length of time between 2:00 and 3:00, etc. That is, time passes at a uniform rate. The sweep voltage must change such that any inch of deflection on the screen will represent the same length of time as any other inch. In Figure 4-32, lengths A, B, and C are 1 inch. Each represents the same interval of time. This establishes what is usually referred to as time base. An undistorted sawtooth waveform is a linear time base.

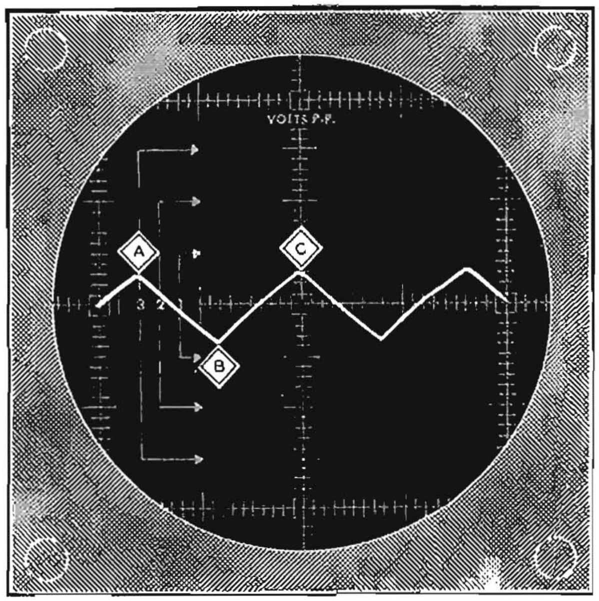


Figure 4-32

In the Experiment at the end of Chapter 2 you built a circuit, a multivibrator that produced a square wave. This chapter will discuss how the multivibrator works and how the sawtooth is produced. You will also see how the unwanted part of the sawtooth, the retrace part, is removed from the CRT trace. Trigger sweeps and other forms of sweeps are also discussed.

Multivibrator

The free-running multivibrator, which is an essential part of the sweep circuitry, is a widely used method of producing sweep frequencies. It is essentially a two-stage oscillator, in which one stage conducts while the other stage is cut off, until a condition is reached where the stages reverse their roles.

A transistor multivibrator circuit is usually the counterpart of a similar circuit that uses vacuum tubes. Since most multivibrator circuits operate the same way, the transistor multivibrator built in Chapter 2 will be used to explain multivibrators.

Since most multivibrator circuits operate the same way, the transistor multivibrator built in Chapter 2 will be used to explain multivibrators.

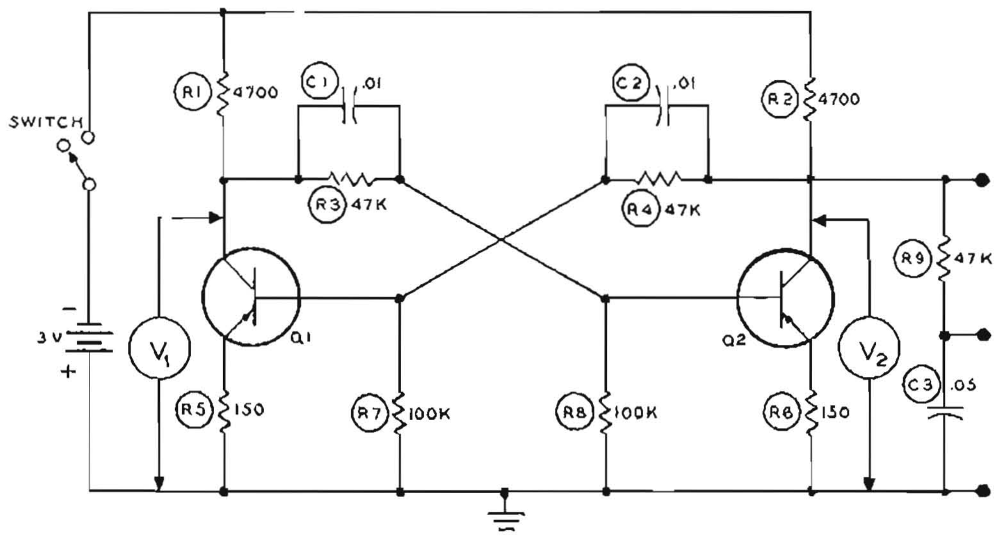


Figure 4-33

It may be helpful to review the chapter on transistors before you begin studying this circuit description. Remember that the negative voltage is connected to the collector circuit and the positive voltage is connected to the emitter circuit for PNP transistors.

A collector-coupled transistor multivibrator circuit is shown in Figure 4-33. The output of the first stage is coupled to the input of the second stage, and the output of the second stage is coupled to the input of the first stage. Resistors R1 and R2 are the collector loads. Emitter resistors R5 and R6 act as stablizers. Base bias for Q2 is developed by a voltage divider consisting of R3 and R8. Base bias for Q1 is developed by a voltage divider consisting of R4 and R7.

Transistors Q1 and Q2 alternately turn "on" and "off." If Q1 is conducting, Q2 is turned "off." If Q2 is conducting, Q1 is turned "off." All the actions described in the following paragraphs actually take place in a small fraction of a second. However, they have been separated into a series of steps to make the circuit operations easier to understand.

For a starting point, assume that Q1 is conducting in a state of saturation (that is, it is carrying all the current that it can) and Q2 is turned off. Assume also that capacitor C1 is charged up to the battery voltage of 3 volts, and capacitor C2 is not charged. The following paragraphs will show how the capacitors reached this condition.

1. In this first condition, as stated above, voltage V_1 is very low, .5 volt, and voltage V_2 is almost 3 volts (since Q2 is turned "off").

2. Capacitor C2 charges up to the voltage of V_2, 3 volts. Capacitors C1 gradually discharges through resistor R8 and Q1.

3. As C1 discharges, the voltage at the base of Q2 gradually becomes less positive (it started at almost a full +3 volts because of the charge on C1) until it is about zero volts, this causing Q2 to begin to conduct.

4. When Q2 begins to conduct, less voltage is dropped across it, thus V_2 becomes smaller. Voltage V_2 is also divided by voltage divider resistors R4 and R7; thus the voltage at the base of Q1 also becomes smaller and the current in Q1 begins to decrease.

5. When the current in Q1 decreases, more voltage is dropped across it, causing V_1 to increase. Voltage V_1 also appears across voltage divider resistors R3 and R8, thus the voltage at the base of Q2 becomes larger, causing the current in Q2 to increase still further.

6. Increasing current in Q2 causes V_2 to become still smaller and this voltage decrease is again coupled to the base of Q1. This whole series of voltage changes quickly until Q2 is conducting all the current it can, and Q1 is turned "off."

NOTE: In the first condition we assumed Q1 was conducting and Q2 was turned "off," now Q2 is turned "on" and Q1 is turned "off." The next two steps show how this process begins again to reverse itself.

1. When Q1 is turned "off" voltage V_1 becomes almost a full 3 volts, and capacitor C1 begins to charge up to this 3 volt level. Voltage V_2 is now .5 volt.

2. This condition (Q1 turned "off" and Q2 conducting) remains until C2 discharges enough across R7 to cause Q1 to begin to conduct again. Then the whole process begins all over again.

The multivibrator continues to oscillate back and forth in this manner, alternately turning the transistors "on" and "off." The frequency at which it will operate is determined by how quickly capacitor C1 and C2 are allowed to discharge. The voltage waveform that appears at both V_1 and V_2 is a square wave, as shown by Figure 4-34.

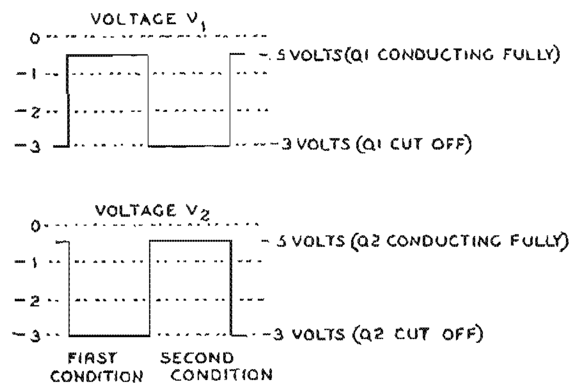


Figure 4-34

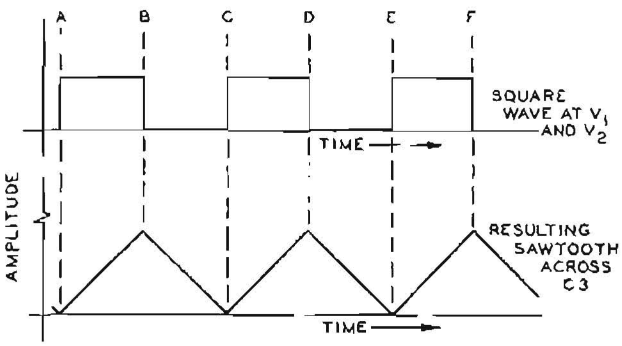


Figure 4-35

A sawtooth output can be obtained across the capacitor, C3. The charging-discharging action of the capacitor results in a sawtooth waveform as shown in Figure 4-35.

Blanking Circuits

If the charging voltage across a capacitor will sweep the electron beam from left to right across the screen, then the discharging voltage will sweep it from right to left. If a symmetrical multivibrator, such as the one shown in Figure 4-33 were used, the trace and retrace times would be the same, and both the trace and retrace would appear on the screen.

The sweep waveform is much more useful if the retrace time is very short, since this part of the waveform is not used. It is also desirable to make the retrace invisible.

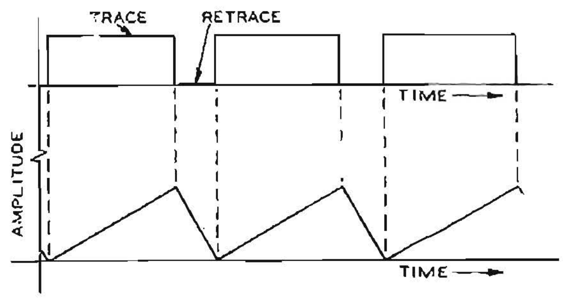


Figure 4-36

The retrace time is shortened by making the multivibrator asymmetrical. This means that one transistor conducts for a longer period of time than the other. The resulting sawtooth then would look like that in Figure 4-36.

The retrace, which is needed to return the beam to its starting point for the next sweep, is made invisible by a process called blanking. When blanking occurs, the retrace is blanked out by making the beam intensity so low during the retrace time that it becomes invisible on the screen.

Blanking is accomplished by applying a large positive pulse to the cathode of the CRT during the retrace time. This makes the control grid very negative with respect to the cathode, thus cutting off the electron beam during the retrace period. This is like mechanically turning the intensity way down each time the sweep retraces.

The positive pulse is derived from the multivibrator transistor that conducts during the short retrace period. If the magnitude of the pulse is not large enough to cause cutoff of the electron beam in the CRT, an amplifier is inserted between the sweep generator and the CRT. This amplifier is called the blanking amplifier.

Some oscilloscopes have a means of removing the blanking voltage from the CRT, allowing the retrace to be seen. In high frequency operation, the retrace time can be much longer than one cycle of waveform. In such cases the retrace may contain needed information and thus blanking is not desirable.

Special Type of Sweeps

A sawtooth sweep produced by a multivibrator is used most commonly. However, other forms of sweeps are useful. These are generally of the nonlinear type. This means the sweep does not travel at a constant rate in the horizontal direction.

The more common types of nonlinear sweeps are sine wave, circular and spiral sweeps. Some of these will be discussed in Part VI on applications. For example, a 60 cycle sine sweep is very useful in audio work where tests are made for "hum." The 60 cycle sine wave sweep can be taken from a winding on the power transformer. Provisions are found on many newer oscilloscopes for a sine sweep; usually there is a line sweep (60 cps) position on the horizontal frequency selector switch.

In this chapter, only the free-running, or continually reoccurring, sweep has been discussed so far. Another special type of sweep is the triggered sweep. When a test pattern repeats itself periodically, the free-running sweep, either linear or nonlinear, will show the desired information. If the waveform occurs only once, or in a random manner, a free-running sweep may be on retrace when the waveform occurs. To assure that the waveform is seen, the sweep is triggered by the signal voltage. This means that the sweep occurs only when the signal comes through. Generally a delay network is used to allow the sweep to get started before the signal is applied to the deflection plates.

Phase

A control that is often added to general purpose oscilloscopes is the phasing control. This control is used with line sweep. Use is also found for this control in connection with sweep generators, and some work with Lissajous figures. A few such applications will be discussed in a later section.

The sine wave signal for line sweep is generally taken from some point in the oscilloscope circuitry, usually a winding on the power transformer. When the sine wave signal is used to drive the horizontal plates, the phasing control is used to vary the point on the sine wave at which the sweep begins.

Figure 4-37 shows an example of a general purpose oscilloscope sweep and blanking circuit. In this chapter, a transistor multivibrator was used to explain multivibrator operation. The experiment for this chapter uses that circuit. Figure 4-37 shows a vacuum tube multivibrator.

Tube V4B and tube V5A constitute the multivibrator. The plates of the tubes are comparable to the collectors of the transistors. The grids act like the bases of the transistors. The cathodes are similar to the emitters of the transistors.

The multivibrator is asymmetrical. The plate-grid coupling between tubes is not the same. The experiment of this chapter will show how making this coupling different makes the multivibrator asymmetrical. In this example, V5A is made the tube that conducts for the short period of time, V4B conducts for the long period.

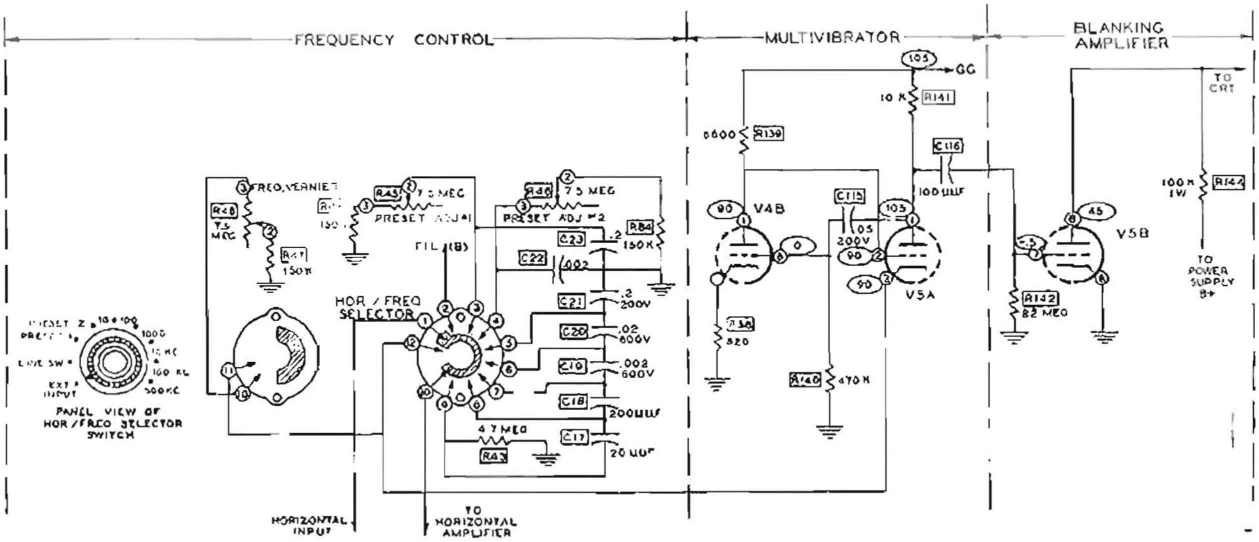


Figure 4-37

Figure 4-38 shows a small section of the total circuit. This is the situation when capacitor C21 and resistor R48 are inserted in the cathode circuit of V5A by the horizontal frequency selection switch.

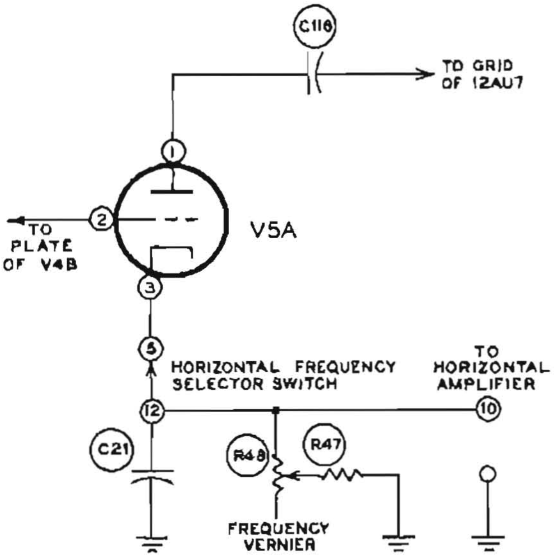


Figure 4-38

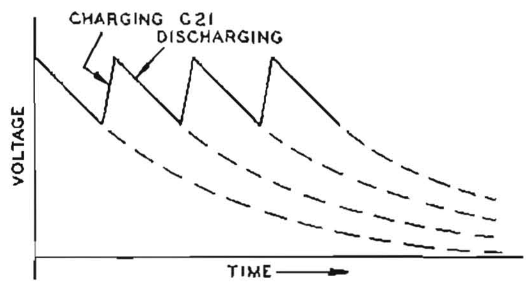


Figure 4-39

When V5A conducts, capacitor C21 charges. When V5A cuts off, C21 discharges through R47-R48. The result is a sawtooth wave as shown in Figure 4-39.

The sawtooth waveform is amplified by the horizontal amplifier and applied to the horizontal plates of the CRT. The value of R47-R48 determines the length of time needed to discharge C21.

In Figure 4-37, when V5A conducts, a negative pulse is fed to V5B through capacitor C116. The pulse is inverted by V5B and amplified to a sufficient voltage that when it is applied to the cathode of the CRT it will cut off the electron beam. This is the same as making the control grid more negative. This operation is called blanking the retrace.

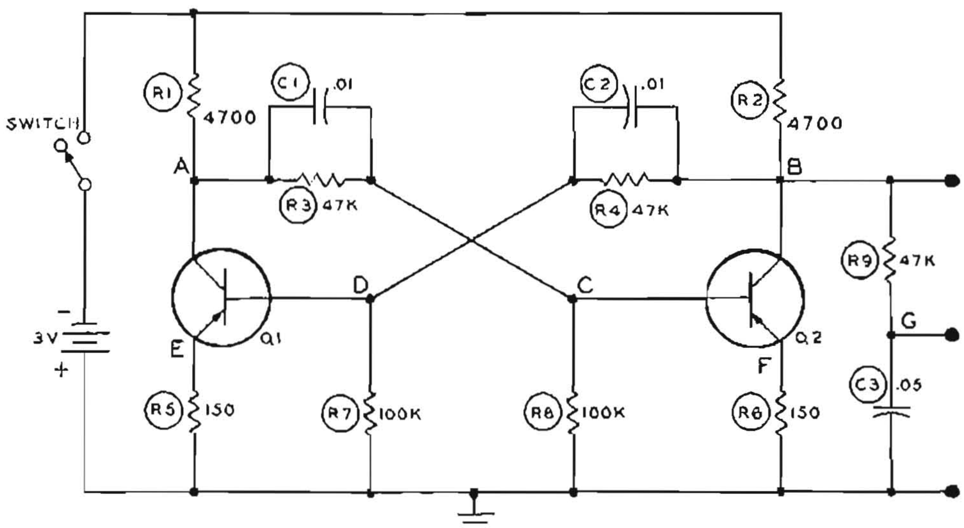


Figure 4-40

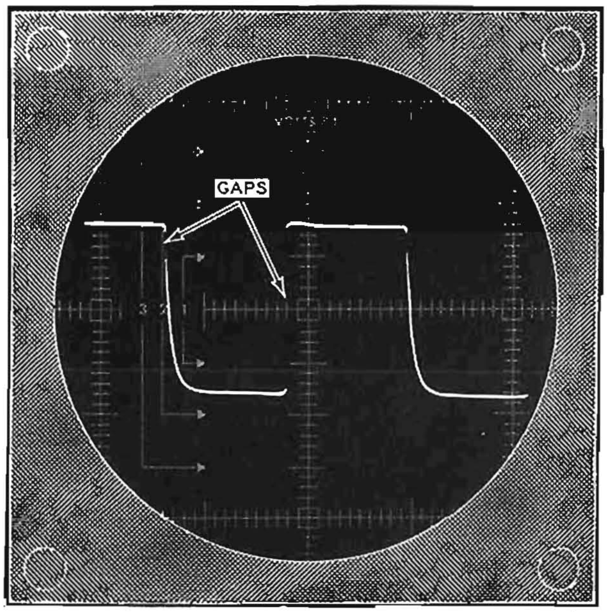
EXPERIMENT 4-3

The purpose of this experiment is to use the oscilloscope to observe how the multivibrator operates. You will also be able to see how the symmetrical multivibrator can be changed to an asymmetrical multivibrator. For the experiment, refer to Figure 4-30 of Chapter 2 and to Figure 4-40.

The other end of the 6" wire that is connected to lug 1 of terminal strip E will serve as a convenient probe. Turn on both the oscilloscope and test chassis, and adjust for the square waveform of the previous Chapter, as shown in Figure 4-41. To show the waveform of Q2, the probe is now connected to point B of Figure 4-40 (pin 3 of terminal strip C).

Connect the 6" wire probe to point A, lug 2 of terminal strip B. This is the waveform of the conduction of Q1. For a symmetrical multivibrator, it should look like the conduction waveform of the other transistor.

Note the gaps in the waveform in Figure 4-41. These gaps only happen where there is a very quick rise at the leading or trailing edge of a waveform. They occur at those places where the beam moves up or down so rapidly that the screen does not have time to fluoresce.



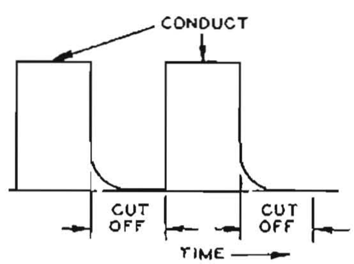


Figure 4-41

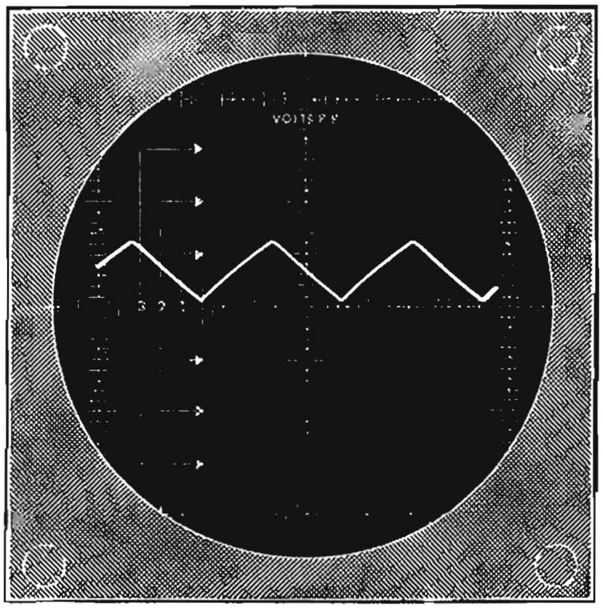


Figure 4-42

Connect the 6" wire probe to point G, lug 3 of terminal strip E. This is the waveform that results when a square wave is applied to capacitor C3. Notice that this sawtooth wave is symmetrical. The length of time of charge is approximately equal to the length of time of discharge. See Figure 4-42.

Connect the 6" wire probe to point D, lug 2 of terminal strip D. This is the waveform at the base of Q1. An actual photograph of this waveform is shown in Figure 4-43.

The first part of this experiment showed the characteristic waveforms of a symmetrical multivibrator. You will now change the multivibrator into one that is not symmetrical. That is, you will make one transistor conduct longer than the other.

First, Q1 will be made to fire for a shorter period of time by decreasing the value of C2 from .01 μfd to .001 μfd.

( ) Connect the 6" wire probe to lug 3 of terminal strip C.

( ) Remove the .01 μfd capacitor from lug 4 of terminal strip D to lug 2 of terminal strip B, and replace it with a .001 μfd capacitor.

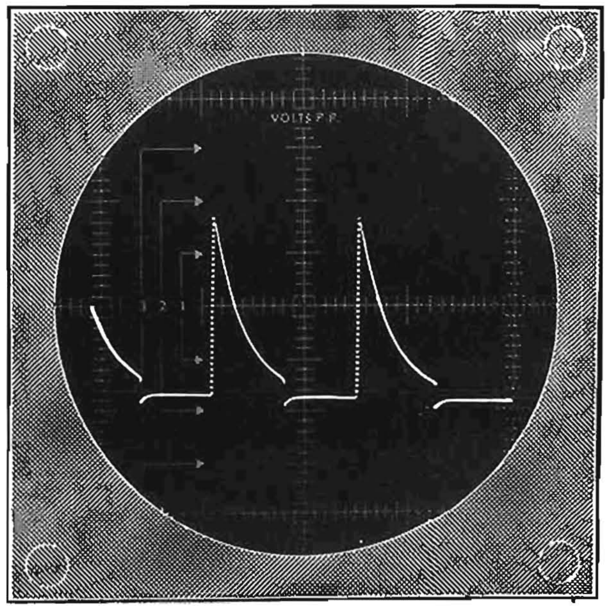


Figure 4-43

( ) Adjust the oscilloscope to obtain a waveform. This capacitor value change also changes the frequency of the multivibrator.

Your waveform on the oscilloscope should look like the one in Figure 4-44.

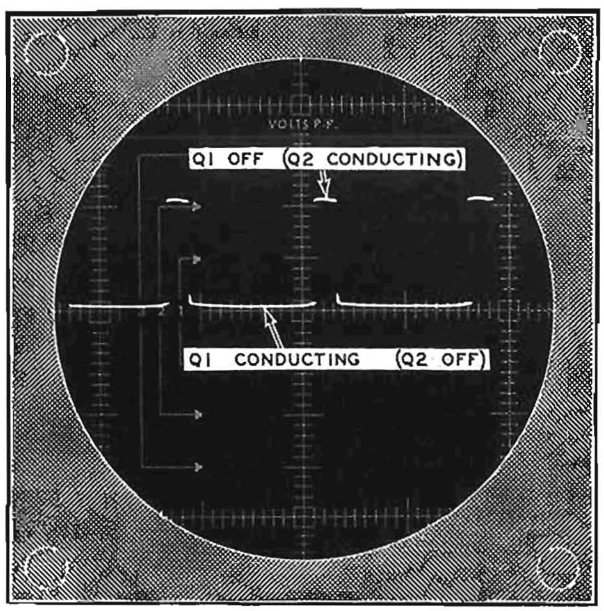


Figure 4-44

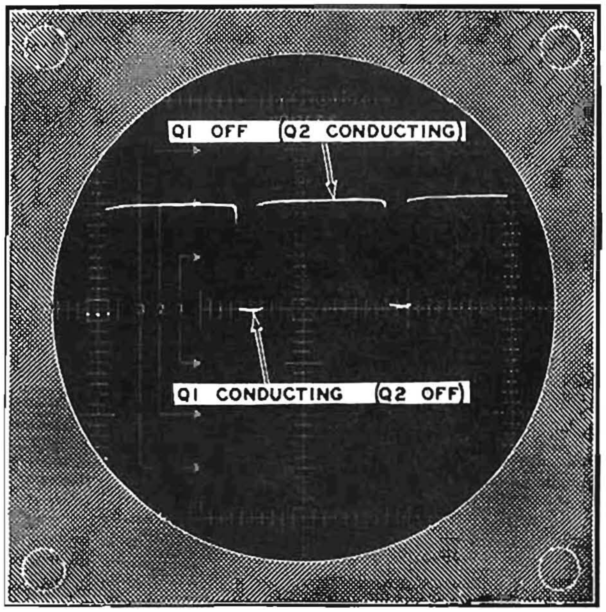


Figure 4-45

Now Q1 will be made to fire for a longer time by increasing the capacitance of C2.

( ) Replace the .001 μfd capacitor from lug 4 of terminal strip D to lug 2 of terminal strip B with a .1 μfd capacitor.

( ) Adjust the oscilloscope for the proper trace. This change will again change the frequency.

The resulting waveform now should look like the one in Figure 4-45. These waveforms (Figures 4-43, 4-44 and 4-45) are the waveforms present at point B, the collector of Q2.

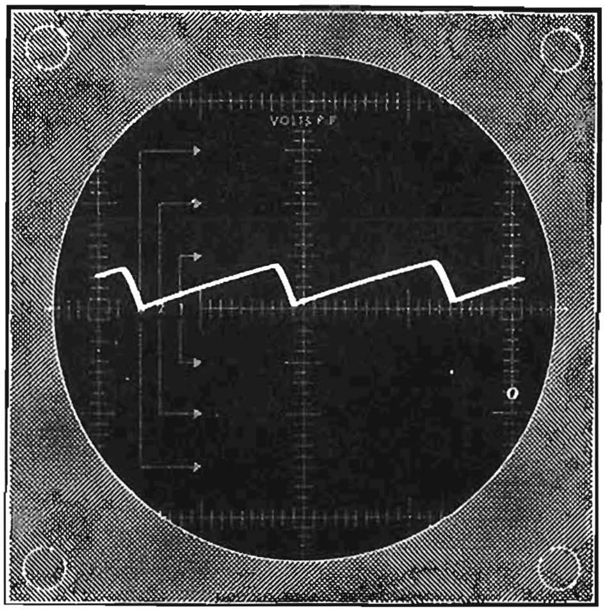


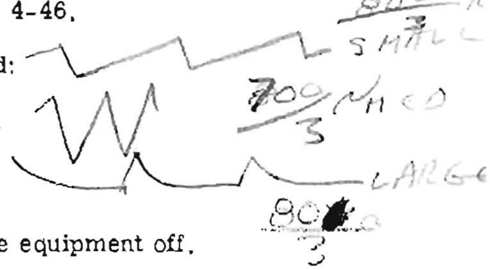
Figure 4-46A

The next step is to look at the change in the sawtooth for each of the conditions of conduction of Q1. This is done by changing the 6" wire probe to point G, lug 3 of terminal strip E. Use each of the capacitors, .001, .01, and .1 for C2. The sawtooth waveforms that you should see are shown in Figure 4-46.

(A) For .001 μfd:

(B) For .01 μfd:

(C) For .1 μfd:



( ) Now turn the equipment off.

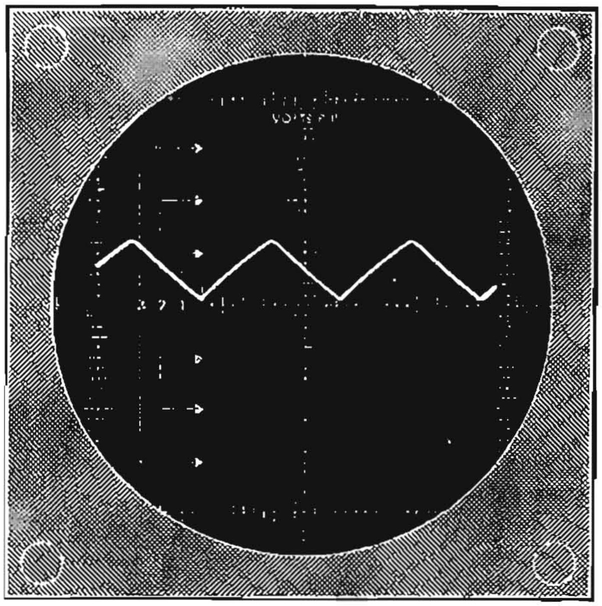


Figure 4-46B

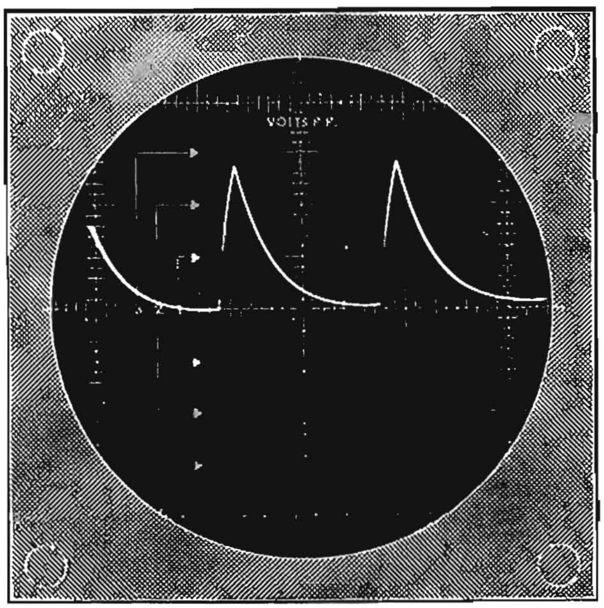


Figure 4-46C

The different forms of sawtooth are not all suitable for a linear sweep. Part B of Figure 4-46 shows the symmetrical waveform where the retrace would be as long as the sweep. Part C shows a waveform that is not linear.

The three capacitors also demonstrate how the frequency of a sawtooth may be varied. The larger the value of capacitance, the lower the frequency.

SUMMARY

A sweep circuit provides the horizontal signal for the CRT. When applied at right angles to the test signal, it produces a two-dimensional waveform on the screen of the CRT. A linear sawtooth waveform produces the linear time base.

A multivibrator circuit produces a square wave. When this waveform is applied to a resistor-capacitor combination, a sawtooth wave is formed. If the pulses are equal, the multivibrator is symmetrical. If the pulses are not equal the multivibrator is asymmetrical. The multivibrators used in oscilloscopes are asymmetrical.

The return sweep is removed from the screen by a process called blanking. This is accomplished by making the cathode of the CRT more positive with respect to the control grid during retrace.

Sweeps other than the linear sawtooth are also used. The 60 cycle line sweep is the more common of the nonlinear sweeps.

CHAPTER 4

Amplifiers

Oscilloscopes have amplifiers to increase signal amplitude before the signal is applied to the horizontal or vertical plates of the CRT. A signal of comparatively high amplitude is required at the plates of the CRT to obtain a useful deflection.

The amplifiers must be able to handle a very wide range of frequencies equally well. They must reproduce a waveform in the same shape as applied to the inputs of the oscilloscope. Finally, proper phase relationships must stay the same. That is, a positive pulse must appear in an upward direction, and a negative pulse in a downward direction.

This chapter shows features of oscilloscope amplifiers that produce the desired sensitivity without distorting or inverting the test signal. Each refinement added to the circuit increases the cost of the oscilloscope, so, compromises must often be made.

The first part of the chapter discusses features that vertical and horizontal amplifiers have in common. The last part of the chapter shows how they differ.

Frequency Response

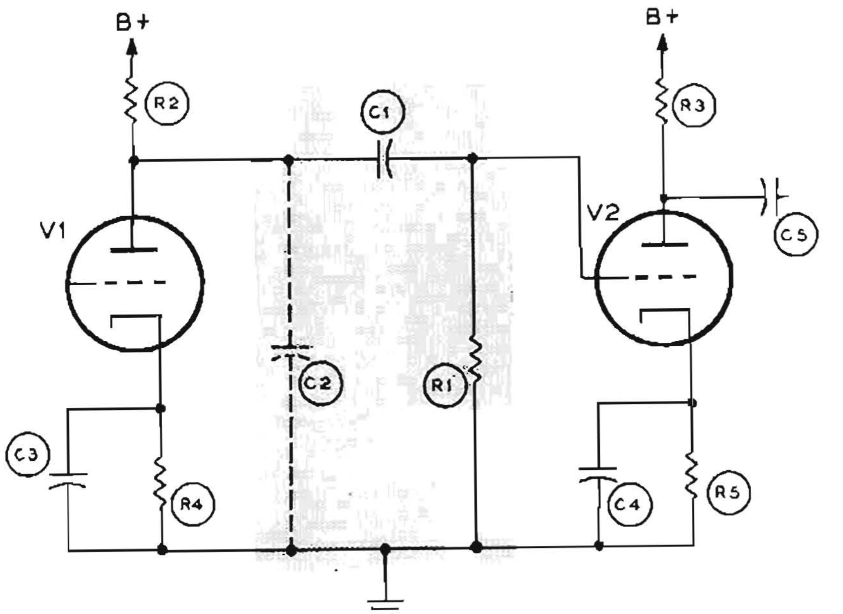
General purpose oscilloscopes are required to handle a wide range of frequencies. The width of the frequency coverage may be as high as 5 mc. Some laboratory oscilloscopes may go as high as 100 mc. The frequency range of hi-fi amplifiers is very limited in comparison to that of amplifiers in oscilloscopes.

The power absorbed by the CRT deflection plates is so small that it is usually disregarded. Because of this, resistance coupled type amplifiers are used. They are relatively low-cost construction and are reasonably easy to compensate for low-and-high frequency response.

Figure 4-47 shows a typical RC coupled amplifier. C2 represents the sum of all the stray capacitance in the circuit (between wires, tube elements and chassis ground). The shaded area covers the coupling elements that are involved.

As the frequency decreases, the capacitive reactance of C1 increases. For very low frequencies this reactance may be much greater than the resistance of R1. In this event, the

Figure 4-47



circuit of C1 and R1 act like a voltage divider, where the voltage across R1 is only a small part of the total voltage output of tube V1. For good response at low frequencies, C1 is made as large as possible.

As the frequency becomes very high, the stray capacitance represented by C2 becomes an important factor. At high frequencies the capacitive reactance becomes very low. This is like putting a small resistor between the plate and ground. The gain of an amplifier falls off at high frequencies because of this shunting effect. To maintain high frequency response, the amplification is boosted to offset the decrease in high frequency response caused by the stray shunt capacitance. This may be done in many ways. Figure 4-48 shows one way; by adding an inductance in series with the plate load. This in effect shunts the tube. At low frequencies, the inductance offers low resistance. As the frequency starts to become very high and the shunt capacitance becomes critical, the inductor, called a peaking coil, increases the plate load, thus offsetting the loss in gain. This extends the frequency range. Figure 4-49 represents in graphic form what the peaking coil adds to the frequency response.

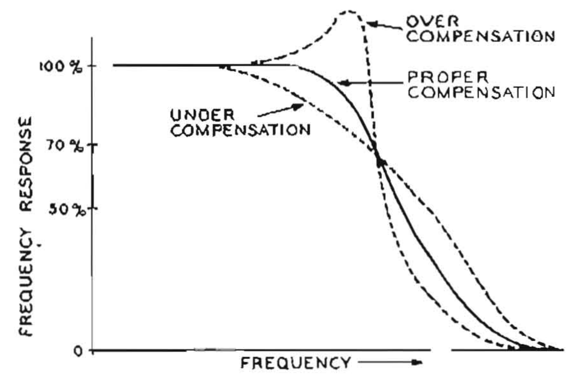


Figure 4-49

In Figure 4-48, capacitors C3 and C4 in the cathode circuits also help to increase the high frequency response. As the frequency increases, the impedance of C3 and C4 decreases. As the frequency of the signal increases, the decreasing cathode impedance causes greater gain in the tube.

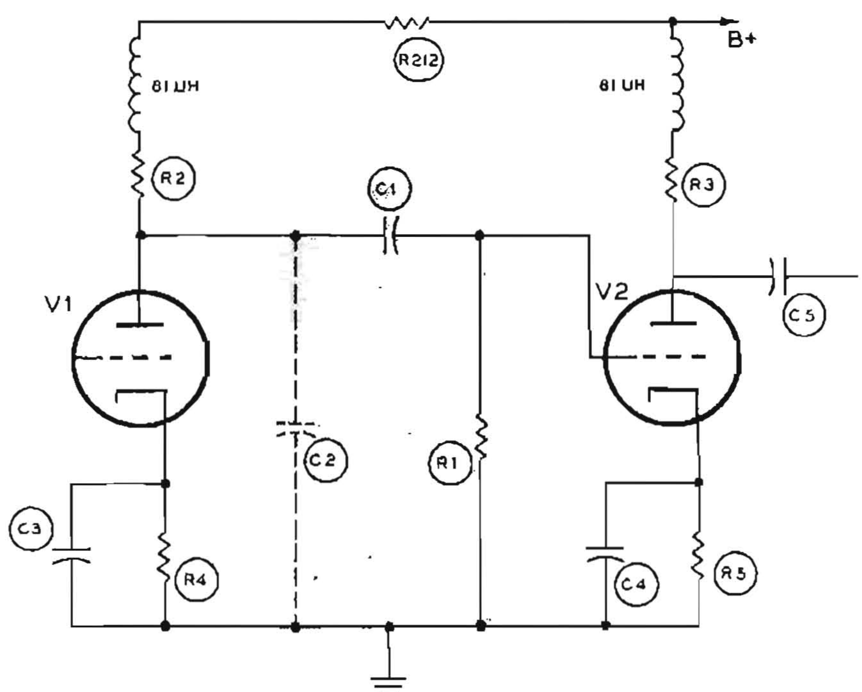


Figure 4-48

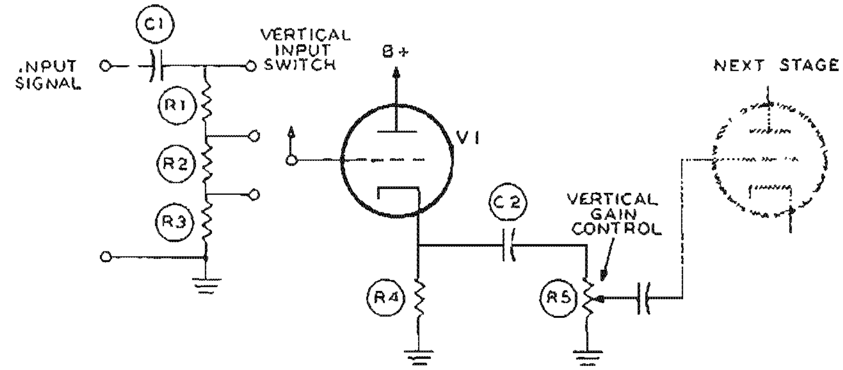


Figure 4-50

The Amplifier Input Stage

The input stage of an amplifier also poses frequency response problems. The input section must control the signal level and it must also have a wide frequency response. The signal level can be controlled by a voltage dividing network, and flat frequency response can be achieved by using a frequency compensation network.

The voltage dividing network that controls the input signal level is usually composed of two sections. The first section is a switching arrangement called the input attenuator (vertical input switch, see Figure 4-50). It is used to divide the input signal into small steps. By changing the switch position, a larger or smaller portion of the input signal is selected and coupled to the amplifier.

The second section of this dividing network is usually a potentiometer (vertical gain control, R5 in Figure 4-50). This control receives the selected portion of the input signal from the attenuator (through V1 - see next paragraph) and divides it further. Here at R5, a smooth continuous variation of the signal can be made, before the signal is coupled from the arm of the control to the vertical amplifier.

Stage V1, called a cathode follower, is used to separate these two sections. It has a high input impedance (it appears to the input as if a very large resistance were at the grid of the tube), thus keeping the input circuit of the oscilloscope from loading down (or drawing current from) the circuit under test. The cathode follower also has a low output impedance (the output from the cathode of the tube appears as if it were coming from a very low resistance); this helps maintain a high frequency response. The signal is not amplified in the cathode follower.

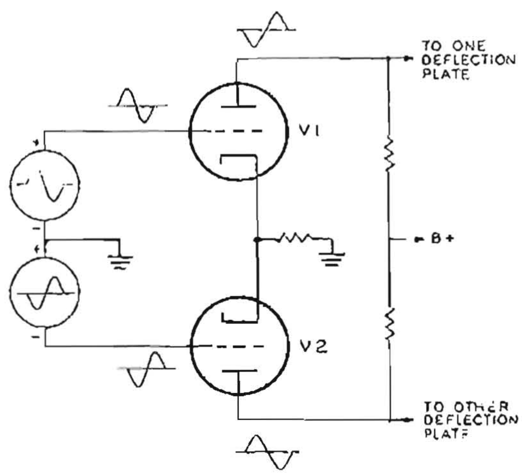


Figure 4-51

Push-Pull

Even many economical oscilloscopes use push-pull (balanced deflection) amplifiers in the final output stage before the CRT deflection plates. High precision oscilloscopes use push-pull amplifiers in all amplifier stages because of their advantages. Figure 4-51 shows two identical tubes connected in push-pull. The grid of each tube is fed the same signal, but the signal at one grid is inverted from the signal at the other. V1 and V2 each amplify the signal. The output of the tubes acts like two batteries in series; that is, the two outputs add. 20 volts applied to one deflection plate and 20 volts added to the other deflection plate would have the same effect as 40 volts applied to the deflection plates from a single-ended (one tube output stage) amplifier.

The reasons for using push-pull are many. Push-pull establishes a balanced condition between the deflection plates. The voltage variation between plates is such that as one increases, the other plate decreases a like amount. In a single-ended amplifier, only one plate varies in voltage from its original value. Push-pull output provides twice the signal voltage compared to that of one tube with the same supply voltage. With push-pull output, the average deflection plate voltage stays constant, since one plate is always decreasing while the other is increasing; thus the beam acceleration and the focusing of the beam stay more constant than they would in a single-ended amplifier.

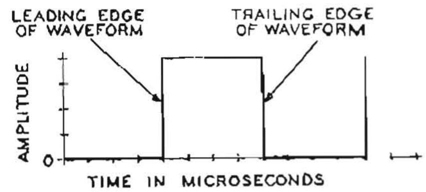


Figure 4-52

Rise Time

The time that it takes for an amplifier to respond to the sharp leading edge or trailing edge of a signal is called its rise time. For example, if a square wave is applied to an amplifier, there is a very rapid change in the waveform. Figure 4-52 shows a typical square wave. Time is plotted along the base in microseconds; 1,000,000 microseconds (μ sec) equals 1 second. The voltage is zero one instant and maximum the next. However, it takes a short period of time for an amplifier to respond to a change of no conduction to maximum conduction. When the oscilloscope is sweeping at high frequencies, the total length of time for a sweep may be long enough for a distortion to appear in the waveform. In Figure 4-51 an example of this effect is illustrated. The time from 10% of the total amplitude to 90% of the total amplitude is the rise time. A smaller rise time indicates a better high frequency response in the amplifier.

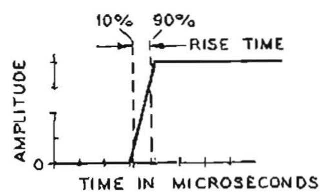


Figure 4-53

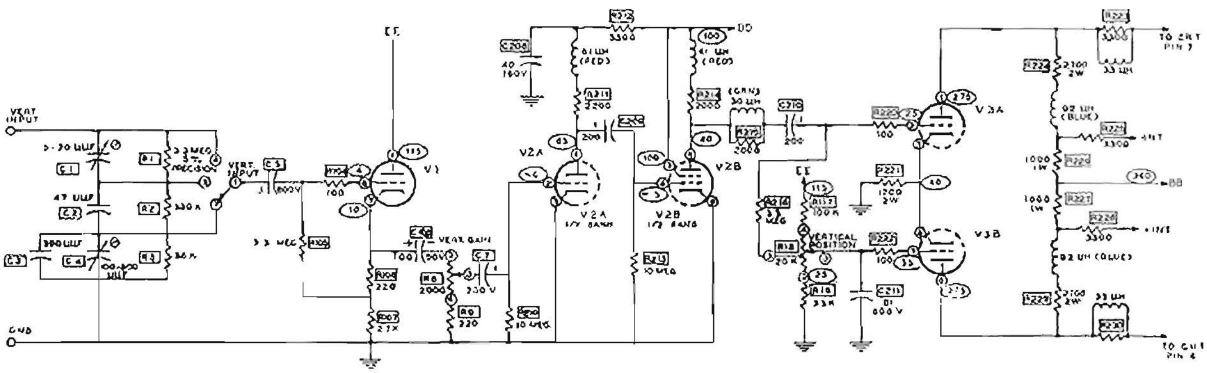


Figure 4-54

This concludes the discussion of common features of oscilloscope amplifiers. The next two sections discuss areas in which oscilloscope amplifiers differ. Two amplifiers, one for the vertical plates and one for the horizontal plates of an actual general purpose oscilloscope, will be compared. You should also compare the circuits of your oscilloscope to these amplifiers.

The Vertical Amplifier

The vertical amplifier is shown in Figure 4-54. The signal enters from the left, is amplified, and is passed on to the deflection plates at the right. This circuit has three levels of attenuation at the input stage. Notice the shunt capacitors, C1, C2, C3, and C4, that are used as frequency compensators. V1 is used as a cathode follower. The vertical gain control, a continuously variable attenuator, is coupled to the grid of V2A. Tubes V2A and V2B serve as two stages of amplification before the push-pull circuit. The push-pull section uses a twin triode.

Several peaking coils are used in this circuit to improve high frequency response. For example, notice the 61 μh peaking coils in the plate circuits of V2A and V2B. R18 serves as the vertical position potentiometer. Vertical positioning is accomplished by adjusting the DC voltage on the grid of V3B.

The Horizontal Amplifier

Figure 4-55 shows a horizontal amplifier. The chief function of the horizontal amplifier is to amplify the sweep voltage. Since this amplifier does not have to amplify as wide a range of frequencies (only the sweep frequencies) as the vertical amplifier it has a much simpler circuit. This circuit does not have a switched attenuator before the cathode follower circuit (the circuit employing V6A). R52 serves as the variable gain control. There is one less stage of amplification before the push-pull output stage since this amplifier usually requires less sensitivity than the vertical amplifier. Because of the decreased need for a wide frequency response, it also has less frequency compensation. For example this horizontal amplifier does not contain peaking coils. R55 serves as the horizontal position control in the same manner as in the vertical amplifier.

EXPERIMENT 4-4

Of all the requirements of an amplifier, none are more important than the ability of an amplifier to handle waveforms without changing their appearance. The purpose of this experiment is to give some experience in simple circuits and how they affect the characteristics of a waveform.

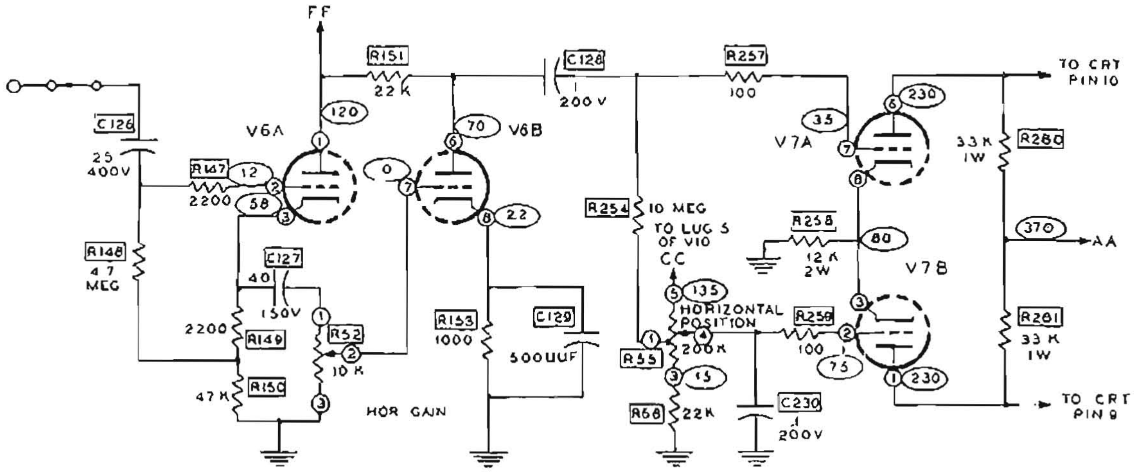


Figure 4-55

The signal source will be the multivibrator used in the chapter on sweep circuitry. Three simple circuits are used to illustrate the changes that can be made in a waveform.

The multivibrator produces a waveform that is almost a square wave. While it may not be good enough for test purposes, it should be sufficient to illustrate a principle.

The square wave is a series of sine waves. This combination is made up of a fundamental frequency and odd multiples of that frequency. If your multivibrator oscillates at 800 cycles/sec., then a perfect square wave will consist of 800, 2400, 4000, 5600, 7200, etc. If the corners of your multivibrator square waveform are rounded off, this means some of the higher odd multiples are missing. Figure 4-56 shows some of the ways a square wave can be distorted.

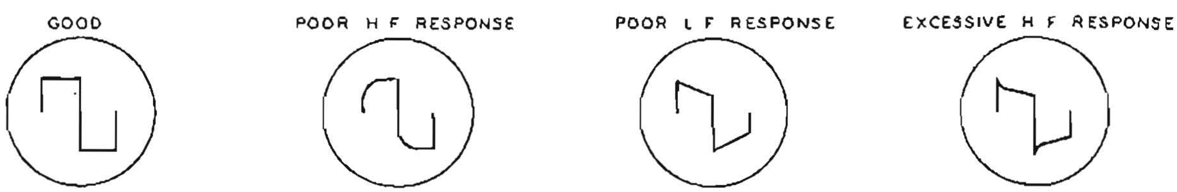


Figure 4-56

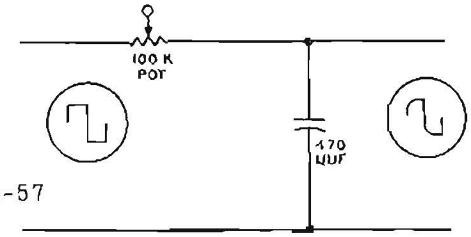


Figure 4-57

The first circuit will illustrate how high frequencies can be attenuated. The circuit in Figure 4-57 is much like the circuit in a RC coupling network. The 470 μμf capacitor acts like the stray capacitance discussed earlier.

( ) Connect a .01 μfd capacitor from lug 4 of terminal strip D to lug 2 of terminal strip B.

( ) Connect a 470 μμf capacitor from lug 3 of terminal strip A to lug 1 of terminal strip D.

( ) Connect a 3" wire from lug 3 of terminal strip C to lug 1 of terminal strip A.

( ) Connect one end of the 6" wire from lug 1 of terminal strip E to lug 3 of terminal strip A.

( ) Turn on the oscilloscope and test chassis. Adjust the oscilloscope for three cycles.

Notice the change in the square waveforms. Figure 4-58 shows how your waveform should now look.

( ) Remove the 6" wire from lug 3 of terminal strip A.

( ) Remove the 470 μμf capacitor from lug 3 of terminal strip A to lug 1 of terminal strip D, and replace it with a 330 KΩ (orange-orange-yellow) resistor.

( ) Remove one end of the 3" wire from lug 3 of terminal strip C.

( ) Connect a .001 μfd capacitor from lug 3 of terminal strip C to lug 3 of terminal strip A.

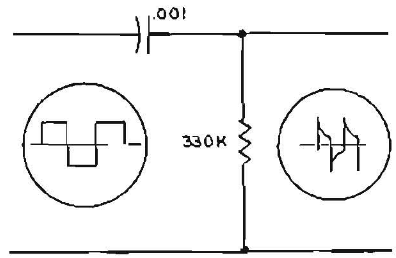


Figure 4-59

( ) Connect the 6" wire from lug 1 of terminal strip E to lug 3 of terminal strip A.

The circuit has now been changed to look like that in Figure 4-59. Figure 4-60 shows a photograph of what you should see on your oscilloscope screen. The medium and low frequencies are now attenuated.

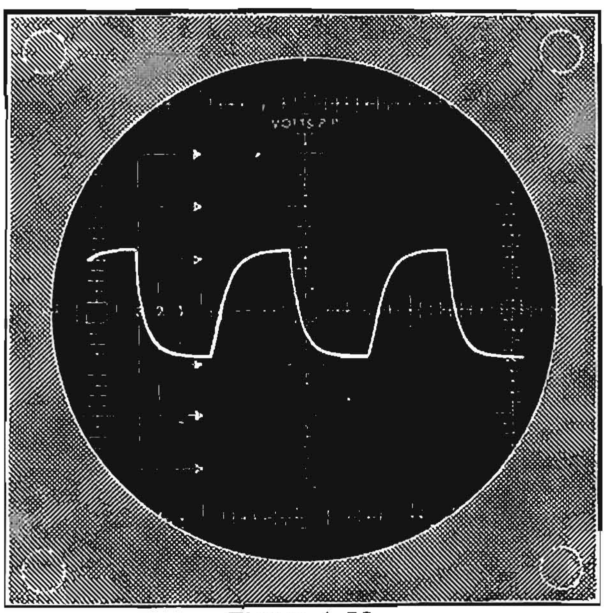


Figure 4-58

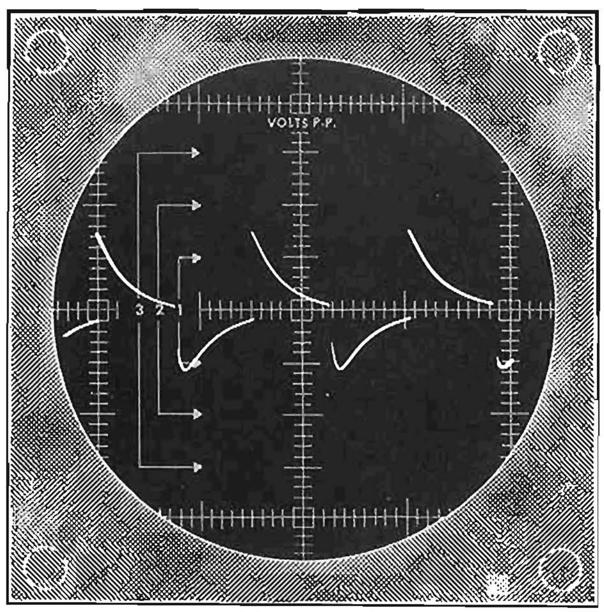


Figure 4-60

( ) Remove the 6" wire from lug 3 of terminal strip A.

( ) Change the lead of the 330 KΩ (orange-orange-yellow) resistor from lug 1 of terminal strip D to lug 3 of terminal strip C.

( ) Connect a 33 KΩ (orange-orange-orange) resistor from lug 3 of terminal strip A to lug 1 of terminal strip D.

( ) Connect the 6" wire from lug 1 of terminal strip E to lug 3 of terminal strip A. Then observe the waveform.

The circuit is now as shown in Figure 4-61. This circuit permits the excessively high frequencies to pass, while attenuating the low frequencies.

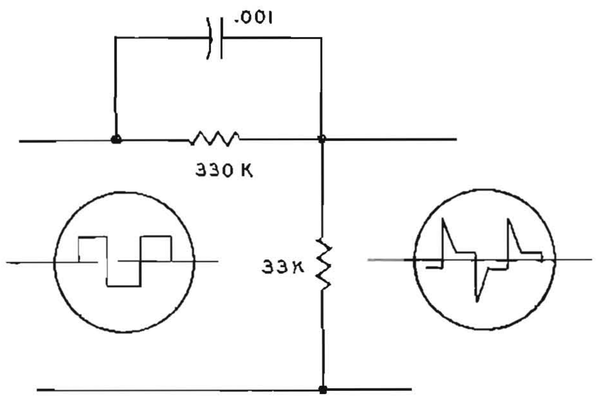


Figure 4-61

Figure 4-62 shows a picture of the waveform that you should see.

( ) Now turn off the equipment.

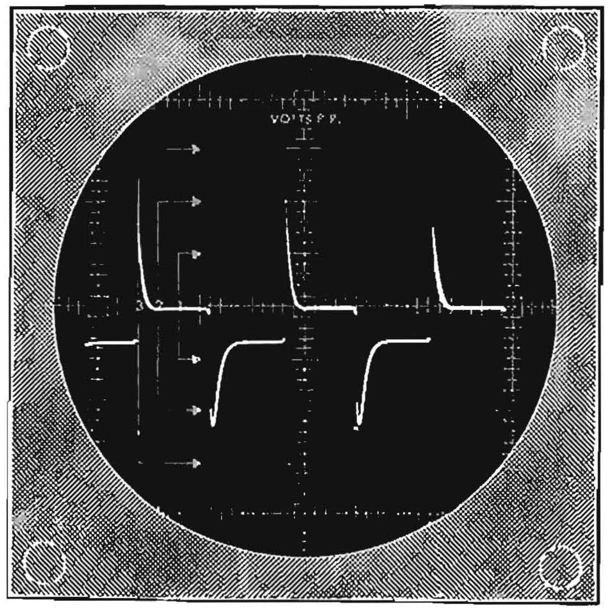


Figure 4-62

SUMMARY

Amplifiers increase the signal amplitude before the signal is applied to the deflection plates of the CRT. Oscilloscope amplifiers must be able to operate over a very wide range of frequencies. Frequency response characteristics are aided by large coupling capacitors, peaking coils, and shunting capacitors in attenuation networks and the cathode circuits.

Attenuation usually is accomplished in two stages. The first, step attenuation, is separated from the second, continuous attenuation, by a cathode follower circuit. The high impedance input of the cathode follower circuit prevents oscilloscopes from changing the characteristics of the circuit under test.

The push-pull amplifier is used in oscilloscopes, especially in the output stages, because of better linearity and lower operating voltages.

Rise time refers to the time it takes for an amplifier to respond to a change in signal. A short rise time generally indicates a high performance amplifier.

CHAPTER 5

Synchronization

Synchronization circuits are used to hold the frequency of the horizontal sweep signal to the exact frequency, or to an exact fraction of the frequency of the input test signal. This causes the beam of the CRT to start at exactly the same point on the input signal each time it sweeps across the screen. Thus, the signal appears stationary on the screen, and does not appear to be moving to the right or to the left.

A moving waveform is very difficult to study. The fine frequency control could be constantly adjusted to synchronize the sweep and input waveforms, but this would be impractical since it would require the operator's constant time and attention, and the result still would not be satisfactory.

A thorough knowledge of the operation of the horizontal tube type multivibrator is needed before you can understand how it can be synchronized. The following paragraphs explain the operation of a typical circuit of this type.

Tube Multivibrator Operation

The modes of operation of the tube type and transistor type multivibrators are quite similar. Therefore, it might be helpful for you to refer back to Chapter 3 at this time to refresh your memory on how a transistor multivibrator operates.

Figure 4-64 shows a simplified drawing of a typical oscilloscope multivibrator circuit. Although this is a different type of multivibrator, it operates in the same manner as the multivibrator you studied in Chapter 3. Tubes V4 and V5 alternately turn on and off. While V4 is conducting, V5 will turn off; while V5 is conducting, V4 is turned off. V5 conducts for a short period of time, V4 conducts for a longer period of time.

1. When V5 conducts, it charges sawtooth-forming capacitor C17. C17 quickly charges up until the voltage at the cathode of V5 begins to become more positive than the voltage at its grid. This begins the rapid chain of events that quickly cause V4 to conduct and V5 to be cut off. C17 then begins to discharge slowly through R48 and R47.

2. When V5 turns off, its plate voltage increases to the full B+ supply voltage, causing C115 to begin to charge through R140. The current flow through R140 then causes a positive voltage to appear on the grid of V4, and V4 begins to conduct.

3. V4 continues to conduct until it is turned off again by a negative-going voltage at its grid, as described in the next step.

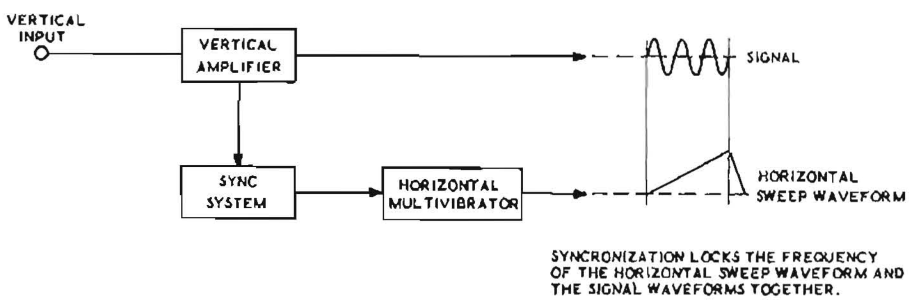


Figure 4-63

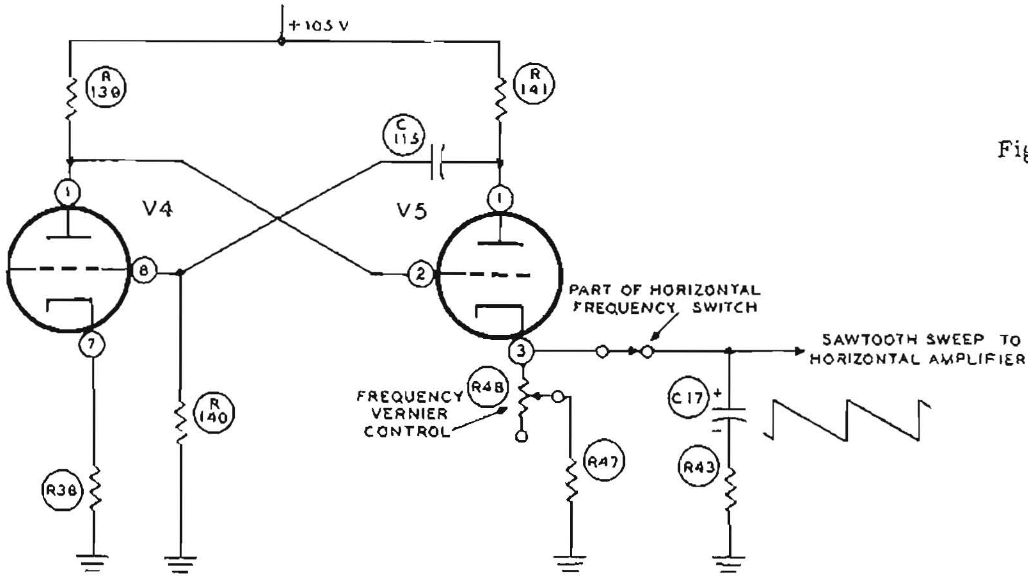


Figure 4-64

4. When sawtooth-forming capacitor C17 is discharged sufficiently through R47 and R48, the voltage at the cathode of V5 becomes less positive than the grid, and V5 begins to conduct again. The plate voltage of V5 then becomes less positive, causing C115 to begin to discharge through R140.

5. The discharge of C115 through R140 puts a negative voltage on the grid of V4; this turns V4 off. The circuit is now ready to begin the cycle all over again, starting with Step 1.

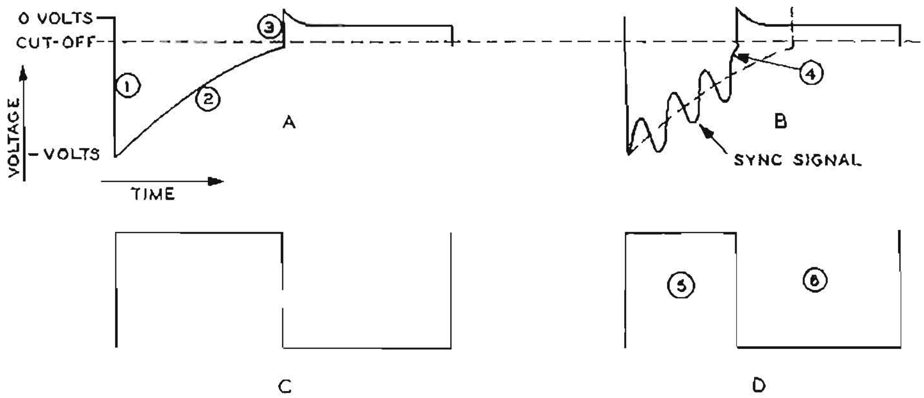
The time, and therefore the frequency, of the horizontal sweep waveform depends on how long it takes capacitor C17 to discharge. When frequency vernier control R48 is set to provide a larger resistance, C17 discharges more slowly, causing the sweep frequency to be lowered. When frequency vernier control R48 is set to provide a smaller resistance, C17 discharges more quickly, causing the sweep frequency to become higher.

Larger changes in the horizontal sweep frequency are made by substituting larger and smaller capacitors for C17 with the horizontal frequency selector switch. The larger capacitor, since it holds a much larger charge; takes longer to discharge.

Synchronizing the Horizontal Multivibrator

In the circuit of Figure 4-64, V5 was turned on and off by the voltage at its cathode. It could also be turned on and off by adjusting the voltage at its grid which is tied directly to the plate of V4.

Figure 4-65



The following paragraphs will explain in detail how synchronization is accomplished.

Part A of Figure 4-65 shows what the waveform at the grid of V5 looks like. (An actual circuit would have a more asymmetrical waveform; this waveform has been shown symmetrical here. When C17 first begins to discharge; the grid of V5 becomes highly negative (1) with respect to its cathode, and V5 is cut off. This negative voltage gradually becomes less negative (2) as C17 discharges, until the cutoff voltage is reached. When the cutoff voltage is reached (3) V5 begins to conduct again and recharge C17, and the second half of the cycle begins. The square wave that is produced at the plate of V5 is shown by Part C of Figure 4-65.

In the synchronizing process, a controlling signal is introduced into the multivibrator. This controlling signal continuously adjusts the multivibrator frequency, in small amounts, to keep the horizontal frequency exactly the same as, or an exact fraction of, the frequency of the input test signal. This keeps the two frequencies locked together, so that small changes in frequency do not make a test signal move to the right or left on the screen.

Usually a small portion of the test signal is connected to the multivibrator for the synchronizing or "sync" signal. In this case, the sync signal is coupled through V4 to the grid of V5. Part B of Figure 4-65 shows the grid waveform of Part A with the sync signal added to it.

Note that each cycle of the sync signal first adds to and then subtracts from the voltage at (2), as that voltage gradually becomes less negative. Finally, at (4), the sync signal reaches the cutoff voltage and causes V5 to begin to conduct. Observe that it has caused V5 to conduct much sooner than it would have without the sync signal, as shown by the dotted line.

The square wave produced by waveform B is shown by Part D of Figure 4-65. Notice that the left side of the square wave is much smaller now than it was in waveform C. This causes one complete cycle of the square wave, (5) and (6), to occur in less time than before, which means that it has increased in frequency, thus increasing the horizontal sweep frequency.

Each successive cycle of the horizontal multivibrator would be started in the same manner, thus the frequency is locked to an exact fraction of the frequency of the input signal.

Types of Synchronization

Figure 4-66 shows a block diagram of a complete sync system. There are three sources from which sync signals are normally obtained: from the vertical amplifier; from a 60 cycle AC (line) voltage of the power transformer; or from the external sync binding post on the front panel of the oscilloscope.

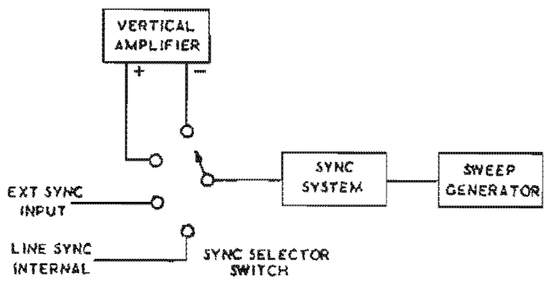


Figure 4-66

Some oscilloscopes provide both positive and negative sync from the vertical amplifier. This allows you to synchronize the waveform so that either the positive or negative half of the input signal is seen first on the CRT. This is often useful when a close examination of one-half of the waveform is desired. It is also used in those cases where a pulse of voltage goes only in the positive or negative direction from zero.

External sync is accomplished by connecting a lead directly from the circuit being tested to the external sync binding post. This type of synchronization could be used in servicing a radio or amplifier with a generator. By connecting the generator to the radio and also to the external sync of the oscilloscope, the operator could check the waveform in many parts of the set, at varying amplitudes, without having to readjust the sync.

Line sync is often used to check waveforms that are multiples in frequency of the 60 cycle line frequency.

Many oscilloscopes also have a sync amplitude control that adjusts the amplitude of the sync that is coupled to the horizontal multivibrator. Before this control is adjusted, the horizontal frequency (frequency vernier) control should be adjusted for approximate synchronization. Then, set the sync amplitude control so that only enough sync amplitude is used to hold the test pattern stationary on the CRT. If too much sync signal is applied, it will cause the sweep voltage to be distorted.

A Complete Sync System

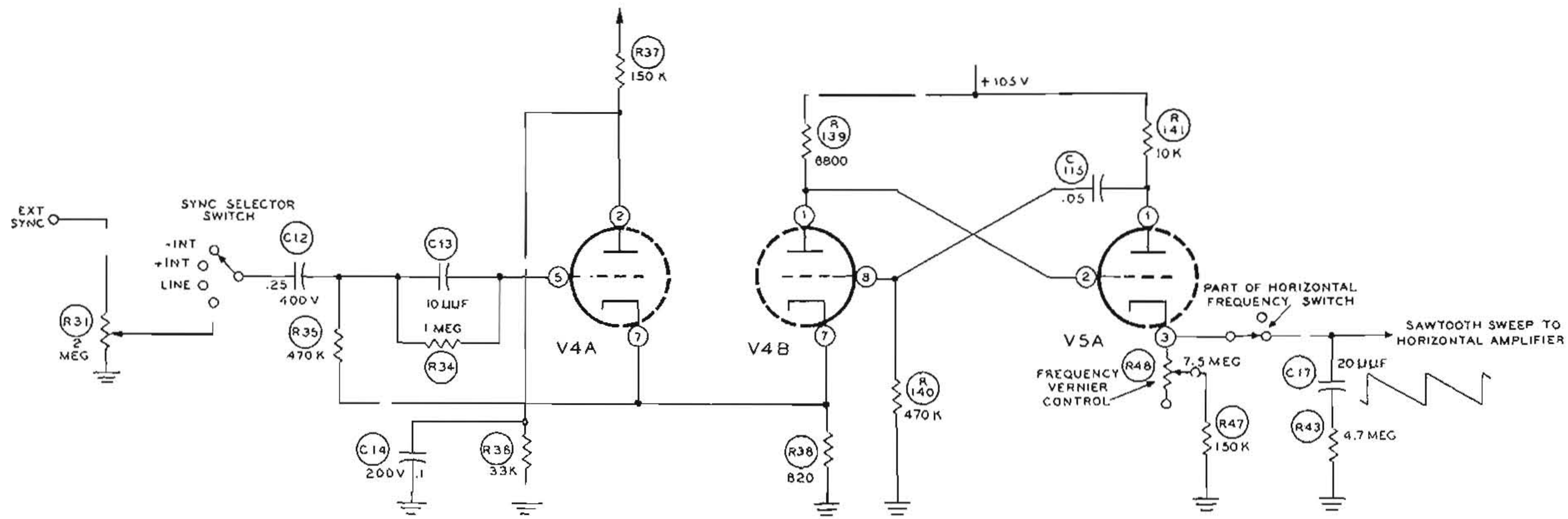
Figure 4-67 shows the complete sync system of a typical oscilloscope connected to the horizontal multivibrator circuit. The type of sync is selected by a sync selector switch. Looking at the main schematic, Figure 4-67, will show you that the +INT and -INT sync signals are obtained from the plate circuits of the push-pull vertical output stage. The line sync is obtained from the filament winding of the power transformer.

The sync signal is coupled from the selector switch to the limiter stage circuit of V4A. A limiter stage is needed to hold the sync signal to a constant level with wide variations in input level, to make sure it does not overdrive and distort the horizontal multivibrator signal.

The same cathode resistor is used for V4A and V4B. This is the point in this circuit where the sync signal and the horizontal multivibrator signals are combined.

V4A is a cathode follower circuit which has its output limited to a very small signal by: a very low plate voltage to voltage divider R36-R37; and resistor R34 in series with its grid. The low plate voltage causes negative pulses to cut off the tube while the amplitude of the pulses are quite small. This causes only a small negative pulse to appear at the output. Resistor R34 limits positive pulses by causing the grid to become blocked, thus these pulses too are limited to a small amplitude at the output.

Synchronization in this circuit is accomplished by connecting the sync signal to the cathode of the multivibrator instead of to its grid. The principles of synchronization are still the same as explained previously. The plate voltage of V4 turns V5 on and off. The multivibrator waveform, as at the grid, is combined with the sync signal at the cathode of V4A, resulting in synchronization.



EXT SYNC
SYNC SELECTOR SWITCH
-INT
+INT
LINE
R31
2 MEG
C12
.25
400 V
R35
470 K
C13
10 UUF
1 MEG
R34
C14
200V
.1
R36
33K
R37
150 K
V4A
V4B
R38
820
+105 V
R 139
6800
R 140
470 K
C 115
.05
R 141
10 K
V5A
PART OF HORIZONTAL FREQUENCY SWITCH
SAWTOOTH SWEEP TO HORIZONTAL AMPLIFIER
FREQUENCY VERNIER CONTROL
R48
7.5 MEG
R47
150 K
C17
20 UUF
R43
4.7 MEG

Figure 4-67

EXPERIMENT 4-5

The purpose of this experiment is to review the material in Part IV and to prepare for Part V. You will do this by identifying circuit elements and tracing out circuits in your oscilloscope. If you have a schematic of your circuit, place it on a wall over your work bench for easy reference. If you do not have your schematic, a circuit schematic, Figure 4-68 and identification pictures of components, Figures 4-69 and 4-70, of a general purpose oscilloscope are provided as a guide to typical circuit components and their location.

To perform this experiment it will be necessary for you to remove the oscilloscope from its cabinet. Oscilloscopes use high voltages which are dangerous if proper precautions are not followed. First, before any attempt is made to remove the cabinet, be sure the line cord is removed from the wall socket. Second, be sure that the various control lugs are not touched while removing the oscilloscope from its cabinet. Many of these controls are connected to the high voltage power supply. A good example of this is the intensity control. Figure 4-71 shows a good way to remove the oscilloscope from its cabinet.

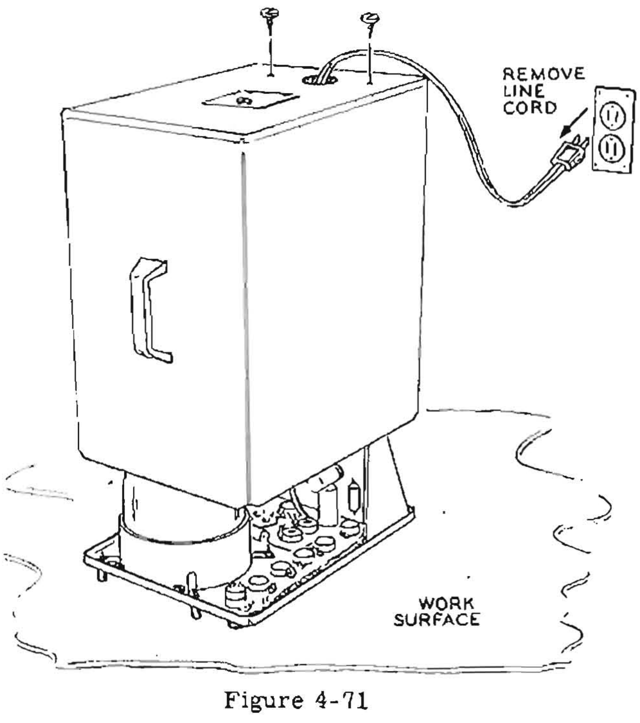


Figure 4-71

After the cabinet has been removed, the filter capacitors should be discharged with an insulated screwdriver. Figure 4-72 shows their physical appearance and the method for shorting them out. Be sure to do this before working on the chassis.

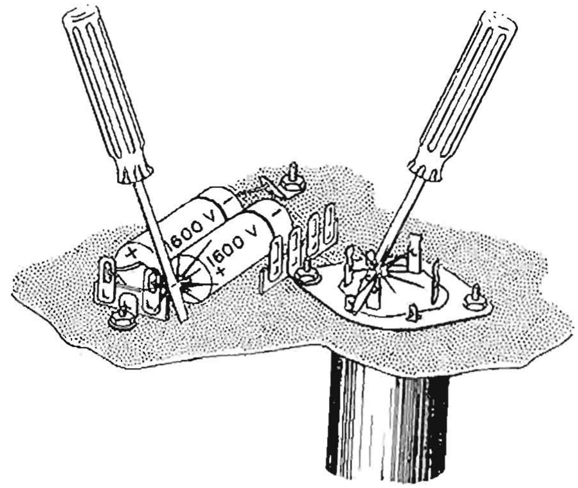
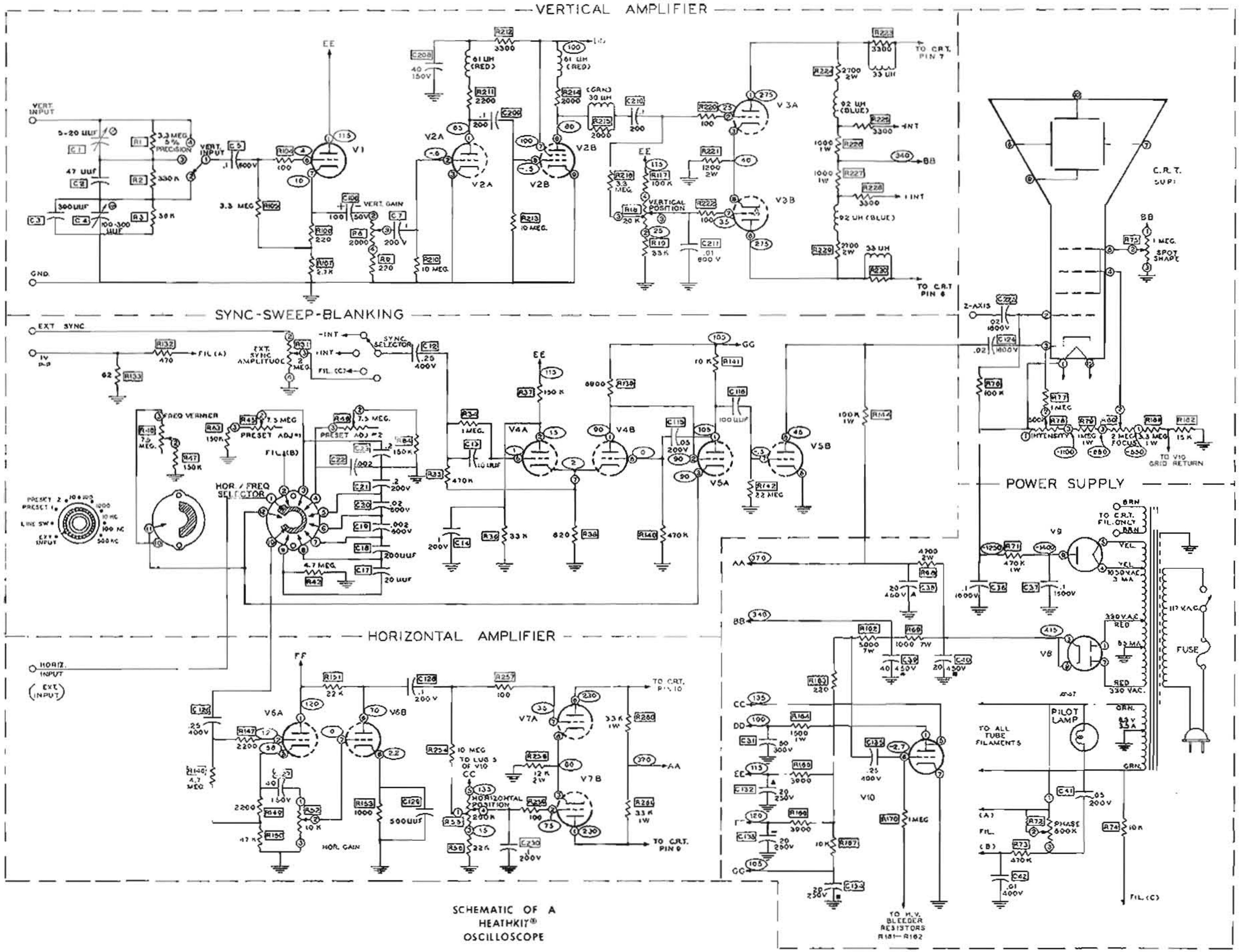


Figure 4-72

The next step is to trace out the more important circuits, identify the major circuit elements, and locate them both on the circuit diagram and on your oscilloscope. Below is a check list of parts and circuits to be used as a guide. Your oscilloscope may not have all the items listed.

The Cathode Ray Tube

( ) CRT
( ) Bulb of CRT
( ) Neck of CRT
( ) Base pins of CRT
( ) Aquadag of CRT
( ) Electron gun of CRT (if visible)
( ) Z - axis input
( ) Post accelerator input of CRT
( ) Connections to vertical plates
( ) Spot control
( ) Focus control
( ) Intensity control
( ) Connections to horizontal plates



SCHEMATIC OF A
HEATHKIT®
OSCILLOSCOPE

Figure 4-68

Power Supply

( ) Power transformer
( ) Fuse
( ) Primary transformer leads
( ) Line switch
( ) HV filament leads
( ) LV filament leads
( ) CRT filament leads
( ) B+ power leads
( ) HV rectifier tube
( ) LV rectifier tube
( ) HV filter section
( ) LV filter section
( ) Voltage regulator tube
( ) HV voltage dividing network

Sweep Circuit

( ) Multivibrator tubes (may be in one envelope)
( ) RC time base circuits
( ) Blanking amplifier tube

Amplifiers

( ) Vertical input attenuation circuits
( ) Horizontal input attenuation circuit
( ) Vertical amplifier tubes
( ) Horizontal amplifier tubes
( ) Peaking coils
( ) Centering controls

Synchronization

( ) Sync limiter circuit
( ) Internal sync circuit

SUMMARY

Synchronization "locks-in-step" the input signal and the sweep signal. The stimulus for synchronization comes from outside the sweep circuit. It usually comes from the amplified input signal in the vertical amplifier.

A sync voltage causes one tube of the multivibrator to change the time of conduction. Increasing the length of time of conduction decreases the sweep frequency. Decreasing the the length of conduction increases the sweep frequency.

An insufficient sync voltage prevents synchronization, too large a voltage distorts the input signal pattern. Many scopes have a sync limiter circuit to avoid pattern distortion.

Several types of synchronizing signals are usually available in a scope: Internal Sync; 60 cps Line Sync; External Sync. Internal sync usually comes from the vertical amplifier. Line sync comes from the power transformer. External sync, which comes from a post on the front panel of the scope, allows you to use synchronizing signals directly from circuits outside the oscilloscope.

An external sync amplitude control is provided to attenuate an external sync voltage. If the external sync voltage is insufficient for synchronization, an external amplifier would have to be used to increase the sync voltage.

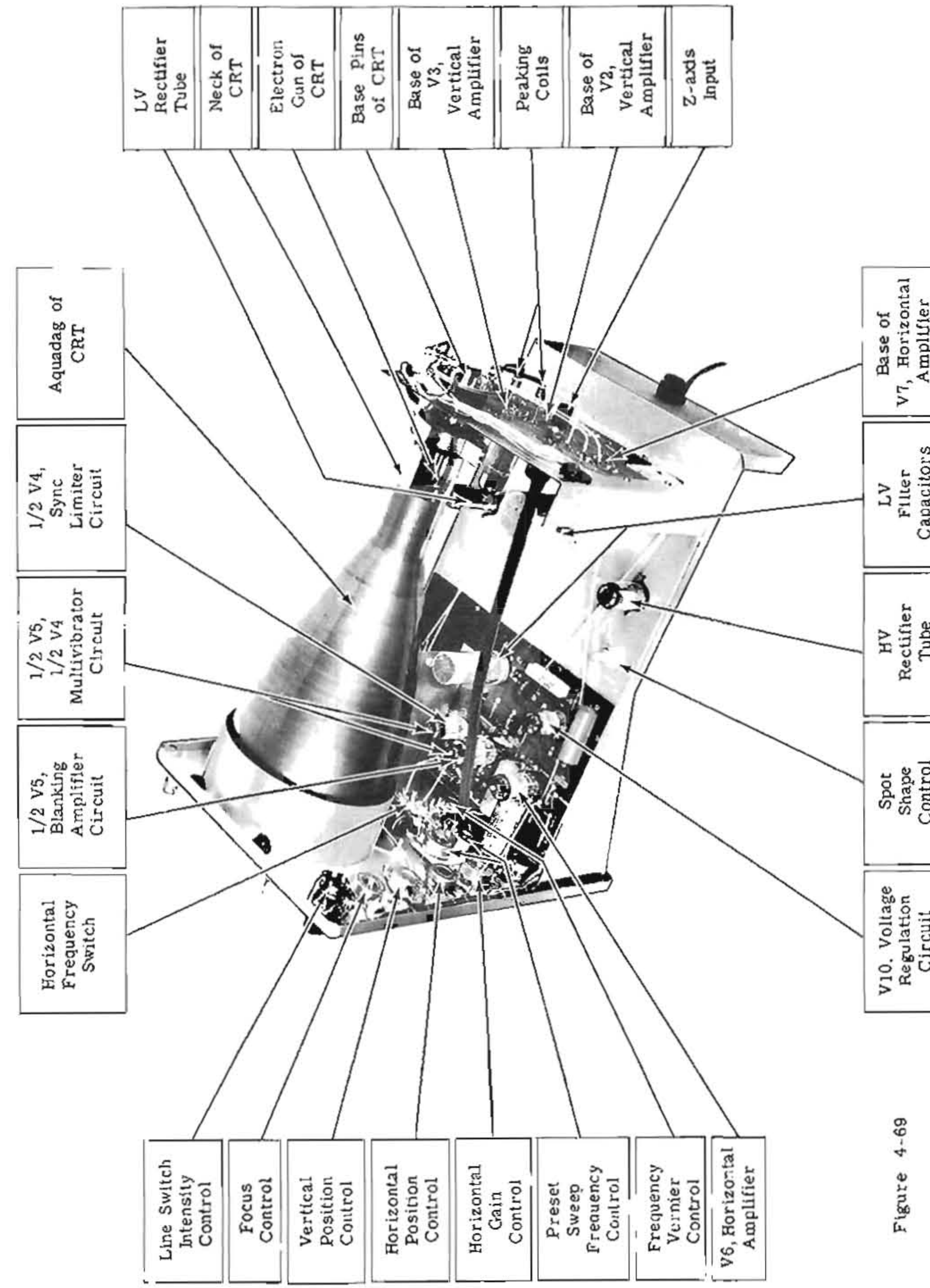


Figure 4-69

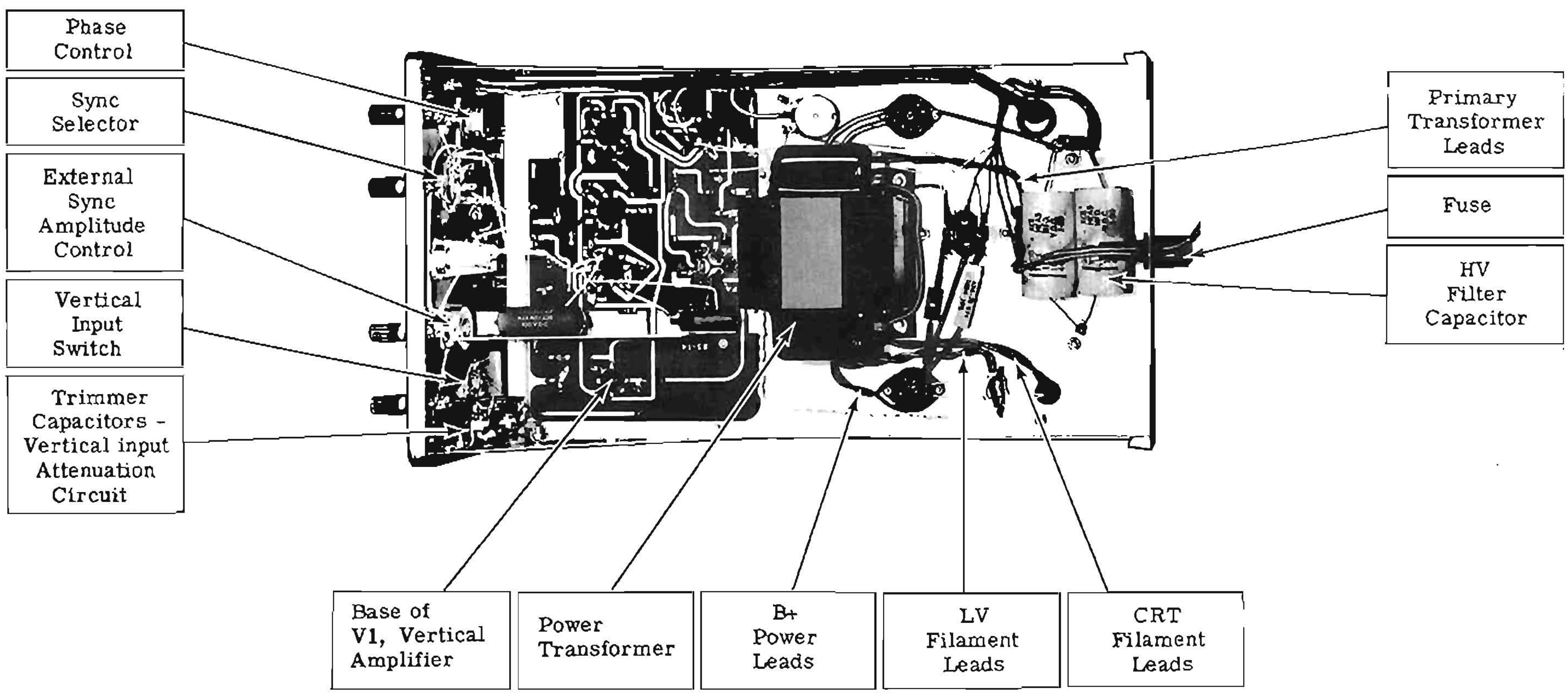

Phase Control
Sync Selector
External Sync Amplitude Control
Vertical Input Switch
Trimmer Capacitors - Vertical input Attenuation Circuit
Primary Transformer Leads
Fuse
HV Filter Capacitor
Base of V1, Vertical Amplifier
Power Transformer
B+ Power Leads
LV Filament Leads
CRT Filament Leads

Figure 4-70

PART V

Oscilloscope Maintenance

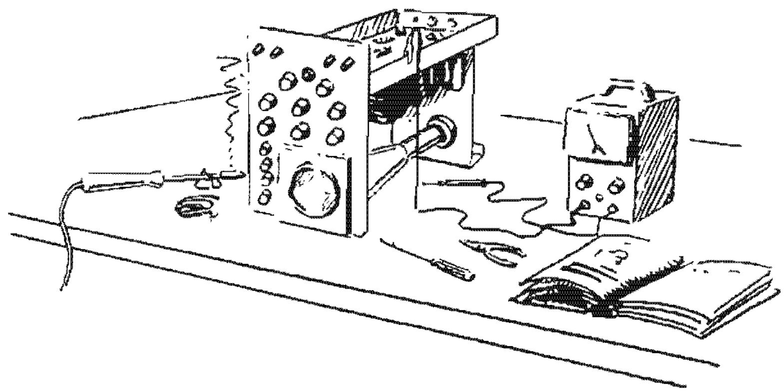


Figure 5-1

Maintenance of your oscilloscope may be divided into two sections: routine maintenance, and troubleshooting and repair. Since very little routine maintenance is needed in oscilloscopes, the majority of this material will show you how to troubleshoot and repair a malfunctioning oscilloscope.

Generally, routine maintenance means that you should periodically adjust the internal controls of your oscilloscope. Refer to the instruction manual furnished with your oscilloscope. Steady, dependable performance will be obtained if these instructions are followed faithfully.

If your oscilloscope has a blower for cooling purposes, the filter for the blower should be cleaned at regular intervals. Otherwise, the oscilloscope is likely to overheat, causing premature parts failure.

Part V will describe how you should go about troubleshooting and repairing a faulty oscilloscope. A number of sample difficulties that might occur will be given, along with some specific examples of possible troubles that might occur.

CHAPTER 1

Troubleshooting - General Principles

HOW TO TROUBLESHOOT

Troubleshooting an oscilloscope, or any electronic device for that matter, means to search through it to find out why it is not operating properly. This search to find the cause of the trouble is like a detective trying to solve a crime. The trouble can most often be found by the clues you get from the symptoms indicated in the circuits and shown on the cathode ray tube.

Study these symptoms carefully. They could lead you directly to the cause of the difficulty without extensive, time-consuming circuit checks.

Finding your difficulty can be divided into two general parts. The first part includes the visual checks, where you try to find the trouble by looking for visible difficulties; that is, difficulties that can be seen by carefully looking over the parts and wires. In the second part of the troubleshooting process, you use your knowledge of how the circuit operates to find the general area of the trouble. Then you locate the faulty part itself, using other electronic test equipment such as a voltmeter or another oscilloscope.

Visual Checks

All troubleshooting usually begins by unplugging the line cord and removing the oscilloscope from its cabinet and placing it on your workbench. Begin the visual checks by inspecting the oscilloscope carefully, checking all wires and parts. Look for any sign of burned parts, broken wires, broken switches, etc. If you have built the oscilloscope yourself from a kit, carefully recheck your wiring against the wiring instructions given in the kit assembly manual. Often having someone else look at the instructions with you will prove helpful, as they will frequently notice something that you have consistently overlooked. The soldered connections should also be checked carefully.

Whenever you work on your oscilloscope with its cabinet removed, observe normal safety precautions to avoid electrical shock. High voltage is normally present at several points in an oscilloscope.

Next, plug in the oscilloscope and turn it on. Observe the resistors and capacitors carefully for any signs of overheating. If a part appears to be overheating, turn the unit off immediately. The next step is not only to replace any overheated parts, but also to find out the cause of the part failures and to remedy this cause. This can be done by replacing the parts and making resistance checks with an ohmmeter to eliminate any short circuits that might be present. It will also be helpful to use the following troubleshooting information.

Check to make sure that the filaments of all tubes are lit. The tubes can be checked by testing them in a tube checker or by substituting good tubes of the same types. If your oscilloscope has a large number of tubes, it may be better to refer to the next section, "Looking for Clues," before checking the tubes.

CAUTION: Handle all cathode ray tubes very carefully. These tubes have been highly evacuated; if the envelope should be broken, the resulting implosion could spray the area with shattered glass and possibly cause serious consequences. Avoid handling the tube while wearing diamond rings which might scratch the glass. Do not strike the glass envelope with tools and do not subject it to impact or shock.

Looking for Clues

Before you can begin to look for clues, you must have a thorough knowledge of how an oscilloscope operates. Only by knowing how all of the different circuits operate normally, can you determine when and where they are operating abnormally. Refer to the instruction manual for your instrument and the oscilloscope theory in Part IV of this manual to refresh your memory on the operation of any section of an oscilloscope.

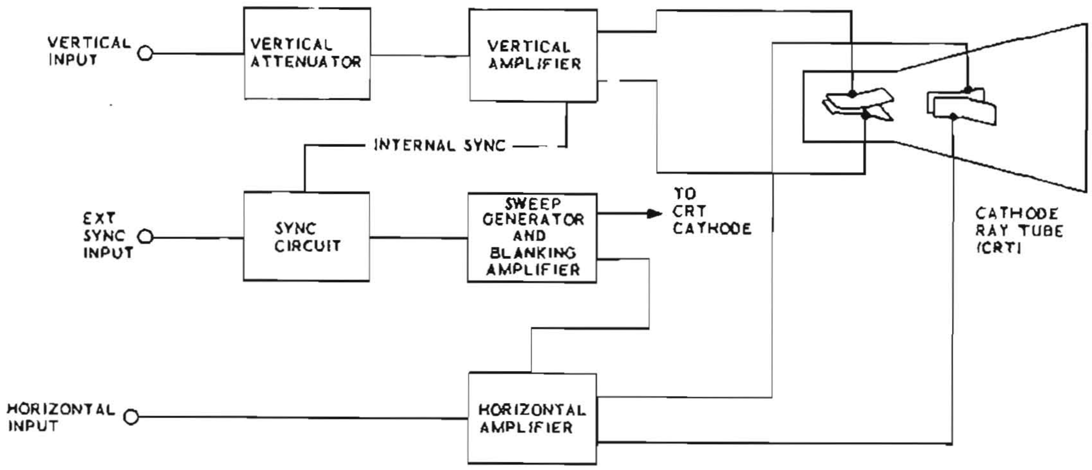


Figure 5-2

Make sure the front panel controls are set properly, then study the indication you get on the cathode ray tube of your oscilloscope. Use this information to try to localize the trouble to some particular area. A block diagram, such as the one shown in Figure 5-2, will be quite useful for this purpose. The following examples show how trouble can be localized.

EXAMPLE 1. When a signal is applied to the oscilloscope, and only a vertical line (See Figure 5-3) appears on the cathode ray tube. This indicates that the difficulty is in either the sweep circuits or the horizontal amplifiers.

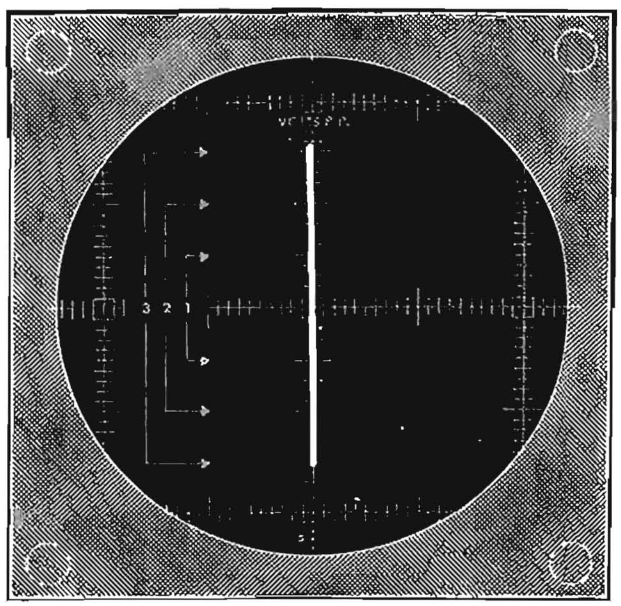


Figure 5-3

EXAMPLE 2. When a signal is applied to the oscilloscope, one cycle of the waveform is considerably wider on one side of the CRT than one cycle is on the other side. See Figure 5-4. This would indicate non-linear horizontal sweep; some part of the sweep circuit is not working properly.

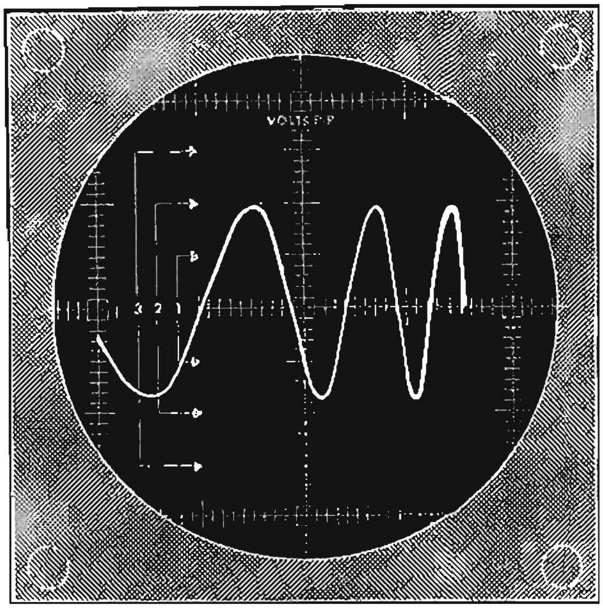


Figure 5-4

EXAMPLE 3. When a signal is applied to the oscilloscope, there is no vertical deflection at all. See Figure 5-5. This would indicate a fault in the vertical amplifier circuits.

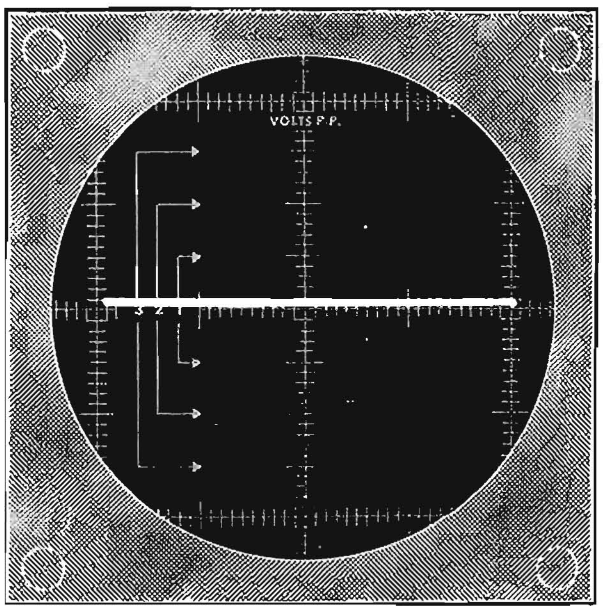


Figure 5-5

The next step after the difficulty has been localized to some particular area, is to check the voltages in the questionable area against the voltages listed in the manual for your oscilloscope. It is also useful to use another oscilloscope to check for correct waveforms in questionable areas. Normally, voltages may vary plus or minus 10% from the voltage indicated.

If improper voltages or waveforms are found, check the values of the parts in that area, either by substituting new parts, or with an ohmmeter or capacitor tester. This should lead you to the faulty part or parts.

CIRCUIT BOARD TECHNIQUES

Troubleshooting circuit boards requires some techniques different from those used to troubleshoot the circuits on a normal metal chassis. Probably one of the most confusing things about circuit boards is to try to trace circuit connections on the circuit board.

To trace connections, shine a strong light on the component side of the circuit board; then, when you study the other side of the board you can trace the foils, and each part mounted on the board will show up as a dark shadow. The connections and tube sockets can be used for landmarks, or reference points, to trace the circuit and find out how parts are connected.

To check for breaks in the foil, shine the light on the foil side and look at the component side of the circuit board.

Faulty solder connections are a common source of difficulty on circuit boards. Check the solder connections over carefully to make sure they look like the proper solder connections shown in Figure 5-6. Make sure that large globs of solder do not bridge between two adjacent foils, shorting them out.

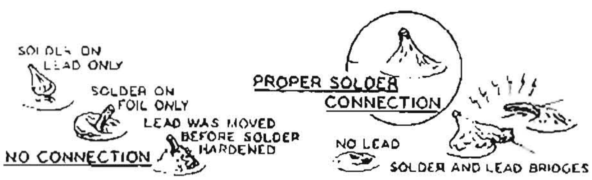


Figure 5-6

When parts are being replaced on a circuit board, make sure that mounting holes are open and clean before the new components are installed. Holes that become plugged can be cleaned by heating the area immediately over the hole while gently pushing the lead of a resistor through the hole from the opposite side. Withdraw the lead before the solder rehardens. Do not force the lead through; too much pressure, before the solder has time to soften, can separate the foil from the board.

If solder is bridged across the insulating area between conductors, it can be cleaned off by heating the connection carefully and quickly wiping or brushing the solder away with a soft cloth or small brush.

In cases where the foil becomes damaged, repairs can usually be made with little difficulty. A break in the foil can be rejoined by soldering a small piece of bare wire across the gap, or between the foil and the lead of a component. Hairline breaks, which sometimes occur, can usually be repaired by bridging them with a small amount of solder.

It is much easier to remove large parts from a circuit board if the leads or lugs are all cut off with diagonal cutters. Then each lead or lug can be unsoldered from the board, one at a time.

TROUBLESHOOTING EXAMPLES

EXAMPLE 1 - NO SPOT

There are a number of possible reasons why no spot (or line) appears on the oscilloscope. The trouble is either from a faulty CRT, no high voltage, an incorrect voltage on the cathode or grids of the cathode ray tube, or from an incorrect voltage in the horizontal or vertical output amplifiers which has pulled the spot so far off to one side that it cannot be seen on the screen.

The first checks to be made in this case are visual ones: To look for any obvious malfunctions such as burned parts, and to check the tubes to make sure that the filaments are lit.

The next step is to remove the low voltage rectifier tube and turn on the oscilloscope. If a spot appears, the trouble is in either the vertical or horizontal amplifier. (When the low voltage power supply is disabled, the beam can no longer be pulled off the face of the cathode ray tube.)

If replacing the low voltage rectifier and removing the horizontal output tubes does not cause a spot to appear on the cathode ray tube, the horizontal amplifiers are not pulling the spot off the screen, and the fault is most likely in the vertical amplifiers.

EXAMPLE 2 - NO HORIZONTAL SWEEP

The search for difficulty in this case also starts with visual checks. If nothing abnormal is seen during the visual check, the next step is to check the horizontal amplifier. Place the horizontal frequency selector in the horizontal input position and connect a sine-wave voltage to the horizontal input posts. If a horizontal sweep appears, the horizontal amplifier is operating properly and the difficulty is in the horizontal oscillator sweep generator circuit.

CHAPTER 2

Internal Adjustments

Vertical Attenuator Adjustments

In most oscilloscopes the vertical input connects directly to the vertical attenuator circuit. Here the input signal is accurately divided into smaller voltages. This circuit is used for a coarse adjustment of the vertical amplitude of the input signal. From the attenuator, the signal is connected through the switch to the vertical amplifier.

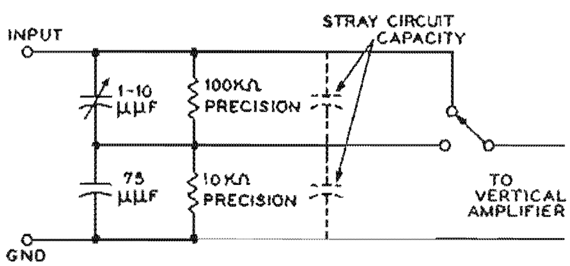


Figure 5-7

Figure 5-7 is a simplified drawing of a vertical attenuator circuit. The precision resistors divide the input signal so that either the full signal or a portion of the signal can be selected by the switch. These resistors divide the signal satisfactorily at lower frequencies, but at higher frequencies stray circuit capacities, shown by the dotted capacitors in Figure 5-7, begin to bypass some of the input signal, making the divider steps inaccurate. To overcome this inaccuracy, the fixed capacitor and trimmer capacitor are added to the circuit. These capacitors are so much larger than the stray capacities, that the stray capacities no longer affect the circuit. The trimmer capacitor that has been added must then be adjusted to compensate for the individual stray capacities of each oscilloscope.

Figure 5-8 shows what happens when the vertical attenuator trimmer capacitor is adjusted. At the center of the figure is a response curve that shows the desired response in the circuit, and also shows what happens when too much or too little capacity is present.

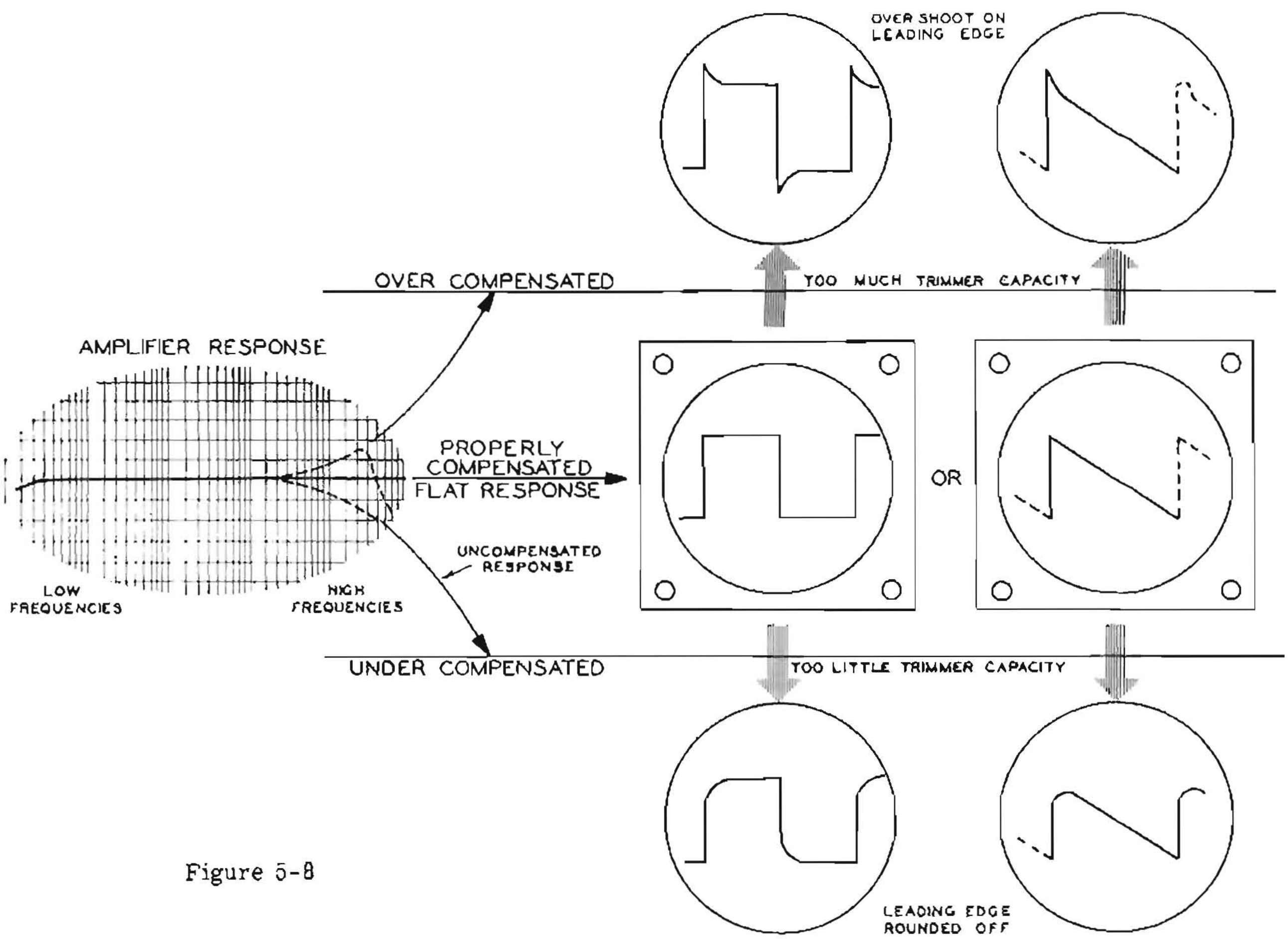


Figure 5-8

An ideal waveform for adjusting this attenuator is the square wave, shown in Figure 5-8. If this square wave were connected to the input of the oscilloscope, and the trimmer were adjusted to the correct point, the leading edge of the waveform would be square as shown by the solid line. If the trimmer capacitor were adjusted to have too little capacity, the high frequency response would fall off, and the leading edge of the square wave would be rounded off. In this case the circuit would be said to be "under compensated."

In the other case, if the trimmer capacitor had too much capacity, the response of the circuit would increase at higher frequencies, and the leading edge of the square wave would tend to overshoot as shown. This condition is called "overcompensation."

In oscilloscopes, the attenuator circuit can also be adjusted using the sawtooth waveform of the oscilloscope itself. In this case, the waveforms would look like the sawtooth waveforms in Figure 5-8, except that only the diagonal part of the line would be seen on the oscilloscope.

Other Adjustments

Since there are so many different types of oscilloscopes, it would be impossible to describe all the internal adjustments on all of them. In general, you must refer to the manual received with your oscilloscope for correct instructions on making adjustments.

An exception to the above rule would be those cases where a control that is generally a front panel control has been made an internal adjustment. An example of a control of this nature would be the spot shape control found in some oscilloscopes. This control, also called an astigmatism control, is often located on the front panel; it is adjusted to make the spot in the center of the screen as round as possible. In some oscilloscopes, to make the front panel as simple as possible, the focus control is also located on the chassis, instead of on the front panel.

Do's and Don'ts

DON'T leave a bright stationary spot on the screen; in time this would burn away some of the phosphor on the screen.

DON'T connect very high voltages to the oscilloscope inputs without using a high voltage probe. The signal input plus any DC voltage present should not exceed the voltage rating of the AC input blocking capacitor. This voltage rating is usually 600 volts.

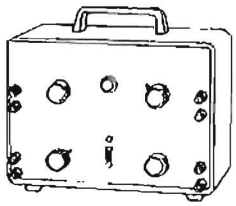
DON'T overload the vertical amplifier of the oscilloscope with too large a signal, or the signal display on the CRT will be distorted. Reduce the amplitude, using the vertical attenuator switch and the vertical gain control.

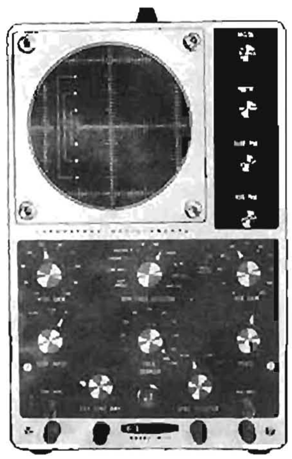
DO use the proper signal input probes. Although the input impedance is high and the input capacitance is low in modern oscilloscopes, many circuits can be loaded down by the input of the oscilloscope when it is connected into the circuit. When necessary, use the correct probe with your oscilloscope to prevent adverse effects in the circuit being checked.

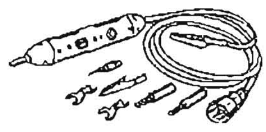
DO use plenty of grounding straps when using the oscilloscope for alignment purposes. Check the need for additional grounds by touching the chassis of the unit being aligned with your hand. Keep the other hand in your pocket. If the response changes, shift the ground connection or add more connections until the response does not change when the chassis is touched.

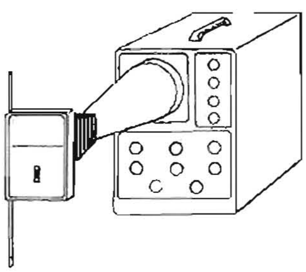
PART VI

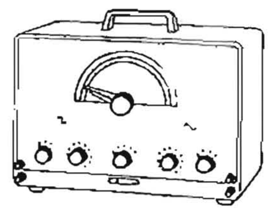
Oscilloscope Applications











You have spent many hours examining the interior and exterior of your oscilloscope; you have learned the proper display of waveforms, and you have performed basic measurements with the oscilloscope. Now is the time to apply your understanding of the oscilloscope to some of the many uses for which it was designed.

In Part VI you will find information and techniques about: waveform measurements; accessories for the oscilloscope; special types of scopes; servicing; audio equipment; amateur radio; photography of oscilloscope waveforms; and teaching applications. The purpose of this material is to make you aware of the many possible applications, and to stimulate you to use your oscilloscope effectively.

Make the best use of your oscilloscope by using it constantly. The oscilloscope is a rugged and durable test apparatus. Its many controls help you make it more versatile. Let the oscilloscope work for you.

Increase your familiarity of the oscilloscope and knowledge of other circuits by observing waveforms from common electronic equipment. Observe waveforms in the different sections of your AM or FM radio, hi fi equipment, or test equipment in normal operation. This will help you to see new uses for the oscilloscope and to learn how these circuits function. You will be able to troubleshoot this equipment later if trouble develops. It is much easier to recognize faulty waveforms if you know what the right waveforms look like.

You will find it helpful to review some of the previous material in Part II and Part IV where it applies to the procedures in this chapter. For example; Experiment 3-3, Chapter 3 of Part III, and the Introduction To Part IV will be helpful for "Calibrating the Oscilloscope as a Voltmeter."

CHAPTER 1

Waveform Measurements

Valid conclusions of circuit testing with an oscilloscope depend on your correct interpretation of the waveforms. The purpose of this chapter is to examine different waveform measurements. This includes measuring voltages, frequency, phase shift, polarity, and time. Some of the measurements may seem difficult the first time you try them. But, if you study the procedure carefully and learn to make these measurements, the value of your oscilloscope to you will be increased greatly.

Calibrating the Oscilloscope with a Voltmeter

AC voltage scales on most voltmeters are calibrated to measure only sine waves of voltage correctly. A peak-to-peak voltage scale will measure other waveforms, but this will often be inaccurate if the waveform is distorted. An oscilloscope, however, can be used to measure the peak-to-peak value of almost any type of waveform, while it shows the actual waveform on the cathode ray tube.

Figure 6-2 shows a method that can be used to calibrate an oscilloscope to read voltages. Connect a source of undistorted sine waves of AC voltage, and an AC voltmeter, to the vertical input of the oscilloscope.

Adjust the AC calibrating voltage so the meter shows a voltage that is somewhat larger than the largest voltage you expect to measure. You must determine the peak-to-peak value of this voltage. Do this either by reading this value directly from the peak-to-peak meter scale or by using the regular AC voltage scale of a meter and multiplying the reading by 2.82; this will convert it to peak-to-peak voltage.

Adjust the oscilloscope so the sine wave is positioned exactly across a group of the grid lines that run horizontally on the screen. See Figure 6-3. These lines can then be used to indicate the amount of voltage in the test waveforms you connect to the oscilloscope. This completes the calibrating procedure of the oscilloscope.

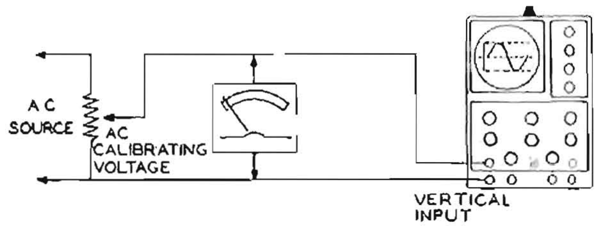


Figure 6-2

The following example shows how the above procedure could be used. See Figure 6-3.

The waveforms to be measured in this example are between 1 volt and 18 volts, so use a peak-to-peak calibrating voltage of 20 volts. First adjust the AC source until the peak-to-peak meter indicates 20 volts. (If you read this voltage on the regular AC voltage range of the meter, you will have to adjust the AC source to an amount of voltage, that when multiplied by 2.82, will equal 20 volts. 20 volts divided by 2.82 is equal to 7.08. Therefore, you will read 7.08 volts on the regular range of the meter.)

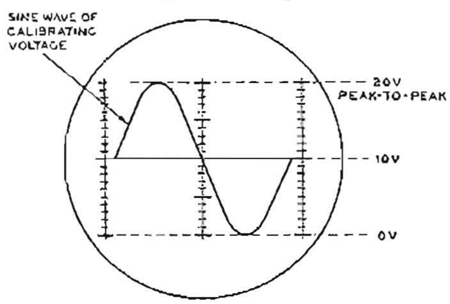


Figure 6-3

Next adjust the vertical controls of the oscilloscope so this 20 volts peak-to-peak sine wave extends vertically for twenty units on the grid screen of the oscilloscope. When the bottom of any test waveform is placed on the bottom one of these grid lines, each unit above it will indicate 1 volt. A test waveform that is five units high is then equal to 5 volts peak-to-peak.

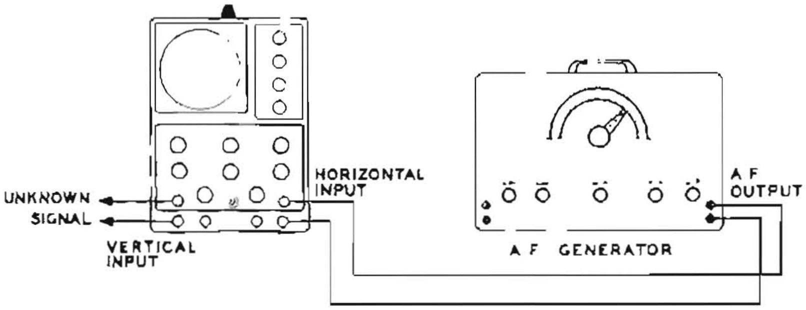


Figure 6-4

The oscilloscope is now calibrated and ready to use. Be careful not to disturb adjustments of the vertical amplifiers since this would disturb the calibration. Adjust only the vertical centering control so the bottom of each waveform to be measured is even with the bottom of the calibrating lines.

Measurement of Frequency

A very crude measurement of frequency can be made by setting the sweep frequency controls for a one-cycle waveform. Then read the approximate frequency from the control settings on the front panel of the oscilloscope.

A more accurate method makes use of special oscilloscope waveforms (see Figure 6-5) that are called Lissajous figures. Figure 6-4 shows a test setup that will produce these figures. The sine wave signal of unknown frequency is applied to the vertical input, and a sine wave of known frequency is applied to the horizontal input of the oscilloscope. The horizontal frequency selector of the oscilloscope is set to the external input position, thus the sine wave from the generator replaces the sawtooth waveform from the sweep circuit of the oscilloscope. When two sine waves are applied to the oscilloscope in this manner, Lissajous figures are produced.

To measure an unknown frequency, adjust the sine wave generator until the pattern in Part A of Figure 6-5 is displayed on the oscilloscope screen. The frequency of the unknown signal is then the same as that from the sine wave generator. The accuracy of the measurement is as good as the accuracy of the sine wave generator.

For measuring frequency, the frequency range of the generator can be extended by using more complex Lissajous patterns. Part B of Figure 6-5 shows typical patterns when the test and known sine waves are not of the same frequency. The frequency of the test signal can be calculated by: $f_x = \frac{Th \times f}{Tv}$

where fx is the unknown frequency; f is the known frequency; th is the number of loops which touch the horizontal tangent line; Tv is the number of loops which touch the vertical tangent line.

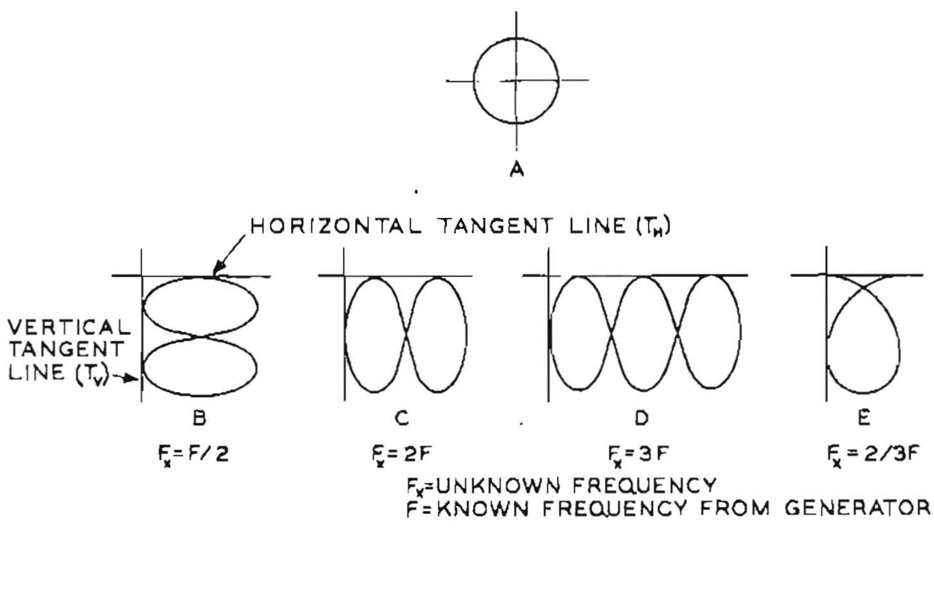


Figure 6-5

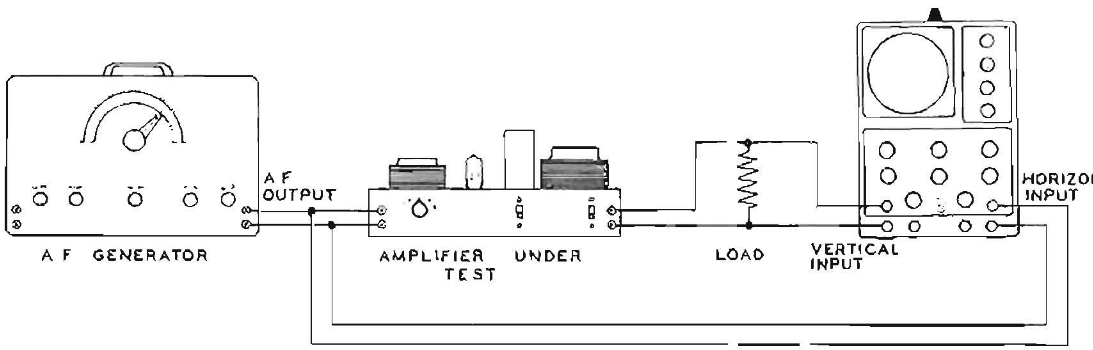


Figure 6-6

Phase Shift

The term "phase" refers to a fractional part of one cycle of voltage (or current). "Phase shift" refers to how far apart the phases of two voltages are at any given instant; that is, at what part of the cycle is one voltage with reference to the other.

Phase shift is usually expressed in degrees, from 0 to 360 degrees. If the two voltages start out in the same direction (+ or -) at the same instant, they are said to be "in phase" and the phase shift is zero degrees. If one voltage starts to go negative at the exact instant the other voltage starts to go positive, there is said to be a 180 degree phase shift between them.

The measurement of frequencies also suggests a method of measuring the phase change of a sine wave. A small change in the procedure for measuring frequency will show how signals in an amplifier change phase relationships at different frequencies. Figure 6-6 shows a typical setup for the phase shift measurements. The output of the sine wave generator is connected to the input of the Amplifier and to the horizontal input of the oscilloscope. The output of the amplifier is connected to the vertical input of the oscilloscope.

The frequency of the sine wave generator should be varied over the entire frequency range of the amplifier. Midrange frequencies will show the least phase shift; therefore, it is better to start the measurement at the middle frequencies, and to observe the increase in phase shift as the frequency is reduced or increased to the frequency limits of the amplifier.

Phase shifts of 0 and 180 degrees, which appear as straight diagonal lines, are easily recognized. For values between 0 and 180 degrees, a simple mathematical relationship will give the phase angle. Refer to Figure 6-7. When the ellipse is properly centered on the vertical and horizontal axes, the distance from the origin (intersection of the two axes) to where the ellipse intercepts the horizontal axis is measured. This is distance B in Figure 6-7. This measurements may be in fractions of an inch, in centimeters, or in any arbitrary units. Next, measure the distance from the vertical axis to a tangent to the

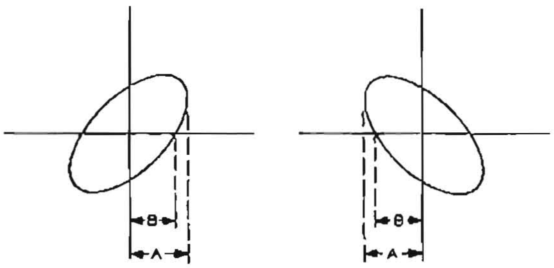


Figure 6-7

maximum horizontal point on the ellipse. Use the same units of distance as before. Finally, the ratio of B to A gives the sine of the phase angle. In other words:

$$\frac{B}{A} = \sin\theta, \text{ where } \theta \text{ is the phase angle}$$

Any standard handbook or set of mathematical tables will contain a sine table where you can look up the angle corresponding to the ratio of B to A.

Polarity

It is important to know whether a positive vertical input signal deflects the spot upward or downward. Either condition may exist, depending on the number of vertical amplifier stages in the oscilloscope and exactly how the vertical deflection plates are connected to the amplifier.

A simple procedure can be used for checking the deflection polarity of most oscilloscopes. An ordinary flashlight cell can be used. Connect the negative base of the cell to the ground terminal of the oscilloscope. Adjust the oscilloscope for a horizontal trace. Touch the positive cell terminal to the vertical input test lead while watching the oscilloscope screen closely. The line trace will be deflected either up or down and then return to center.

If the deflection is upward, the positive portion of any observed signal will appear on the upper part of the oscilloscope screen, and vice versa.

On some oscilloscopes the symbol ♆ is used to denote the direction of deflection by a positive signal.

Time

When studying complex waveforms, the length of time of a pulse, or one complete cycle is often needed. Some elaborate oscilloscopes have provisions for measuring time directly in microseconds per unit of deflection. A general purpose oscilloscope without this feature can be calibrated easily for this specific application as follows: Connect a signal generator to the vertical input terminal of the oscilloscope. The frequency of calibration can be determined by:

$$T = \frac{1{,}000{,}000}{\text{frequency}}$$

where T is time in microseconds for one cycle. Adjust the sweep until one cycle occupies a fixed number of squares on the oscilloscope scale. When adjusting the oscilloscope sweep, use as little sync as possible and obtain the single cycle by carefully adjusting the fine frequency control. This procedure insures that the oscilloscope sweep is at the correct frequency.

As an example, if the calibration signal is 50 kc and the oscilloscope sweep is adjusted so one cycle occupies 10 horizontal spaces on the scale of the screen, then each space represents 2 microseconds. Then, after the signal generator is disconnected, if a test pulse is observed and it rises from 10% to 90% of its peak value in 1/4 of one space on the horizontal scale, its rise time is 0.5 microsecond. While this method of measuring rise time may be used, the results will not be accurate due to some instability in the sweep oscillator.

Repeat the measurements described in this chapter as time allows. When you become familiar with them you will find your oscilloscope to be a more useful tool.

CHAPTER 2

Accessories and Special Oscilloscopes

Accessories are available to increase the usefulness of the general purpose oscilloscope. Oscilloscope accessories range from simple test probes to complex electronic switches.

Many oscilloscopes are available that have special features built into their design. These special oscilloscopes incorporate such items as DC amplifiers, electronic switches, calibrated time base sweeps, and triggered sweeps. The reason for some of these features will be discussed in this chapter.

Some items of electronic equipment are more useful when used with an oscilloscope, but are not generally classed as accessories. Items such as AF and RF sine and square wave generators and sweep generators are discussed in respect to their use with oscilloscopes.

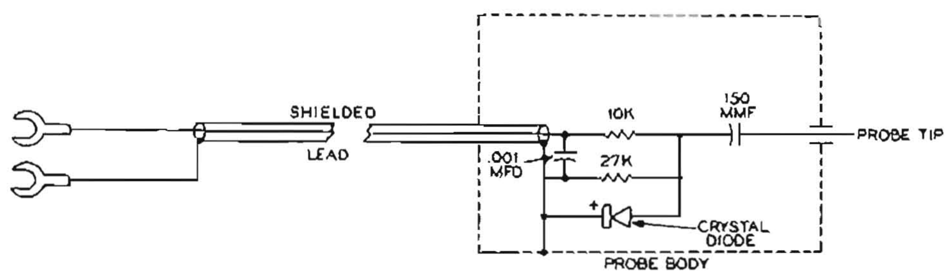
Probes

The simplest type of probe is the test lead. Test leads are convenient lengths of wire with appropriate tips to fit the input jacks of the oscilloscope on one end, and clips or some other convenient means for attaching to the test circuit on the other end.

Since the oscilloscope inputs have high impedance and high sensitivity, the test leads may be shielded to avoid pickup of stray signals.

Shielded test leads add capacitance in the input circuit, often as much as 75 $\mu\mu$f. Low capacitance probes can be used when capacitance-adding shielded leads cause distortion. Electrically, the low-capacitance probe consists of a very large resistance, shunted by a small variable capacitor. Most probes have an adjustment to balance out the probe's input capacity.

To extend a low-frequency oscilloscope's range for use in RF and IF circuits, such as in TV, a RF probe is available. The RF probe has two major characteristics. The first is low capacitance to prevent detuning the test circuit. The second is a detector or demodulator for converting the modulated high frequency RF or IF signal to video or audio, or to DC in the case of pure RF such as a carrier or generator signal. Figure 6-8 shows a typical circuit for a RF probe. The use of this probe in some circuits is limited by the DC voltage rating of the blocking capacitor, and by the AC voltage limit of the crystal diode. When a RF probe is being used, the waveshape of the modulation can be seen, but the waveshape of the RF signal can not be seen.



R F PROBE

Figure 6-8

Voltage Calibrators

Separate voltage calibrators are available for general purpose oscilloscopes. A voltage calibration instrument serves the same purpose as the oscilloscope calibration circuit described in Chapter 1 of Part V. The advantage of a voltage calibrator over the procedure described in Chapter 1 is its ease and speed of operation. Consult the manufacturer's manual for proper operation.

Electronic Switches

An electronic switch makes it possible to display two waveforms at the same time on the oscilloscope screen. It does this by first connecting one signal to the oscilloscope input and then switching to the other signal. The process is repeated at a high rate to give the impression of two separate waveforms.

Often, waveform observations are more convenient or easier to analyze when viewing two related voltages simultaneously. For example, comparisons can be made between the same signal at two different points in a circuit. This permits observing the effect a segment of the circuit has on the signal. A comparison of phase shift between the input and output of a circuit can be made.

The electronic switch generally consists of two amplifiers and a multivibrator. The symmetrical multivibrator is used to drive first one then the other amplifier to cutoff. The amplifiers generally have a common plate load so that first one then the other signal appears at the same output. The frequency of the multivibrator is controlled with RC circuits in much the same manner as the multivibrator in the oscilloscope.

For most popular switches, the switching rate is not related to signal frequencies. This is "chopped operation" and converts the signal into a square wave with amplitude modulation of a sort. Thus DC signals can be displayed on an AC scope (with loss of the DC zero reference). Another common mode used mainly as an integral part of the oscilloscope is "alternate sweep" where the switching rate is half the sweep rate. This is particularly valuable in oscilloscopes with driven sweeps for observation of two signals not synchronized and harmonically related.

Signal Generators

Signal generators can be used without oscilloscopes but they are often more valuable in connection with oscilloscopes. Because they are so often used with oscilloscopes they are included here as an accessory.

Signal generators include sine wave, square wave, sweep, and pulse generators. These instruments are often used to provide a signal that will best bring out circuit performance. The oscilloscope will display wave shape irregularities as well as the change of amplitude of the waveform.

Sine wave generators are divided into two areas, audio and radio frequencies. The audio generator frequency range is approximately 20 to 100,000 cps. The audio generator is used mainly for checking amplifier characteristics such as phase shift, output power, distortion, amplification, and frequency response.

It takes several radio frequency generators to cover the entire frequency range now in use. RF generators are used in alignment, signal tracing, frequency measurements, response curve marking, and many more applications.

The sweep generator is generally a RF generator that can be varied in frequency above and below a reference frequency. The more common sweep rate is 60 cycles per second. This is done by applying the sweep voltage to a reactive element in a RF oscillator. In this way, the RF oscillator repeatedly sweeps through its frequency range, once for each cycle of the sweep frequency.

The sweep generator provides, with the help of an oscilloscope, a quick and convenient means of displaying the frequency response curve of a tuned circuit, or other frequency-discriminating circuit. This procedure is very useful in FM and TV servicing and alignment.

Transducers

Transducers are instruments which convert other forms of energy such as light and sound into electrical energy. The cartridge in the tone arm of a phonograph is a transducer that converts mechanical energy into electrical energy. Microphones convert sound energy into electrical energy.

A transducer when used with an oscilloscope, allows you to examine many physical variations of energy by converting them into electrical signals. Some common types of transducers are: photo-cells, which measure light; displacement transducers to measure very small movements; pressure transmitters to measure pressure; thermocouples to measure heat; strain gauges (with amplifiers) to measure strains in metals; and many others. For an example, the vibrations of a washing machine can be seen by attaching a displacement transducer to it and connecting the circuit of the transducer to the oscilloscope. From such a visual display, an engineer can often pinpoint the source of the vibrations and thus reduce them to a minimum.

Special Oscilloscopes

The main purpose of this manual is to describe the general purpose oscilloscope, but the user of such an instrument should also be aware of special purpose oscilloscopes that are available. Such oscilloscopes are the same in principle as the general purpose oscilloscope, but include added features that increase the quality and the range of some oscilloscope functions.

DC Oscilloscopes

DC oscilloscopes are oscilloscopes that use DC coupled amplifiers instead of AC coupled amplifiers like those in Chapter 4 of Part IV. All coupling capacitors are eliminated in DC amplifiers; this allows the amplifier to faithfully reproduce very low frequency waveforms and DC level changes.

There are many places where very low frequencies make DC oscilloscopes necessary in many transducer applications, such as in testing for mechanical vibration, 60 cps would be a relatively high frequency. Low frequency square waves, and many low frequency pulse applications also require the use of a DC oscilloscope to eliminate low frequency distortion.

Triggered Sweep Oscilloscopes

A feature that is extremely useful in certain modes of operation, such as in pulse work, is the triggered sweep circuit. In this circuit, the multivibrator is not free running as in the general purpose oscilloscope. The triggered multivibrator is designed to fire only when an outside pulse is applied to the circuit. The multivibrator functions for one cycle and then waits for the next pulse to trigger it for the next cycle.

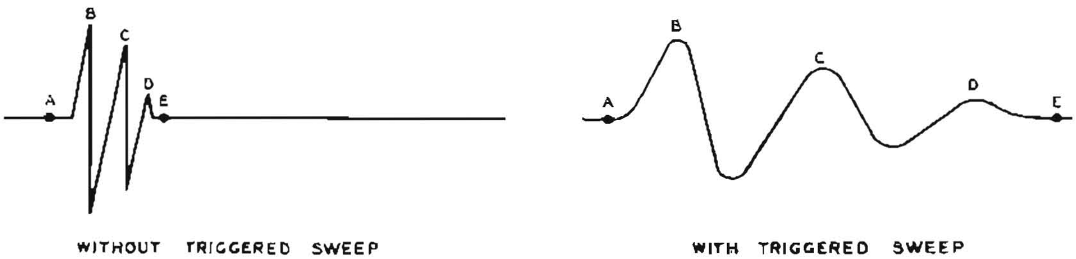


Figure 6-9

Figure 6-9 shows how the transient waveforms caused by the closing and opening a switch might look, first without and then with trigger sweep.

Much of the time during the sweep, nothing of interest happens. Much of the screen is used up waiting for the waveform to occur. If closer examination is desired, increasing the horizontal gain may not help as the waveform may be lost completely in "off-screen" time.

The triggered sweep circuit will not sweep until the first portion of the waveform comes along. Increasing the horizontal gain will expand the waveform without losing it during "off-screen" time.

Since the sweep is started only when the signal pulse comes through, some of the information may be lost from the leading edge. To prevent this, a small delay of the signal pulse by electronic circuitry permits it to be applied to the vertical plates slightly after the start of the sweep. See Figure 6-10.

Other Types of Oscilloscopes

Additional features, such as cathode ray tubes with long persistence screens, and plug-in vertical amplifier units for AC, DC, or special purpose operation, are built into some scopes. Many of the accessories described in this chapter are also included as standard features in some oscilloscopes. Oscilloscopes are also available for special purposes such as in radar applications or in engine analyzers.

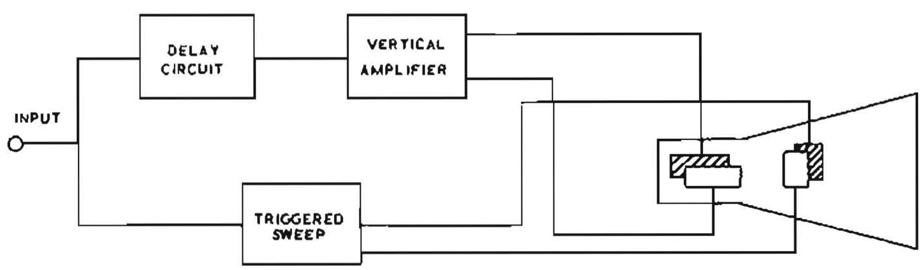


Figure 6-10

CHAPTER 3

Use of the Oscilloscope in Radio-TV-FM Service Work

Basic principles of troubleshooting are given in Part V on servicing the oscilloscope. These general principles apply equally well to all areas of electronic servicing and should be reviewed before starting this chapter.

The oscilloscope is a time-saving instrument in dynamic testing such as set alignment, checking set performance, signal tracing, locating faulty circuit elements, finding sources of hum and distortion, and other general troubleshooting. Dynamic testing is testing under operating conditions.

It is strongly recommended that servicing with an oscilloscope be preceded by examination of equipment in good working order. First, this will give you valuable experience with correct oscilloscope patterns. Only if you know correct test patterns can you recognize faulty patterns. Second, this will give you a better knowledge of additional circuits. It is easier to service a circuit that is thoroughly familiar. Your personal AM and FM receivers, test equipment, and TV could provide the necessary experience. You must remember that high voltage danger exists in TV receivers, as in oscilloscopes, and one "hand in the pocket" is a good safety measure.

Circuit descriptions and schematics with waveform patterns at test points are available. Such information for most receivers is available from such service organizations as Rider and Sams.

This chapter will give you examples of how the oscilloscope can be used as a service instrument. Specific details about the equipment being serviced are not given as these are obtainable from the circuit diagrams. For example, to service your TV receiver you need the circuit schematic for that particular make and model. You will also need the manufacturer's manual for the sweep generator you use if you align the TV set.

Finding Receiver Faults from Oscilloscope Patterns

Oscilloscope patterns often indicate the source of trouble in a circuit by the way a test signal is altered. A properly AF modulated RF sine wave reveals the source of trouble by a recognizable pattern change.

Figure 6-11 shows an example of how the sine waveform may appear in a faulty AM radio receiver. In Figure 6-11, Parts 1, 2, 3 and 4 are obtained on the screen of the oscilloscope when the oscilloscope vertical input is connected across the speaker voice coil. An amplitude-modulated signal is applied to the antenna and ground terminals of the receiver, or a sine wave is applied to the input circuit of the audio amplifier circuit of the receiver. The oscilloscope would display a normal sine wave if the receiver is working properly.

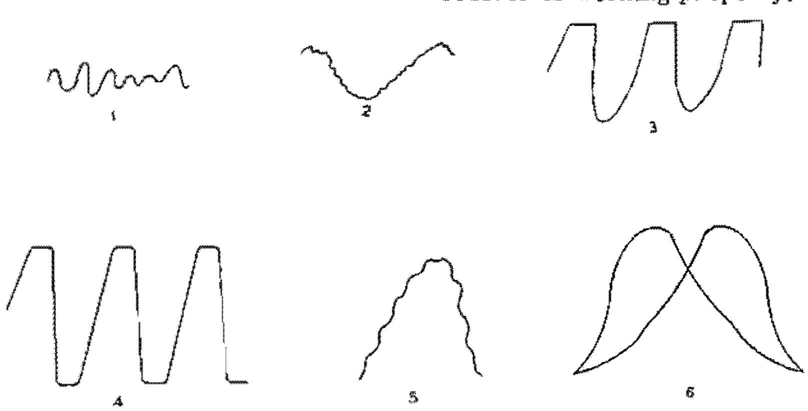


Figure 6-11

If the signal pattern looks like Part 1 or 2 of Figure 6-11, this may indicate "hum." Common sources of hum at line frequency (60 cps) are defective tube cathodes, heater-cathode short circuits, open grid circuits, misplacement of heater wiring or ungrounded or unbypassed tube heaters. Hum that is twice the line frequency (120 cps) is often due to trouble in the power supply filter section. This type of hum could be caused by an open filter capacitor or a filter capacitor too low in capacitance.

Parts 3 and 4 of Figure 6-11 shows overloading of the audio amplifier. Possible sources of overloading are incorrect grid bias voltage, too large a signal applied to the grid of an amplifier stage, and for push-pull, one tube malfunctioning.

Parts 5 and 6 of Figure 6-11 are obtained with a FM signal generator connected for alignment (alignment will be discussed later in the Chapter). These curves should be smooth and coincident. Part 5 is usually due to noise or outside signal pickup. The two irregular curves of Part 6 that will not merge give evidence of regeneration or local oscillation in the circuit. This could be caused by a coupling capacitor having changed value.

In the same manner, the equipment above can be used for signal tracing by moving the oscilloscope probe from point to point through the circuit. A modulated RF signal must be applied to the input of the receiver and the proper probe used for the section of the receiver being checked. The signal is traced from the antenna input to the speaker. Insufficient gain or distortion in any stage is quickly seen in the oscilloscope pattern.

Test and Power Supplies

The oscilloscope will quickly show difficulties in the power supply. Connect a DC blocking capacitor in series with the "high" vertical input terminal of the oscilloscope if the DC voltages in the circuit to be checked exceed the DC blocking capacitor rating on the oscilloscope. Place the probe, in succession, at each plate of the rectifier and before and after each capacitor in the filter network. Failure of the ripple height to lessen after each check point in the filter may point out the defective part.

Circuit Alignment

Visual alignment of receiver circuits permits you to see a complete response curve on an oscilloscope screen that would take much time and tedious effort to plot point-by-point with a voltmeter. Visual alignment also allows you to immediately see the effects produced by changes in adjustments.

There are several tuneable circuits in the average radio or TV receiver. Usually they are designed to accept or reject certain frequencies so that these frequencies can be amplified or eliminated entirely. The adjustment of these tuned circuits for proper performance is called alignment.

The procedure for alignment of AM, FM, and TV receivers are the same in principle. The FM alignment procedure is taken as typical and is illustrated here. Figure 6-12 shows a block diagram of the hookup procedure for FM alignment. The equipment needed is a sweep generator, marker generator (if not built into the sweep generator), the FM receiver to be aligned, and your oscilloscope.

Preparation for visual alignment includes connecting the sweep generator, FM receiver, and oscilloscope as in Figure 6-12. The RF sweep generator repeatedly sweeps across a whole band of frequencies, and this signal is applied to a point ahead of the circuits to be aligned. The oscilloscope vertical input is connected to some point following the circuits to be aligned, usually after the detector in the receiver.

The signal from the sweep generator must be detected (this is usually done in the receiver) before it is connected to the oscilloscope. Detection is necessary because the sweep generator is usually set to cover a band of frequencies that are beyond the range of the oscilloscope vertical amplifier. The oscilloscope then shows the response of the receiver circuits to all the frequencies being presented by the sweep generator.

Usually the oscilloscope is adjusted for line sweep (60 cps sweep). For IF alignment, the sweep generator and marker generator are set at the intermediate frequency (IF) used (generally 10.7 mc) in FM receivers.

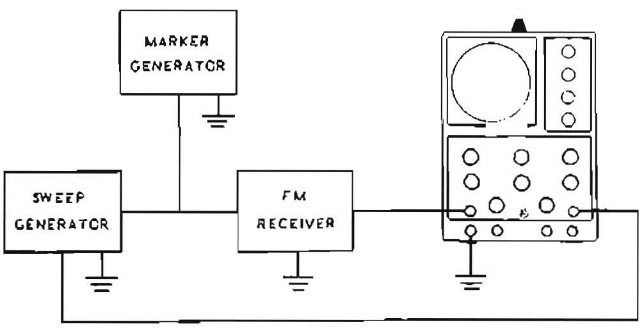


Figure 6-12

The amplitude of the audio signal obtained from the detector circuit is determined by how far the IF signal varies from 10.7 mc. The frequency of the audio signal is determined by the number of times per second the IF signal deviates from 10.7 mc.

The sweep generator supplies a signal that is continuously changing through a range of frequencies. The width of this frequency range is controlled by the sweep width control; the center frequency of the sweep is controlled by the main tuning control of the sweep generator. The pattern seen on the oscilloscope is a graph that shows receiver amplification as vertical deflection, and frequency variation as horizontal deflection.

Additional signals from an accurate RF generator, called a "marker generator" are also inserted into the receiver. These marker signals are used to accurately mark the exact position of important frequencies on the response curve.

Figure 6-13 shows typical response curves for an FM circuit with marker signals to show the approximate width of the curves in megacycles. Part A shows the response curve for the IF stages, and Part B that for the ratio detector stage.

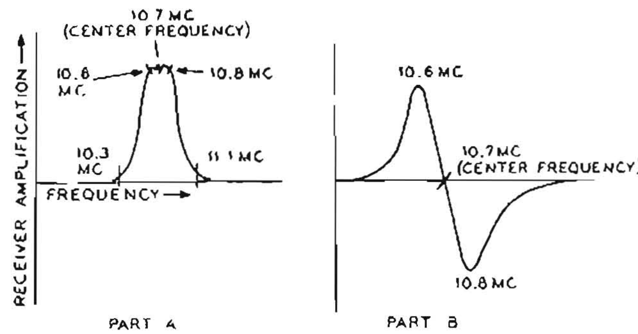


Figure 6-13

The curves should be symmetrical on either side of the 10.7 mc center frequency. The 10.7 mc marker signal, should remain at the center of the curve, to indicate the center frequency. The IF stages amplify all frequencies around 10.7 mc equally well and reject all other frequencies. This is indicated in Part A of Figure 6-13 by a flat top curve with steep sides.

The ratio detector stage must handle the frequencies on both sides of 10.7 mc equally well. This is indicated by a straight line from 10.6 mc to 10.8 mc in Part B of Figure 6-13. If this line is not straight, the amplitude of the audio signal will be limited and loud sounds will be distorted.

A typical step-by-step alignment procedure for the FM tuning section through the audio detection of a FM receiver is given in Figure 6-14. Figure 6-15 is a typical FM circuit with which this alignment procedure can be used.

COMPLETE ALIGNMENT PROCEDURE

USING A SWEEP GENERATOR, MARKER GENERATOR AND OSCILLOSCOPE

TUNING Control - off station position VOLUME Control - full clockwise AFC Switch - OFF

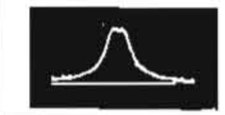
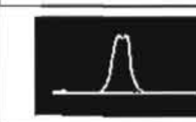
PREPARATION	SWEEP GENERATOR		OSCILLOSCOPE	ADJUST	
	Connect sweep generator	Sweep generator and marker generator frequency	To be connected	for maximum gain and bandwidth	for approximate response
Disconnect the positive (+) lead of capacitor C34 from lug 1 of terminal strip E.	Through .01 µfd capacitor to Pin 1 of V4	10.7 mc	Across 6.8 KΩ resistor (R14) to lugs 3 and 2 of terminal strip E.	Bottom slug of T4	
	Through .01 µfd capacitor to Pin 1 of V3	10.7 mc		Top and bottom slugs of T3	
	Through .01 µfd capacitor to Pin 1 of V2	10.7 mc		Top and bottom slugs of T2	
	Through .01 µfd capacitor to Pin 1 of V4	10.7 mc	To audio output jack	Top slug of T4 for straightest center portion of curve and balanced plus (+) and minus (-) swing	
Reconnect (+) lead of C34. Tune the dial pointer to 98 mc.	To Antenna input, with 240 Ω in series with hot lead (for 50 Ω generator Z)	Sweep generator 98 mc Marker generator 10.7 mc	To pin 1 of V4 through 100 KΩ resistor. Ground lead to V4 center post	Top and bottom slugs of T1	

Figure 6-14

CHAPTER 4

Audio and HiFi Applications

Audio frequency circuits are widely used in broadcasting, receiving, hi fi, public address systems, recording instruments, and in industrial and scientific laboratories. The oscilloscope is a very useful instrument in checking the performance of audio circuits. This chapter will discuss many methods of testing audio circuits with your oscilloscope and how to detect particular faults.

Oscilloscopes are used to determine frequency response, phase shift, tone control action, stability, equalization patterns, distortion, plus other specialized checks.

Testing audio circuits consists primarily of applying a known signal and interpreting the resulting waveform. Sine wave, square wave and sweep frequency generators are used (individually) with the oscilloscope for making tests.

Sine Wave Testing

An audio signal generator applies a sine wave of variable amplitude and frequency to the input of the audio circuit. For best results, proper input impedance matching and output loading of the audio circuits must be used. Figure 6-16 shows an audio generator connected to a single amplification stage. Figure 6-17 shows an audio generator connected to a complete audio amplifier.

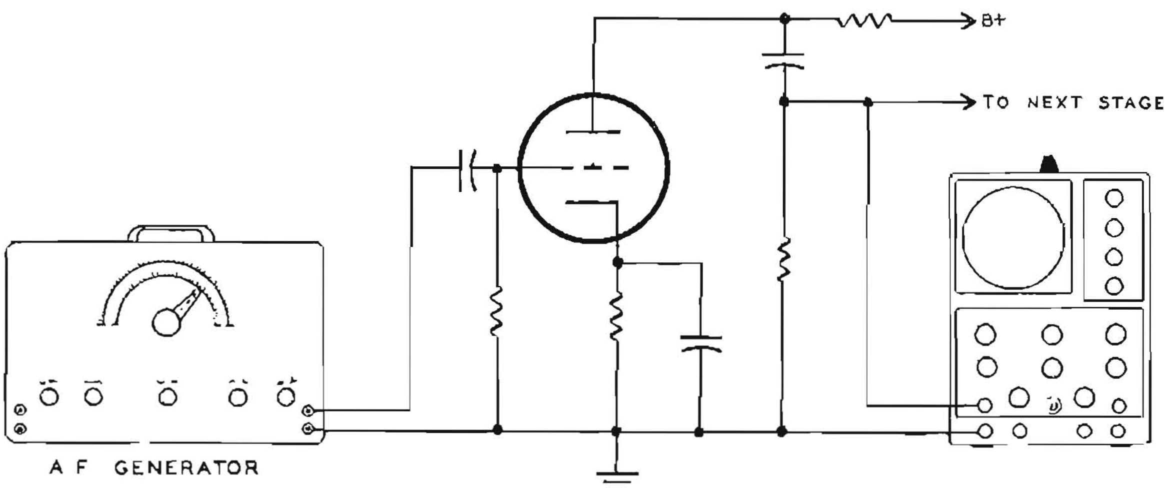


Figure 6-16

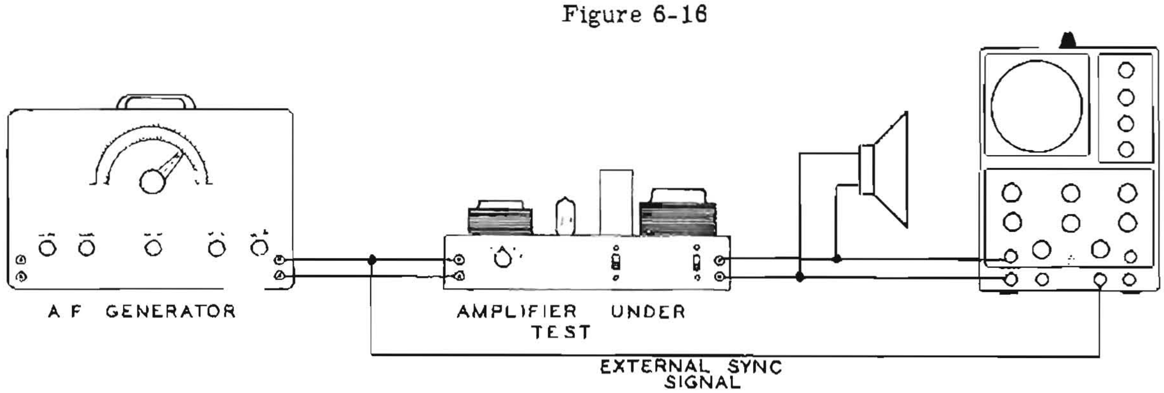
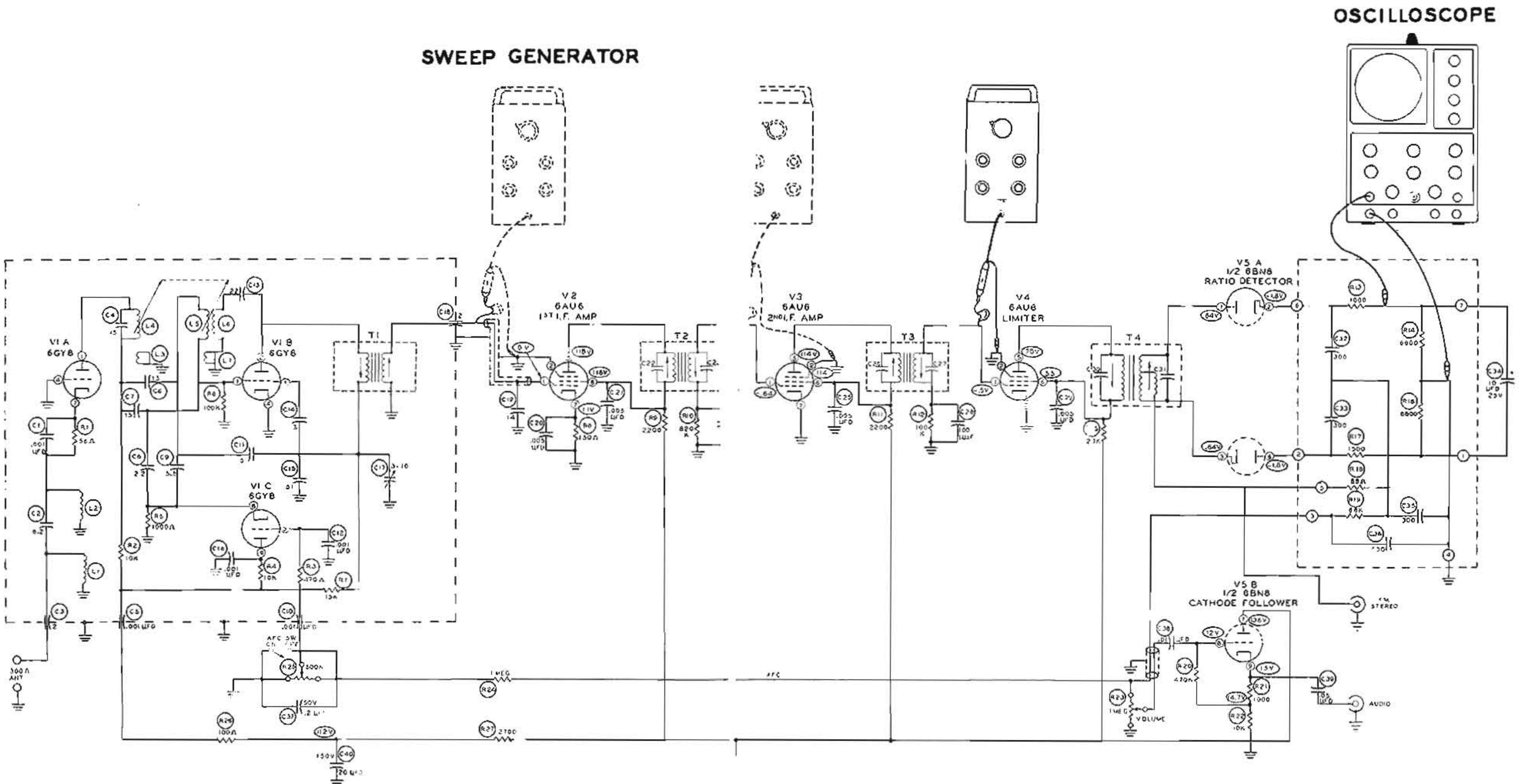


Figure 6-17



SWEEP GENERATOR
OSCILLOSCOPE
V1 A
6GY8
V1 B
6GY8
V1 C
6GY8
V2
6AU6
1ST I.F. AMP
V3
6AU6
2ND I.F. AMP
V4
6AU6
LIMITER
V5 A
1/2 6BN8
RATIO DETECTOR
V5 B
1/2 6BN8
CATHODE FOLLOWER
T1
T2
T3
T4
AFC
VOLUME
AUDIO
300Ω ANT

Figure 6-15

The test of an amplifier's fidelity is the degree of similarity between the input and output signals. The output waveform is almost never exactly the same as the input waveform.

The changed test waveform at the amplifier output is a complex waveform that consists of two or more simple waveforms. For example, if a 60 cps sine wave and a 120 cps sine wave are mixed together, a new waveform is produced. Figure 6-18 shows the two sine waves, where both are of the same amplitude and same phase. The 120 cps waveform is twice the frequency of the 60 cps waveform and is called the second harmonic. A 180 cps waveform is the third harmonic.

When amplifier circuits are not operating properly, unwanted harmonic waveforms are impressed on the signals connected to the amplifier. This causes the waveshape of the signal to be altered, and therefore distorted, just like the 60 cps sine wave in Figure 6-18 was distorted by adding the 120 cps sine wave to it. This type of distortion is called "harmonic distortion."

The complex waveform that is produced would sound different from the 60 or 120 cps waveform. Any such change in waveforms is called distortion. Figure 6-19 shows a few examples of distortion patterns obtained in audio amplifier testing. For example, Parts D and G of Figure 6-19 show second harmonic distortion. This would indicate improper grid bias or too small a plate load resistor in one or more of the amplifier stages.

Various phase changes could further distort the patterns in Figure 6-19.

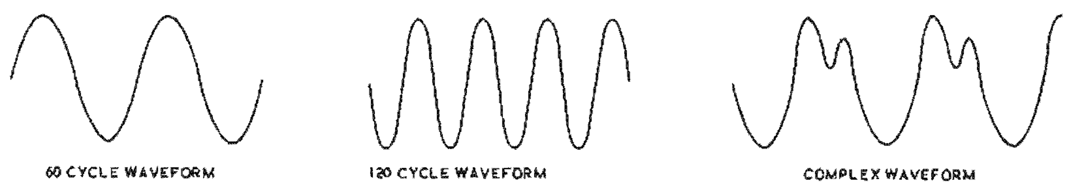
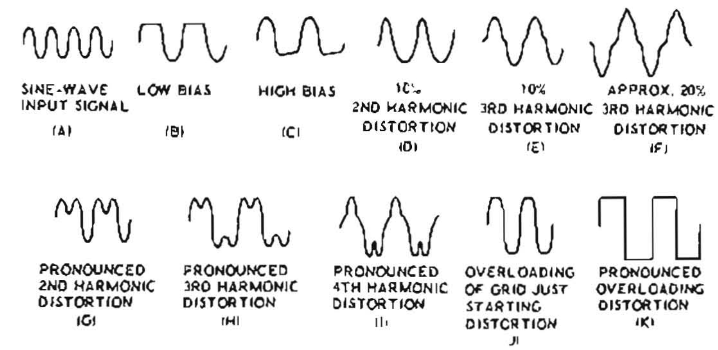


Figure 6-18



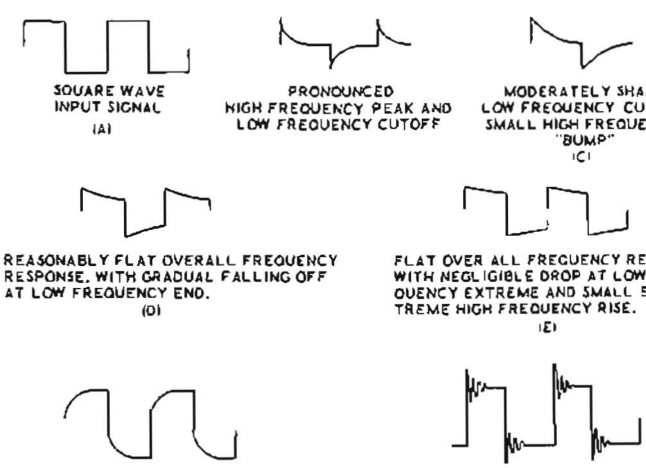
DISTORTION PATTERNS OBTAINED IN AUDIO AMPLIFIER TESTING

Figure 6-19

Square Wave Testing

An introduction to the use of square waves is given as an experiment in Part IV. The square wave is a complex waveform composed of many sine waves, a fundamental and all its harmonics. The square wave test permits, in one operation, the testing of many frequencies, from 1/10 to 10 times the fundamental frequency. A few settings of the fundamental frequency on the square wave generator will give results comparable to a wide range of frequencies. Settings of 100 cps and 10 kc would check the frequency response curve for an amplifier from 10 to 100,000 cps.

The physical hookup is similar to that for the sine wave generator, as in Figure 6-17. Figure 6-20 shows response patterns that might be obtained with the square wave test and what they indicate. For example, Part G of Figure 6-20 shows an example of ringing in an amplifier. Ringing is a form of oscillation that dies out quickly. The steep wavefront of the square wave can jar unstable amplifiers into ringing. A loud high frequency note of music or a pulse of fast rise time would do the same thing. The ringing frequencies are often higher than the audio range but may react with the audio signal to cause distortion.



RESPONSE PATTERNS OBTAINED IN SQUARE-WAVE TESTING OF AUDIO AMPLIFIERS.

Figure 6-20

Phase Testing

The oscilloscope trace produced in checking phase relationship from the input to the output of an amplifier gives valuable information about the distortion of the circuit. Phase shift causes trouble because all frequencies are not changed in phase by the same amount. Improper phase shifting can cause trouble in feedback networks.

As shown in Chapter 1 in Part VI Figure 6-6, the same signal is applied to both the audio circuit and to the horizontal input of the oscilloscope. The output of the amplifier is connected to the vertical input of the oscilloscope. The sweep frequency control is set to horizontal input. The trace without phase shift will appear as a straight line tilted to the left or right.

A phase relationship of 180 degrees or zero degrees produces a straight line. A phase relationship different than 180 or 0 degrees will produce an oval, open by different amounts. In addition, any irregularities of shape of the straight line or oval indicates distortion produced in the circuit. Figure 6-21 shows several phase patterns that result when a sine wave is applied to a faulty circuit. With each phase pattern, the output waveform of the circuit is given. The method of measuring the phase angle for an oval pattern is given in Chapter 1 of Part VI.

Additional procedures that can be used in audio circuit analysis are found in earlier chapters. Hum can be isolated in audio circuits the same as in receivers, as described in Chapter 3 of Part VI.

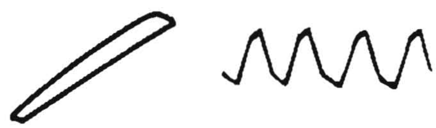
0° phase trace for sine waveform output

Phase trace for negative peak flattening.

Phase trace for positive peak flattening and increased negative flattening.

Phase trace for severe positive and negative clipping.

Phase diagram showing about 10° phase difference between input and output for sine waveform output.



Phase diagram showing distortion by action of amplifier.

Phase diagram showing pronounced distortion.

Figure 6-21

CHAPTER 5
Amateur Radio Transmitter Applications for Your Oscilloscope

RF TO V.
AF TO HOZ

The radiotelephone transmitter can be adjusted most effectively by using an oscilloscope. The oscilloscope will give more information, more rapidly, than almost any collection of other instruments.

This chapter deals with AM radio transmission waveforms. Other types of transmission, such as "single sideband," give different waveforms on the oscilloscope. Some specialized oscilloscopes are made just for checking transmitters and receivers. Most general purpose oscilloscopes, however, can also be used to check a transmitter as follows.

The vertical amplifier frequency response of most oscilloscopes is not adequate to accurately reproduce the frequencies of the RF carrier; direct connections to the deflection plates of the CRT are required. Most oscilloscopes have an access door at the rear of the cabinet to permit making these direct connections to the CRT. Refer to your oscilloscope instruction manual for directions.

Trapezoid Patterns

Two types of transmitter patters are most common; one is the trapezoid. Radio frequency voltage is applied to the vertical CRT plates and audio frequency voltage from the modulation is applied to the horizontal CRT plates. As the instantaneous amplitude of the audio signal varies, the RF output of the transmitter likewise varies. This produces a wedge-shaped pattern, or trapezoid, on the screen. Figure 6-22A shows a 100% modulated signal. Figure 6-22B shows less than 100%. Figure 6-22C shows over modulation.

A trapezoid pattern is useful for determining percentage of modulation. The maximum (H_2) and minimum (H_1) heights of the trapezoid are measured, using any convenient unit of length. Percentage of modulation may be calculated as follows:

$$\frac{H_2 - H_1}{H_2 + H_1} \times 100 = \text{percentage of modulation}$$

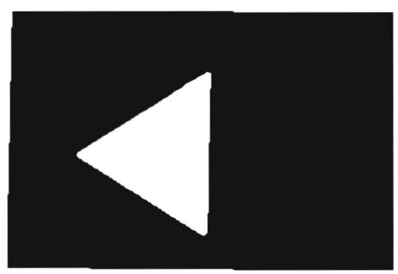


Figure 6-22A

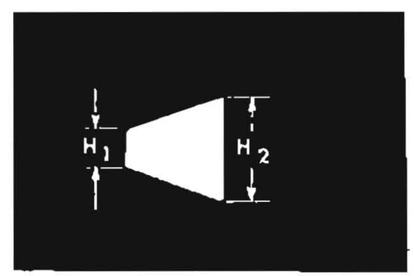


Figure 6-22B

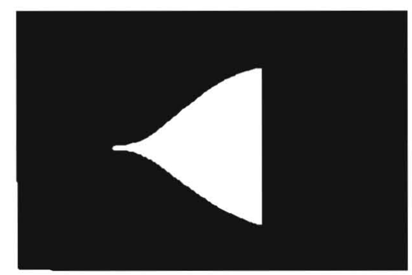


Figure 6-22C

The oscilloscope connections needed in a typical transmitter to obtain a trapezoid pattern are shown in Figure 6-23. Voltage divider R2 makes the pattern width adjustable. Resistor R1 limits the maximum signal available.

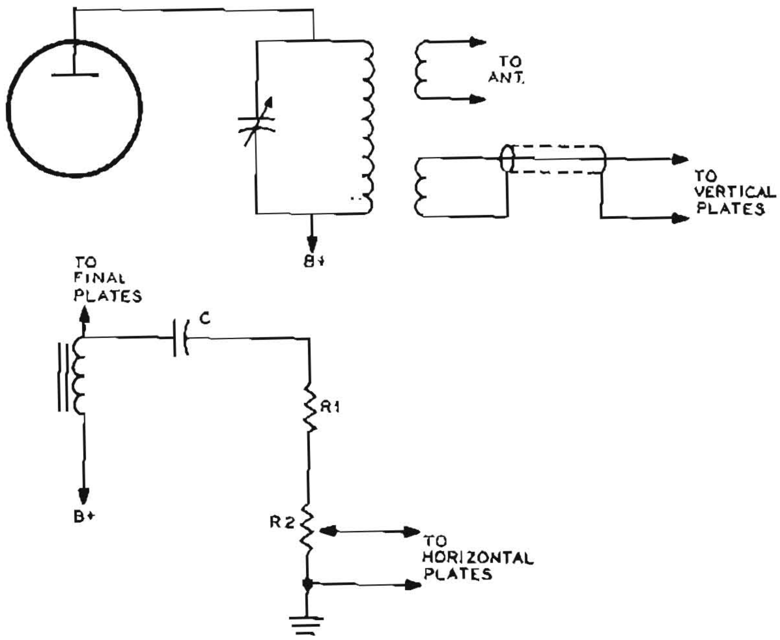


Figure 6-23

The Wave Envelope Pattern

If the built-in horizontal sweep of the oscilloscope is used, the RF voltage can be applied to the vertical CRT plates. The sweep will produce a pattern that follows the modulation envelope of the transmitter output, provided the sweep frequency is lower than the modulation frequency.

When voice modulation is applied, a rapidly changing pattern of changing height will be obtained. When maximum height of this pattern is just twice that of the carrier alone, the wave is modulated 100%. See Figure 6-24A. Less than 100% is shown in Figure 6-24B.

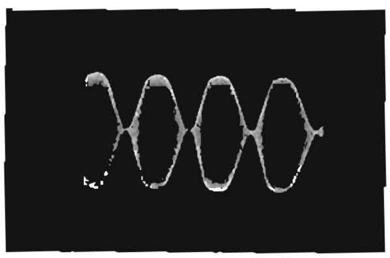


Figure 6-24A

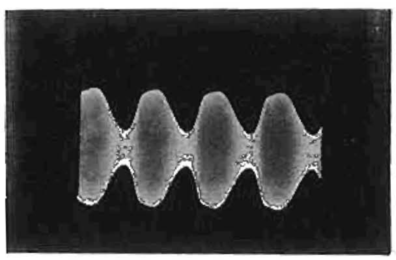


Figure 6-24B

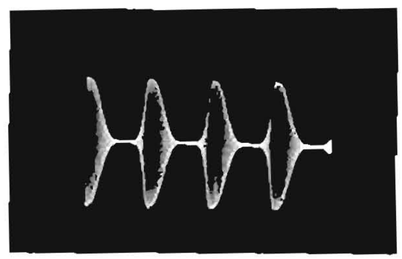


Figure 6-25

Overmodulation is indicated in Figure 6-25. Connections for the wave envelope pattern are shown in Figure 6-26.

The vertical deflection plates are coupled to the amplifier tank coil (or antenna coil) through a low-impedance (coax or twisted pair) line and pickup coil. Vertical amplitude is varied by adjusting the coupling or tuning of the output line.

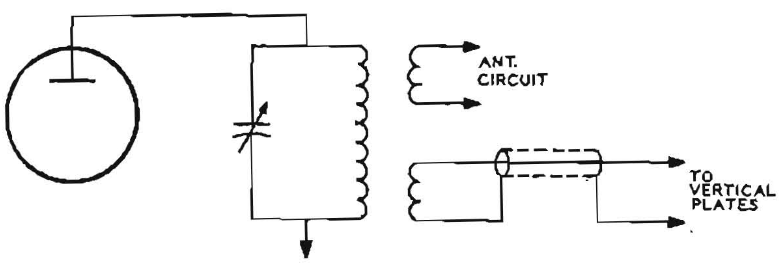


Figure 6-26

CHAPTER 6

The Oscilloscope as a Teaching Aid

The oscilloscope is a useful addition to the list of audio-visual aids for the classroom. Not only can demonstrations in the physical sciences be made more vivid, but demonstration in physiological sciences, music, and mathematics, are dynamically illustrated with an oscilloscope.

The purpose of this chapter is to point out some areas where the oscilloscope can be used effectively in classroom demonstrations. Examples from these various areas will be given. The areas include mechanics, sound, electricity and biology.

In practically all applications, the oscilloscope is used with other pieces of equipment; some are quite standard, others very specialized. This chapter will discuss some special pieces of equipment that are useful in connection with an oscilloscope.

At least one example from each general area is discussed briefly. Others are mentioned. The experiments that were performed in Parts III and IV should not be overlooked. Most of these experiments would also make usable demonstrations in science classes.

Visual Solution of Problems with a Computer

Computers can be used with a DC scope as a read-out device to demonstrate the mathematical solution of a number of physical problems. Small analog computers in kit form are available for classroom demonstration.

A computer is a machine which performs physical operations that can be described by mathematical operations. In general, computers may be classified as digital or analog. Digital computers operate by discrete steps, that is, they actually count. Common examples of digital computers are the abacus, desk calculator, punched-card machine, and the modern electronic digital computer. The fundamental operations performed by the digital computer are usually addition and subtraction. Multiplication, for example, is accomplished by repeated additions.

Analog computers operate continuously, that is, they measure. Examples of analog computers are the slide rule (which measures lengths), the mechanical differential analyzer, the electromechanical analog computer and the all-electronic analog computer. The last three generally measure electrical voltages or shaft rotations. Physical quantities such as weight, temperature or area are represented by voltages. Voltage is the electrical analog of the variable being analyzed. Arbitrary scale factors are set up to relate the voltages in the computer to the variables in the problem being solved. For example, 1 volt equals 5 feet or 10 volts equals 1 pound. The name "analog" comes from the fact that the computer solves by analogy by using physical quantities to represent numbers.

One of the most powerful applications of analog computers is simulation in which physical properties, not easily varied, are represented by voltages which are easily varied. Thus the "knee-action" of an automobile front wheel suspension can be simulated on an analog computer in which the weight of the automobile, the constant of the spring, the damping of the shock absorber, the nature of the road surface, the tire pressure and other conditions can be represented by voltages. In practice these factors cannot be readily changed, but on the computer any one or all of these may be varied at will and the results observed as the changes are made.

Some of the types of problems which can be solved by these methods are radioactive decay, chemical reaction, beam oscillation and heat flow. With the addition of crystal diodes and relays, simulation of discontinuous functions is possible. This makes possible solution of problems involving saturations, backlash, hysteresis, friction, limit stops, vacuum tube characteristics, and different modes of operation such as sonic vs subsonic flow.

The solution of a problem in elementary physics is shown as an example of the type of problem that can be solved. The solution is shown as it appears on the oscilloscope.

Falling Body Problem

One of the simplest problems encountered in elementary physics is that of a body moving under the influence of a constant force, such as the earth's gravitational field near the surface of the earth. The equation for the motion of a body in such a field is

$$\frac{d^2y}{dt^2} = g$$

where g is the acceleration which a body experiences when in the earth's gravitational field and y is the distance the body falls in time, t.

Solution of Falling Body Problem

(a) As observed on oscilloscope. Body was given initial horizontal velocity.

(b) As recorded on pen recorder.

The solution may be viewed on a DC oscilloscope as in Figure 6-27 by connecting the vertical input of the oscilloscope to the computer amplifier output. A sweep voltage is necessary if you want to show the path when an initial horizontal velocity is given the body.

The Study of Sound

Equipment for using the oscilloscope in sound demonstrations is generally very simple. A microphone is connected to the input terminals of the vertical amplifier. Some oscilloscopes may not have enough gain in the vertical amplifier to give suitable deflection on the screen of the CRT. In such cases, a small additional amplifier before the vertical input will help.

The waveform of speech, whistling, singing, vibrating tuning forks, musical instruments, and other sources of sound can be viewed directly on the oscilloscope.

Two tuning forks nearly the same frequency can be used to demonstrate beats. A tuning fork struck very hard will show a complex waveform, consisting of the fundamental and overtones (harmonics) mixed together.

The method of measuring phase relationship from Chapter 1 of Part VI can be used to measure the speed of sound. Figure 6-28 shows the physical connections. A small speaker, microphone, scale, audio oscillator, amplifier, and oscilloscope are needed for this demonstration. A tube that fits over the speaker and microphone will help increase the amplitude of the horizontal input.

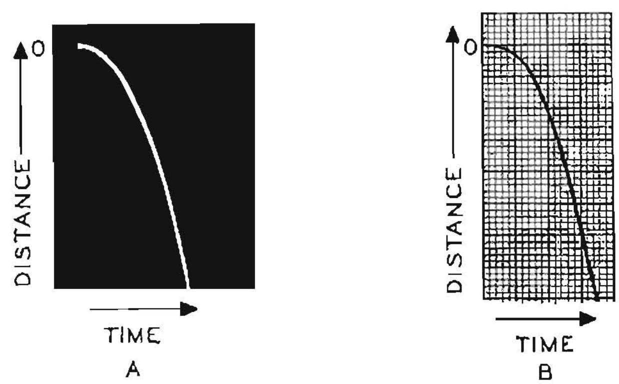


Figure 6-27

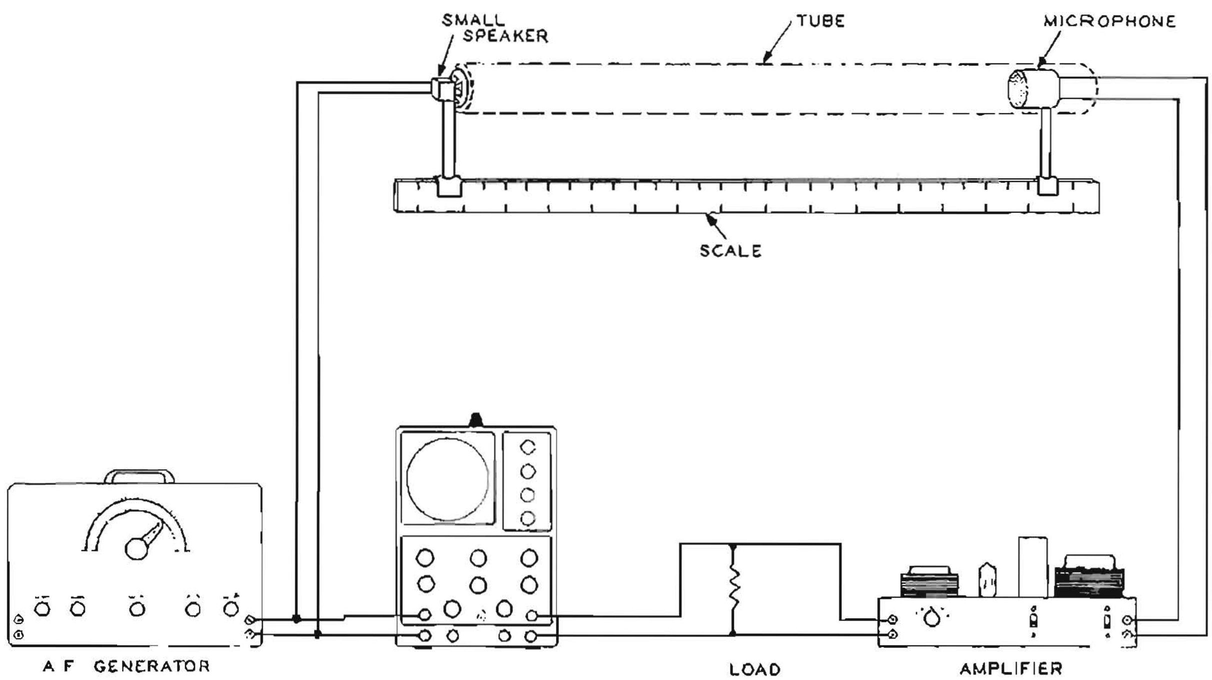


Figure 6-28

The velocity of sound in air is related to the frequency and wavelength by: $V = \lambda F$; where V is the velocity in feet per second, λ is the wavelength in feet, and F is the frequency in cps. Frequency is provided by an audio generator, and Figure 6-29 shows how to determine the wavelength. The distance that the microphone has to be moved away from the speaker to obtain oscilloscope patterns A, B, C, D, and finally E is the wavelength. To calculate the velocity of sound in air, V in feet per second = λ in feet times F in cps.

The Study of Electricity

This kit includes a number of circuits and procedures for studying and demonstrating many principles of electricity and magnetism. The oscilloscope aids in understanding the operating principles of amplifiers, oscillators, multivibrators, power supplies, filtering networks, attenuation networks, coupling networks, compensation networks, and many others. The oscilloscope provides a means of displaying changing voltages at different points in the circuit as a signal passes through, or is amplified or generated by the circuit.

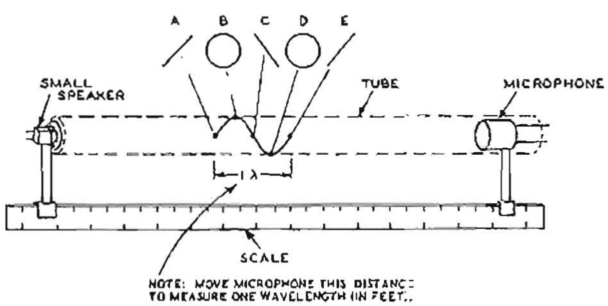


Figure 6-29

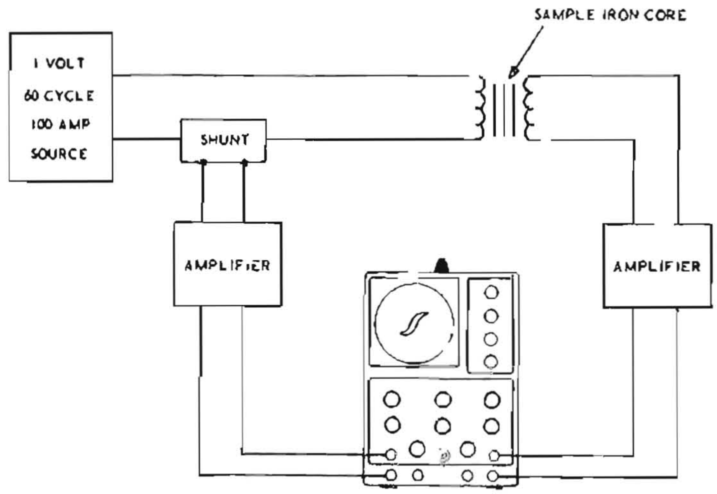


Figure 6-30

The following material includes two areas difficult to demonstrate without an oscilloscope; hysteresis and phase relationship in RLC circuits.

Figure 6-30 shows in block diagram form the equipment and connections for demonstrating hysteresis. The AC source is a very low voltage, high current, adjustable source. The voltage is in the order of 1 volt and the current up to 100 amperes. The induced voltage in the secondary of the sample core transformer is directly proportional to the induction field in the sample.

Figure 6-31 shows the physical setup for demonstrating phase relationship in RLC series circuits. R1 acts as a reference. The voltage drop across R1 is in phase with the voltage applied to the circuit by the AF generator.

The generator voltage is applied to one of the inputs of an electronic switch. In position one, the voltage across R1 and R2 is in phase with the current. In position 2, the voltage across R1 and C1 is not in phase with the current. In position 3, the voltage across R1 and L1 is the phase difference between voltage and current; it is opposite that of R1 and C1. This voltage is applied to the other input of the electronic switch. The output of the electronic switch is applied to the vertical input of the oscilloscope.

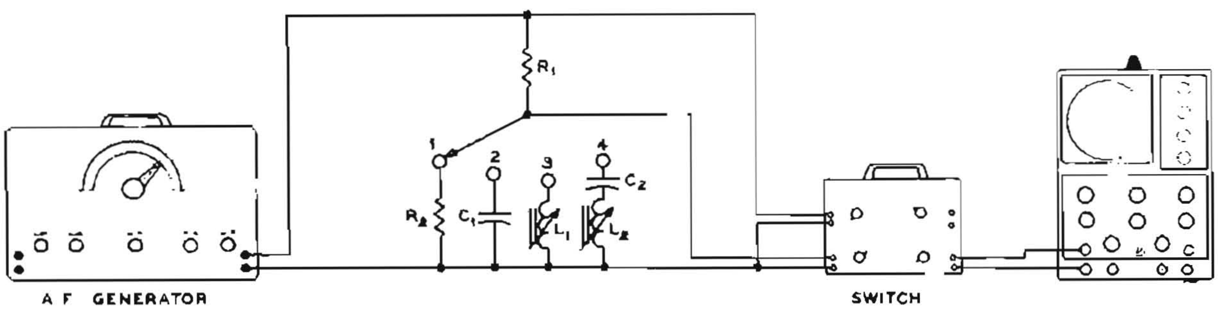


Figure 6-31

In position 4 of the switch in Figure 6-31, the inductor can be varied such that the RLC series circuit can be adjusted for resonance. This is shown by the in-phase relationship of current and voltage across the test components.

Common articles in the science classroom can be used with the oscilloscope to improve their demonstration effectiveness. Magnets can be used to deflect the electron beam of an oscilloscope showing the relationship between electricity and magnetism. This is discussed in Chapter 1 of Part IV.

Panel demonstration boards with power supplies, superheterodyne receivers, amplifiers, and other circuits can be effectively demonstrated by point-to-point examination with the oscilloscope.

Transient effects of opening and closing a DC circuit can be demonstrated with an oscilloscope, switch, and dry cells.

Induced voltages in inductors can be shown easily with an oscilloscope. This can be done in many ways. A coil of wire connected to the vertical inputs of an oscilloscope cut by magnetic lines of force will produce corresponding pulses on the screen. A small clock motor with its leads connected to the vertical input terminals and spun by hand will show the action of an AC generator. The phase inversion of a transformer can be demonstrated with a center-tapped filament transformer, electronic switch and oscilloscope. The Lissajous figures method for showing phase relationships can also be used.

Biology

The oscilloscope is not limited to the physical sciences. The oscilloscope can be used for any transient effect if a suitable transducer can be obtained.

The heart beat of humans and animals can be viewed with a microphone, high gain amplifier and oscilloscope. A hearing aid makes a convenient amplifier and microphone. The output of the hearing aid is applied to the vertical input of the oscilloscope and the hearing aid is applied over the heart area. A DC oscilloscope with a triggered sweep would give better results than a general oscilloscope for this demonstration.

CHAPTER 7

Waveform Photography

Waveforms can be photographed from the CRT screen of your oscilloscope with an ordinary camera. It is only necessary for you to be familiar with the camera and to observe a few basic rules. Scientists who do much photographic work with the oscilloscope use a special adapter hood and usually use a Polaroid attachment to obtain finished prints as quick as possible. This method will be discussed at the end of this chapter.

Still Camera Photography

One of the simplest methods of photographing an image on the face of the CRT is to use an ordinary camera in a dark room. All light must be eliminated from the room, except that which comes from the CRT. If the oscilloscope has a pilot light, it should be removed or covered with opaque tape; even this small amount of light might fog the picture. If the room cannot be completely darkened, Figure 6-32 shows a possible setup that might be used.

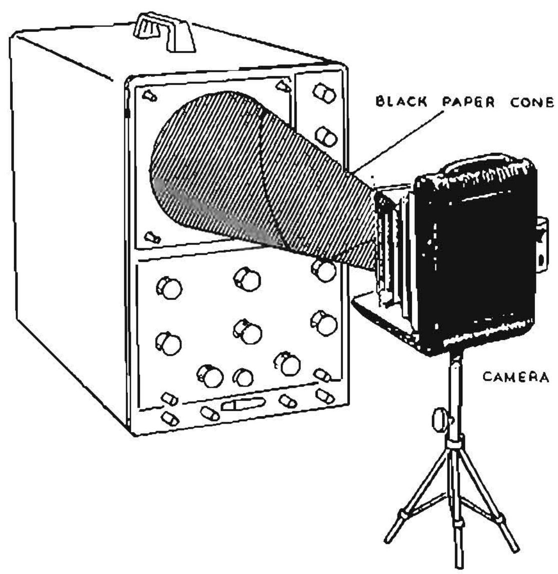


Figure 6-32

Type of Camera

One of the best types of cameras to use, other than Polaroid, is one with an adjustable lens and a device for removing one negative at a time. This type of camera is referred to as a "press" camera, or as a "view" camera. Its features include a ground-glass viewing screen so focusing can be accomplished easily. Most of these cameras take film that is 2-1/4" x 3-1/4" or larger.

If your camera is of the type that takes roll film and has an adjustable lens, pictures can still be taken, but you will have to wait until the whole roll is used before the pictures can be seen.

A simple box type camera can also be used if it has provisions for holding the shutter open for a period of time. Usually this is marked on the front of the camera as "time" or "T", meaning when the shutter release is pushed it will remain open until it is again pushed. "B" or "Bulb" means that when the shutter release is pushed, the lens will remain open only as long as the button is held. A box camera that has no adjustments for shutter speed, or exposure settings usually will not produce good oscilloscope pictures.

Type of Film

Generally, you should buy the fastest film available for your camera. The faster film requires less light going into the lens and striking the film. New faster film is continually being introduced; your photographic dealer should be consulted as to the most suitable type of film for your camera.

Taking Stationary Pictures

Usually no difficulty will be experienced in obtaining good quality pictures when photographing a stationary pattern on a continuous-running oscilloscope sweep. The camera shutter may be left open for as long as necessary.

Proceed then, by setting up the camera, preferably on a tripod or some other firm base. Focus the camera on the image. The view finder should not be used unless the camera is the kind that allows viewing through the lens. Focusing is accomplished before film is inserted into the camera. Most cameras have a back that is removable or partially removable. Remove the back and open the shutter and lens as far as possible. Take a piece of ground glass (or any translucent material such as wax paper) and place it as near the rear opening of the camera as possible. This will be approximately where the film would travel. See Figure 6-33.

Move the camera back and forth until the image is sharp and clear.

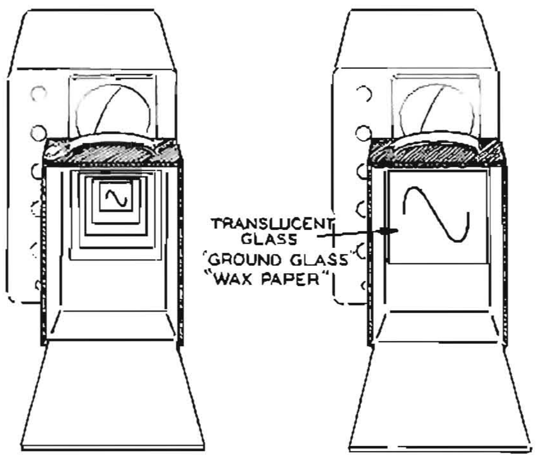


Figure 6-33

Shutter Setting

If the camera has adjustable speeds (1/100, 1/50, 1/25, 1/2, or 1 second) begin with the slowest speed (1 second). Or if the camera has "T" or "B" shutter control, use these first and begin with 5 to 10 seconds. Then decrease the time as you take each picture. Keep a record so when the film is processed the correct shutter speed can be determined for taking pictures in the future, making sure the same trace intensity is used.

Exposure

If the camera has an adjustable shutter opening (f stops, 2, 3.5, 4.5, etc.), begin with the widest opening your camera has. The lowest f stop number is the widest opening.

When the opening is not adjustable, use a longer shutter speed. Keep a record. The intensity control on the oscilloscope should be set about normal or a little above regular viewing brightness.

When the film is processed the prints will show which exposure is best.

Polaroid Cameras

Polaroid cameras offer the advantage of a finished print ready to use right after the picture is taken. Focusing can be accomplished in the same manner as described earlier, using wax paper or ground glass.

Exposure will vary depending on the type of film you use. Type 44 (10 second) film was used for the following pictures in Figure 6-34.

Exposure was f8 at four seconds. Polaroid cameras using the light value system of #10 to #17 should use #13.

If the print is too light, use a higher f stop number. If when the highest number is used, the print is still too light, use "time" or try a faster film (type 37).

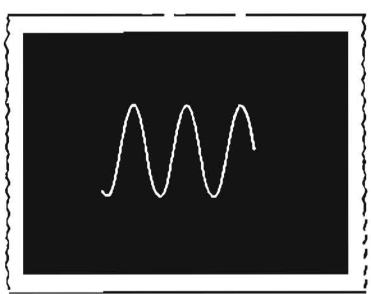


Figure 6-34

Double Exposures

If your camera allows the shutter to be opened and closed a number of times without advancing the film, a picture such as in Figure 6-35 can be made.

First take a normal flash or flood light picture of the oscilloscope with the CRT face covered with a circle of black paper. Then turn out all the lights and remove the black paper. Expose for a normal oscilloscope picture. When the film is processed you should have a picture of the trace plus the front of the oscilloscope. This also works for TV. To start with, use a 1/25 second shutter speed for the TV picture, after the overall picture of the set has been taken.

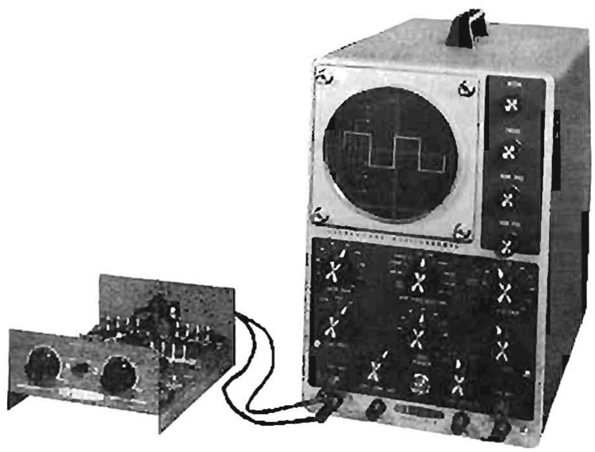


Figure 6-35

CHAPTER 8
Medical Applications

Medical uses of the oscilloscope are advancing rapidly. Someday the surgeon will view a room of CRT's and be able to see such things as brain waves, pressure in arteries and veins, muscle reactions, and a three-way view of the heart, all at a glance.

Much research is being done with the oscilloscope in medical schools, and more articles are appearing everyday on the new uses doctors have found for the oscilloscope.

Dentists may someday use a probe which when connected to an oscilloscope will enable the dentist to diagnose the unbalanced bite of his patient. A diamond-pointed probe transducer would be placed against each of the patients teeth and when he bites down, the pressure-sensitive transducer connected to the diamond point would send an electrical signal voltage to the vertical plates of the oscilloscope. With internal sweep voltage applied to the horizontal plates, patterns like the ones in Figure 6-36 would show the condition of the patients bite.

Electroencephalography

An electroencephalograph (EEG) is a permanent record of brain waves. Often this is done on a recording oscillograph which uses a continuous strip of paper and a sensitive amplifier to control a marking pen.

A radioelectroencephalograph is a device which allows the patient to move around while his brain waves are being recorded. The brain waves are picked up by scalp electrodes, and then amplified and transmitted by a small radio transmitter carried by the patient. The whole package that the patient wears might be transistorized.

The transmitted signal is picked up by a radio receiver, the brain waves are then sent either to the vertical input of an oscilloscope or to an oscillograph. Figure 6-37 is a block diagram of a radioelectroencephalograph.

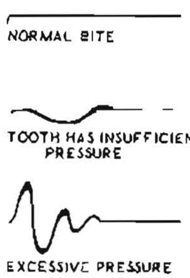


Figure 6-36

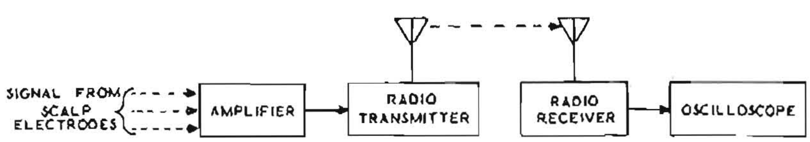


Figure 6-37

Cardiography

Vectorcardiography is an electrically recorded view of several different planes of the heart. An electrocardiogram (ECG or EKG) is an oscillograph (pen recording) of electrical changes caused by the heart.

As the heart contracts and relaxes, electrical energy is created by the cell membrane. Voltage is created each time a muscle membrane contracts. When the heart relaxes the discharge of the electric current must be built up again. The heart might be considered as a capacitor in the build up and discharge of electrical current.

The electrocardiograph shows the result of all electrical forces generated by the heart in each instant. In vectorcardiography, a special oscilloscope is used to actually view each vector (direction) of current flow in the heart. The pattern on the face of the CRT may take a shape similar to an elliptical view. This pathway of current as the heart discharges is called a QRS loop, or vectorcardiogram. The vectorcardiograph machine may also have an electric shocking device which, in case of cardiac arrest (heart stoppage) will apply a controlled stimulating voltage to the heart by the anesthetist.

Neurophysiology

In the biology classroom or medical school, the standard instrument for recording muscle and nerve activity is the kymograph. However its use is limited because it is a mechanical device and the inertia needed to start the device sometimes means the immediate loss of vital information. The oscilloscope with its almost inertia-free electron beam allows viewing these reactions microseconds or fractions of microseconds after they occur. To record the action potential of a muscle of a live frog, for instance, the oscilloscope becomes the recording device; a stimulator (voltage source) and a preamplifier are needed. The muscle reaction creates a small signal voltage that can be taken directly from the muscle with wires or probes. Because some oscilloscopes do not have the required sensitivity to measure the signal directly, a preamplifier is needed. One with a 10-times gain should be sufficient for most general purpose oscilloscopes. Figure 6-38 shows a setup that might be tried. Set the oscilloscope sweep frequency as necessary for a trace that shows the whole duration of the signal.

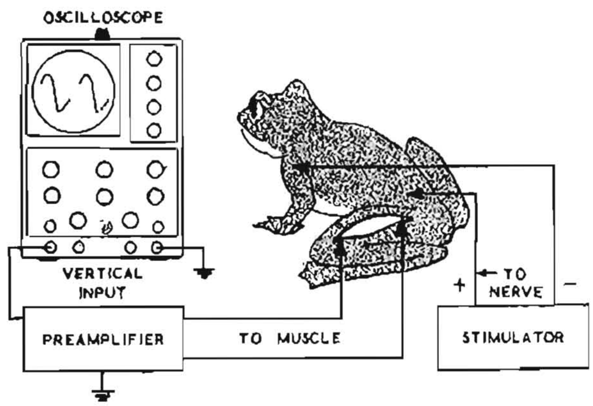


Figure 6-38

BIBLIOGRAPHY

Additional details on many of the subjects covered in this book can be obtained from the following publications. Other books on oscilloscopes can probably be found in your local library.

Heath Company Educational Series
Heath Company
Benton Harbor, Michigan

Heath Company Technical Applications Series
Heath Company
Benton Harbor, Michigan

"A Catalog Of Equipment For Oscillography"
Allen B. DuMont Laboratories, Inc.
Clifton, New Jersey

"Basic Theory And Applications Of Transistors"
TM-11-690
For sale from:
Superintendent Of Documents
U.S. Government Printing Office
Washington, D.C.

Hass, Alfred
"Oscilloscope Techniques"
Gernsback Library, Inc.
New York, New York

Middleton, Robert G.
"101 Ways To Use Your Oscilloscope"
Howard W. Sams
New York, New York

Middleton, Robert G.
"101 Ways To Use Your Scope In TV"
Howard W. Sams
New York, New York

Rider, John F. and Uslan, Seymour D.
"Encyclopedia On Cathode Ray Oscilloscopes And Their Uses"
John F. Rider Publisher, Inc.
New York, New York

Ruiter, Jacob H.
"Modern Oscilloscopes And Their Uses"
Murray Hill Books, Inc.
New York, New York

GLOSSARY OF ELECTRONIC TERMS

This glossary should assist you with some of the more unfamiliar terms used in the EF-2 text. These definitions of terms apply to electronics in general, but in many cases specifically refer to their use in the EF-2.

Accelerating anode. One of the electrodes of the CRT electron gun. It is used to accelerate the electron beam before it is deflected.

Alignment. Adjustment of circuits to pass specified frequencies.

Alternating Current (AC). An electrical current that reverses its direction of flow at regular intervals.

Ampere. Unit of measurement of electrical current flow. One ampere equals 6.25×10^{18} electrons passing a given point in one second.

Amplitude. The quantity of voltage or current of a waveform.

Anode. The plate electrode, as in a tube.

Aquadag. A black conductive coating on the inside bulb of the CRT. It is connected electrically to the accelerating anode.

Astigmatism. A CRT focusing defect.

Atom. The fundamental particle of an element.

Attenuation. Reduction of the amplitude of a signal.

Audio Frequency (AF). Electrical signals within the hearing ability of the human ear. This range of frequencies is nominally 20 to 20,000 cycles per second.

Base. A transistor section that corresponds to the grid of an electron tube.

Bias. A fixed DC voltage used to establish an operating point in a circuit; as in the grid bias of a tube.

Blanking. The process of decreasing the intensity of the electron beam in a CRT such that the trace cannot be seen. This is done generally on retrace, or for time marking.

Capacitor. An electronic circuit element capable of storing electrical energy.

Cathode. In a vacuum tube, it is the electron-emitting electrode.

Cathode Follower. A vacuum tube circuit with a gain of less than 1, used for impedance matching.

Charge. A quantity of electricity.

Coupling. Association of two or more circuits in such a way that power may be transferred from one to another.

cps. Cycles per second.

Crystal diode. A two-element device capable of passing an electrical current in one direction only. Consists usually of germanium or silicon.

Current. Generally the movement of electrons through a conductor. Movement of "holes" can constitute current flow in transistors.

Cycle. A complete oscillation.

Decoupling. Reduction of coupling.

Deflection. Either magnetic - or electrostatic - caused change in direction of the electron beam in a CRT.

Degeneration. Negative feedback.

Detection. The process, in a receiver, that separates the intelligence being transmitted from the carrier frequency.

Direct Current (DC). An electric current that flows only in one direction.

Distortion. The result when a signal is given an undesired change in an electronic circuit.

Electrons. Small electric particles orbiting about the nucleus of an atom.

emf. Electro-motive-force. See voltage.

Farad. The unit of capacitance. A million microfarads (µfd) equals one farad.

Feedback. The process of feeding a portion of the output signal back to the input of an electronic circuit.

Filtering. The process of eliminating or reducing the AC ripple in a rectified current.

Fluorescent screen. The coating on the inside of the face of the CRT, which glows when hit by an electron beam.

Frequency. The number of cycles per second.

Graph. A line drawing that shows the relationship between two or more quantities, such as voltage and time.

Grid. The electrode in a vacuum tube that is used to control the current from cathode to plate.

Ground. The reference point from which voltages are generally measured.

Heater. An electrical element in a vacuum tube for supplying heat to an indirectly-heated cathode.

Henry. The unit of inductance for a coil.

Impedance. The total opposition to the flow of alternating or pulsating current in an electronic circuit.

Inductance. The property of a coil that enables it to store electrical energy.

Interelectrode capacitance. The small capacitance between the metal electrodes in a vacuum tube.

Kilo-(K). A prefex meaning 1000 X; such as a kilocycle equals 1000 cycles.

Linear time base. The sweep voltage for the CRT which changes uniformly with time.

Lissajous figures. Figures produced by applying harmonically-related sine waves to both the vertical and horizontal plates of the CRT.

Meg-(M). A prefex meaning 1,000,000 X. A megacycle is a 1,000,000 cycles.

Meter. An electrical measuring instrument.

Network. A combination of interconnected circuit elements.

Neutrons. A neutral particle in the nucleus of an atom.

NPN Transistor. A semiconductor device with a P-type section sandwiched between two N-type sections.

Ohm (Ω). The unit of electrical resistance.

Ohm's Law. The relationship between resistance, voltage, and current. The product of current and resistance equals the voltage.

PDC. Pulsating direct current.

Peaking coil. A small inductor used to extend high frequency response.

Peak-to-peak (p-p). The voltage measure of a waveform from the maximum value in one direction to the maximum value in the other direction.

Pentode. A five-element vacuum tube.

Phase. An expression that refers to the fractional amount of the time period of one cycle that has elapsed since the quantity passed through the zero reference point. Usually expressed in degrees.

Plate. The common name for the anode of a vacuum tube.

PNP transistor. A semiconductor device with a N-type section sandwiched between two P-type sections.

Polarity. The characteristic of having two opposite charges, plus and minus.

Potentiometer. Mechanically changeable variable resistor.

Protons - Positive charged particles in the nucleus of the atoms.

Pulse. A change of current or voltage of very short duration.

Push-pull amplifier. A two-tube or transistor amplifier, each operating 180 degrees out-of-phase with the other.

Radio frequency (RF). Those frequencies employed for the transmission of radio signals; from 10 kilocycles to 1,000,000 megacycles by government regulation.

Reactance. The opposition of inductance and capacitance to the flow of alternating or pulsating current, the imaginary part of impedance.

Rectifier. A circuit element that changes AC to DC.

Regeneration. Positive feedback.

Retrace time. The length of time for the electron beam to return from the end of one sweep to the start of the next sweep in a CRT.

Rise time. The time it takes for a pulse to increase from 10% of its maximum value to 90% of its maximum value.

rms. Root means square; the effective value of alternating current that corresponds to the value of direct current that will produce the same amount of energy in heat.

Schematic. Symbolic drawing of an electronic circuit.

Screen grid. A grid placed between the control grid and plate to decrease interelectrode capacitance in a vacuum tube.

Semiconductor. A material whose resistivity is between that of metals and insulators.

Shunt. A component that is connected in parallel with another circuit device.

Signal. A varying voltage.

Synchronization (sync). The process of putting the sweep voltage in step with the signal in an oscilloscope.

Suppressor grid. A grid placed between the plate and the screen grid to minimize secondary emission.

Sweep voltage. The voltage that produces horizontal deflection in a CRT.

Tetrode. A four-electrode vacuum tube.

Time base. The sweep voltage (for the CRT) which is proportional to time.

Triggered sweep. A sweep that starts only when an outside signal is applied. It occurs for one sweep cycle only and must be started again.

Triode. A three-electrode vacuum tube.

Transducer. A device that converts energy, such as mechanical energy, to another form, such as electrical energy.

Transient. A signal that occurs only once for an initial set of conditions.

Transistor. A semiconductor device for rectification and/or amplification.

Tuned Circuit. A circuit with capacitance, and inductance adjusted to a specific resonant frequency.

Voltage. The electrical pressure that causes current to flow in a circuit.

Voltage regulator. A device to maintain a constant voltage across a circuit.

Watt. A unit of energy consumption. Electrically, one watt equals one volt times one ampere.

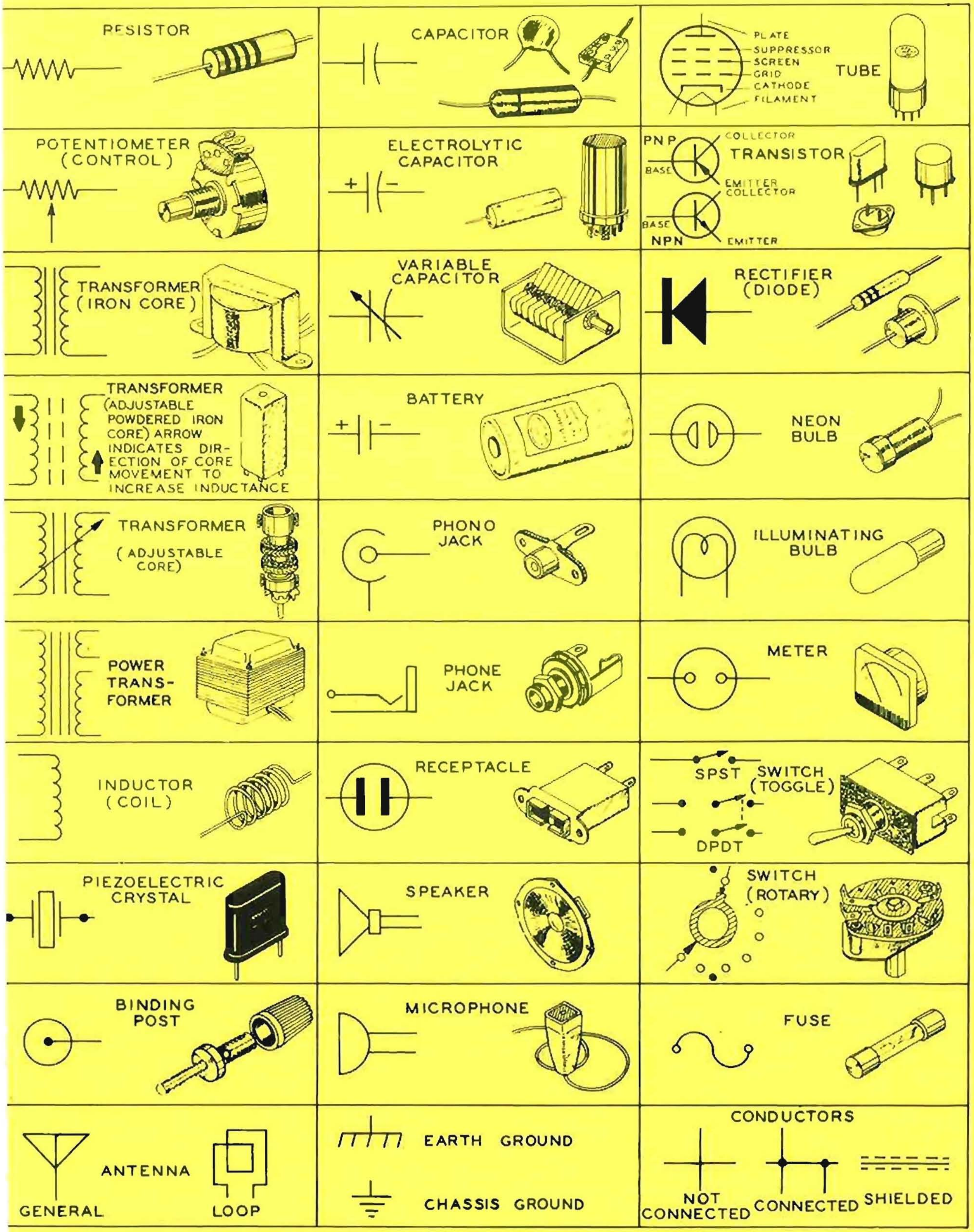
Waveform. Graphic representation of a signal.

Wave envelope. The outline of a high frequency waveform.

Z-axis input. Connection to the CRT control grid for intensity modulation.

TYPICAL COMPONENT TYPES

ıis chart is a guide to commonly used types of electonic components. The symbols and related illustrations should prove helpful in identifying most parts and reading the schematic diagrams.



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