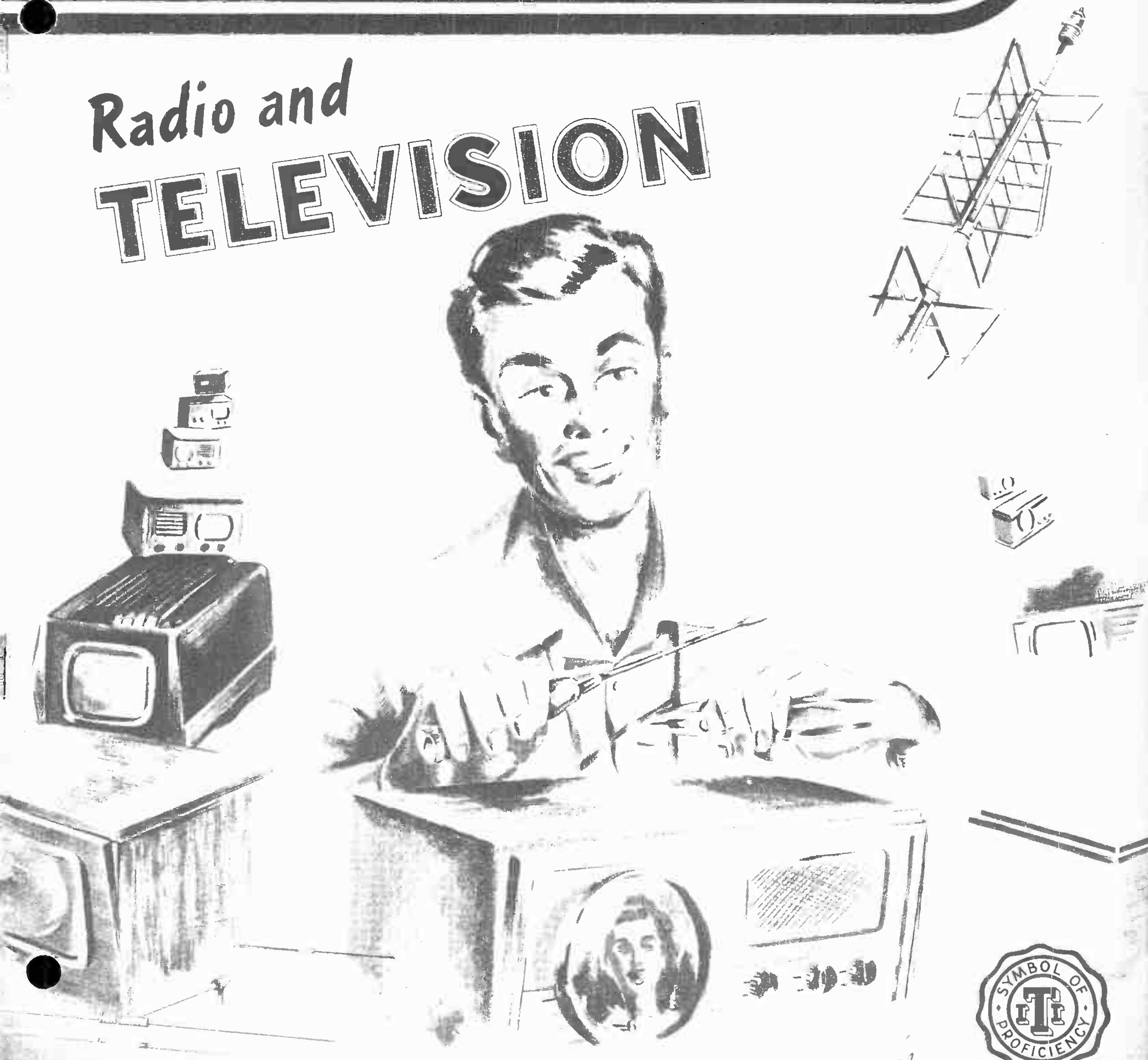
Technical Training
SERVICE

Radio and TELEVISION



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INDUSTRIAL TRAINING INSTITUTE
CHICAGO, ILLINOIS

RADIO AND TELEVISION LESSON AND SUBJECT LISTING - 1

This lesson-subject listing for your first twenty (20) lessons will enable you to study and keep in order, the assignments you receive from us. In addition, it serves as a splendid index to locate subject material you may wish to find later.

These lesson-subject listings will be sent to you from time to time as you progress in the Course. There will be seven (7) in all. Keep them together for ready reference. Be sure to study the lessons in this sequence.

At this time, you receive twelve (12) of the assignments -- more will be sent as you submit successive examinations to us for grading.

LESSON NUMBER	TITLE AND CONTENT
1	Introduction to Radio and Television History of Communications - Wireless Communications - Wave Motion - Wave Lengths - Radio Waves.
2	Fundamentals of Electricity Conductors and Insulators - Things Affecting the Flow of Electricity - Current Measurement - The Electric Current - Diagrams of Circuits - Electrical Pressure - Source of Potential.
3	Electrons Introducing the Electron - The Atomic Theory - Early Attempts to Put the Electron to Work - Vacuum Tubes.
4	Electrical Resistance How Conductors Hinder Current Flow - Measuring Cross-Sectional Area - Effect of Conductor Material on Resistance - Effect of Temperature on Resistance - Hot and Cold Resistance - The Ohm-Electrical Symbols and Diagrams - Series Circuit - Resistance in a Series Circuit - Putting Resistance to Work.
5	Magnetism Early History of Magnetism - Kinds of Magnets - Magnetic Lines of Force - The Earth as a Magnet - Why Iron Becomes a Magnet - Inducing Magnetism in Soft Iron - No Insulators for Magnetism - The Magnetic Field Around an Electric Current - Magnetic Field Around a Coil - The Electromagnet - Moving and Static Lines of Force - Magnetic Terminology - The Gauss - Permeability and Reluctance - Magnetomotive Force and Ampere-Turns.
6	Electromagnetic Induction Factors Affecting the Induced Voltage - How Lines of Force Move - Induced Voltage from Moving Lines - Causing the Lines to Expand and Contract - Varying the Primary Current - Mutual Induction - Direction of Current Flow in the Primary and Secondary - Self-Induction - Measuring the Effect on Self-Induction - Eddy Currents.

LESSON NUMBER	TITLE AND CONTENT
7	Ohm's Law Ohm's Law - Other Uses for Ohm's Law - What Ignorance of Ohm's Law Can Do - Ohm's Law and Voltage Drop - Short Forms of Ohm's Law - More About Resistors - Wire Wound Resistors - The Resistor Code.
8	Electrical Power Power - Work - Work and Power - Measuring Mechanical Power - Energy - Power in Moving Electricity - Voltage - Amperes and Power - The Unit of Electrical Power - Power Consumed in Electrical Devices - Measuring Electrical Power - Large and Small Units - Converting Electrical Power into Mechanical Power.
9	Direct Current and Alternating Current Currents in Radio and Television - Direct Current - Direction of Current Flow - The Dry Cell - Dry Cell Construction - Dry Cell Performance - Connections of Dry Cells - Other Sources of Direct Current - Alternating Current - The Sine Wave - Opposition to the Flow of Alternating Current.
10	Transformers Where Transformers are Used - Types of Transformers - Direction of Induced Voltage and Current - Strength of Induced Voltage - Secondary Current - Television Power Transformers - Audio Frequency Transformers - Intermediate Frequency - Intermediate Frequency Transformers.
11	Capacitors Construction of a Capacitor - Where Capacitors are Used - What Capacitors Do - How Capacitors Operate - Action of Capacitors in Alternating Current Circuits - Capacity - Capacitive Reactance.
12	Vacuum Tubes Electrons in the Vacuum Tube - Electron Emission - Thermionic Emission - Indirectly Heated Cathodes - The Electrostatic Field - The Space Charge - Electrostatic Fields - Arrangement of the Vacuum Tube Elements.
13	The Diode Rectifier Cathode Emission - Charting Cathode Emission - Making a Graph - Using the Information From the Graph - Temperature Saturation - Effect of Anode Voltage - Voltage Saturation - Effect of Negative Anode Voltage - Vacuum Tube Rectifiers - Filters - The Filter "Choke" - The "Pi" Filter - Full-Wave Rectifiers - The Duodiode - Filter Capacitors.
14	Vacuum Triodes The Grid - Triode Symbols - Action of the Grid - Effect of Anode Potential on Anode Current with "Zero" Grid - Effect of Anode Potential on Anode Current with Negative Grid - Putting the Graph to Use - Families of Curves - The Triode as an Amplifier - Tube Conditions Which Affect Amplification Factor - Names of Tube Voltages and Currents.

LESSON NUMBER	TITLE AND CONTENT
15	Multi-Grid Vacuum Tubes Interelectrode Capacitance - The Tetrode - Secondary Emission - The Suppressor Grid - What the Suppressor Grid Does - Electrostatic Fields Within a Pentode - Amplification Factor of Pentodes - How the Suppressor Grid is Connected - Beam Power Tube - Tube Constants - Plate Resistance - Transconductance (Mutual Conductance).
16	Series and Parallel Circuits Advantages of Parallel Connections - Series Connections - Where Series Connections Cannot be Used - Current in Series Circuits and Parallel Circuits - Effective Resistance - Unequal Resistances in Parallel - The Reciprocal Method of Finding Effective Resistance - Tapped Resistors in Parallel - Increasing the Range of a Meter - Another Method for Determining Effective Resistance - Finding the Value of One Parallel Resistor When the Other is Known - Series-Parallel Circuits.
17	Vacuum Tube Amplifiers Relative Values of Anode Current - Dynamic Characteristic Curves - Phase Inversion - Methods of Obtaining Grid Bias - Cathode Bias - Degeneration - By-pass Capacitor - Stage Gain - Power Amplifiers - Load Lines.
18	Coupling Circuits Types of Coupling - How Transformers are Used for Coupling - A-C Component and D-C Component - Step-Up Coupling Transformers - Limits to Stepping Up the Amplification - High Frequencies and Low Frequencies - Resistance Coupling - Using a Capacitor - Advantages and Disadvantages of Resistance Coupling - Where Transformer Coupling is Always Used - Resistance Coupling Action, Step by Step - Successive Stages of Amplification - Impedance Coupling - Cathode Follower.
19	Oscillators The Armstrong Oscillator - Feedback - Oscillator Frequency - Oscillator Grid Bias - Hartley Oscillator - Hartley Series Fed Oscillator - The Electron Coupled Oscillator - Comparing Frequencies.
20	Electrolytic Capacitors Special Features of the Electrolytic Capacitor - The Factors of Capacity - Capacity Factors in an Electrolytic Capacitor - Voltage Breakdown - The "Forming" Process - The Electrolytic Capacitor at Work - The Electrolytic Capacitor as a Filter - Action of C-2 - Action of C-1 - Current Through the Load - The Electrolytic as a Cathode By-pass - Multiple Section Electrolytics - Power Factor in Electrolytics - Defective Electrolytics - Testing for Defective Electrolytic.

Please send in only two examinations each time. Hereafter you will be sent two new lessons for each two examinations you send in for grading.

F. L. Howard

INDUSTRIAL TRAINING INSTITUTE
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RADIO AND TELEVISION LESSON AND SUBJECT LISTING - 2

Here is the lesson-subject listing for lessons 21 to 30 inclusive.

There will be five (5) more of these lesson-subject listings. Arrange them in order for greatest usefulness as a study guide and index.

LESSON NUMBER	TITLE AND CONTENT
21	Sawtooth Oscillators Voltage in a Capacitor - A Gaseous Discharge Tube - Time Constant - Tapping Off the Generated Voltage - Thyratron Oscillator - The Multivibrator - Action of the Multivibrator - Tube and Socket Identification.
22	Cathode Ray Tubes The Cathode Ray Tube - Deflection - Frequency of Deflection - Vertical Sweep - Field and Frame - Blanking and Synchronizing Circuits - Vertical "Sync." - Raster and "Aspect Ratio" - Electromagnetic and Electrostatic Deflection - Retrace and Flyback.
23	Resonant Circuits Mechanical Resonance - Resonant Frequency of Pendulums - Electrical Resonant Circuits - Effect of Frequency on Inductance - Effect of Frequency on Capacitance - More About Capacitive and Inductive Reactance - Effect of Capacitance and Inductance in the Same Circuit - Resonance - How to Find the Resonant Frequency by Calculation - The Resonance Curve - The Circuit "Q" - The Parallel Resonant Circuit - Variable Tuned Circuit.
24	Impedance Nature of Impedance - Pythagorean Theorem - Combining Resistance and Reactance into Impedance - Why We Can Use Pythagoras' Theorem to Find Impedance - Combination of Resistance and Capacitive Reactance - Combining Capacitive Reactance, Inductive Reactance and Resistance - Impedance Matching - Ohm's Law for A-C - Power Transfer Through Impedance Match - Impedance Matching by Transformer Action - Low Pass Filters - High Pass Filters - Band Pass Filters.
25	The Pentagrid Converter Radiating Oscillator - Grounding - Carrier Wave - Modulation - Biasing Points - Systems for Amplifying Radio Signals - Mixer Circuits - The 6A8 Tube - Triode Heptode Converter.
26	Harmonics Harmonics of Sound - Harmonics in Electrical Work - More About the Frequency Doubler - Class "C" Biasing - The Tri-Tet Oscillator - Image Frequency - Trouble from Harmonics - Other Troubles from Harmonics.

LESSON NUMBER	TITLE AND CONTENT
27	Types of Receivers Basic Requirements - The Tuned Radio Frequency Receiver - Volume Control - The Superheterodyne Radio Receiver - Console Model Radio Receivers - Table Model Radio Receivers - Portable Radio Receivers - Automobile Radio Receivers - Communications Receivers.
28	Test Equipment The Volt-Ohm-Milliammeter - Vacuum-Tube-Voltmeter - The Signal Tracer - Signal Generator - The Tube-Checker - Capacity Analyzers - Using Radio and Television Test Equipment - How to Use the Tube-Checker - When to Use the Tube-Checker - How to Use the Voltmeter - When to Use the Voltmeter - How to Use the Ohmmeter - When to Use the Ohmmeter - Precautions in the Use of the Ohmmeter - How to Use the Milliammeter - When to Use the Milliammeter - How to Use the Signal Generator - How to Use the Signal Tracer - Frequency Modulated Generator - TV Antenna Compass.
29	The Oscilloscope The Incredible Oscilloscope - Applications of the Oscilloscope - The Sections of an Oscilloscope and Their Functions - A Statement of the Problem - Applying the Oscilloscope to the Problem - The Cathode Ray Tube - Deflection Plates - Voltages on Both Sets of Plates - Other CR Tube Elements - The Sweep Section of the Oscilloscope - The Vertical Amplifier - The Power Supplies - Genescope.
30	Using the Oscilloscope Getting Acquainted With the Oscilloscope - Applications to Radio Receivers - Using the Oscilloscope as a Voltmeter - Measurement of High Frequency Voltages - Measuring Gain in the Radio Frequency Stages of a Receiver - Aligning Superhet Receiver and Setting I-F Band Width - Measuring High Voltages - Other Radio Receiver Tests.

TECHNICAL TRAINING SERVICE

REVISED 1953

RADIO TELEVISION

INTRODUCTION TO RADIO AND TELEVISION

Contents: Introduction - History of Communications - Wireless Communication - Wave Motion - Wave Lengths - Radio Waves - Notes for Reference.

Section 1. INTRODUCTION

Radio and Television are today so much a part of the American way of living it is hard to realize there was a time when they did not exist. Radio, especially, has found its way into almost every home in the land. There are actually more radio receivers in operation than there are homes. This is true because so many homes have two or more, and because so many families have a radio receiver in their automobile in addition to those in their homes.

When most people speak of a radio they usually have in mind the large console combination radio receiver and record player which is to be found in the living room of so many homes. Or possibly they are thinking of the smaller table model so frequently found in the kitchen or in the children's rooms, or even downstairs in the recreation room. It is even possible they are referring to the radio receiver in the automobile. It is these types of radio receivers with which most people are familiar. All these types are important, partly because there are so many of them, and partly because they contribute so much pleasure to so many people.

Actually there are many other kinds of radio receivers in daily use which play an even more important, if less well known, part in our daily lives. The transcontinental airliner flying at 300 and more miles per hour through foggy or snow-laden skies is completely dependent upon radio for the safety of its passengers. The business man on the trans-Atlantic steamer who picks up the telephone in his stateroom and talks to his office back in the United States is making another use of radio. The locomotive engineer, who phones from his moving train to his conductor in the caboose, the operator at the way-side station, or the dispatcher back at the terminal, is making still another use of the radio.

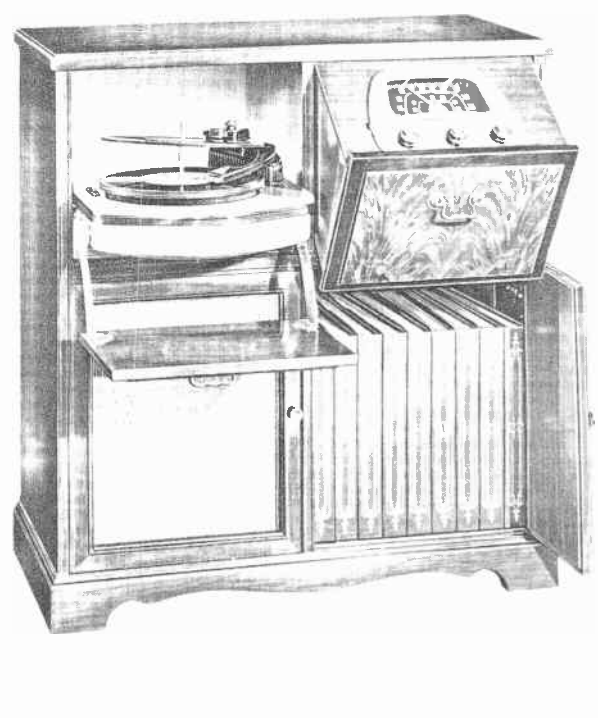

Fig.1. Console Type Radio Receiver. (Courtesy of Admiral Radio Corp.)

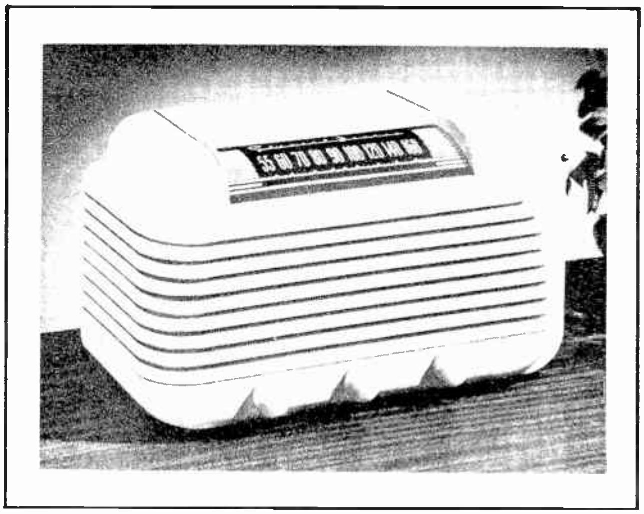

Fig. 2. Table Model Radio Receiver. (Courtesy of Stewart Warner.)

Although most people are familiar with the radio-equipped police squad cars and the radio-dispatched taxi-cabs, not so many know that fire trucks, highway busses and trucks, public utility repair trucks, forest rangers, private automobiles of physicians and some business men, supervisors of street cars and busses, as well as many others, also utilize radio to keep in touch with their office or other headquarters.

In much the same way when most people mention the television receiver, they have in mind the big console model standing beside the radio in their own living room, or in the home of a neighbor. It is possible of course, that they might be thinking of one of the smaller table model receivers.

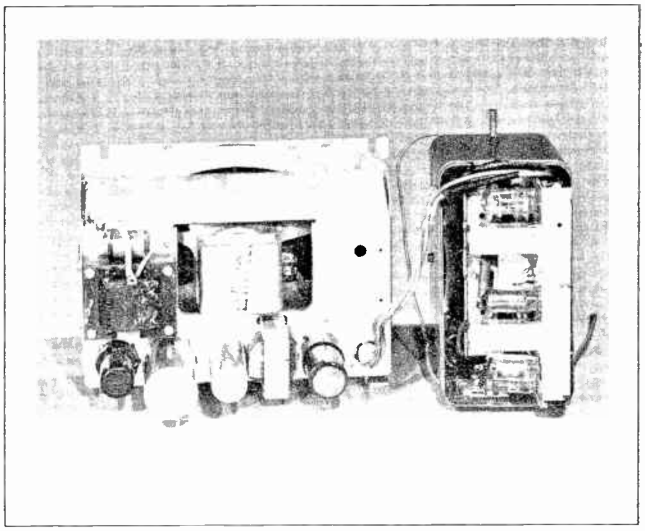

Fig. 3. Type of Radio Receiver for use in Automobiles. (Courtesy Delco Radio Corp.)

But very few would be thinking of the many television receivers which are used in the hospitals so that medical students and interns can watch the famous surgeons perform delicate and difficult operations. Where only a half dozen or so students could observe such operations a few years ago, and even then had to remain at such a distance they could scarcely see, it is now possible for hundreds of students to watch the progress of an operation. And they can now observe the details much more clearly than was formerly the case. Probably no other

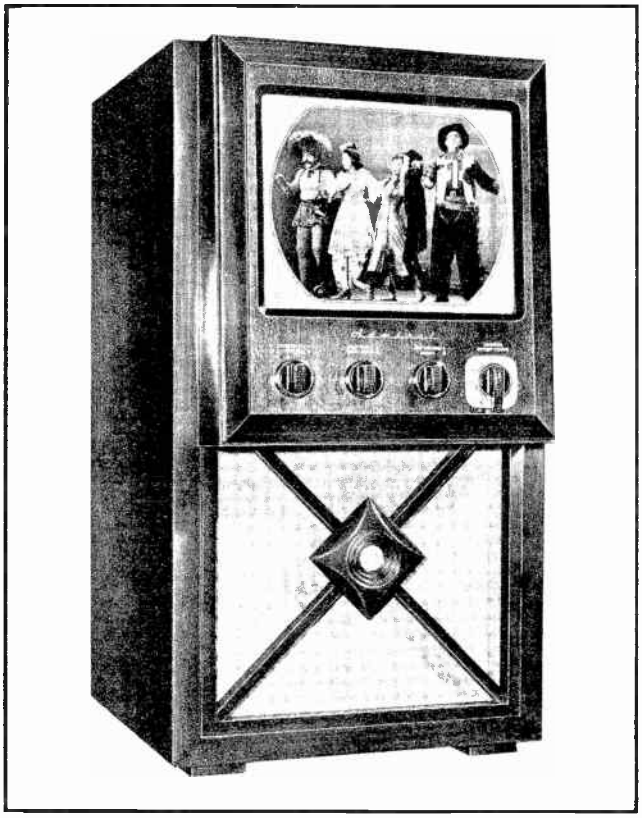

Fig. 4. Console Type Television Receiver. (Courtesy of Admiral Radio Corp.)

invention in recent years has contributed so much to medical knowledge as has television.

Somewhat less dramatic, but nonetheless useful, has been the introduction of television into the supervisory control of large manufacturing plants. In the properly equipped plant it is now possible for the manager to maintain complete control over every portion of the plant, no matter how remote it might be from his office. Television supervisory control has already demonstrated its usefulness. It is expected that within relatively few years

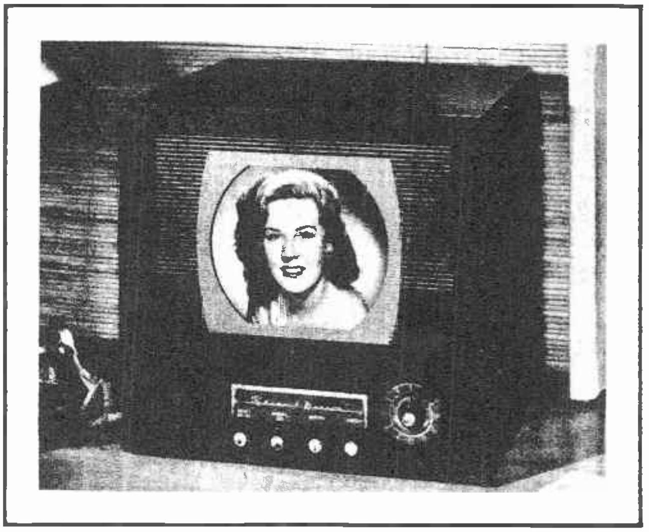

Fig.5. Table Model Television Receiver. (Courtesy of Stewart Warner Corp.)

every large manufacturing plant in the country will make use of its advantages.

With radio and television occupying such an important place in our lives, it is extremely hard for us to realize what a short time we have had them with us. Although most of us think of the automobile as being a relatively new thing, we had the automobile for more than twenty-five years before the first radio found its way into an American home. Our parents and grandparents easily remember back to the days when the radio first thrust itself into our consciousness, and quickly made itself indispensable to us.

The important thing for us who are in radio, and for those who want to get into it, is that if radio can grow from nothing to the tremendous place it now occupies in our lives in such a short time, what is going to happen to radio in the future? Even though radio does not continue to grow in importance at the same spectacular rate of the past years, it is reasonable to expect that much expansion is in store in the years ahead.

Despite the almost phenomenal growth of television in the years since the recent war, it is the belief of those who are close to television that the surface of the possibilities of that field have been barely

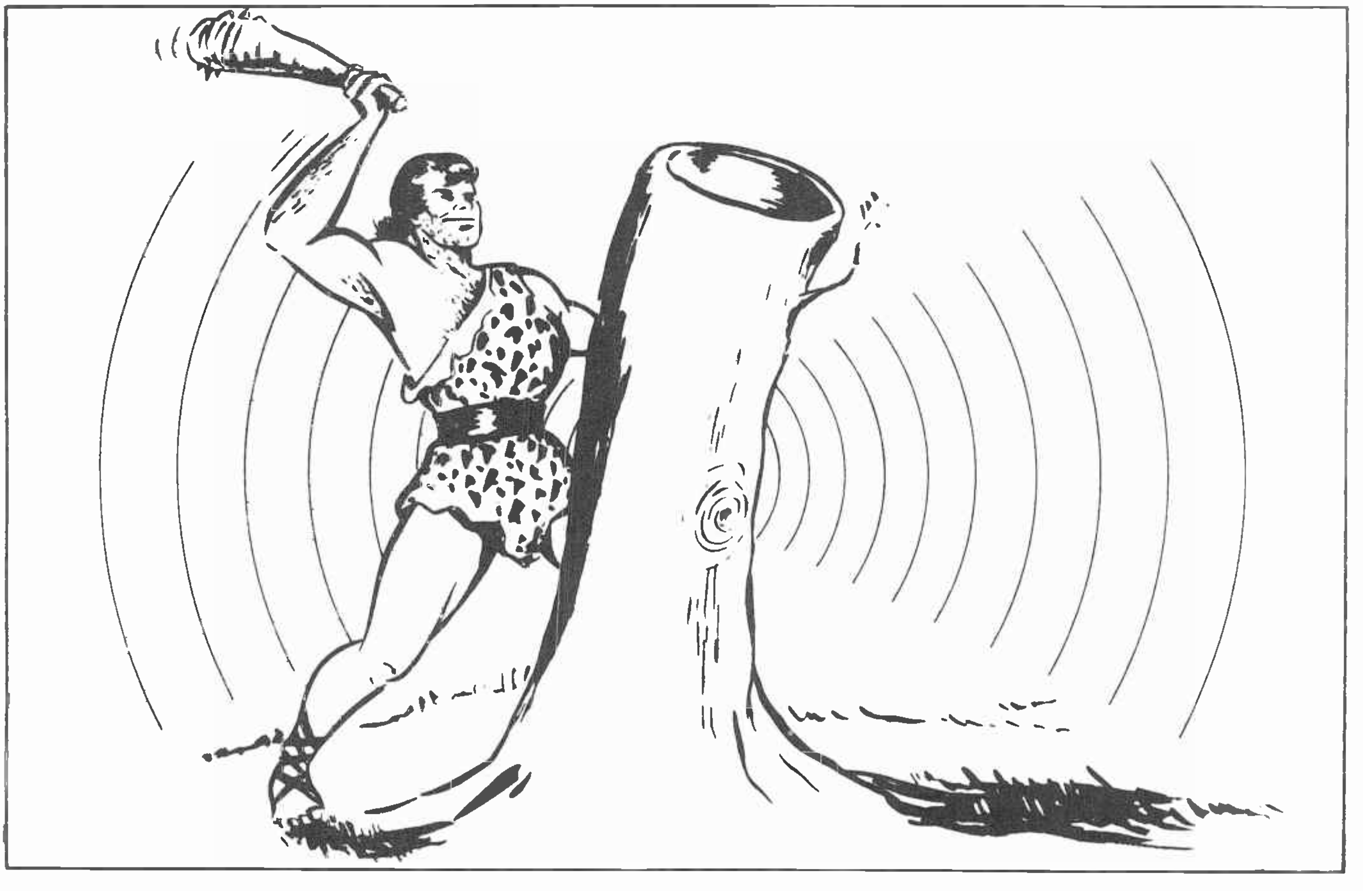

Fig.6. Primitive "Long Distance" Communication.

Fig.7. "Signal Drums" such as are still in use in some parts of Africa.

scratched. One of the worst retarding forces to even greater expansion of television has been the inability to obtain trained technicians to build, and to install and service television receivers for those people who want to buy them. There is probably no other field of endeavor which offers more to a young man than that of radio and television.

Everything about radio or television is intensely interesting. Many business men find radio so interesting that they spend their own money to make radio a personal hobby. How fortunate then is the man who can work at it, and actually get paid for the work.

Section 2. HISTORY OF COMMUNICATION

The dawn of communication between man and man has been lost in antiquity. It is reasonable to presume that ever since man has been able to make a sound, he has attempted to transmit messages over ever increasing distances. The first "long distance" message was probably a shout by one primitive man directed toward another.

Nobody knows how many centuries passed before man discovered that he could make himself heard over greater distances by beating on a hollow tree with a club. But after making such a discovery, he gradually worked out a means of communicating with a distant neighbor by a system of signals. Among the primitive tribes of Africa a system of communication by beating on specially prepared drums still exists, and has reached a high degree of development.

Primitive man also used the sense of sight to communicate over distances too great for the human voice to carry. The American Indians perfected an elaborate system of smoke signals by means of which they could send their messages relatively long distances.

Military men designed a method of reflecting the sun's rays by means of mirrors, and then blinking this reflected light in accordance with a signal code. This method of communication was called the Heliograph. It was widely used during the American Civil War and the Spanish-American War. It was still used to some extent during the first World War, but its usefulness had begun to decline by that time.

So it can be seen that since the beginning of time man has been striving to develop newer and better means of communicating with one and another. It will be noted that all of the methods of communication which have been described have one fault in common, they are useful over only comparatively short distances. A few miles is at best, their greatest range.

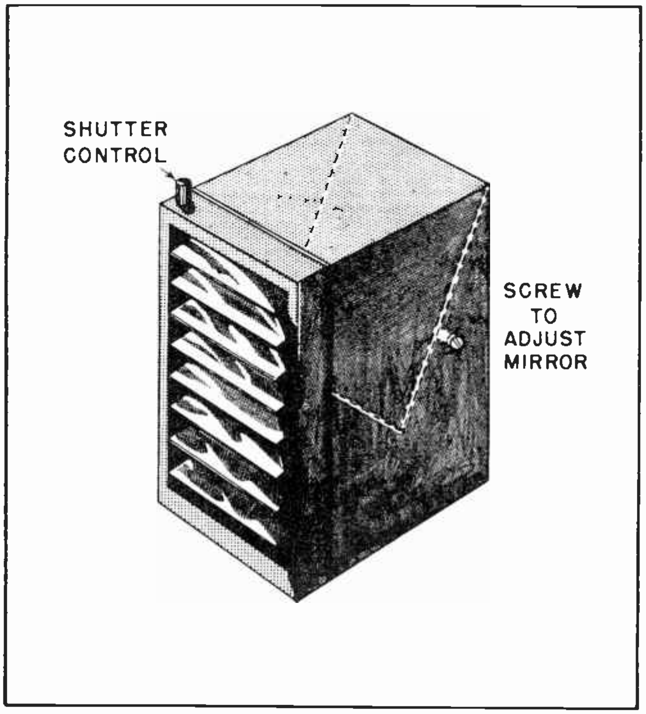

Fig.8. Heliograph.

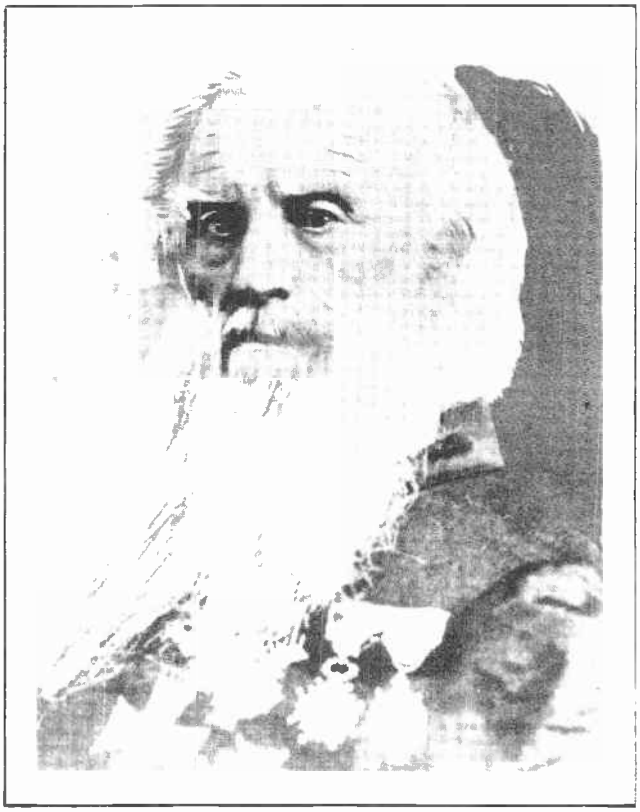

Fig.9. Samuel F. B. Morse, Inventor of the Telegraph. (Courtesy of Western Union.)

During the thousands of years man has inhabited the Earth, and his persistent attempts to devise better means of communication, it was not until a little over a hundred years ago that a really big improvement was obtained. It was in 1832 that Samuel F. B. Morse finally perfected the electric telegraph which made it possible to communicate over a relatively long distance by means of electrical impulses which were sent along a wire. The electrical impulses operated an electromagnet which moved an iron bar between two stops. The movement of the iron bar created audible clicks which, by means of a special code, could be translated into words.

For the first time man could communicate over really long distances. He was no longer limited by his own sense of sound and sight. Wires could be strung from city to city, and from village to village. Over the wires the electrical impulses could be transmitted at the speed of light. The incredible speed of 186,000 miles per second.

Thirty-four years later, in 1866, after several expensive and unsuccessful attempts, an underwater cable was laid between the United States and Europe. Now for the first time messages could be sent from the United States to Europe in a matter of seconds rather than a matter of weeks.

Progress was coming thick and fast. Man had tried for thousands of years to improve his methods of communication. Once he had broken through the barrier imposed by the limitations of the human senses, he had succeeded in extending his range so as to span the Atlantic Ocean. All within the span of a relatively few years.

Just nine years after the first message was sent across the Atlantic, a method of sending the human voice over a wire was invented by Alexander Graham Bell. It was no longer necessary to depend upon the

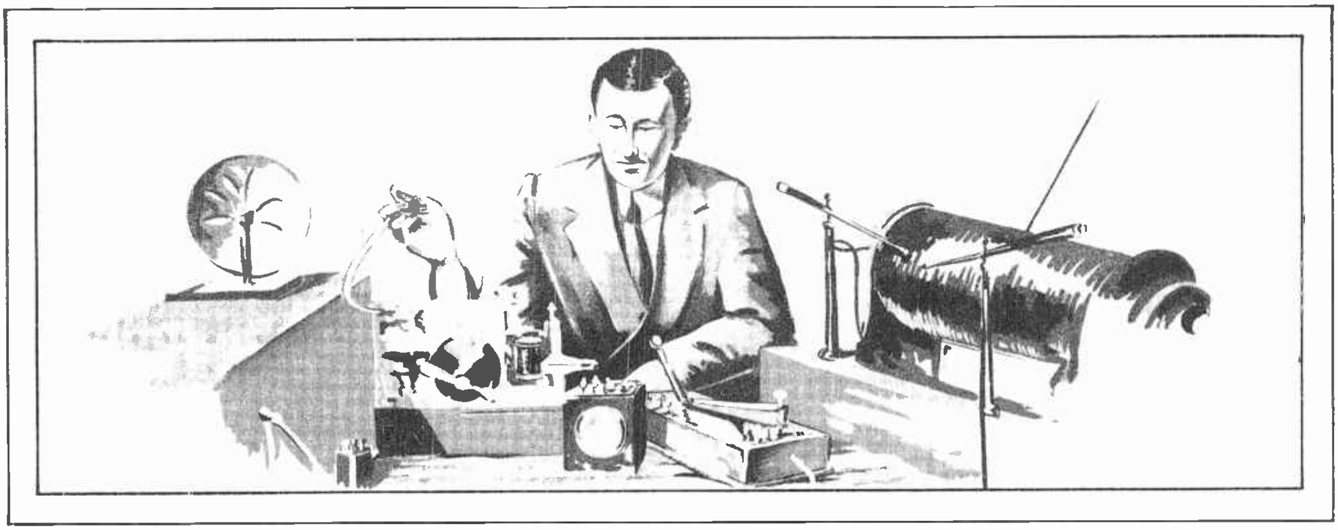

Fig.10. Early types of Wireless Equipment.

Fig.11. Guglielmo Marconi, Inventor of the Wireless Telegraph System.

clicking telegraph to transmit a message. The human voice itself could now be sent over great distances, thus making it possible for any two individuals to communicate directly with each other.

The invention of the telegraph and the telephone made possible marvelous advances in man's ability to communicate with one another. Yet marvelous as they were, they still had definite limitations. They depended upon the stringing of wires between the points of communications. But there were many places where it was not possible, or convenient, to string wires.

Vessels upon the open sea needed to communicate with the shore, and with each other. But it was not possible to string wires out over the open ocean to a moving ship. After the Wright Brothers invented the airplane, some way of communicating with it while it was in flight was needed. The need for some means of communicating over long distances without the medium of wires was clearly indicated.

Just twenty years after Bell invented the telephone, a young Italian named Guglielmo Marconi was granted a patent on the first wireless telegraph. But unlike some other inventions, the wireless telegraph was not the product of only one man's activity. Back in 1864, even before the Atlantic cable was laid or the telephone had been invented, an English scientist proved mathematically the possibility of wireless communication, or radio as we now call it.

The English scientist, James Clerk Maxwell, was an exceptionally able mathematician. More than a quarter of a century before any radio wave was actually created, Maxwell demonstrated mathematically how such waves were possible. His calculations were so precise, so accurate and so comprehensive, that even today, almost a century after he first demonstrated them, his work, now

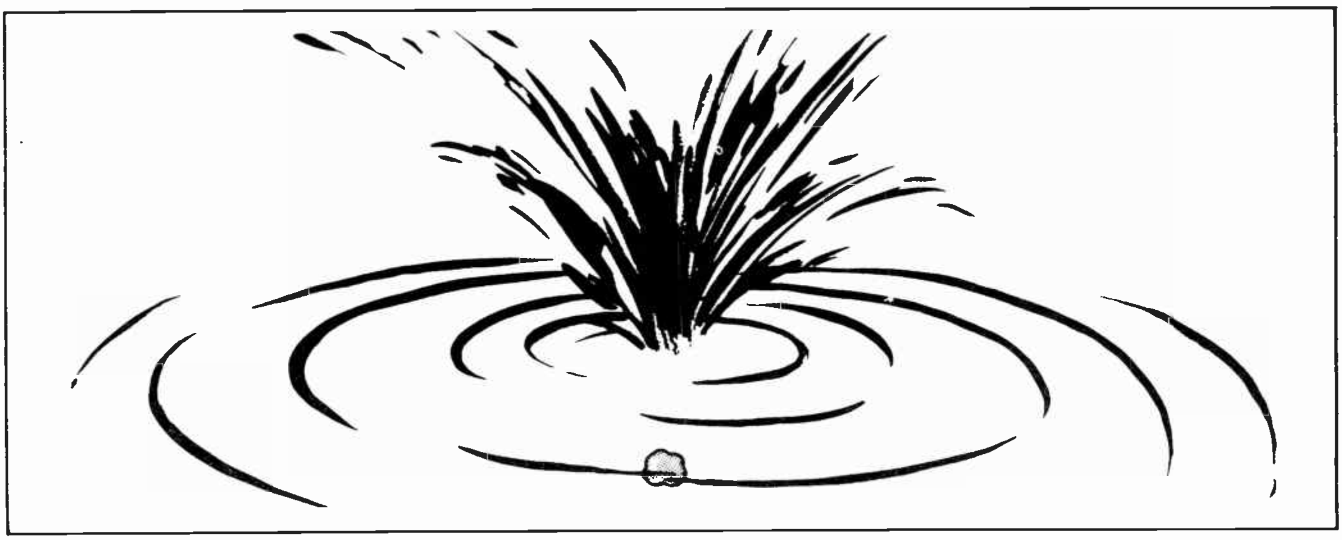

Fig.12. Waves radiating from the point where a pebble is dropped into a still pond of water.

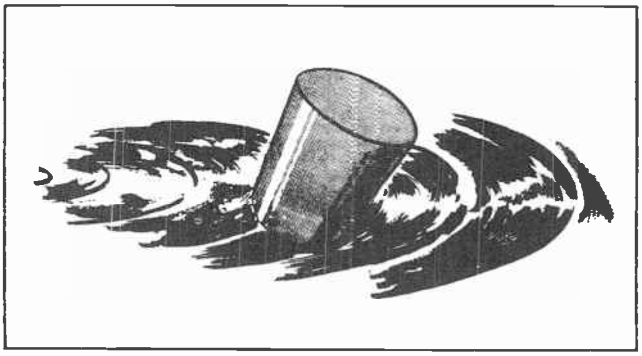

Fig.13. The cork bobs up and down on the water as the waves pass by, but does not move in the direction the waves are moving.

called "Maxwell's Equations", is generally regarded as the starting point for every serious Radio Engineer. His theory of electromagnetic waves has not been improved upon.

But despite his mathematical demonstration that such waves were possible, Maxwell never actually created a radio wave. It was not until 1888 that a young German scientist named Heinrich Rudolf Hertz actually succeeded in transmitting electrical energy through space without the medium of wires. His first radio signal was sent across the length of a room and there picked up on a very crude form of receiver. His equipment was crude, and the signal he picked up weak, but there was no question about the success of his experiment. He had actually succeeded in doing what no other person had ever done -- transmit electrical signals without wires.

It was just seven years later, in 1895, that Marconi built his wireless telegraph apparatus by which he was able to send messages over a distance of several miles without the use of wires. It was on this apparatus that he obtained his patent. Six years later, in 1901, he had so improved his equipment that he was able to span the Atlantic ocean with messages. At last a means had been found by which communication could be maintained over long distances without the use of wires.

Section 3. WIRELESS COMMUNICATION

Many people who do not have any technical training in radio and television work have the idea that an electrical current, similar to that which lights an incandescent lamp, flows from a radio transmitter to the receiver. Such an idea is entirely wrong.

It is true, of course, that we use electricity -- lots of it -- in radio transmitters, and also use electricity in the radio receivers. In fact, radio is so completely bound up with electricity that it is impossible to understand radio or television without first having a thorough understanding of electricity. But it is not true that an electrical current passes in some mysterious way from the radio transmitter to the radio receiver.

What the transmitter does is to set up a series of *electromagnetic* waves which are *radiated* out into space. It is these waves which are picked up by the radio receiver and make radio communication possible.

Before getting into a discussion of electromagnetic waves it is well that we make certain we know exactly what a wave is. Most of us have seen waves on the surface of the water. Many have seen the large waves rolling in from the ocean or on the Great Lakes. But how many of us have stopped to analyze exactly what a wave is?

Section 4. WAVE MOTION

In watching waves on the water we often get the impression that large masses of water are actually moving toward the shore, or away from some central disturbance. As a matter of fact, such is not the case.

Suppose you are standing on the shore of a body of very still water -- water which is mirror-smooth. Now toss a pebble, or small stone, into the water. Ripples, or waves, will be created by the splashing of the pebble. The waves will form circles around the spot where the pebble was dropped and will appear to move away from the spot in ever-increasing circles. To all ap-

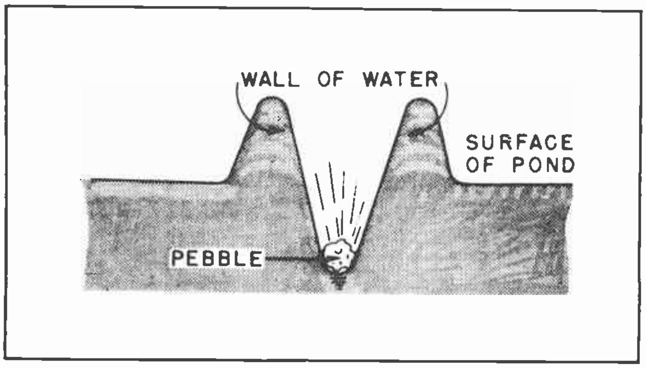

Fig.14. As the pebble hits the surface, some of the water is displaced and is forced upward.

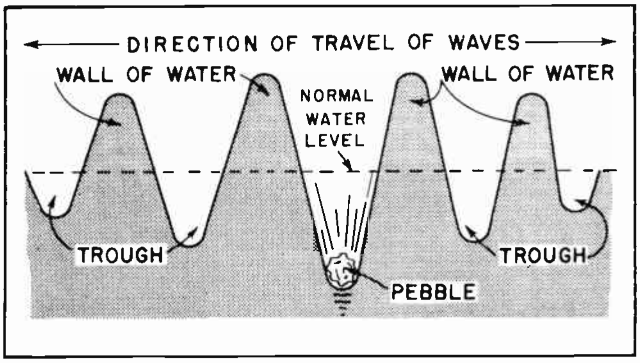

Fig.15. The waves move away from the pebble in the form of a series of walls and troughs.

pearances the water itself is moving away from the point where the pebble was dropped.

Now suppose we place a piece of cork, or a small block of wood in the water and again drop a pebble into the water near the cork. As the waves reach the cork, we can see the cork moving up and down on the surface of the wave. But it does not move noticeably in the direction the waves are moving. This is conclusive proof that the water itself is not moving away from the point where the pebble was dropped. But our eyes also tell us unmistakably that something is moving. Which brings us to the point of our discussion; it is merely *waves* which are moving.

And that brings us to the question: Just what is a *wave?*

Let's see just what did happen when the pebble was dropped into the water. The pebble had a certain amount of force, or energy, behind it when it hit the surface of the water. Thus, when it struck the surface it forced some of the water out of its way in order to force a passage for itself. Since all the space around is filled with other water, there is only one place for the displaced water to go. That is straight up. This is shown rather clearly by Fig. 14.

Now the displaced water has weight, and it is not going to remain poised up in the air after the force which caused it to rise has been removed. The natural tendency is for that water to fall back into the main body. In falling back, the inertia it acquires in falling causes it to sink below the normal surface of the water. This in turn displaces other water which rises above the normal surface. A moment later this second mass of displaced water will fall back and displace still more water. This action is repeated over and over, with the rising and falling masses of water moving farther and farther from the point of the original disturbance. Fig. 15 shows a cross-sectional view of the series of circular walls and troughs caused by the falling pebble.

This rising and falling continues on and on. Because of the resistance to the movement of the water, each wall is slightly lower than the one before it, and when it falls back it does not form a trough quite so deep as the trough before it. As the waves move farther and farther from the point where the pebble fell, their height will become less and less until eventually they decay to the point where they are not visible.

If you are still not clear as to exactly what it is that travels, you might try setting up a row of dominoes. Tip the first one over as shown in Fig. 16. It will push over the one next to it, and the second will push over the third, etc., until all the dominoes have been tipped over. The *motion* (or wave) will pass along the entire row. But each domino will move only a very short distance.

This can be said another way. It is the *energy*, or motion, of the falling dominoes which travels, not the dominoes themselves. In the case of the wave on the water, it is the *energy* of the falling water which travels across the pond, not the particles of water themselves. Energy can be caused to travel in the form of a wave through many substances. Energy traveling along

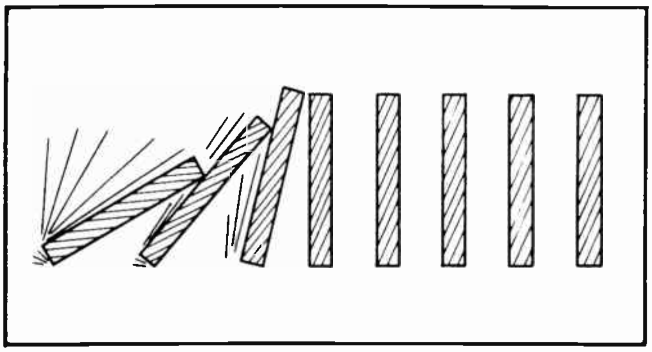

Fig.16. The energy of the first falling domino is transmitted from one domino to another in the form of a wave. No domino moves any great distance, but the energy is quickly transmitted from the first domino to the last.

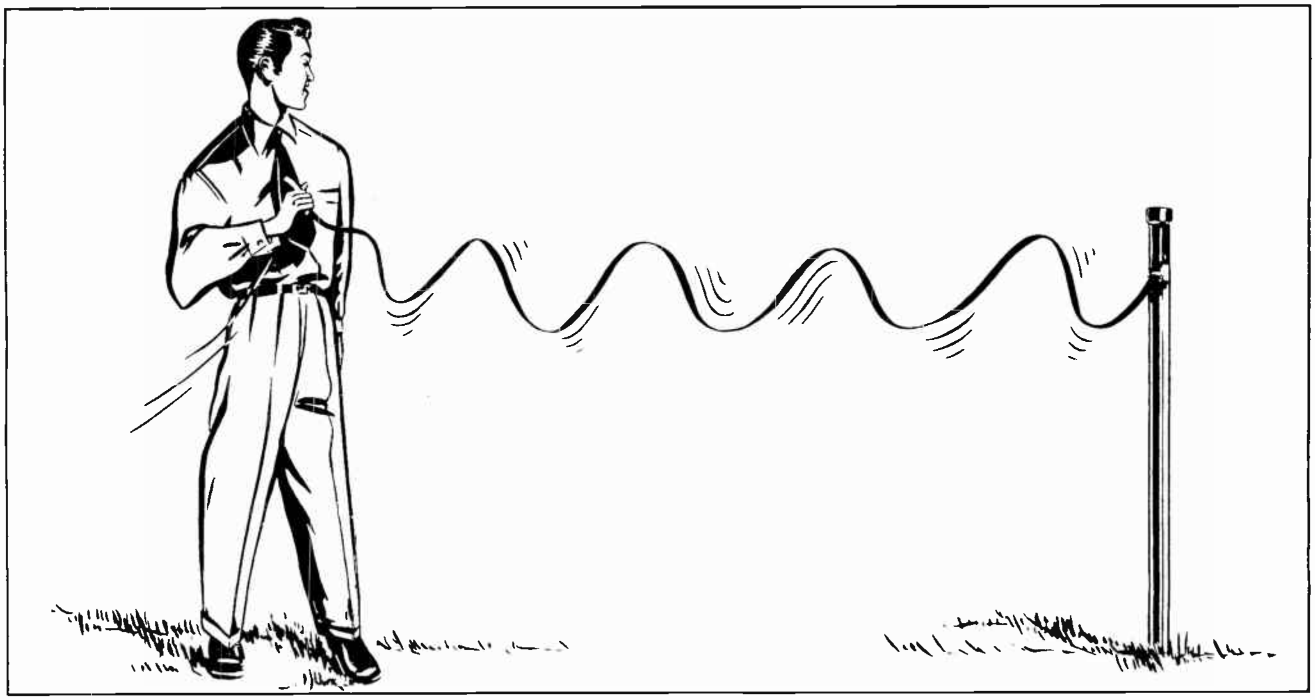

Fig.17. The energy imparted to the end of the rope by the man's hand is transmitted in the form of a wave to the end attached to the post.

the surface of water in the form of a wave is something we are all familiar with. Likewise, the example of the falling dominoes.

Another method of demonstrating the movement of energy in the form of a wave is to tie an end of a rope securely to a post and then impart a wave motion to the other end. This is illustrated by Fig. 17. The energy imparted to the end of the rope by the movement of the hand will travel to the other end of the rope. It will travel in the form of a wave. You can test this out for yourself, if you have not done so before, by obtaining a fairly heavy rope about fifteen or twenty feet long and using it as described. To all appearances, the rope is traveling from your hand to the post. But you know full well that is not the case. Actually what is traveling is the energy. It is moving in the form of a wave.

Energy can assume many forms. Heat is one form. A moving object is another. A falling object is still another. But it is energy in the form of a wave with which we will be most concerned in much of our studies of radio and television.

Section 5. WAVE LENGTHS

There is something else about this idea of wave motion with which we should become thoroughly familiar because we are going to work with it just as long as we work with radio or television. That is the matter of *wave length*.

Let us go back to our illustration of the pebble in the still pond and examine again the waves formed there. It was described how the falling pebble caused a wall of water to form. Then the wall of water fell and created another wall of water. Next, the second wall of water fell, and in so doing, created still a third wall. It should be noted that the walls of water and the trough between them alternate. First there is a wall, then a trough; then another wall and a second trough.

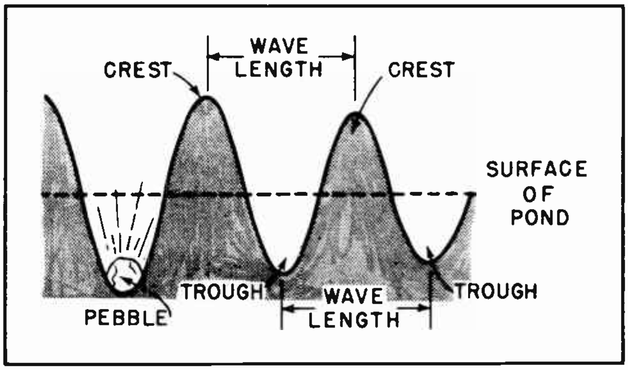

Fig.18. The wave length is measured from the crest of one wave to the crest of the next wave.

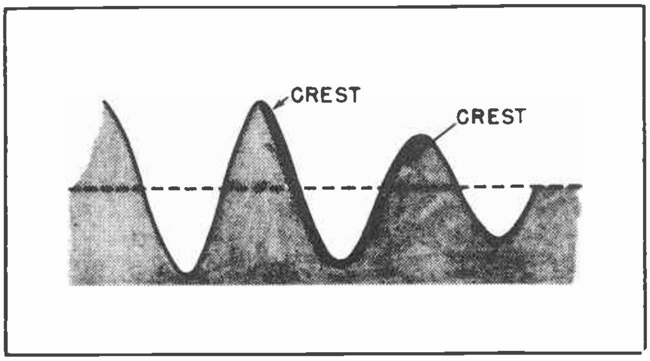

Fig.19. A cycle is measured from a point on one wave to a corresponding point on the next wave. One cycle is shown by the darker line.

The top of the wall of water is called a *crest*, as is shown in Fig. 18. The *distance* between the *crest* of one wave and the *crest* of the next wave is called the *wave length*. The distance between the bottom of one trough and the bottom of the next could also be called the wave length. It is the same length as the distance between the crests.

There can be many different wave lengths. The pebble you drop into the water might create wave lengths only a few inches long. A different object dropped into the water might create waves with wave lengths a foot or more long. The waves you see on the seashore might be many yards long. But waves on water all have one thing in common. They all move along the surface of the water at the same speed.

The rise of the wall of water, its sinking into the trough and its rise again constitutes a passage through several stages. The series of changes from the crest of one wave to the crest of the next wave can be spoken of as the passage of the wave through one *cycle*. (See Fig. 19.)

The heavy line in Fig. 19 marks the passage of the wave through one complete cycle. The number of cycles through which the waves pass in a given unit of time is called the *frequency*.

In the case of the waves caused by the falling pebble, there might be as many as fifteen risings and fallings of the water at a given point during the period of one minute. In this case we could say the waves had a *frequency* of fifteen cycles per minute. On the seashore there might be only two waves pass a given point during the period of one minute. In that case the frequency of the waves would be two cycles per minute.

It should be noted that there is a very close relationship between the frequencies of the waves in cycles and the wave length. The waves travel at a given speed. If the waves are short and close together, the wave length will be short. Since they are close together, more of them will pass a given point during a given time. Thus the frequency in cycles will be high. This holds true with all forms of wave motion. If the wave length is short, the frequency will be high. But if the wave length is long, the frequency will be low.

There is another thing about wave motion we should get clear at this time. That is the matter of *amplitude*. Amplitude is something you will be working with in nearly every phase of radio and television. The height of the crest of a wave above the normal level of the water is called the *amplitude*. The depth of the trough below the normal level is also called the amplitude, but it is usually more convenient to consider the crests rather than the troughs. The illustration in Fig. 20 shows how the amplitude is measured.

In our discussion of wave motion we have used the example of waves on the surface of water for the purpose of illustration because they are something with which we are all familiar. Actually, we are not concerned in radio work with water, except that the wave motion of water is so similar to the movement of electromagnet waves which serve us so well in radio and television work. But by becoming familiar with the wave motion of water, it is much easier to understand the wave motion of electromagnetic waves which we cannot see. And a thorough understanding of electro-

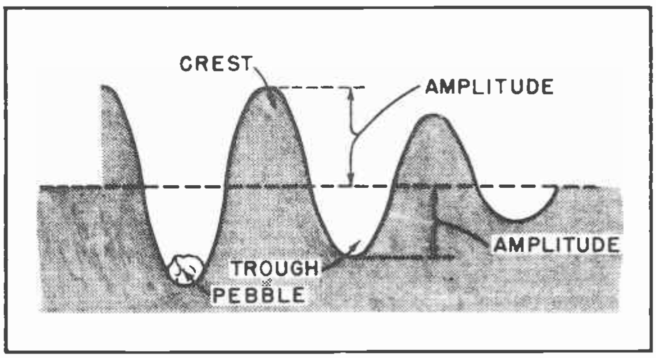

Fig.20. Amplitude is measured from the normal level to the crest of the wave.

magnetic wave motion is quite important to the understanding of radio and television.

Section 6. RADIO WAVES

In much the same manner that the energy of a falling stone is converted into radiating waves on the surface of a pool of water, so is the energy which is developed in a radio transmitter radiated out into space. But where the waves on the water move at a speed of a relatively few feet per minute, the electromagnetic waves radiating from the radio transmitter travel through space at the almost unbelievable speed of 186,000 miles per second.

Just as the *wave length* of the waves on the water was directly related to the *frequency* with which they passed any given point, so is the distance between the crests of electromagnetic radio waves (wave length) also related to their frequency.

If a radio transmitter is so adjusted that it sends out an electromagnetic wave 1,000,000 times each second, it is said to be radiating on a frequency of 1,000,000 cycles per second. Since numbers involving millions are a little unwieldly to handle, it is more convenient to count frequencies in *kilocycles*. A kilocycle amounts to 1,000 cycles. Thus, instead of speaking of 1,000,000 cycles, we can say 1,000 kilocycles, and mean exactly the same thing.

Supposing now we have our transmitter sending out electromagnetic waves at the rate of 1,000,000 waves per second, or at a frequency of 1,000 kilocycles per second. The energy is being radiated out into space all right. But the human ears cannot detect frequencies which are that high. No physical object can move at that frequency because of the inertia involved. So, in order for us to obtain any benefit from the radiations from the transmitter, it is necessary to create some kind of electrical apparatus which will be affected by the high frequency electromagnetic waves. This involves a process called "tuning".

To understand tuning it is necessary to discuss briefly a natural phenomenon called *natural frequency*, or *resonance*. Let us take the simple example of a child's swing. Start the swing moving to and fro. When it is moving freely give it a slight push each time it reaches the end of its swing. (See Fig. 22.) A very slight push given at exactly the right instant will keep the swing

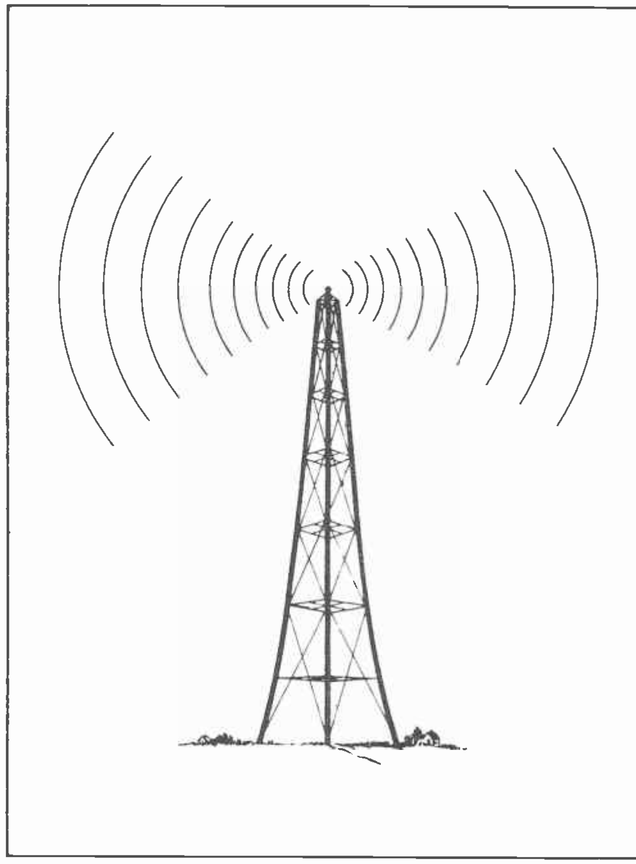

Fig. 21. Radio energy moves away from the transmitter in the form of a series of electromagnetic waves.

swinging. But if the push is given a little too soon, or a little too late, the swing will slow down.

To obtain the maximum transfer of energy from the push to the swing, the *frequency* of the pushing must be exactly equal to the *frequency* of the swing. We can say, the pushing is in *resonance* with movement of the swing, or in step.

Now for a more closely paralleling illustration. Suppose you have two tuning blocks, such as are used in the tuning of pianos and other musical instruments. They must both have the same natural frequency. Suppose their natural frequency is the same as the frequency of middle *C* on the piano. This would be a frequency of 256 vibrations per second.

These tuning blocks consist of a bar of steel specially designed so it will vibrate at a certain frequency when struck. The bar of steel is mounted on a hollow wooden

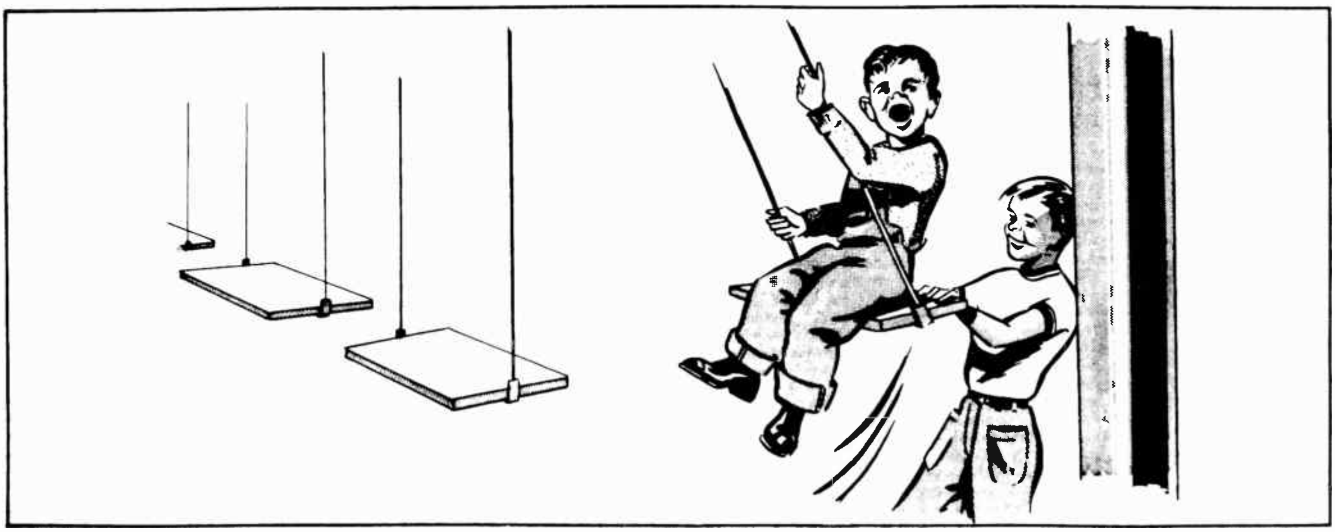

Fig.22. A child's swing illustrates the principle of natural frequency. The swing will move higher and higher if given a push at exactly the right instant. But if the push is given at any time which does not correspond with the swing's natural frequency the swing will slow down.

block which has the ability to increase the volume of the tone when the bar is struck.

If we place these two blocks about ten or fifteen feet apart and then strike one a sharp blow it will start vibrating at its natural frequency -- 256 cycles per second, the pitch of middle *C*. By placing a hand on the struck block its vibrations can be stopped. But stopping its vibrations will not completely kill the sound of middle *C*. Investigation will show that the second block is vibrating although it was not struck. If a hand is then placed on the second block, it too, will stop vibrating.

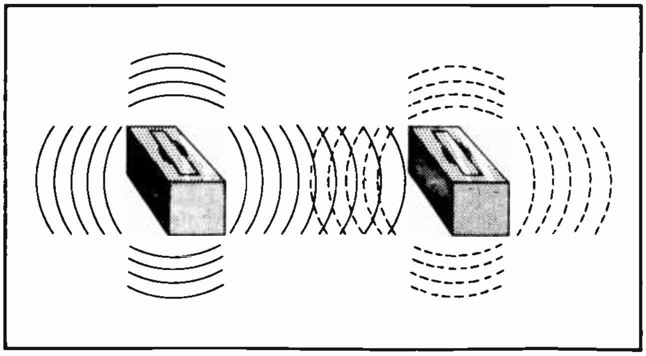

Fig.23. Vibrations in the air set up by the first tuning block will cause similar vibrations in the second tuning block which will cause it, in turn, to give off vibrations of its own. The first tuning block will not have any effect on the second if their natural frequencies of vibration are not identical.

Now for the explanation of what happened. When the first block was struck it began vibrating at its natural frequency, 256 cycles per second. The vibrations set air waves in motion much as the dropped pebble set waves in motion on the water. When the air waves struck the second tuning block it set that block vibrating also because its natural frequency was exactly the same as the frequency of the air waves striking it.

In other words, the energy of the air waves was transferred to the second block, and it in turn was set in vibratory motion. The second block then began making air waves of its own, and it was these that were heard after the vibration of the first tuning block was stilled.

To emphasize the fact that both tuning blocks must have exactly the same natural frequency of vibration, this experiment can be repeated by using one of the blocks previously used which had a natural frequency of 256 vibrations per second, and a second tuning block of 240 vibrations per second. This would correspond to *B* on the piano. When this experiment is attempted, the second block will not vibrate in unison with the first. The air waves are not vibrating at the natural frequency of the second tuning block. Therefore, there is no transfer of energy. The blocks are not in *resonance* with each other.

And so it is in the case of radio. The radio transmitter creates and radiates into space a succession of electromagnetic waves. These waves are then picked up by a specially designed piece of electrical equipment which we call a radio receiver. It is so designed that it is sensitive to the particular frequency of the waves from the transmitter. It is "tuned" to the frequency of the transmitter. When it is so tuned, it will pick up the message from the transmitter and convert it into such form as can be understood by the human ears.

In this lesson we have taken up the basic fundamentals of wave motion and discussed briefly the part such wave motion plays in radio and television work. In later lessons we will discuss in considerably more detail the electrical and electromagnetic forms of wave motion.

In our next lesson we will take up the study of some of the fundamentals of electricity. Some radio students, when confronted with the need for learning the principles of electricity, are prone to complain that they want to learn radio and television -- not electricity. But it should be understood that nearly everything about radio and television is electrical. It is as absurd for a man to expect to learn radio and television without learning something about electricity as it would be for a man to expect to become a great writer of literature without first learning the alphabet and how to read.

NOTES FOR REFERENCE

Wave Motion is energy traveling through some medium by means of vibrations transmitted from particle to particle.

Wave Length is the distance between one crest of a wave and the next crest.

A *Cycle* is the series of changes from normal that are produced as the wave travels in going one wave length.

Frequency is the number of cycles during a given unit of time.

The *speed* with which the wave travels depends upon the nature of the medium through which it travels.

The speed of electromagnetic waves through space is 186,000 miles per second.

Resonance is the condition of two vibrating bodies when the natural frequency of one body is equal to the natural frequency of the other body.

Samuel Morse invented the telegraph in 1832.

The first message was sent over a trans-Atlantic cable in 1866.

Alexander Graham Bell invented the telephone in 1875.

James Maxwell published his theory of electromagnetic wave motion in 1864.

Marconi invented the wireless telegraph in 1895.

First wireless message was sent across the Atlantic in 1901.

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FUNDAMENTALS OF ELECTRICITY

Contents: Introduction - Conductors and Insulators - Things Affecting the Flow of Electricity - Current Measurement - The Electric Circuit - Diagrams of Circuits - Electrical Pressure - Source of Potential - Notes for Reference.

Section 1. INTRODUCTION

The man who wants to become an expert in radio and television work must learn many things which might seem, at first glance, to be of little importance. Some of the things he must learn include the physics of wave motion, the peculiar phenomenon of electrical resonance, the chemical composition of certain materials, the physics of sound, the peculiar properties of certain natural minerals, and probably the most important of all, the basic fundamentals of electricity. Because the radioman works with electricity right from the beginning of his entrance into the radio field, we will take up the discussion of electricity first.

Practically everything about radio and television has its beginning in electricity. The electromagnetic waves we discussed in the previous lesson are produced by carefully controlled electrical currents. The filaments of the vacuum tubes, which are used so widely in radio and television work, are heated by the passage of electrical current in much the same manner that the filaments of incandescent lamps are heated. The action of the electromagnetic waves when they reach the receiver is to create electrical currents in the receiver. Because these currents are very small they must be magnified by mixing them with other, and stronger, electrical currents. All this gives a hint of the importance of electricity in radio work. It is essential for a man to become thoroughly familiar with electricity if he expects to become a really capable radioman.

There are few things in our lives more familiar than the incandescent electric lamp. It is so familiar, and so much a part of our daily lives, that we are prone to take it for granted and give it little thought. While most of us are vaguely aware that the electrical power which is used to

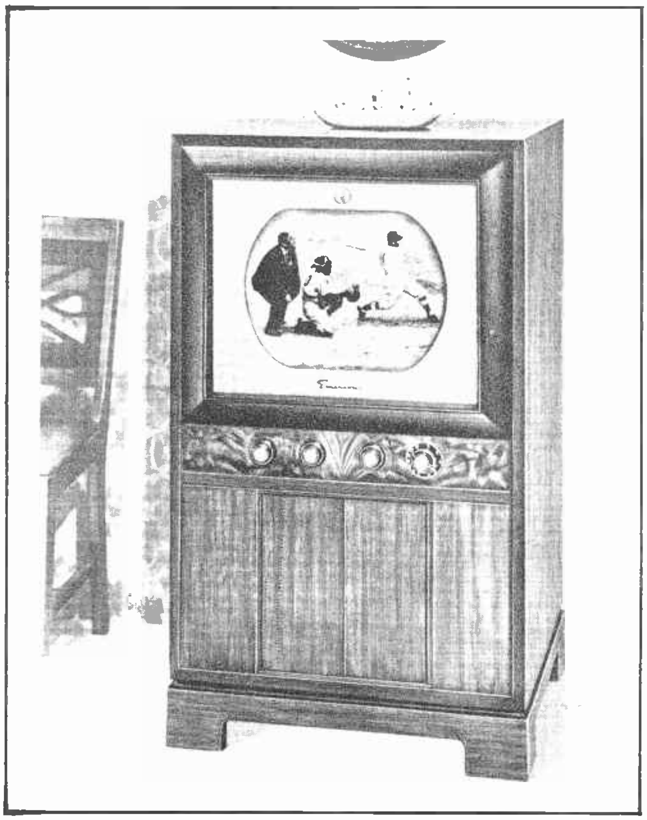

Fig. 1. Television Receiver. (Courtesy of Emerson Radio)

Fig.2. It is not possible to detect a passing electrical current by weighing the wires.

light the lamps is brought to them by a pair of wires, we seldom give any thought to just exactly how the power travels through the wire.

It might seem rather strange that power capable of lighting lamps, running motors, and doing many other kinds of work can be so easily carried from place to place through wires. This will seem all the more strange if you take the time to carefully examine the wire while power is passing through it, and again when there is no power passing. The most careful examination will disclose no apparent change in the wire when it is carrying power and when it is not.

A close examination of the wire will disclose a long strand of metallic copper. The copper may be in the form of a single solid strand, or it might be composed of a number of smaller strands twisted together. Surrounding the copper will be one or more layers of rubber, fabric, or some other non-metallic material. But nothing in the appearance of the wire will give any clue as to how it can carry electrical power.

No matter how closely you listen you cannot hear any rush of electricity through the wire while a lamp is lighted. The most sensitive scale will not detect the slightest change in the weight of the wire while electricity is passing through it. If you disconnect one end of the wire the lamp will go out, but nothing will come out of the end of the disconnected wire. Yet common sense tells us that with the lamp lighted, some-

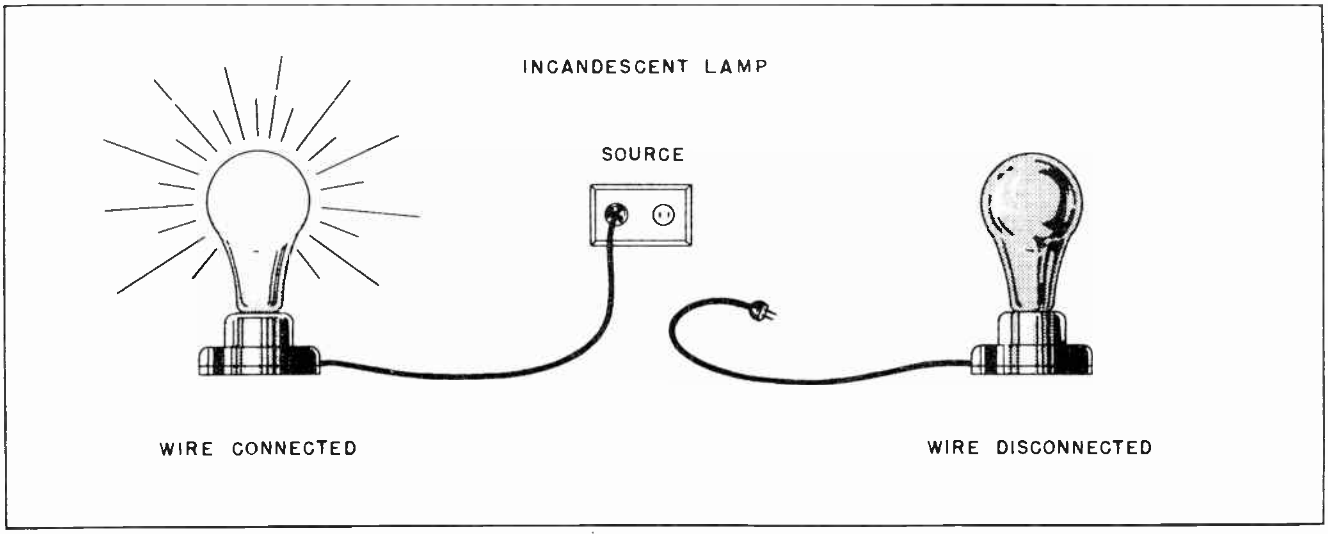

Fig.3. There must be a complete metallic path through which the electrical current can flow.

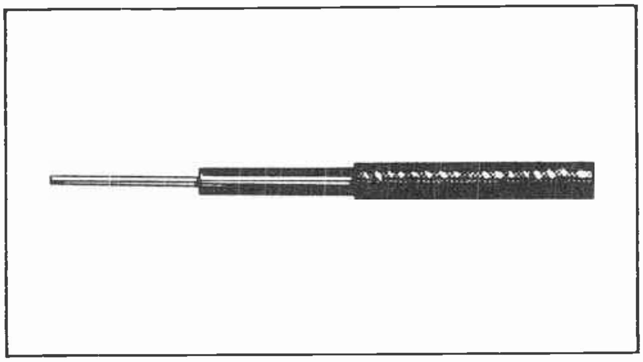

Fig.4. A metallic wire with its insulated outer covering.

thing must be passing through the wire. This something is what we call electricity.

The fact that the lamp goes out when the wire is disconnected shows us one thing. That is, that electricity will not pass through the air between the disconnected wire and the place it was disconnected from. Instead of stopping the flow of electricity by disconnecting one of the wires, it is more customary to use an instrument we call a *switch* to stop the flow of electricity. Several types of such switches are shown in Fig. 5.

A careful examination of such a switch will show that when the switch is opened to turn off the electricity, the metal parts will be separated from each other. This stops the electricity because the electricity will not pass through the air between the separated metal parts. A still closer examination of the switch will show that the metal parts are either surrounded by, or are mounted upon porcelain, fibre, bakelite or some other material which is not metal. It is quite evident that electricity does not flow through these non-metallic parts. If it did, the lamp would continue to burn just as it did when the metal parts were touching each other. These observations tell us that non-metallic materials such as rubber, bakelite, fibre, glass, porcelain and some others, as well as air, will not pass electricity. By surrounding the metal of the wire with one of these materials it becomes possible for us to confine the flow of the electricity to those paths we want it to follow.

It may seem strange that electricity, which is invisible and without weight, can pass through wires of solid metal but not through other solids of non-metallic materials. Yet this action is no more strange than the fact that light passes freely through solid glass, but is stopped by a piece of solid wood. Neither is it any more strange than the fact that heat readily passes through solid metal, but can pass through solid asbestos only with the greatest difficulty.

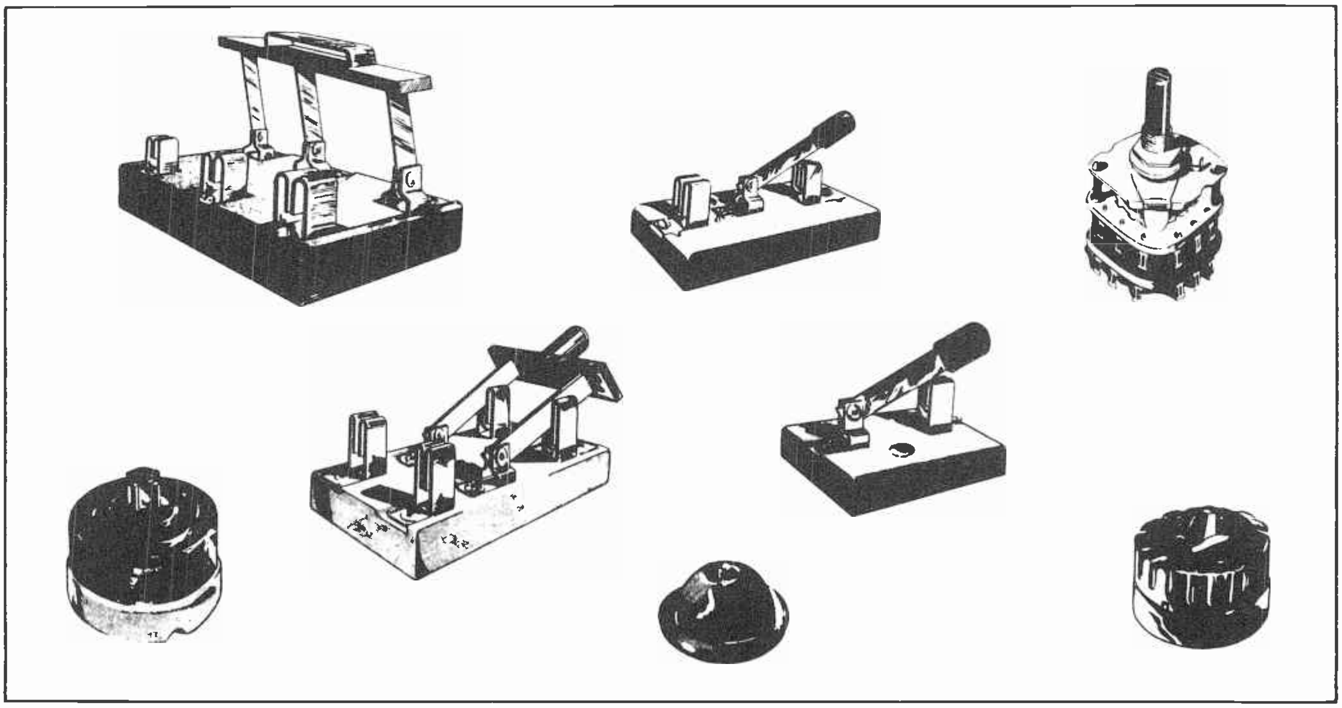

Fig.5. Electrical switches which are used to open and close electrical circuits.

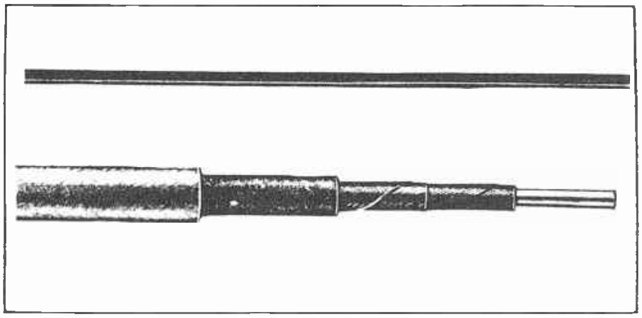

Fig. 6. A bare copper wire and a wire covered with insulation.

Section 2. CONDUCTORS AND INSULATORS

Any substance or material which passes electricity freely is called an electrical *conductor*. All metals are conductors. But aside from metals, the only generally useful electrical conductors are carbon and a few liquids.

Any substance through which electricity does not pass freely is called electrical *insulation*, and electrical parts made from such materials are called electrical *insulators*. Except for metals, carbon, and certain liquids, all substances are insulation, and they may be made into electrical insulators.

Electricity does not flow through all conductors with the same ease. It flows through silver, for instance, easier than through any other substance. But it flows through copper almost as easily. Because copper is much less costly than silver, it is used far more widely in electrical work. More copper is used for conducting electricity than all the other metals combined. Aluminum, brass, bronze, steel and iron are the other metals most often used as electrical conductors. For the most part they are used in special applications where for some reason copper is not considered to be suitable. It is harder to send electricity through wires made from aluminum or iron or steel than through wires made from copper. Yet it is much easier to send electricity through aluminum or iron metals than it is to send it through carbon or the liquids.

An electric wire may consist of a bare copper wire as is shown at the top of Fig. 6. Electricity will not escape from the wire if it comes in contact only with the surrounding air and other insulating materials. But should the wire touch another metal object it would be possible for the electricity to escape from the wire and pass into the other object. Should a person touch a bare wire while it was passing electricity and while he was also touching another metal object it is quite likely he would get an electrical shock. To prevent the escape of electricity from the conductor, and also to

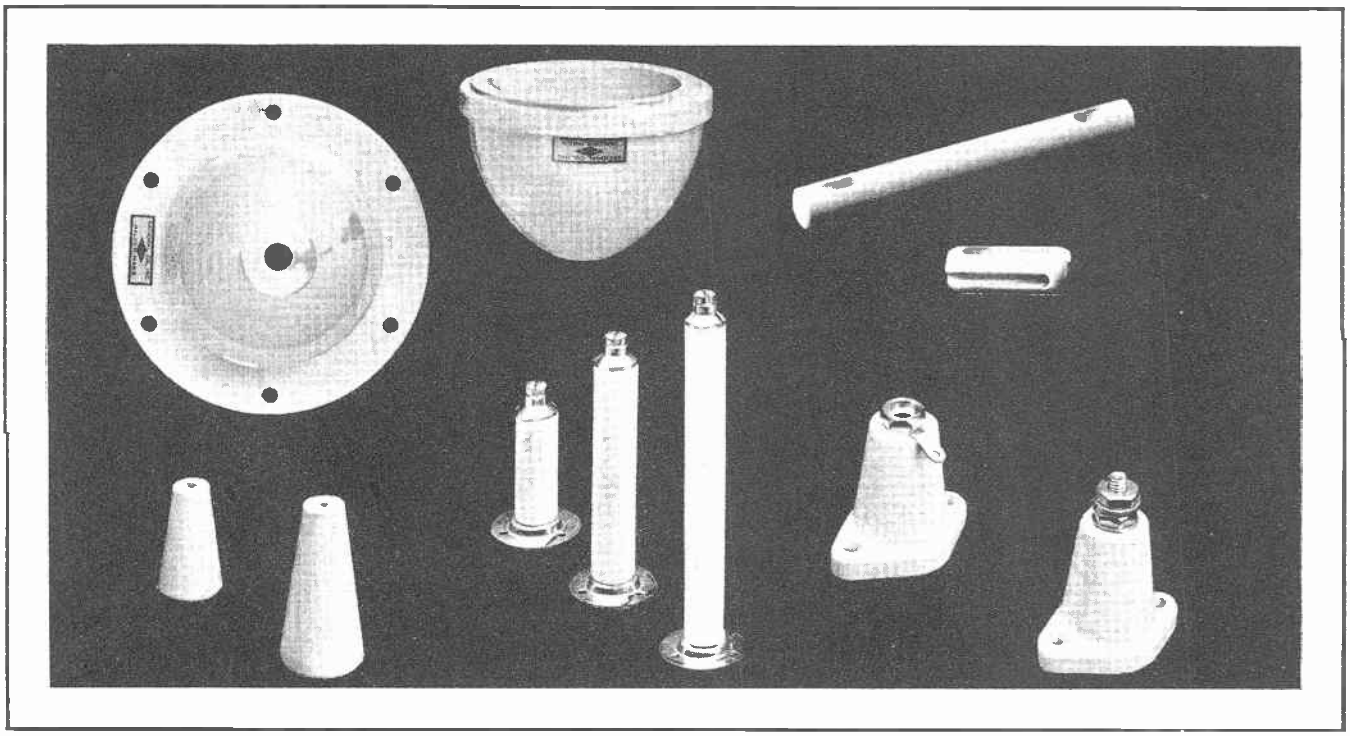

Fig. 7. Several types of insulators used in electrical work.

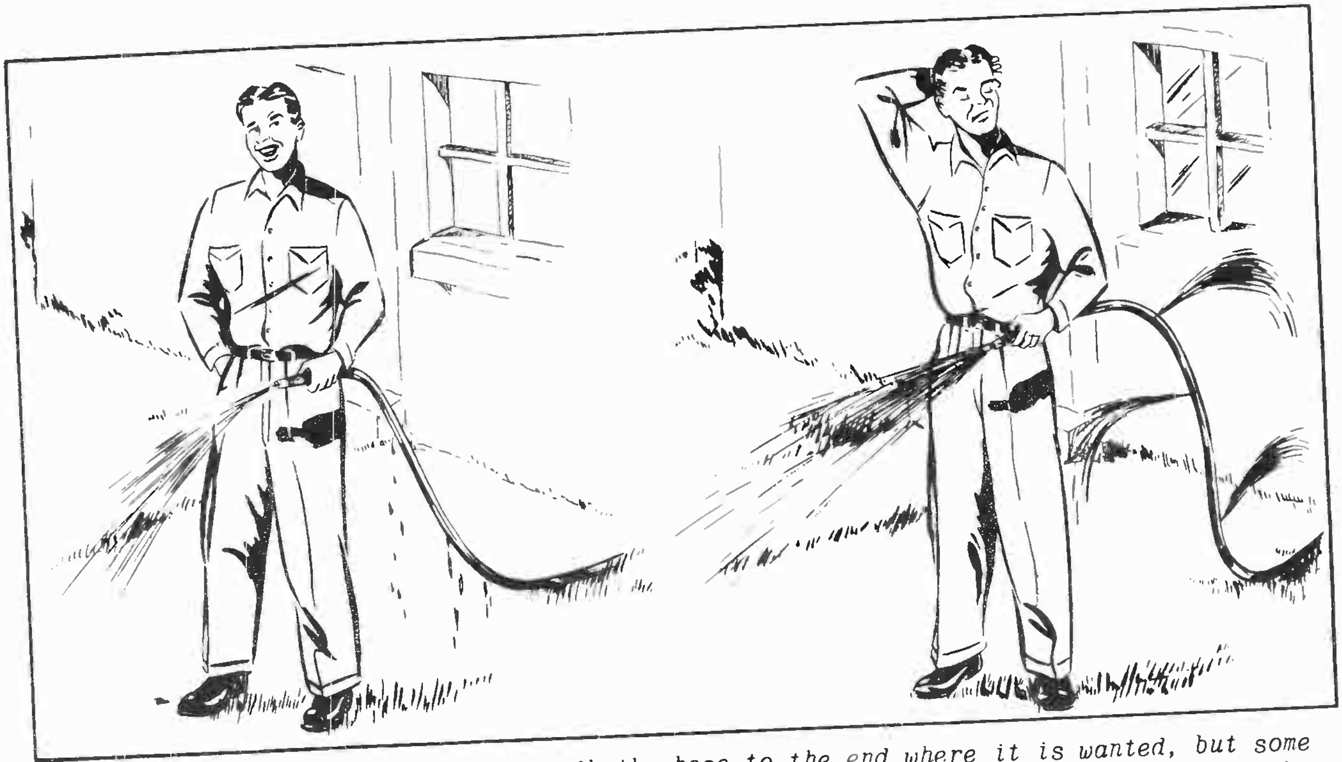

Fig.8 Much of the water goes through the hose to the end where it is wanted, but some is lost through the leaks. The higher the water pressure the greater will be the amount of water lost through the leaks.

protect people against shock, the metal is often covered with one or more layers of insulating materials. Such an insulated wire is shown at the bottom of Fig. 6.

Electricity can be confined to certain paths by means of insulation in much the same manner that water can be confined within a certain path through a hose. A rubber hose confines the water flowing through it and does not allow any to escape unless the pressure becomes so high as to burst the hose.

Among the most generally used insulating materials are rubber, glass, mica, porcelain, bakelite (which is a form of rubber), waxed paper or cloth, and fabrics which have been impregnated with insulating varnish.

Flexible insulation, such as rubber, paper and fabric is placed around wires, or in other places where the insulation must be wrapped or tucked into place. Solid insulators, like porcelain and molded compositions, are used for supporting conductors and for many parts of electrical apparatus where strength is required. Specially created insulating materials made of plastic and glass are widely used in radio and television where the more common types of insulators do not work satisfactorily. Polystyrene, steatite, pyrex and mycalex are a few of these special types of insulators. Extremely high frequencies are used in radio and television work. Some of the more common types of insulators seem to lose some of their insulating properties at those frequencies. Thus it became necessary to develop special types of insulators for use at the higher frequencies.

Some insulating materials are not absolute insulators. That is, they allow a little electricity to pass through. They might be compared to a water hose constructed of heavy canvas. The heavy canvas would confine the major part of the water to the path desired. But a little of the water would leak through the fabric of the canvas. The higher the pressure of the water, the more water will leak through the canvas. So it is with some insulators. They are plenty good enough for ordinary work, but are unsuitable where either the frequency or the electrical pressure is too high.

Section 3. THINGS AFFECTING THE FLOW OF ELECTRICITY

There are several things which affect the flow of electricity through a conductor. To understand this more clearly we can again resort to the method of comparing the flow

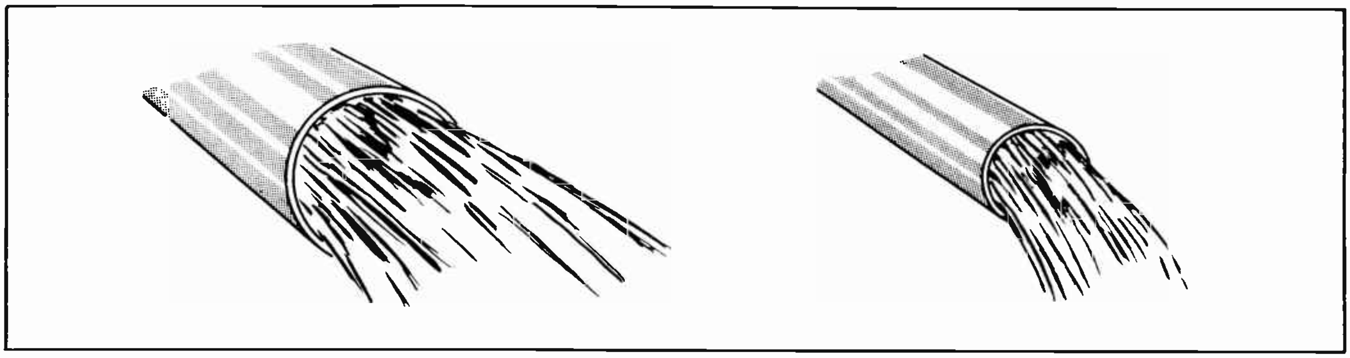

Fig.9. More water will flow through the large pipe than through the small one.

of electricity to the flow of water. The amount of water that flows through a pipe depends upon several things just as does the flow of electricity through a conductor. But where we are unable to see the flow of electricity we can see some of the things that happens to water as it flows through the pipe.

The amount of water that flows through a pipe depends in a large measure upon how long the pipe is, how big around it is, and whether the inside of the pipe is clean or is partially obstructed by dirt and scale. With a given pressure at the pump, more water will flow through a short pipe than will flow through a long one. It is also true that more water will be able to flow through a large pipe than through a small one. And common sense tells us that more water will flow through a clean pipe than through one that is partially obstructed.

Very much the same thing is true with electrical current. The flow of the electrical current will meet less opposition in moving through a short conductor than through a long one, and will thus allow more current to flow with any given electrical pressure. Furthermore, the same electrical pressure will cause more electrical current to flow through a large conductor than through a smaller one.

Even the pipe which was partially clogged with scale has its counterpart in the flow of electrical current through conductors. We have already mentioned that electricity does not move through all kinds of conductors with equal ease. Thus the smooth water pipe might be compared with the ability of silver to conduct electricity, and the pipe with just a little bit of scale might be compared with copper as an electrical conductor. But the pipe which had a lot of scale could be compared with a piece of iron or steel wire. Water can move through a pipe which has a lot of scale in it, but it meets much more opposition than if the pipe were clean. Likewise, electricity can move through iron or steel but it meets considerably more opposition than if it were passing through silver or copper.

The effect of the various sizes of wire, and the lengths of wire, and the composition of the wire is shown rather graphically in Fig. 11. There it will be noted that more current flows through the shorter wire, through the larger wire, and through copper,

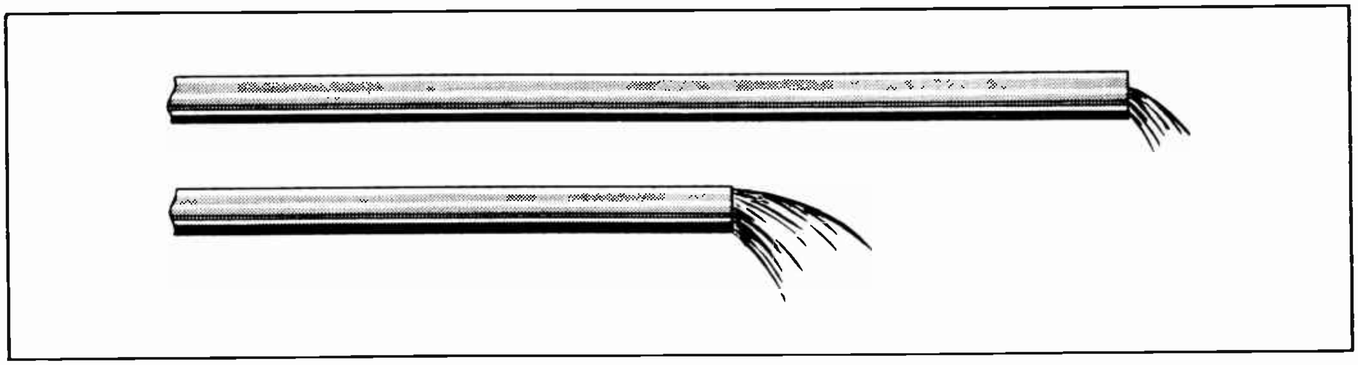

Fig.10. More water will flow through the short pipe than through the long one.

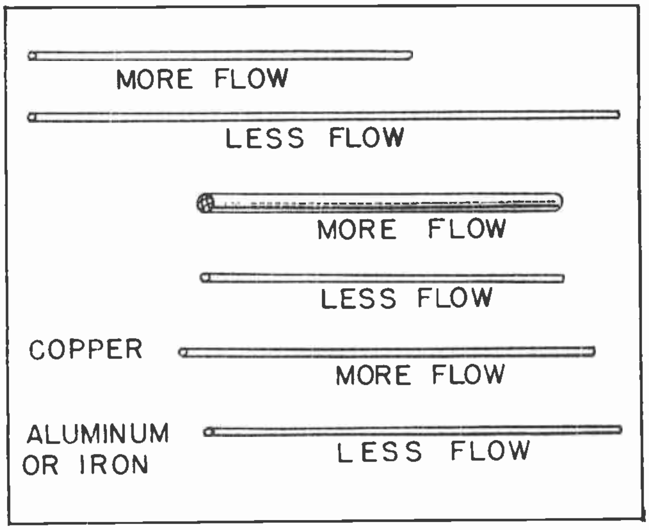

Fig.11. Flow of electricity depends upon length, diameter, and the material from which the wire is made.

than flows through the longer wire, the smaller one or that made from iron or aluminum.

Section 4. CURRENT MEASUREMENT

The amount of water which flows through a pipe depends upon the pressure applied by the pump, and upon the opposition presented by the pipe. And as we have just been discussing, the opposition of the pipe depends upon the length of the pipe, upon its size, and upon its condition.

The amount of electricity which flows through a conductor depends upon the electrical pressure behind it, and upon the opposition of the wire through which the current flows. The opposition of the wire depends upon the length of the wire, its size in diameter, and the material from which it is made.

The amount of current which is flowing is specified in an electrical unit called the *ampere*. The ampere is not a definite quantity such as a gallon is a definite quantity of water. Rather, the ampere is a measurement of the *rate of flow* of electricity. We might say that *50 gallons of water per minute* was flowing through a pipe. In a like manner, we could say that *50 amperes* of electrical current was passing through a wire. The difference is that in the case of water we must mention both the quantity and the time. But with electricity we have a unit which expresses both quantity and time together.

In this respect it is very similar to a nautical knot. As most of us know, it is not correct to say 15 knots per hour. If a vessel is moving at the rate of 15 nautical miles per hour it is traveling at a speed of 15 *knots*. Not 15 knots per hour.

In a like manner, it is not correct to say 15 amperes per second, or per minute, or per any other unit of time. The unit *amperes* is a complete unit in itself. When we say that electrical current is flowing at the rate of so many amperes we know that a certain number of tiny electrical particles are passing a given point per second. Since for most practical purposes we are not concerned with the actual number of these tiny particles of electricity, we speak merely of their *rate of flow*. And the rate of flow is measured in amperes.

The meaning of amperes in the measurement of current flow will become a little more clear if we consider the electrical currents which flow in a few common electrical appliances. An ordinary household electric toaster uses from 5 to 6 amperes, an electric iron will use from 5 to 12 amperes, and an electric range will use from 4 or 5

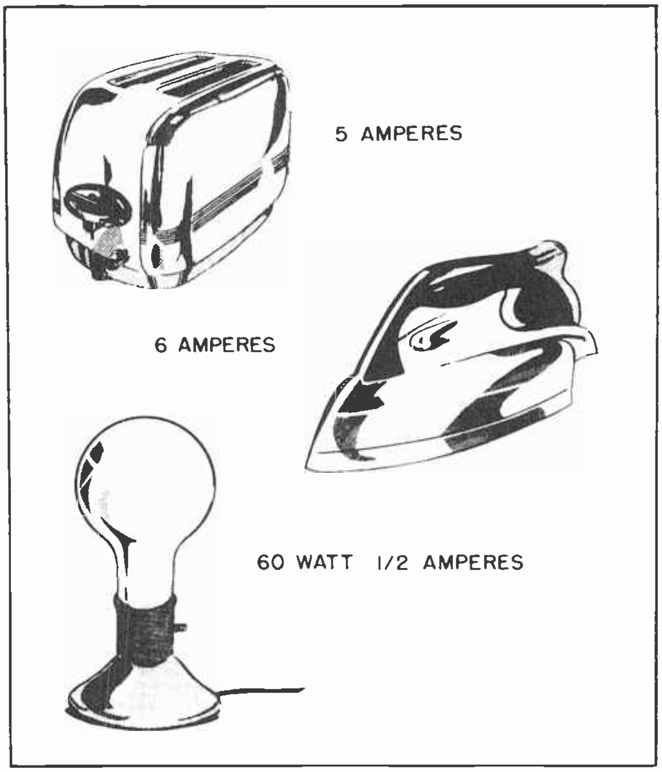

Fig.12. Currents which are required to operate some familiar electrical appliances.

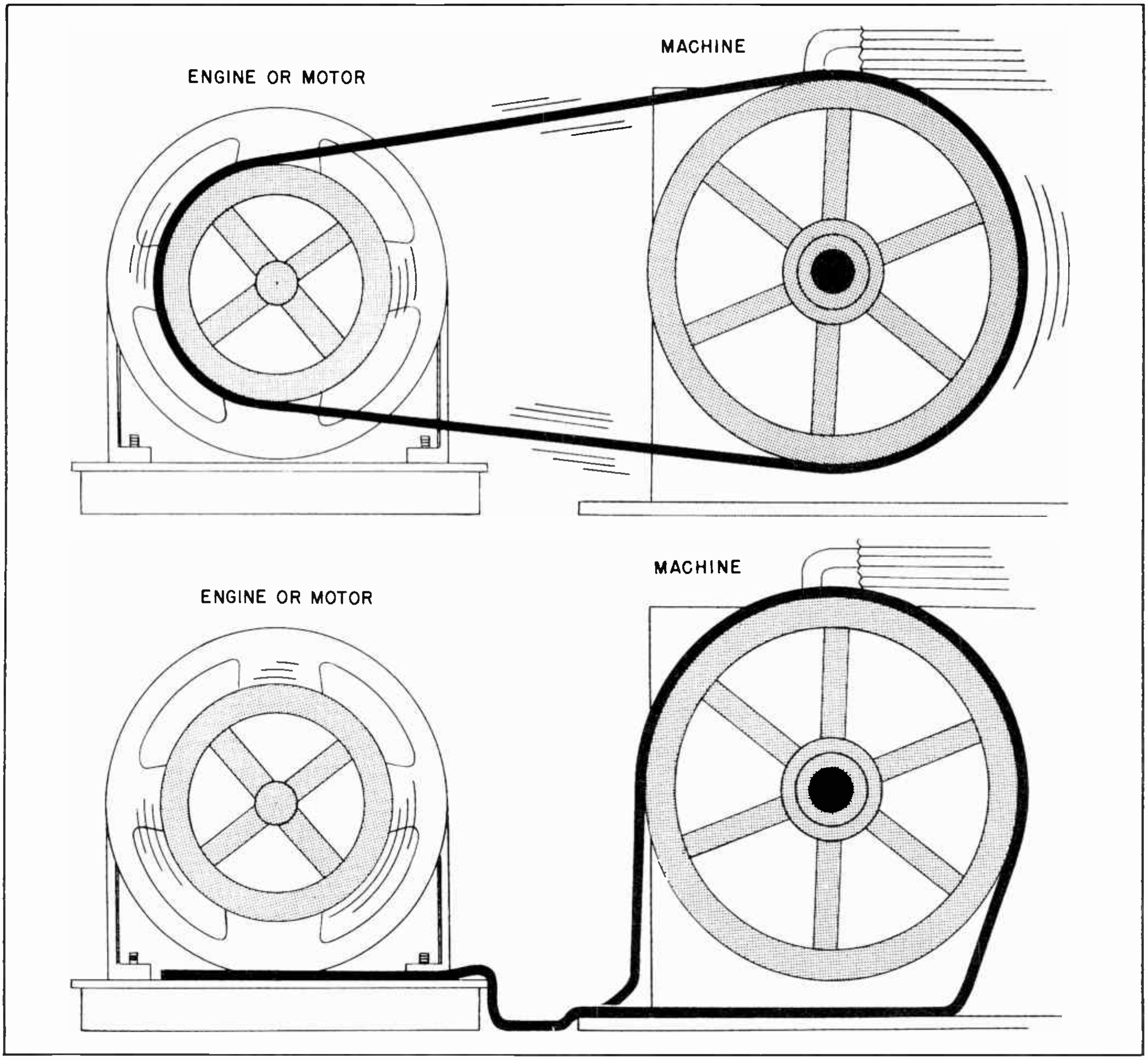

Fig. 13. The belt must make a complete circuit of the pulleys in order to transmit power. If the belt is broken at any place, no power can be transmitted.

amperes up to about 35 amperes. An ordinary 60-watt incandescent lamp will use about 1/2-ampere of current, while a 100-watt lamp will use almost an ampere. Fig. 12 illustrates a few of the common household appliances and the amount of current they use.

It might be well to remember that the flow of current in amperes has nothing to do with the speed of electricity any more than the flow of water in gallons per minutes is a measure of its speed through the pipe. We might have a large number of gallons of water per minute flowing through a large pipe at a slow speed or the same number of gallons per minute flowing through a small pipe at a high speed. In a like manner we might have a large number of amperes flowing through either a large or a small wire. We are never concerned with the speed of electricity when speaking of amperes, but rather with how much gets through the wire in a given time.

Section 5. THE ELECTRIC CIRCUIT

There are many points of similarity between the flow of water through pipes and the flow of electricity through wires. But there are also several very important matters in which they are not alike at all. For example, in a water supply system the pump may draw the water from a well, lake or reservoir, and then send it through a single continuous pipe to where the water is drawn off through a faucet and leaves the water system forever.

But in an electrical system we must have at least two wires, or two conductors, one extending from the source of electrical power to the point where the power is used, and a second wire leading back to the source of the power. Unless we have this complete circuit it is impossible to have any flow of electricity at all.

It is a common practice to speak of the place where the electric power originates as the *source*, and of the appliances and apparatus which use the power as the *load*. The source is something which creates an electrical pressure. It might be a mechanical generator, a storage battery, or even a dry cell battery. We will discuss this matter of electrical pressure just a little further along.

We can make the statement with scientific certainty that in any electrical system there must be a complete conductive path all the way from one side of the *source* to the *load*. And there must also be another complete conductive path from the load back to the source. This complete round-trip conductive path is called an electric *circuit*. It might be a good idea to note that word well. So long as a man works with electricity, radio or television, he is going to be constantly working with electrical circuits. In modern radios, and more particularly in the latest model television receivers, the circuits can become almost unbelievably complex. But for the trained technician, one who is really familiar with how the various circuits work together, the most complex circuit is merely an incident, something to be taken in stride.

If there is any break in the conductors of an electric circuit no electricity will flow. It doesn't make any difference which part of the circuit is broken, no electricity will flow in any part of it. The electricity cannot get past the part of the circuit which is open, so it stops moving everywhere else.

We might well compare the action of electricity flowing in a circuit, carrying power from the source to the load, with one of the huge belts which carries power from an engine to a machine which it is driving. The belt must be continuous all the way around. Just as much belt must come back to the engine pulley as leaves the engine pulley. If the belt is opened, or broken, at any place on either side there can be no further delivery of power to the machine. (See Fig. 13.)

Section 6. DIAGRAMS OF CIRCUITS

In working with electrical circuits it is often convenient to mark them down on paper so they can be studied, or recorded. A definite set of rules for describing circuits have been worked out by electrical and radio men. The conductors are usually drawn in the form of straight lines, or at

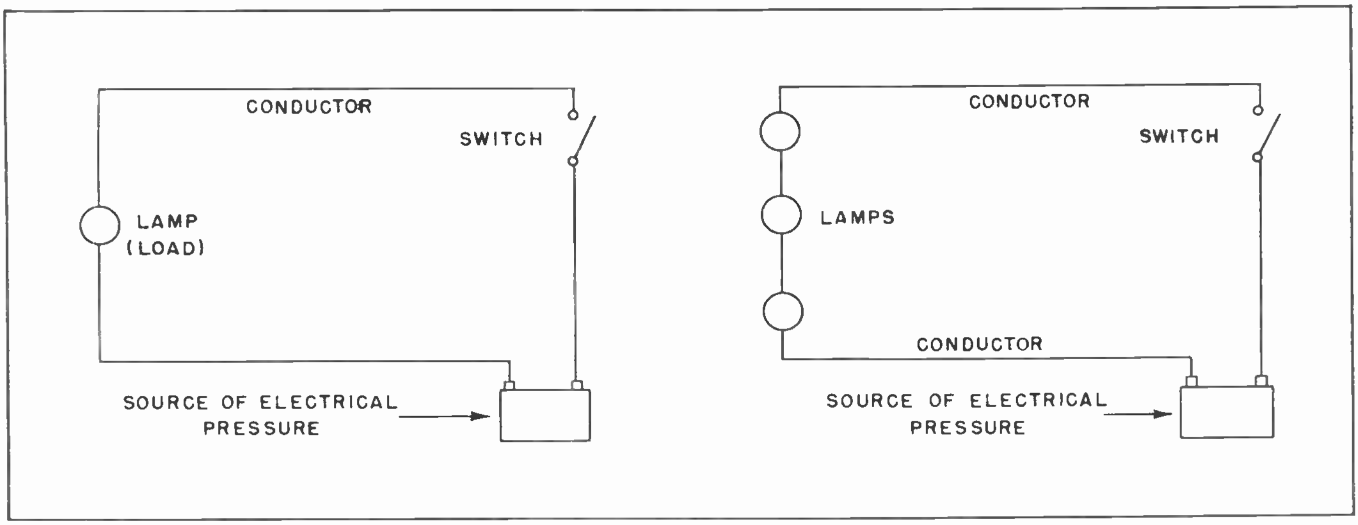

Fig.14. Series Circuits.

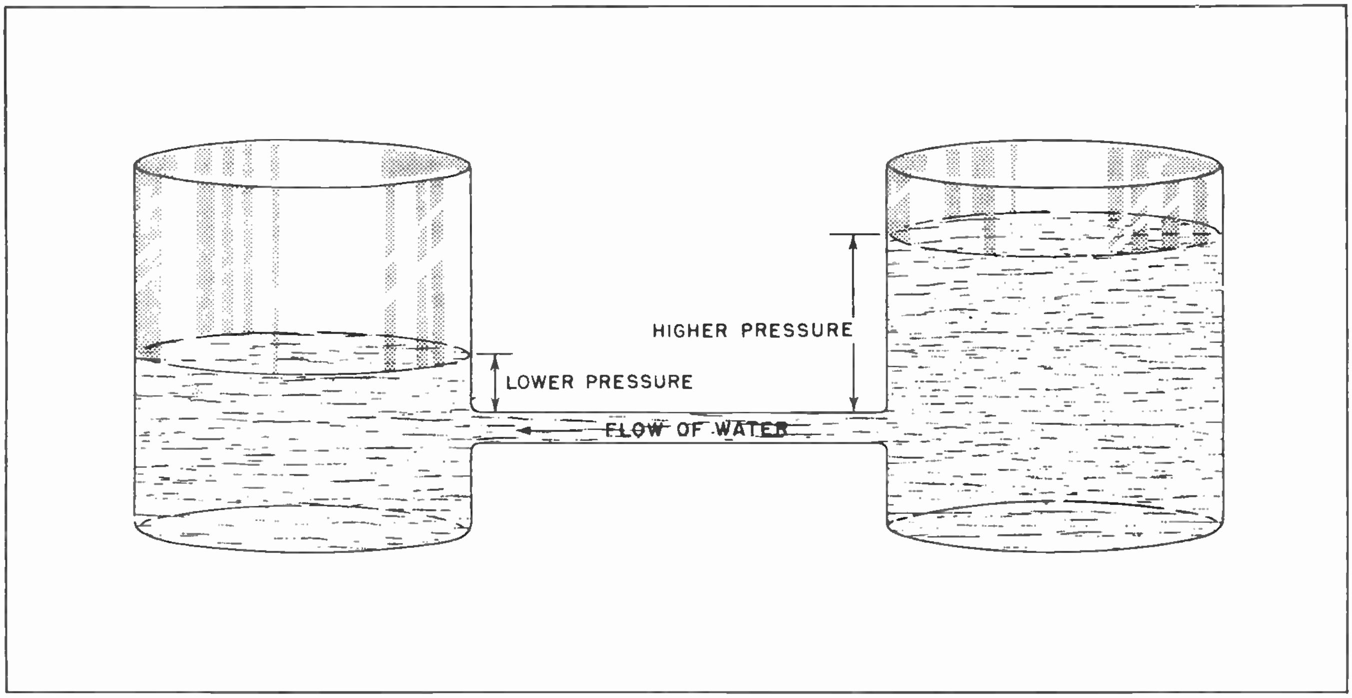

Fig.15. Water will flow through the pipe connecting the two tanks as a result of the difference in the pressure at the two ends of the pipe.

least lines that run as directly as possible from one part of the drawing to another. The drawings are usually referred to as diagrams. Sometimes they are called electrical diagrams. Again they are called schematic diagrams. Regardless of what they are called, they are usually made in a manner which all other electrical men can readily understand.

Fig. 14 illustrates a pair of very basic circuits. The diagram at the left hand side of Fig. 14 is one which shows a source of electrical pressure, a single lamp as a load with the circuit completed through connecting wires. The switch is shown in its open position. To light the lamp, the switch would have to be closed to complete the circuit. The current could not flow unless the circuit was a complete conductive path. This is very similar to the belt-driven machine. There no power could be delivered unless the belt made a complete circuit.

At the right hand side of Fig. 14 is shown two more lamps added into the circuit. They are connected in such a way that the current passes through the lamps, one after another, the same current going through all the lamps.

When electrical apparatus of any kind is so connected together that all the current which flows through any part must also flow through every other part in the circuit, the parts are said to be connected in *series*. The circuit itself is called a *series circuit*.

Section 7. ELECTRICAL PRESSURE

Electrical pressure, like any other pressure is a kind of force. It is the force that causes electricity to move, the force which acts as the motive power for the electricity moving in a circuit. It is quite customary to speak of the pressure which causes electricity to move as *electromotive force*. Electromotive force is usually abbreviated *EMF*.

Electromotive force, like any other force, has its own unit of measure so the amount of electrical pressure can be determined. Steam pressure is measured in *pounds per square inch*. Other types of pressure have their own units of measurement. So it is with electrical pressure. Electrical pressure is measured in units called *volts*. It would be well to remember exactly what the term *volt* means because it is used constantly in radio and television work. It is the unit of measurement for measuring the electrical pressure in any part of any electrical system.

Another method of describing electrical pressure, or voltage, is to refer to it as a *difference of potential.* In speaking of the difference in potential, we are usually referring to differences in voltage or pressure between two points in an electrical circuit. The difference in potential between two points in an electrical circuit can be compared to the difference in pressure in the water between two water tanks in which the water is at unequal heights. Fig. 15 shows an example of such a situation. There two water tanks are connected together with a pipe. The water in one tank is much higher than is the water in the other tank. Therefore the pressure on the pipe where it enters that tank is much greater than is the pressure on the other end of the pipe where it enters the other tank. As a result of this unequal pressure, or *difference of potential,* water will flow through the pipe from the point of high pressure to where the pressure is less.

So it is with electricity. Whenever there is a difference of potential between any two points in an electrical circuit, this difference of potential will cause an electrical current to flow. Current is always caused to flow when there is a difference of potential between two points -- and there is a complete circuit.

A common electrical example of the difference of potential in a circuit is that which commonly exists across an incandescent lamp when it is burning. We speak of the *potential difference* across the lamp as being about 115 volts, or 120 volts as the case might be. By this we mean there is a potential difference of 115 volts, or 120 volts, between the electrical pressure on one side of the lamp and the electrical pressure on the other side. This difference in potential causes an electrical current to flow. It is the flow of electrical current through the lamp which causes it to light up.

Section 8. SOURCE OF POTENTIAL

We have discussed at considerable length the matter of potential difference, but so

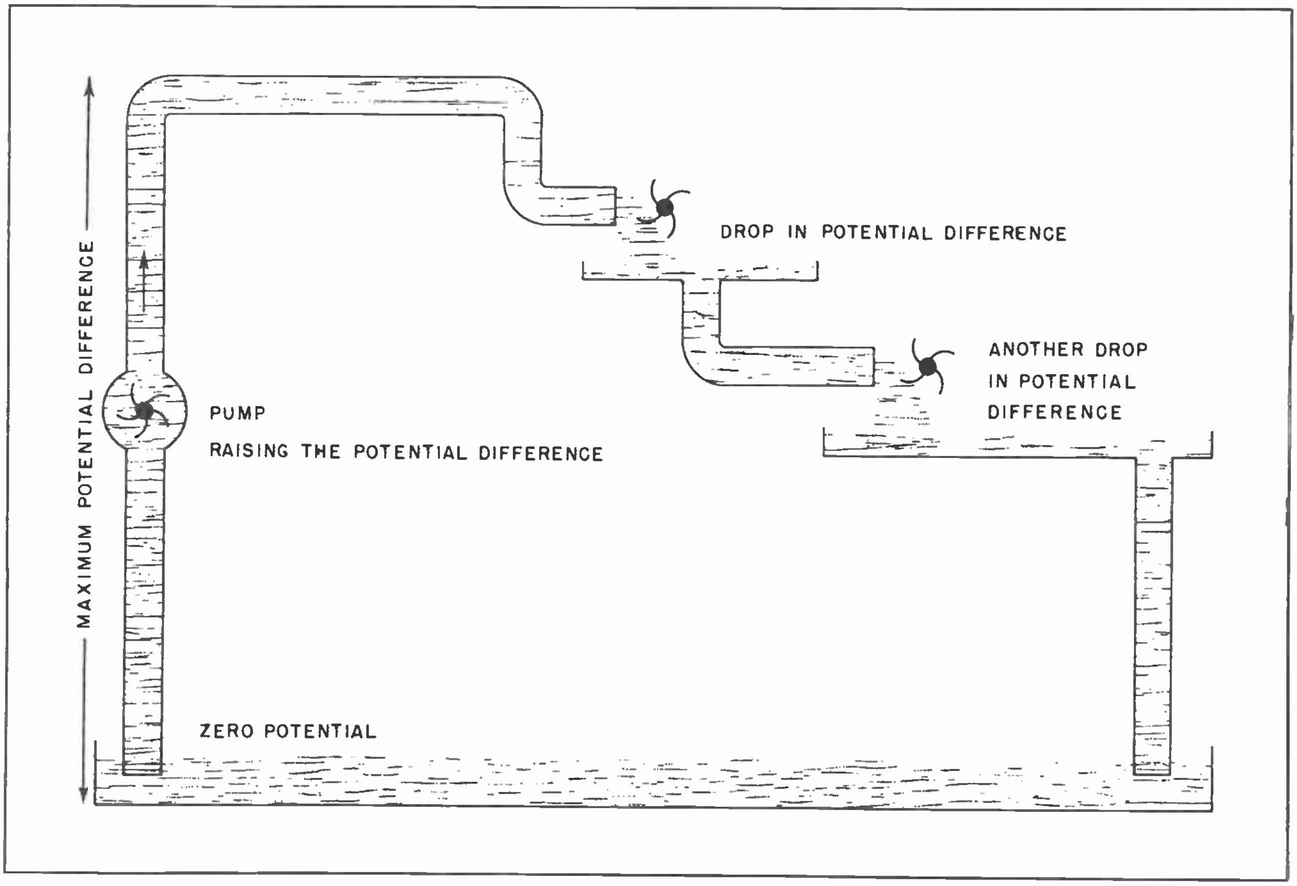

Fig.16. The water in the tank is at zero pressure, or "potential". The pressure is raised by the action of the pump. Part of the pressure is lost at the first water wheel. More pressure is lost at the second water wheel. When the water returns to the tank it loses the balance of its pressure and is again at zero pressure.

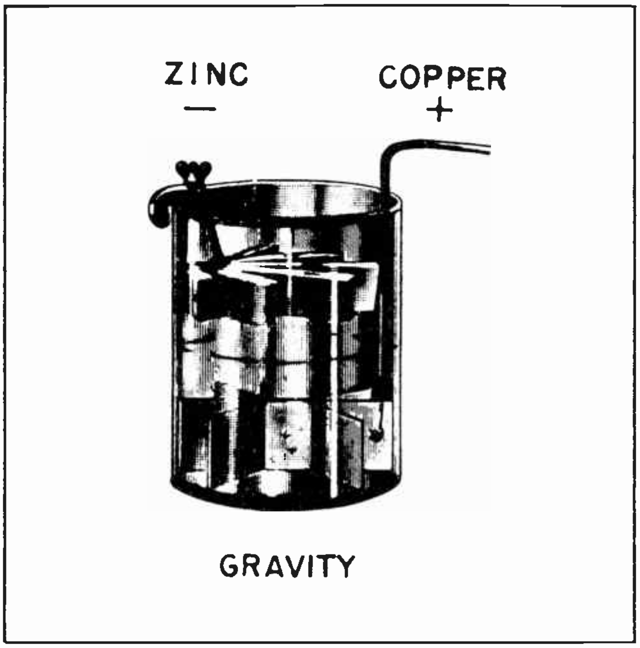

Fig.17. A gravity cell.

far we have said little about how a difference of potential is obtained. An electrical pressure, just as any other kind of pressure, must be created.

The water falling over the side of the mountain at Niagara Falls represents a difference in potential. There the difference of potential is not electrical but physical. It was created by the sun drawing up water into the clouds, then the clouds disgorging their water into the higher country above the Falls, and finally the water finding its way into the lakes and rivers through which it reached the upper lip of the Falls. The point is, the difference in potential had to be created. And in that case we could trace its creation back to the action of the sun.

The steam pressure within the boiler that furnishes power for steam engines and turbines had to be created. In that case, the pressure was created by the action of heat on water.

By returning again to the use of water to describe a point we want to make clear, the illustration of Fig. 16 will show how the creation of a difference of potential can be used to do useful work. The pump at the left hand side of the illustration raises the water through the pipe, and thus, in effect, raises the potential. The water flows through the pipe, then down to strike the waterwheel. In falling, the water loses some of its potential and does useful work. But it does not lose all of its potential. It is still much higher than its normal level. The water then passes through another pipe and falls some more to strike another waterwheel where it does more work.

The pump is used to create a difference in potential in the pressure of the water. The water in falling loses its potential. But the lost potential is converted into useful work.

And so it is with electrical pressure. The differences of potential can be created either by nature or by man. Since the naturally created differences of potential, such as those displayed in the discharge of lightning, are of little importance to us at the moment, we will pass them by without comment. But man has managed to build devices which will furnish him with a constant source of electrical pressure -- a source that is both inexpensive and dependable.

As far back as 1786 a scientist by the name of Galvani discovered that if two different metals were brought into contact

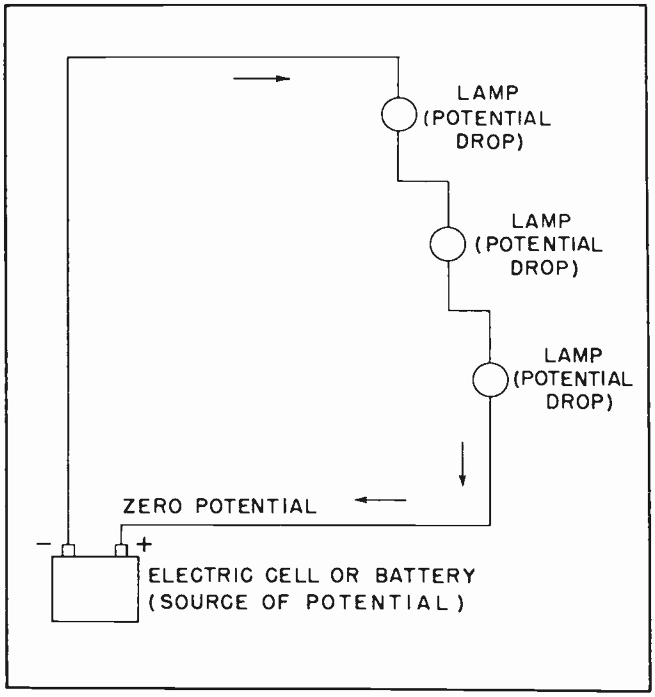

Fig.18. The battery raises the electrical pressure, or "potential", from zero to a higher value. There is a drop of potential across each lamp. By the time the current gets back to the positive side of the battery, the pressure has again dropped to zero.

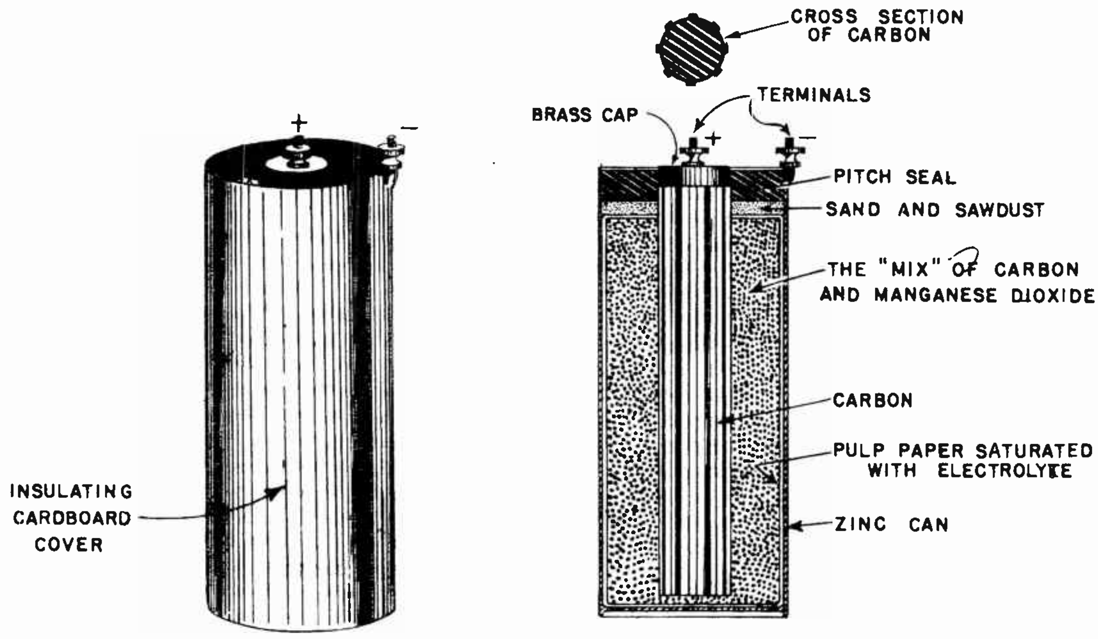

Fig.19. A primary cell. This type is commonly called a "dry" cell.

with each other he could obtain a slight flow of electrical current. About twenty years later an Italian named Volta placed alternate layers of copper and zinc in a pile with moist pieces of cloth between them. From this "voltaic pile" he was able to obtain a small but continuous flow of electricity.

It was only a step from the voltaic pile to the first electrical cell, or "battery". Volta placed a piece of copper and a piece of zinc in a dilute solution of sulphuric acid. He connected a piece of wire to this copper and another piece of wire to the zinc. When these two pieces of wire were connected together, a heavy electrical current would flow.

The chemical action which took place within the cell changed the electrical characteristics of the two pieces of metal. The acid acting on one piece of metal raised the electrical potential on it, and acting on the other piece of metal lowered the potential there. Thus a very definite difference of potential was created between the two wires which were connected to the pieces of metal.

With the difference of potential thus created it was possible, for the first time, for electricity to be put to useful work.

If we look again at the illustration in Fig. 16, it will be seen that the differences of potential are distributed equally throughout the system. The potential in the pipe at the left hand side is being raised by the action of the pump. The potential in the other parts of the system is falling at all points.

Much the same situation exists in an electrical system. This is shown by Fig. 18. The electric cell, or battery, at the left hand side of the illustration raises the electrical potential from zero to a somewhat higher value. Raising the potential causes an electrical current to flow. As the current flows through the first lamp there is a drop in the potential difference. Then as the current flows through the second lamp there will be another drop in the potential difference. Then as the current flows through the third lamp the rest of the potential difference is lost and now we find there is no longer any difference in potential. There is no longer any electrical pressure.

This is probably just what we expected to find. The electric cell created a certain amount of potential difference, or voltage. Then the lamps used up the voltage as the current passed through them. In other words, a certain amount of pressure was used in forcing the current through each lamp. By

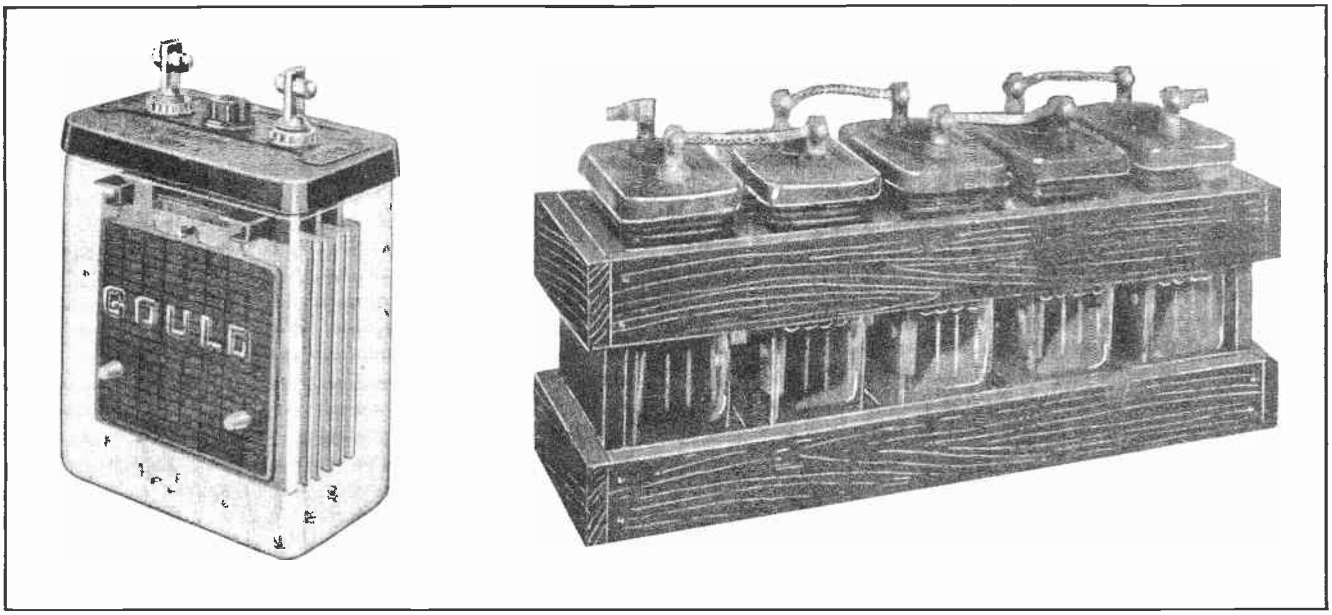

Fig.20. Secondary cells. These are commonly called storage batteries.

the time the current had passed through the last lamp all the pressure had been used up. There was no more. Just as in the case of the water pump and the water wheels. By the time the water returned to the main reservoir all the pressure had been used up -- there was no more.

As we advance in our studies we will learn that the voltage drops in any electrical circuit always exactly equals the voltage created by the battery or generator. It might be said that an electrical battery raises a voltage from zero to some higher value and then as the current passes through the load, the voltage will drop until it again reaches zero.

In radio and television work we are continually concerned with voltages and voltage drops. In television circuits the voltage often reaches very high values. Voltages of 25,000 to 35,000 volts are not at all uncommon, and voltages in excess of 5,000 volts will be found in all except the very smallest television receivers. Even the average radio uses voltages running up to 600 and 700 volts. Few people except trained technicians realize the value of the voltages which are used in these everyday household appliances.

It might be well to add that voltages of these values are not put into radio and television receivers just for the fun of putting them there. They are there because they are needed. Many of these voltages are divided up, and various amounts of the voltages tapped off and used at such places as they are needed. We will not go into the technical phases of voltage divider networks at this time. These will be taken up a little later and covered in great detail.

We have discussed how the voltaic cell was first discovered, and how it made possible the first actual use of electricity. Electric cells of many kinds are in use today. Some, such as the *dry cell* which is shown in Fig. 19, can be used until the acid, or "electrolyte", eats up the zinc. Then the cell must be discarded and thrown away.

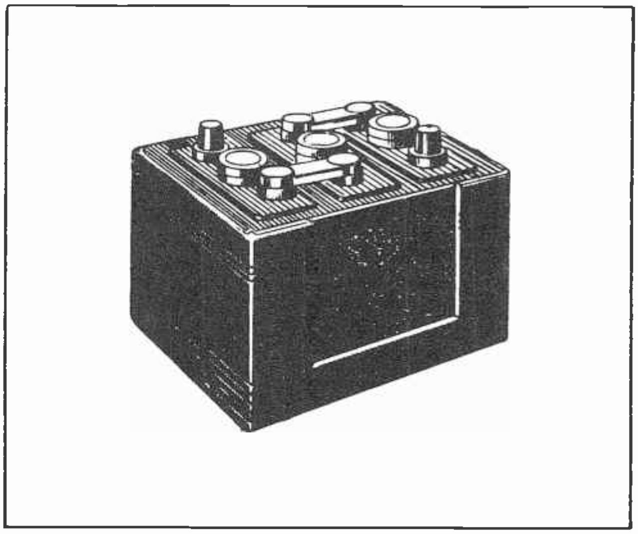

Fig.21. A type of secondary cell used in automobiles.

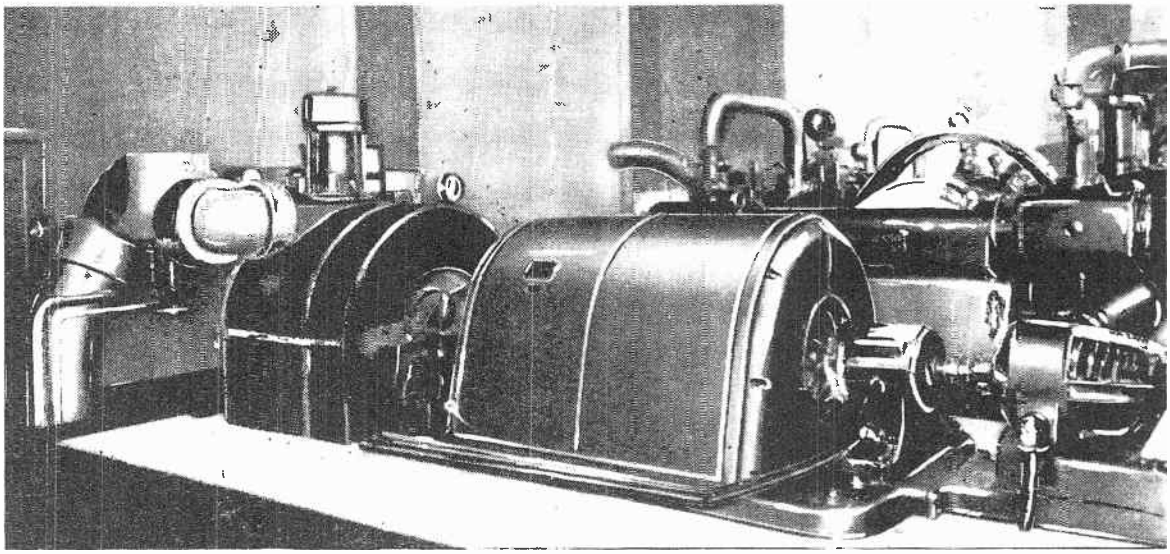

Fig.22. A turbine-driven machine for creating electrical potential difference.

Cells, such as the dry cell and the gravity cell shown in Fig. 17, are known as "primary" cells. This is because once their active ingredients have been used up, they are of no further value as producers of an electromotive force.

There is another type of electrical cell which is called a "secondary" cell. Illustrations of such electric cells are shown in Figs. 20 and 21. Electric cells of this type can be "recharged". By this is meant that when they have lost their ability to create an electrical potential difference, or an electromotive force, a current can be caused to run through them in reverse, and again build up their voltage. Secondary cells are more commonly called "storage batteries". A familiar use for them is in automobiles. There they can be used to operate the lights, the horn, or the radio when the automobile is not running. They are also used to operate the starting motor so the automobile engine can be started without cranking.

Other common uses for secondary cells, or "storage batteries", is for farm lighting systems where "high-line" power is not available, in airplanes, on Diesel-electric locomotives for starting the engines, for radio equipment on ship-board, and in the central offices of telephone companies.

It should be mentioned that when two or more electrical cells are connected together, they are referred to as a "battery". A single cell is never referred to -- correctly -- as a battery, although it must be admitted that some people through ignorance of the meaning of the word do say "battery" when they mean only one cell.

It should not be thought that the creation of electromotive force is entirely dependent upon storage batteries and primary cells. In fact, these sources of EMF are generally resorted to these days only when other sources are not available. But they do have the advantage of being portable, and thus do not have to depend upon wires for connection with a central source of EMF.

The source of EMF for most uses today is the central generating plants of the large power companies. There the EMF is created by huge mechanical machines called generators. The generators are now usually driven by turbines which turn under the influence of terrifically high steam pressures. An illustration of one of these generators is shown in Fig. 22.

(Reference Notes on the Page following)

NOTES FOR REFERENCES

Materials through which electricity passes freely are called *conductors*.

Materials through which electricity will not pass freely are called *insulators*.

A switch is a device which is used to break the continuity of an electrical circuit.

Polystyrene, Steatite, Pyrex and Mycalex are special types of insulators for use at high frequencies.

Diameter of the wire, length of the wire, and the material from which the wire is made all affect the flow of electricity through it.

An *Ampere* is the unit of measure of electrical current flow.

An electrical circuit must consist of a complete round-trip conductive path in order for electricity to flow in any part of it.

A *volt* is the unit of measurement of electrical pressure.

Electrical cells and mechanical generators are sources of electrical voltage.

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ELECTRONS

Contents: Introduction - Introducing the Electron - The Atomic Theory - Early Attempts to Put the Electron to Work - Vacuum Tubes - Notes for Reference.

Section 1. INTRODUCTION

Probably no other way of making a living holds such a fascination for those engaged in it as does the field of radio and television. Few who are true radiomen ever grow hardened to the wonderful and mysterious ways of radio, nor weary of seeking newer and wider knowledge of its ever-unfolding secrets. Sometimes it seems no man can ever know all there is to know about radio and television. Almost every day some new and exciting chapter is opened, and a new adventure beckons to the never-unwilling experimenter. Fortunate indeed is the man who chooses radio and television for his life's work. He is definitely assured of one thing -- his life will never be dull.

The very expanse -- the wide scope -- which is embraced within the general field of radio and television includes so many

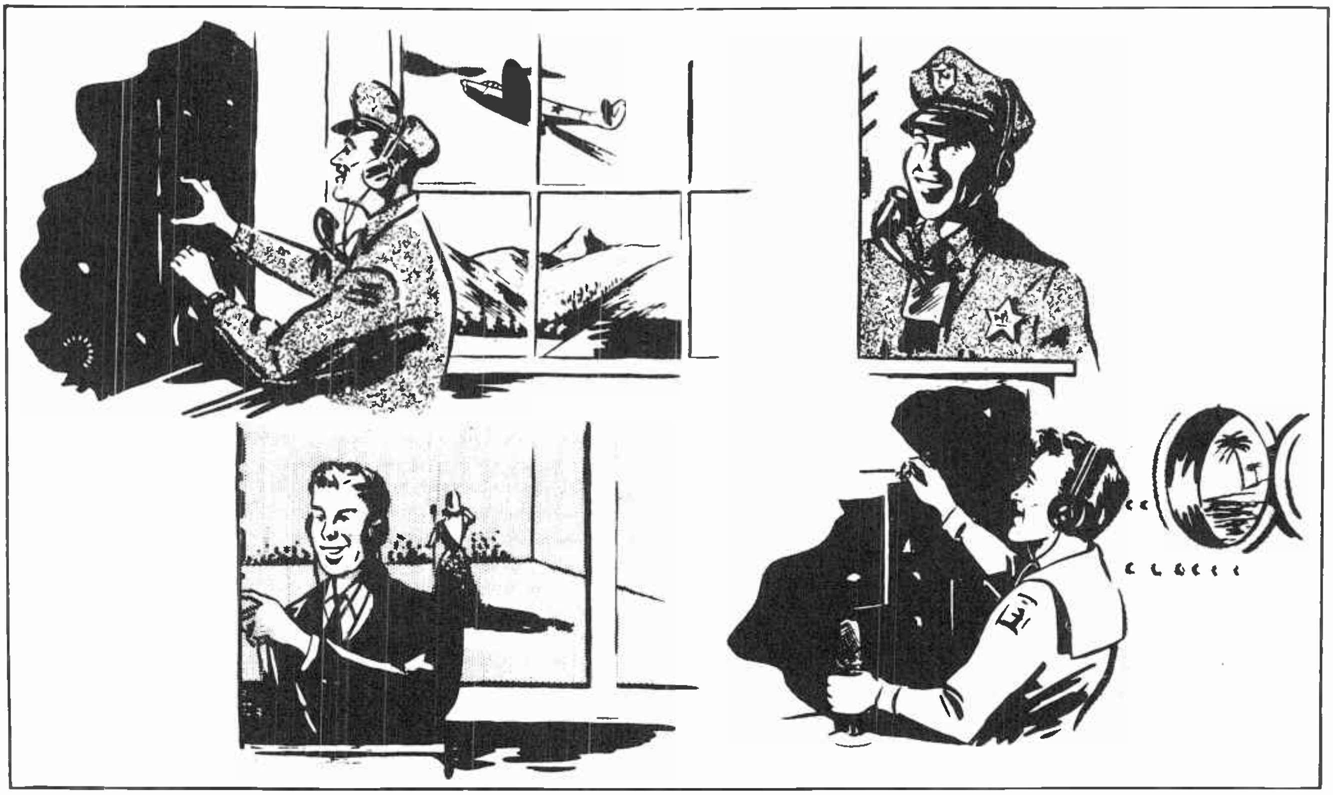

Fig. 1. Radio and television offer endless opportunity for the ambitious man.

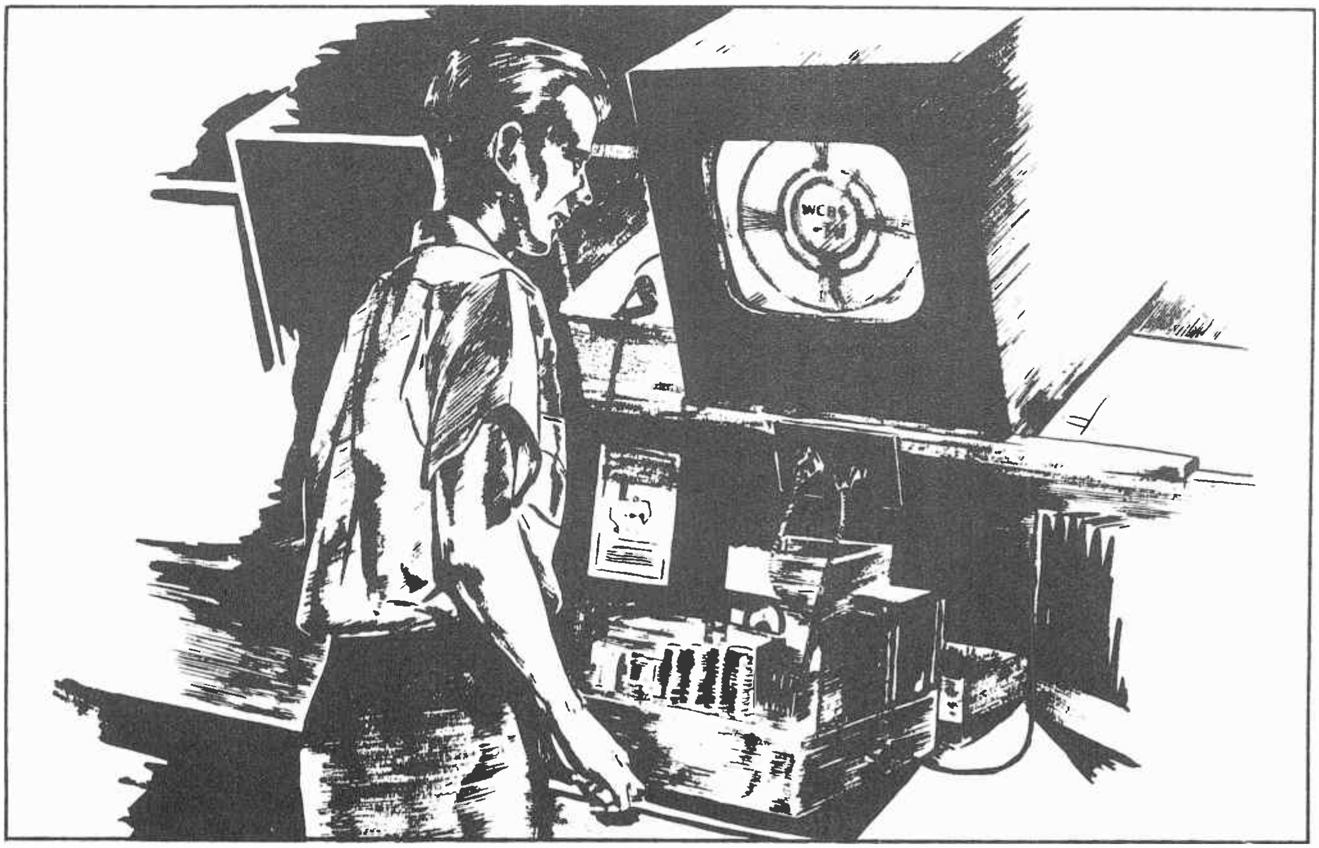

Fig.2. Technician servicing a television receiver.

apparently unrelated subjects it is sometimes a little difficult to know just where to begin one's studies. The transmission of radio and television signals from the transmitter and their reception at the receiver calls for the use of many pieces of equipment. Some of them are quite small, and some are not found in use anywhere except in radio and television. All this means that if the technical side of radio and television is to be made intelligible to the newcomer into the field it is necessary to explain the operation of all these many parts before trying to explain the operation of the actual radio and television equipment itself.

The very heart of all modern radio and television transmitters and receivers is the vacuum tube. It will be necessary to spend much time explaining the operation of the vacuum tube before getting into a discussion of the actual operation of the radio and television equipment. But even before we begin our studies of the vacuum tube there are a few other things we should understand quite thoroughly.

We must understand a few more things about electricity and the things which affect its passage through wires. But even more important -- we must learn something about *electrons*. Without a full and complete working knowledge of electrons it will be quite difficult to understand the operation of the vacuum tube. And, of course, if we do not understand the vacuum tube quite thoroughly we can never hope to get very far in the field of radio and television.

Section 2. INTRODUCING THE ELECTRON

The story of the electron is the story of the smallest thing in the world. It is so small that no man has ever seen it — and it seems probable that no man ever will. But despite the fact it has never been seen we know a surprisingly lot about it. We know how heavy it is, how big it is, and much about how it acts. And every day scientists are learning more about it.

For many centuries man sought to discover the electron -- but he did not even know what he was looking for. As far back as the dawn of the Christian era the learned men were thinking and guessing about it, and strangely enough many of their guesses were surprisingly accurate. They had a feeling there was "something" of which all things were built, but exactly what this something was they did not know.

For many centuries little progress was made in tracking down this elusive unknown. Gradually the guesses became better. Closer and closer they came to the truth. At last the learned men agreed that the thing they were looking for was a universal building block. Something that was common to everything.

The chemists and the physicists pursued their researches and their experiments until -- about half a century ago -- they finally discovered the Electron. Perhaps *discovered* is not exactly the word to use. It might be better to say that they finally proved the existence of the Electron.

It is safe to say that no other discovery since the beginning of time has changed the lives of so many people as has that of the electron. The incredible thing is that so many changes could have taken place in such a short period of time. There are millions of people living today who were born before the electron was known to exist. Yet during the space of their lifetime the electron has grown in importance until today it is one of the most important things in this world.

Knowledge of the existence of the electron, and how it acts, has made possible not only radio and television but also radar -- which is actually one form of television -- loran, sonar and other similar ranging and detecting devices. It has made possible the creation of the atom bomb and all the other associated atomic derivations, some of which hold great promise of providing man with weapons with which to combat certain diseases which have previously been considered incurable. It led to the development of an

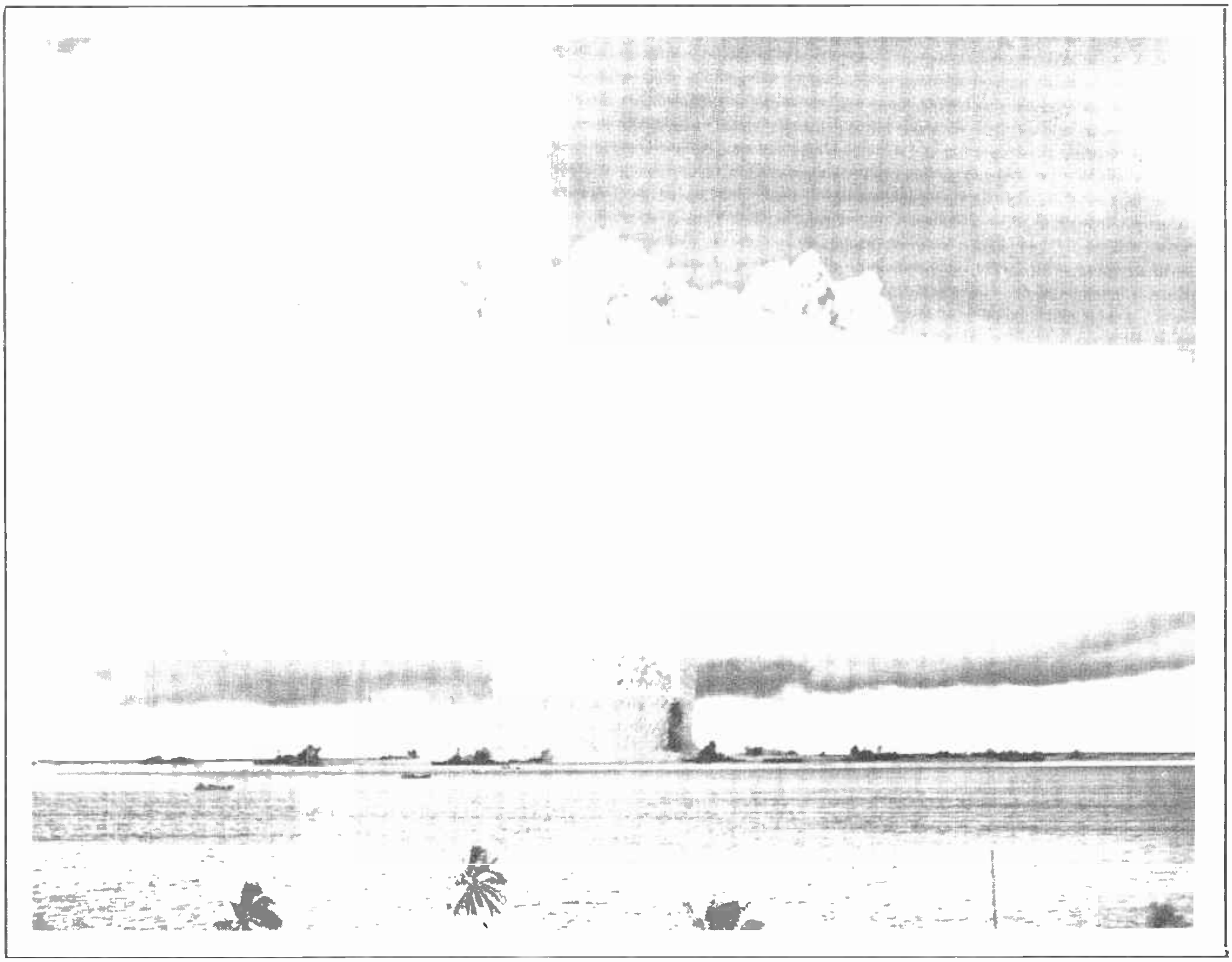

Fig. 3. Atom bomb explosion at Bikini.

Fig.4. Everything in the world is made of matter.

entirely new branch of the physical sciences — that of nucleonics.

But perhaps we are wandering a bit too far from the thing we want to talk about -- the electron itself. In our previous discussion of electricity we made no attempt to define exactly what electricity is. It is readily apparent that electricity is "something". It is also apparent that this "something" moves from place to place, or is moved from place to place. This is proved by the fact that if we break an electrical circuit at any point the electricity ceases to move.

Through a seemingly endless series of experiments, and many years of work, scientists have proven that a tiny particle of matter, which they have chosen to call the *electron* is responsible for the flow of electricity. The relationship of the electron to the flow of electricity can be viewed in two ways. The electron can be viewed as being the carrier of a certain amount of electricity. Or, it can be viewed as being itself a certain amount of electricity. The general trend in scientific thinking is toward the belief that the electron is itself a tiny particle of electricity. Whichever viewpoint is adopted is of little importance to us, both lead to the same conclusions. But since the majority of the learned men are inclined to favor the latter viewpoint, and for the sake of simplicity, we will always refer to the electron as being a tiny, but definite, *amount* of electricity.

As to the exact amount of electricity that is involved when one speaks of an electron, it should be understood that it is an extremely small amount. Since the electron is the lightest thing in existence we know that it must be very small, but when we say that 6,000,000,000,000,000,000 electrons must pass a given point in a wire *each second* when one ampere is flowing, one begins to get some idea of the unbelievable smallness of the electron. The number of electrons we have just mentioned is so large that many of us can't even say the number after it has been written down. Fortunately for us we do not have to worry about that. Since all electrons are alike we can discuss the action of one of them, and then understand that the same reasoning applies to them all regardless of how many of them there are.

From what we have said about the electron it can be decided that the electron is something physical -- something tangible -- something real. While it must be admitted that no one has ever seen an electron it is perfectly in order for a person to form a mental picture of an electron and to accept its existence as a tangible particle of matter. Since scientists commonly speak of the radius and of the mass of an electron it would be a safe assumption to conclude that its shape is round.

It would also be well to make another attempt to form some idea of the smallness of the electron. This is because there are occasions for discussing the movement of electrons under conditions which would be difficult to understand if we did not realize how incomparably small the electron is. When one first tries to comprehend the unbelievable smallness of the electron the idea is extremely hard to grasp, and even a comparison is more than enough to tax the imagination. Fortunately, if you fail to completely understand the full degree of the electron's smallness it will not interfere with your ability to understand the part the electrons play in radio and television work. If we were perfectly truthful it is doubtful if there are many of us in such work who are capable of fully understanding the electron. But it really isn't hard to learn enough about the electron to work with it intelligently, even though it is hard to grasp the idea of how small it is.

One commonly used illustration of the comparative size of the electron is to compare it with a ping pong ball and with the orbit of the earth. As you probably know, the orbit of the earth -- its path around the sun -- is about 185,000,000 miles across. The size of a ping pong ball in comparison with the enormous size of the earth's orbit is so insignificant as to be almost no comparison. Yet the size of the electron compares with the size of the ping pong ball in just about the same way the size of the ping pong ball compares with the earth's orbit.

Section 3. THE ATOMIC THEORY

Everything in existence contains electrons. While we normally think of electrons in connection with electricity, with radio and with television, the fact is that they are the building blocks from which *everything* is made.

Before attempting to digest such an assertion it might be well if we first explain that everything which occupies space, and has weight, is made up of something which we usually designate as being *matter*. We can break *matter* down as consisting of smaller particles which are called *molecules*. And can in turn break molecules down into still smaller particles which are called *atoms*.

Atoms are extremely small particles which are too small to be seen. They are accepted as existing, and of having such dimensions a million of them would fit upon the point of a pin. Until recent years it was generally accepted that there were 92 different kinds of atoms. One atom for each of the then known *elements*. An element being the smallest subdivision into which man could break down matter.

Recent experiments with breaking down the atomic structure, during which the atomic bomb came into existence, has resulted in the creation of several additional elements.

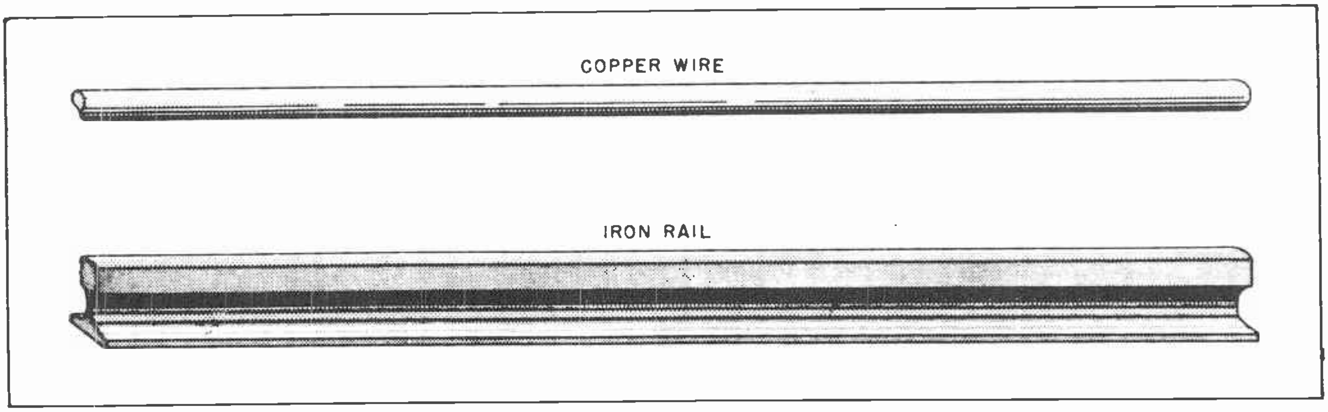

Fig.5. Copper and iron are both elements.

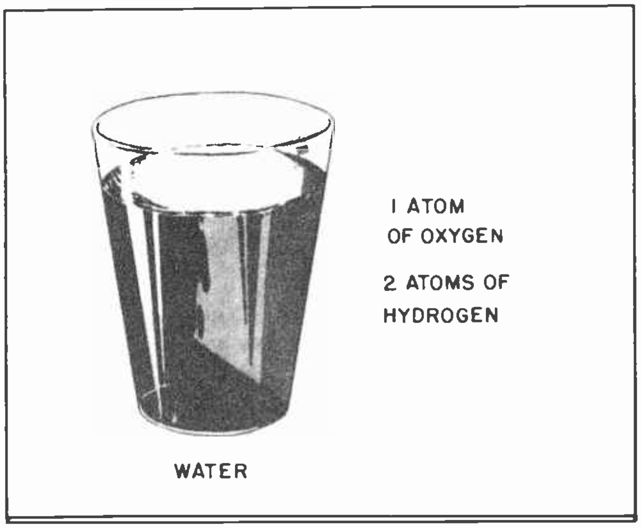

Fig.6. Water is a compound. A molecule of water contains one atom of oxygen and two atoms of hydrogen.

But for the purpose of our work we need not go into a discussion of the exact number of known elements -- such a discussion is of no importance to us.

Most everyone is familiar with copper. The radioman quickly becomes familiar with it if he is not already. Copper is used for many things in radio and television. Now the smallest particle into which copper can be broken down is an *atom of copper*. Likewise the smallest particle into which iron can be broken down is an atom of iron. And the smallest particle of oxygen is an atom of oxygen.

Water on the other hand can be broken down into an atom of oxygen and two atoms of hydrogen. Water is not an *element*. It is a *compound*. A compound is a combination of two or more kinds of atoms. There is almost no limit to the kinds of compounds which exist, or can be created.

While the atom is a fundamental building block it is not an indivisible particle. It, too, can be broken down. We have mentioned the 92 different kinds of elements, and how there was a different atom for each element. The natural question is: how do these atoms differ from each other? What is the difference between an atom of copper, which is a metal, and an atom of oxygen, which is a gas?

If you do not already know the answer it is almost certain to surprise -- even shock -- you. *The difference between atoms is in the amount of electricity within the atom and the arrangement of the particles of electricity within each atom.*

If you get the idea from this statement that everything in the world is made up of electricity, you are right. If you are one of those who have looked upon storage batteries and electrical generators as being devices which manufacture electricity you might find such a statement hard to understand. The truth is that *electricity is never created*. Batteries and generators do not *make* electricity. What they do is create a difference of potential -- a voltage. The electricity -- electrons -- which are already in everything, including the wire, begin to move under the influence of the pressure of the voltage. If the electrical circuit is complete the electrons in that circuit will begin to move the instant an electrical pressure is applied to the circuit.

You may wonder, if this is true, why the electrons in the insulators do not begin to move under the influence of the electrical pressure in the same manner as the electrons in the wire. To understand why they do not it is necessary to continue our studies of the atom and the electron a little farther.

The generally accepted theory among scientific men today is that the structure of the atom resembles somewhat a miniature solar system. It is something like our sun and the planets which revolve around it.

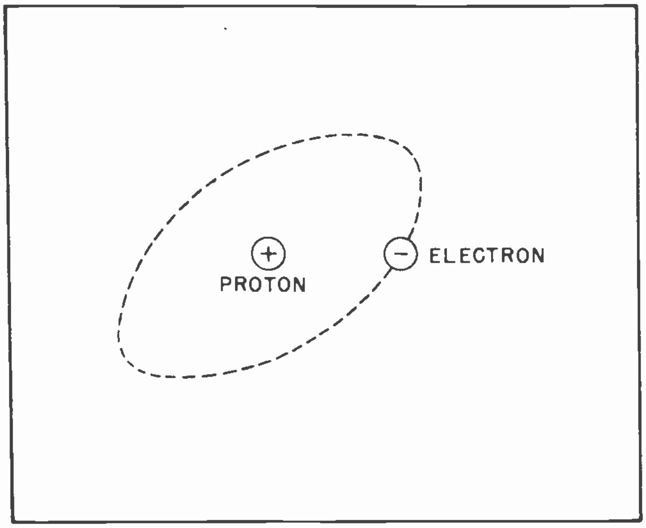

Fig.7. An atom of hydrogen consists of one positive proton around which is circulating a negative electron.

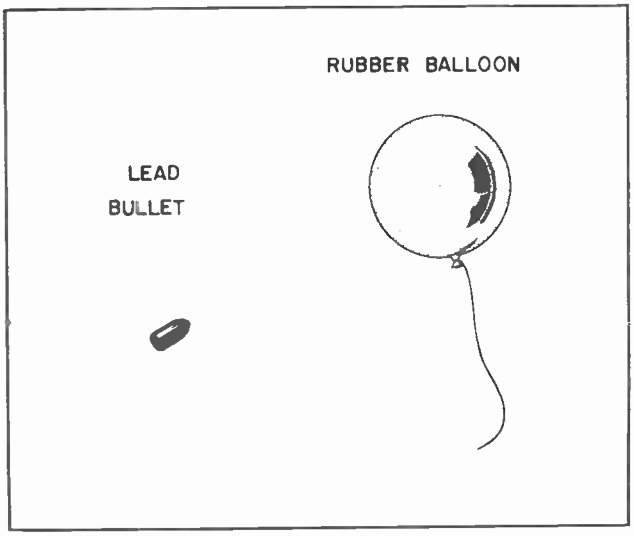

Fig.8. The lead bullet weighs much more than the rubber balloon, but the balloon is larger in diameter.

Following this theory, the atom contains a nucleus -- a center -- which corresponds roughly to the sun in our solar system.

To better understand the make-up of an atom we will first analyze the structure of an atom of hydrogen. An atom of hydrogen is the simplest of all the atoms. The nucleus of an atom consists of one *positive* particle of electricity. This positive particle of electricity is called a *proton*. Revolving around the proton, and at a relatively great distance from it, is a single electron. We have mentioned before that an electron is a particle of electricity. We will now go a step further and say that an electron is a particle of *negative* electricity. See Fig. 7.

We now have the *proton* which is a tiny particle of *positive* electricity, and the *electron* which is a tiny particle of *negative* electricity. The amount of electricity represented by the proton and the amount represented by an electron is equal in magnitude, but opposite in sign. It might be well to mention at this time that there is considerable difference in the size and the weight of the proton and of the electron. The proton weighs about 1850 times as much as the electron, but the diameter of the electron is many times larger than the proton. A rough comparison would be a lead bullet and an inflated rubber balloon. The bullet is heavier than the balloon. But the balloon has the greatest diameter. See Fig. 8.

We have just mentioned that the atom of hydrogen is the simplest of all atomic structures, having one proton in the nucleus and one electron revolving around it like a planet in our solar system. The next most simple atomic structure is that of helium. The atom of helium consists of two protons in the nucleus and two electrons revolving around the nucleus in the same orbit. See Fig. 9.

In the case of the atom of helium, both electrons revolve around the nucleus in the same path. In this respect helium and hydrogen are very much alike. They both have only one path, or orbit, along which the electrons move. But most other atoms

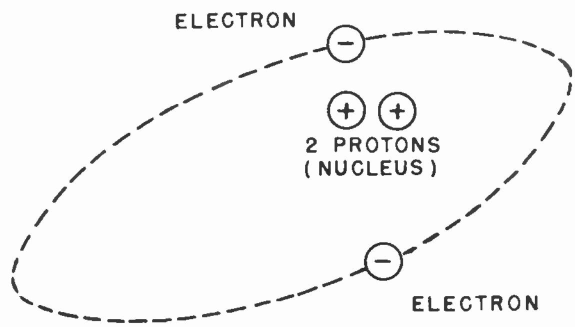

Fig.9. An atom of helium consists of two protons which form the nucleus, and two electrons which rotate around the protons.

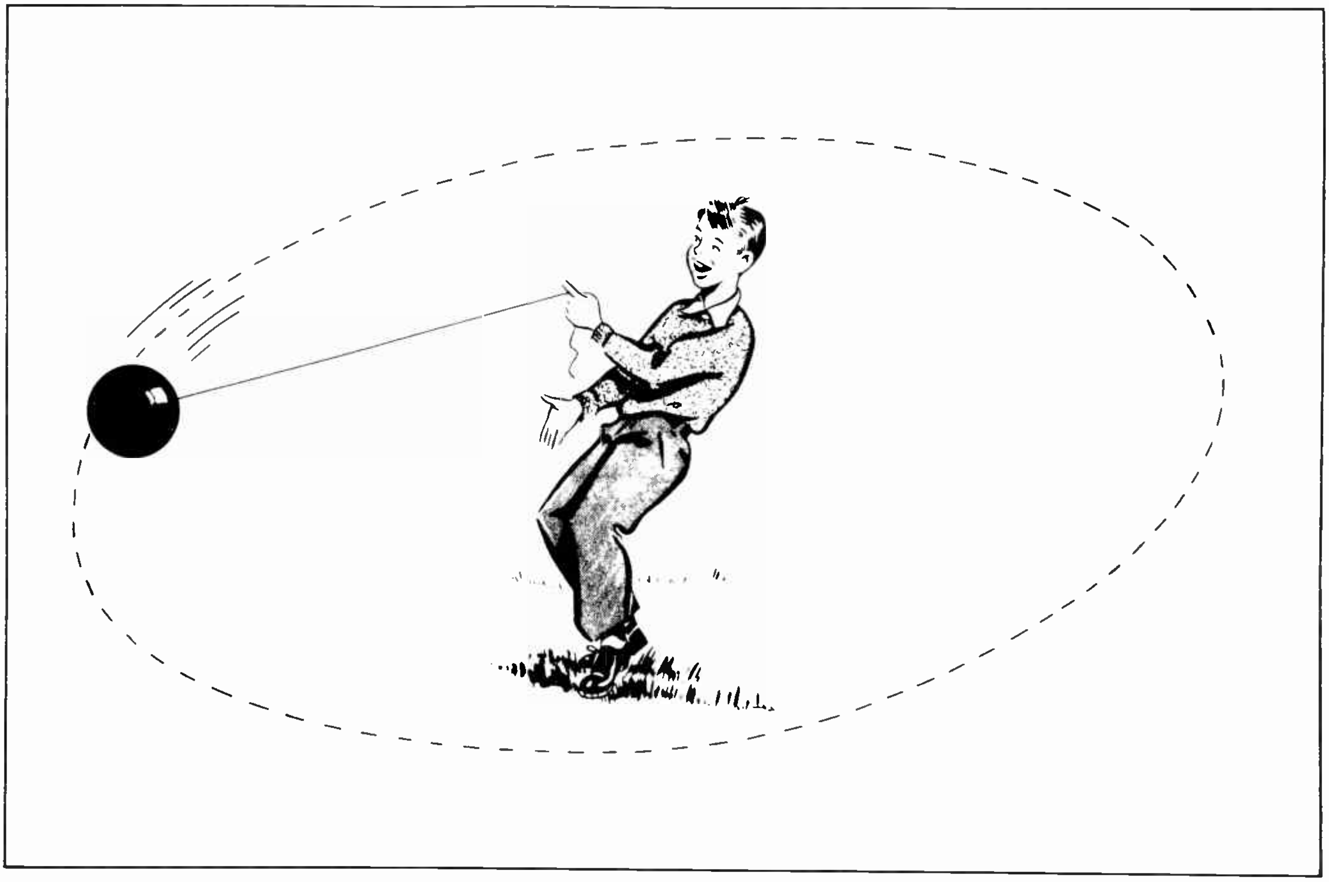

Fig. 10. The inertia of the fast moving ball tries to send it off through space, but the restraining influence of the string holds the ball in its orbit around the boy.

have more than one orbit within which the electrons move. Some atoms have many orbits.

A somewhat different type of atomic structure is that of lithium. And since the structure of the lithium atom introduces a new arrangement it would be well to explain a few things about the action of the protons and electrons first. It should be understood that since the proton is positive and the electron is negative there is a very great attraction between them. The electron keeps trying to approach the proton. It is much easier for the electron to approach the proton than for the proton to approach the electron. This is because the electron is so much lighter than the proton. But despite the attraction between the protons and the electrons the speed with which the electron is moving in its orbit keeps it from actually getting any closer to the proton.

This situation can be compared with that of a boy twirling a ball on the end of a string as shown in Fig. 10. The inertia of the ball as it follows its orbit around the boy is comparable to the inertia built up by the electron as it revolves in its orbit, the inertia which keeps it from actually approaching the proton. The string attached to the ball can be compared to the attraction between the electron and the proton which keeps the electron in its orbit.

But in some atomic structures some of the electrons do actually approach the protons. When the electron and the proton come together their opposite charges neutralize each other and they become electrically neutral. When they come together they form what is called a *neutron*. The neutron is a very important factor in atomic research, and in the science of nucleonics. But fortunately for us, it is of little importance in electrical or radio work.

Now to get back to our discussion of the atomic structure of lithium. Lithium has two electrons which revolve around the nucleus in one orbit, and another which revolves in another orbit. In addition to these *planetary* electrons -- electrons which move in orbits — there are several neutrons in the nucleus. See Fig. 11.

We can practically ignore neutrons in most of our electrical work, but the orbits of the electrons are very important, especially the distance of the orbits from the nucleus. It should be noted that one of the orbits of the lithium atom swings out much farther from the nucleus than does the other one.

It has probably become apparent by now that the only difference between the atom of one element and the atom of another element is in the number of electrons and protons in the atom, and the way in which they are arranged. For instance, the only difference between an atom of hydrogen and an atom of helium is that the hydrogen atom has only one electron and one proton, while the atom of helium has two of each. And so it is with all the other elements. Some have more electrons and protons, and some have less.

Instead of having one or two orbits which the electrons follow in revolving around the nucleus some atoms have many orbits. As these orbits become larger and larger the distance between the electron and the nucleus becomes greater. And as the distance increases the attraction between the electron and the nucleus becomes less.

While it is true that the protons inside the nucleus have a strong attraction for the planetary electrons, this attraction is not the same in all atoms. In some atoms the electrons which are in the outermost orbit can come under the influence of some outside attraction, or other outside force. This can result from the nearness of another atom which is temporarily deficient in electrons, or from a collision between atoms, extreme agitation of the atoms, or from a collision between an atom and a fast moving, free electron. As a result one of the outermost electrons might be knocked from its orbit and detached from the atom.

When an atom loses one of its electrons it will have more protons than electrons, and will thus be electrically positive. Being positive it will have an attraction for any lost electrons which might be in the vicinity.

Sometimes the reverse is true. An electron which has been freed from some other atom may, under the influence of an electrical action, attach itself to an atom which is already electrically neutral. After the electron has attached itself the atom will then become negative.

The freedom with which such inter-atomic movement can take place among electrons determines the suitability of that substance

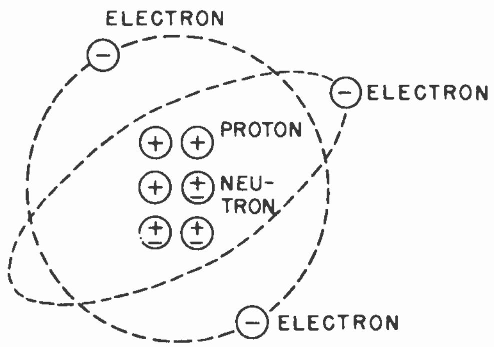

Fig.11. Atoms of most elements have many orbits within which the electrons rotate. The Lithium atom has two orbits. There are two electrons in one orbit and one in the other. The nucleus of Lithium also contains neutrons which are electrically neutral.

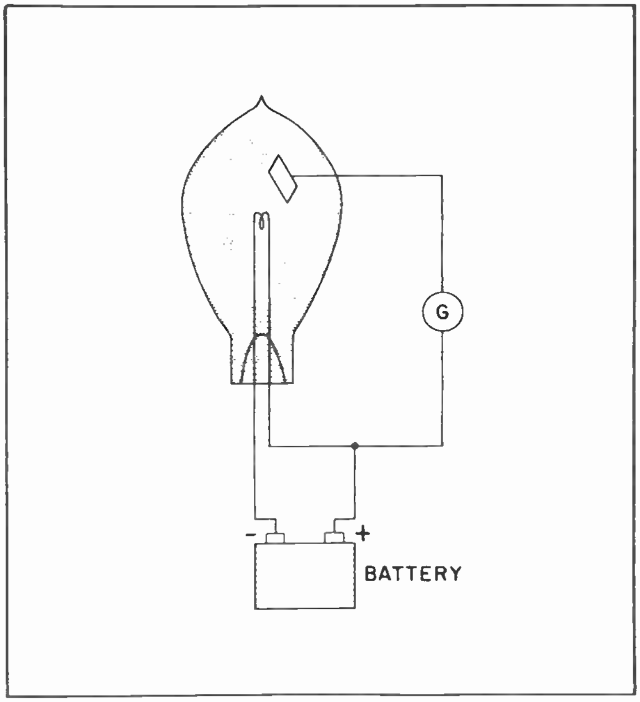

Fig. 12. Experimental set-up used by Edison at the time he discovered the "Edison effect."

as a conductor of electrical current. The more free electrons there are in any particular substance the better conductor it will make. Free electrons are quite plentiful in most metals. Silver has more free electrons than any other substance. Copper has almost as many free electrons as silver has.

The difference between electrical conductors and electrical insulators is that there are plenty of free electrons in a conductor, but there are very few in insulators. Where the electrons can move about with great freedom in a conductor, they hang onto their own atoms very tightly in an insulator. It should be mentioned that some gases as well as metals are so constructed that their electrons can move around freely. As will be discussed later in great detail, these gases play a very important part in vacuum tube operation.

Section 4. ATTEMPTS TO PUT THE ELECTRON TO WORK

Even before the electron was discovered there is at least one recorded instance of an attempt being made to put it to work. This occurred during Thomas A. Edison's experiments with his incandescent lamp. He had patented his lamp in 1879, but not being completely satisfied with it, he continued experimenting.

During the course of one of his experiments, Edison sealed a small metal plate within the glass bulb of his lamp. He connected the metal plate with a galvanometer, and from the galvanometer to the positive terminal of the battery which was used to heat the filament of the lamp. The connections are shown in Fig. 12.

Edison noticed that when the connection was made to the positive terminal of the battery there would be a deflection of the needle of the galvanometer. This indicated there was an electrical current flowing through the galvanometer. Since the metal plate was not electrically connected to anything it was evident that in some manner there was an electrical current passing through the space within the glass bulb.

He also noticed that when the connection was made to the negative terminal of the battery there would be no deflection of the galvanometer needle. Apparently the only thing Edison could imagine such a device being used for, was as an indicator of

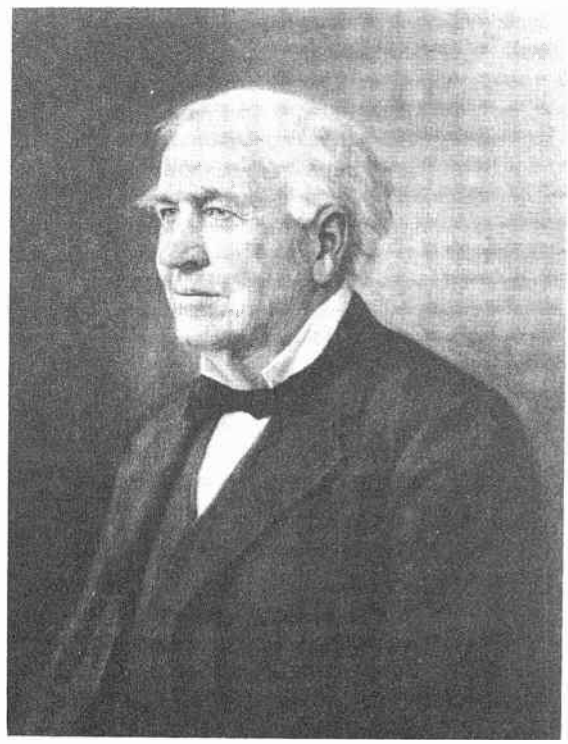

Fig. 13. Thomas A. Edison, discoverer of the "Edison effect", which led to the invention of the vacuum tube. Edison was the holder of dozens of patents on electrical devices.

voltage variations in a lighting circuit. As a result he applied for a patent for a *voltage indicator* in 1883. But Edison made a report of his discovery to the scientific world. There it aroused considerable interest, and his discovery of the peculiar phenomenon came to be known as the *Edison effect*. It is still known by that name down to this day.

An English scientist named Sir William Preece persuaded Edison to give him one of his new lamps. He proceeded to make a series of measurements of the Edison effect. During his experimentation another Englishman, Professor J. A. Fleming, who was an adviser to the Edison Electric Light Company of London, became interested. He carried the experimentation much further.

The result of Fleming's experiments was a device which he called *Fleming's valve*. It was a device which changed alternating current into electrical current which flowed in only one direction. He developed the device for use with high-frequency alternating currents with which he was experimenting. It might be mentioned that in England vacuum tubes are still referred to as *valves*.

It was several years after Fleming introduced his *valve* before an explanation of what was happening was given. In 1900 Sir John Joseph Thomson, another English scientist announced his discovery of the Electron, and gave to the scientific world his *electron theory*. His electron theory fully explained the Edison effect, and explained what was taking place inside Fleming's valve.

Section 5. VACUUM TUBES

Fleming's valve was the first practical vacuum tube to come into existence. It is in use today with the operating principles little changed from the day he presented it to the world. The physical characteristics have been greatly changed and improved, but electrically it is much the same. Its purpose, when first introduced, was to allow the passage of electrical current in one direction, but to prevent its flow in the other direction. It was thus able to accomplish its announced purpose -- the changing of alternating current into current which flowed in only one direction.

In Fleming's valve there was a filament which could be heated. The filament was made of a special material and in such a way

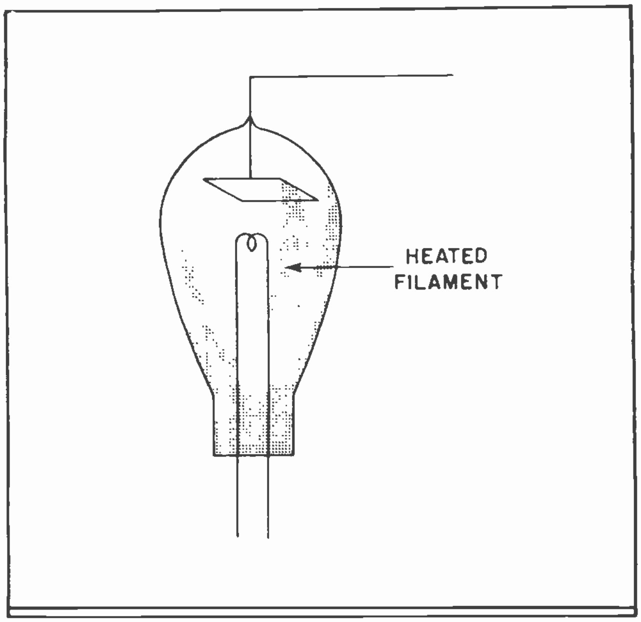

Fig. 14. Diagram of Fleming's valve.

that when it was heated it would give off clouds of electrons. There was a metal plate sealed into the glass tube similar to the one Edison had sealed into his Lamp. When there was a positive voltage applied to the metal plate it would attract the negative electrons to it. The movement of the electrons into the metal plate, and from it out through the connecting wire, caused an electrical current to flow. Since the metal plate would attract the electrons only during the time when it was positive, a current would flow through the external wire only during the time there was a positive voltage applied to the plate. When alternating voltage -- voltage which is alternately positive and negative -- was applied to the plate, a current would flow through the wire only half the time. That was during the half in which the voltage was positive.

Nearly every radio receiver uses a modification of Fleming's valve today. Such vacuum tubes today are called *rectifier* tubes rather than valves. One of the main uses of such a tube is to change the alternating current which is furnished by the power company into the direct current which the other radio tubes need for proper operation. The larger television receivers will have from three to five, or possibly six, of these rectifier tubes to furnish the various voltages needed by the many tubes. One or two of them will be used to furnish the power for the amplifier tubes. One or two others will furnish the high voltage for use with the "picture" tube itself. This is where the highest voltages are used in the television receivers. Other types of rectifier tubes will be used in the "detector" circuits.

The actual operation of these rectifier tubes will be gone into in far greater detail a little farther along in the course. We are just mentioning them at this time to show the connection between electrons and the part they play in one kind of radio tube. So far we have mentioned only very briefly the action of the simplest type of radio tube. In following lessons we will discuss many other types of tubes. It is necessary to understand how all the various types of tubes operate in order to know just what function each plays in the operation of radio and television receivers.

We have just mentioned how the rectifier tube can change alternating current into direct current. There are other tubes which can change direct current into alternating current. In fact, the vacuum tube is the only thing which can create alternating current with frequencies over about 15,000 cycles per second. At 15,000 cycles per second the vacuum tube is just loafing along. It is capable of creating alternating current with frequencies running up into the millions of cycles per second. Yes, even into the billions of cycles per second.

In fact the very existence of radio and television depends upon the creation of these extremely high frequencies. The radio broadcast band, over which music and newscasts and other entertainment programs are broadcast to the general public, operates on frequencies from 550 kilocycles to about 1600 kilocycles. This would be from 550,000 cycles per second to about 1,600,000 cycles per second.

About the lowest frequencies used by radio transmitters are around 50,000 cycles per second. There seems to be no limit to how high the frequencies can go and still be usable. The frequencies used for broadcasting television include those from a little under 100,000,000 cycles per second, to others which operate at several hundred million cycles per second.

In radar work, which is actually a modification of television but is used for somewhat different purposes, the frequencies commonly exceed several billion cycles per second. It is not necessary for us to delve into the technical details which revolve around operation at such frequencies. At

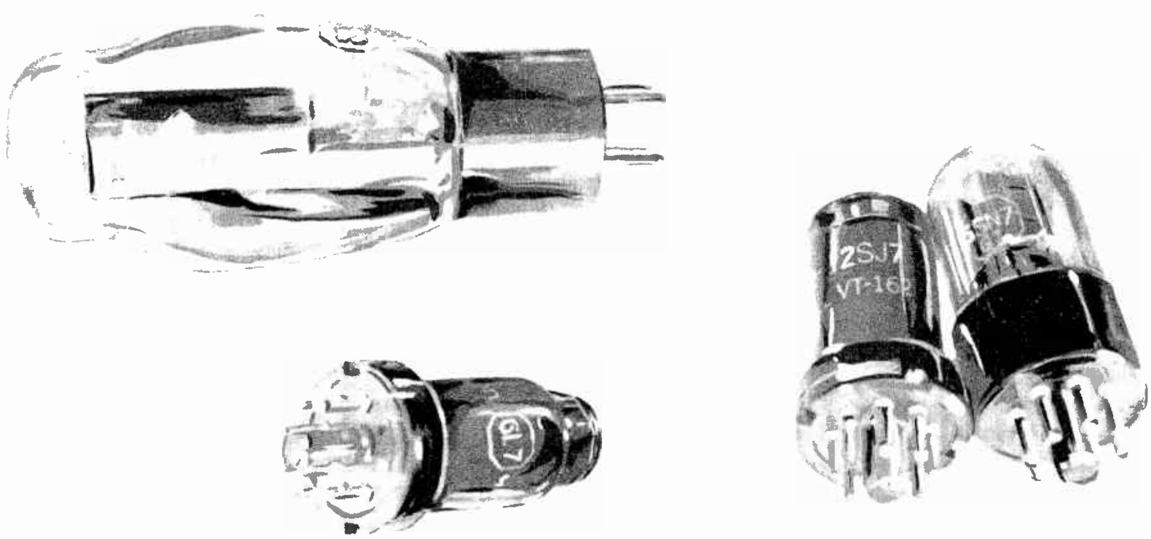

Fig.15. A variety of radio tubes.

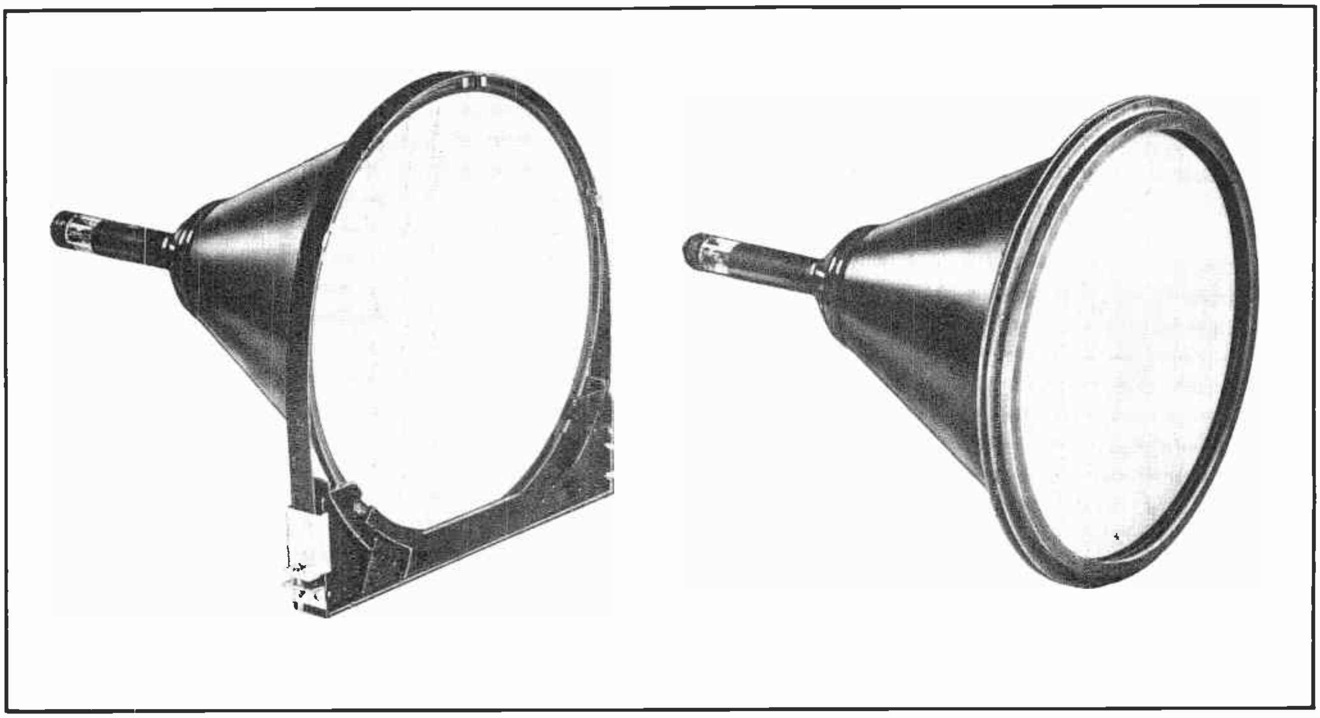

Fig.16. Television "Picture tube".

least it is not necessary at this time. All of these things will be discussed in their proper order, and at the proper time. It may seem, at this time, that some of the things we have mentioned are completely fantastic. Something entirely outside man's ability to understand. But you will find that as you go along and learn more and more about the operation of electricity, and radio, and the operation of the vacuum tubes, that it is relatively easy to completely understand all the things, which have just been mentioned.

When one is first introduced to the high frequencies which are encountered in radio and television work the natural inclination is to scoff at the thought of any man being able to tell exactly what frequencies are being used when they rise higher than man's senses can perceive. But as a little more is learned about radio it becomes readily apparent that the trained men are not talking through their hats about something of which they know nothing.

Trained men become so accustomed to working with these various frequencies they think nothing of creating an alternating current of any frequency which might strike their fancy, and to know the exact cycle of the frequency. There is no guesswork among trained radiomen -- they know. You will too.

There are still other uses for the vacuum tube besides changing alternating current into direct current, and changing direct current into alternating current. If these were the only things for which vacuum tubes could be used, their uses would be limited indeed.

Probably the most important use of vacuum tubes is as amplifiers. By amplifiers we mean something which increases, or magnifies. In electrical and radio work we usually refer to increases in voltage or in power when we speak of amplifying.

More than half the tubes used in radio and television transmission and reception are used for the purpose of amplifying a voltage, or amplifying the power. In a radio receiver the voltage which is first impressed upon the receiver by the passing radio wave is extremely small. It is so small that it is measured in tiny fractions of a volt called *microvolts*. A microvolt is equivalent to one-millionth of a volt.

Such a voltage is so small it can do little or nothing by itself. So this is where we put the vacuum tube to work. This tiny voltage which has been picked up by the receiver from the passing radio wave is fed into a vacuum tube. The vacuum tube *amplifies* the voltage. That is, it increases or magnifies the voltage. When the

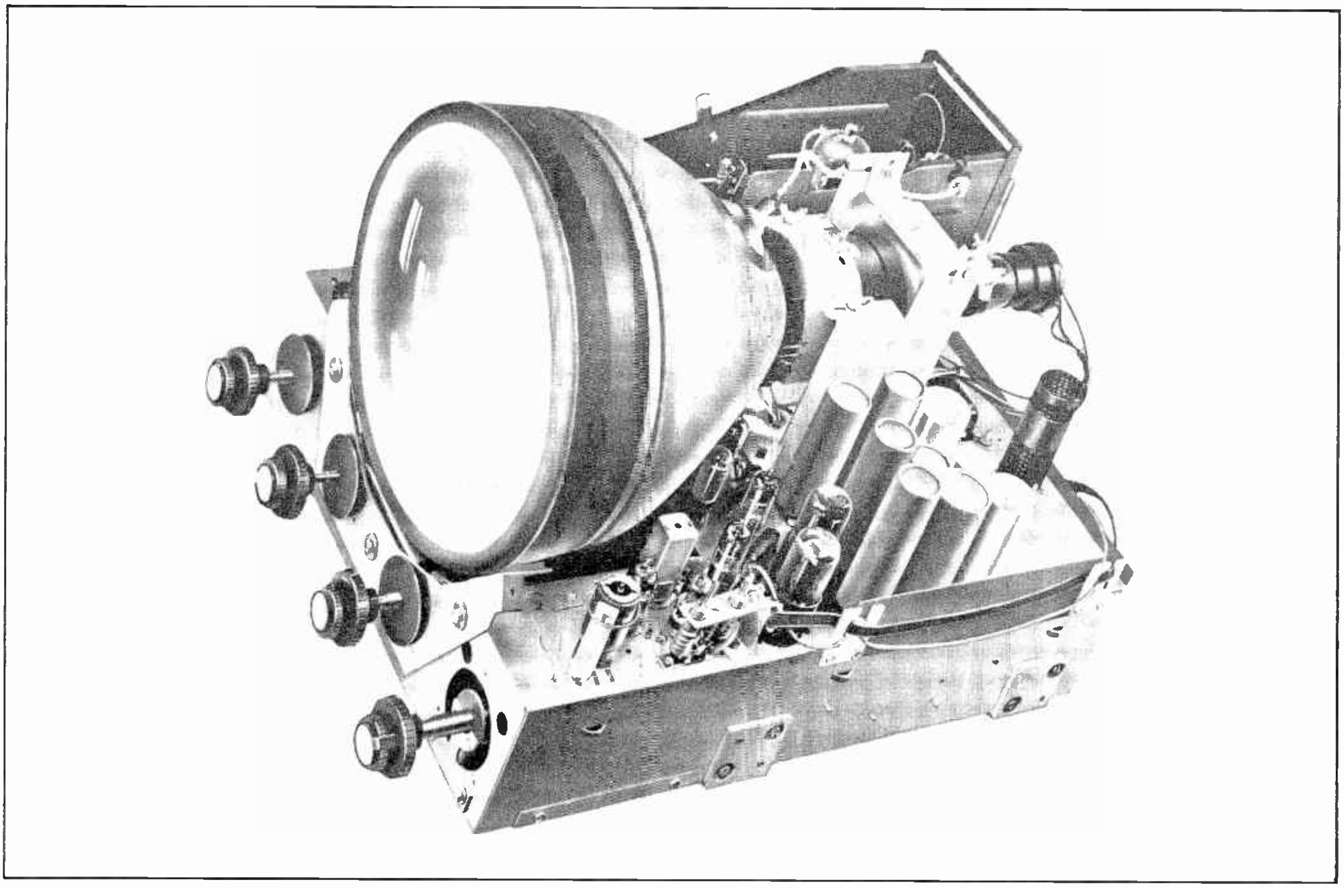

Fig 17. The "chassis" of a television receiver. All the working parts of a receiver are mounted on the chassis.

voltage comes out of the tube it is much larger than it was when it went in.

Even though the voltage has been magnified many times by the action of the tube it is quite often still too small to be put to any practical use. In this case the magnified voltage is fed into another vacuum tube and *amplified* again. It is run through one tube after another until the voltage is high enough to be put to work. In many television receivers the voltage which paints the picture on the face of the picture tube is run through as many as five amplifier tubes to raise it up to the value which is needed.

In addition to the tubes which amplify the *signal* voltage to the *picture* tube there are other vacuum tubes used to amplify the voltage which carries the voice, or sound, which accompanies the picture. There are other amplifier tubes which are used for still other purposes. A modern television receiver often has from 21 to 50 vacuum tubes, each of which has a specific job to do. Is it any wonder that a man has to have special training if he hopes to become really expert at radio and television servicing?

While it may seem at this time that it is an almost hopeless task to ever learn all the things necessary to become a competent service man, such is not the case. When the subject is approached methodically, as we do, it is broken down into each of its various components. Each of the various parts are carefully studied until everything about it is thoroughly understood. Then when the parts are put together in a working unit the operation of the whole thing becomes clearly understandable -- almost simple.

In the learning of radio and television work, as in the study of anything else, the first few weeks always do seem hardest There are so many new things to get acquainted with. Many of the things which must be discussed often seem to have so little connection with the thing we are trying to learn. It is at a time like this, that the most patience must be exercised.

It is also at this time that those who are fired with a real ambition are separated from those who are satisfied to drift through life with the least effort, accepting that which the whims of fate toss their way.

NOTES FOR REFERENCE

The vacuum tube is the heart of all modern radio and television receivers.

The electron, and its electrical partner the proton, are the smallest particles into which matter can be divided.

The electron is a tiny particle of negative electricity.

The proton is a tiny particle of positive electricity.

Electrons and protons are attracted to each other.

Electrons tend to *repel* other electrons.

Atoms are the smallest part into which an element can be divided.

The only difference between the atoms of one element and the atoms of another element is in the number of electrons and protons within the atom.

Vacuum tubes are used as rectifiers, as A.C. generators and as amplifiers.

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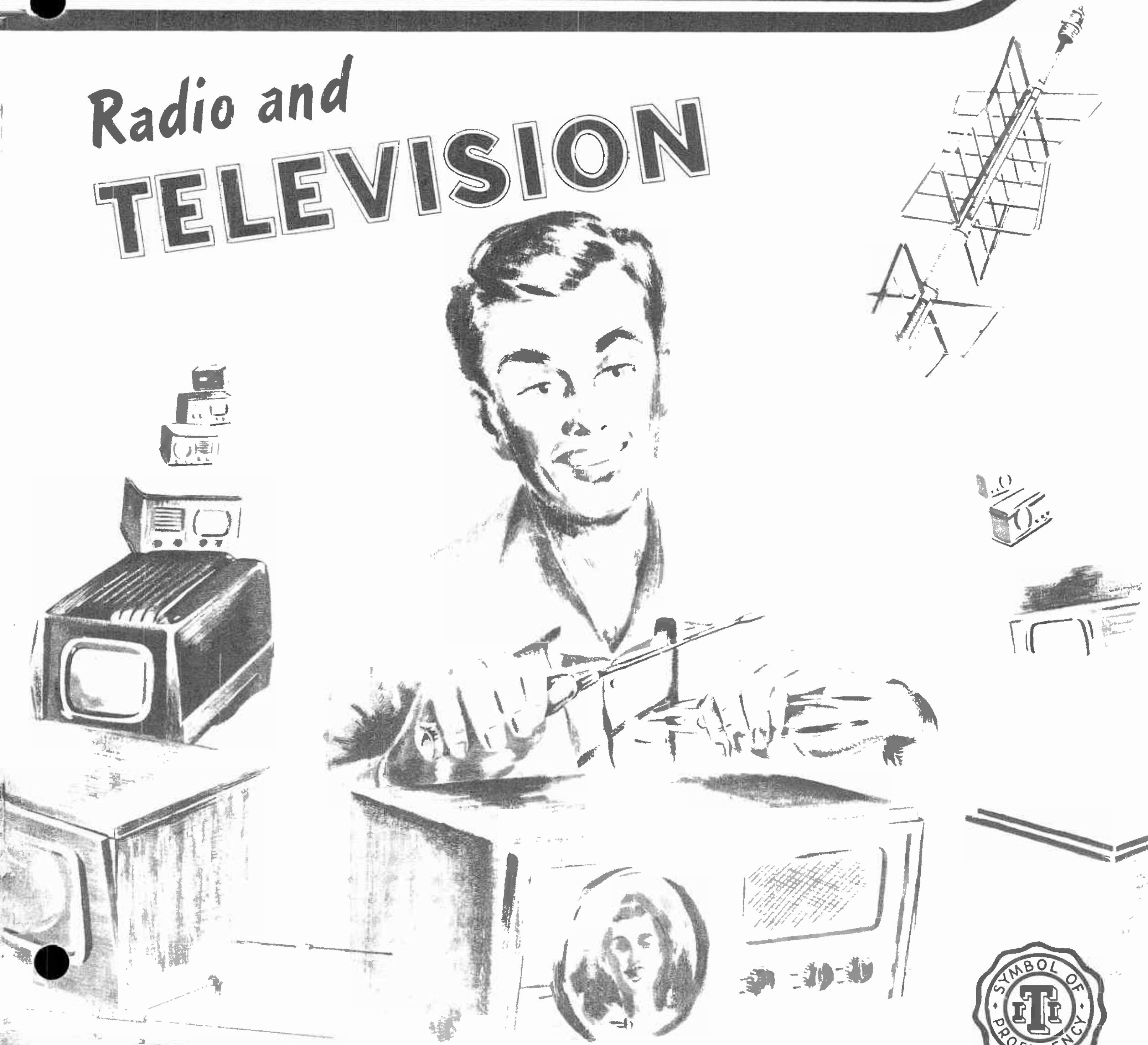

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Section 1. INTRODUCTION

The young man who decides to make radio and television his life's work is truly a fortunate individual. There is probably no other line of endeavor where a man can earn an excellent living for himself and his family and at the same time find so much fun in his work.

No matter how many years a man may have devoted to radio work it seems that a new thrill of discovery touches him on nearly every working day. Radio is constantly revealing something new to reward the natural inquisitiveness which is so much a part of most men. Even the most ordinary service job is frequently the means which launches a man into an excitingly new scientific adventure.

The sheer fascination which radio holds for so many men is clearly demonstrated by the frequency with which professional radiomen carry their daily work into their home lives and make of it a hobby. Tens of thousands of radio engineers, radio service men and radio operators do not get enough radio during the time of the day they are paid to work with it. After their working hours are over, they wend their way to their own little private radio workshops -- paid for with their own money -- and there continue their experimenting.

Is there any other occupation by which men earn their daily bread which contributes at the same time so much fullness to their lives?

Radiomen who have made their work into a hobby have organized themselves into an International group which is now recognized by most governments of the world. They call themselves Radio Amateurs. By "Amateurs" they mean they are engaged in radio on a non-professional status. But it should be understood that when they say they are "Amateurs" they do not mean to imply they are novices. The ranks of the Amateurs

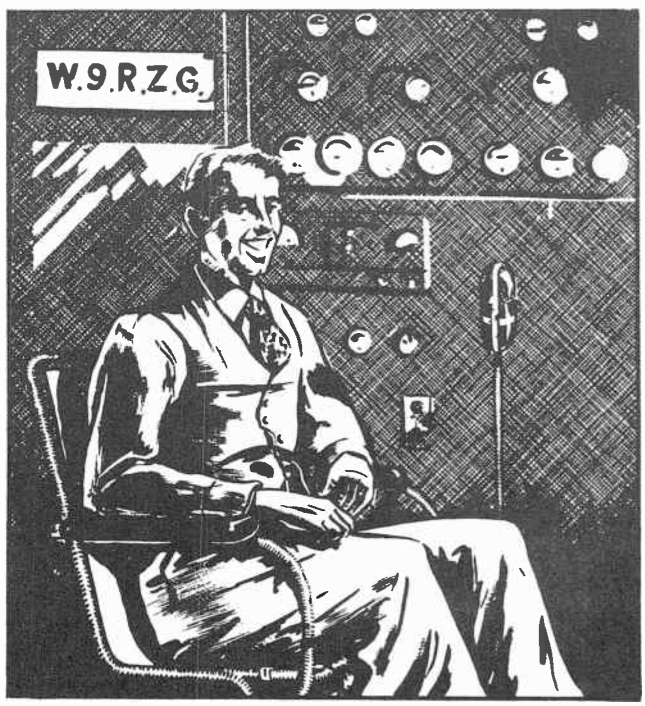

Fig.1. Radio Amateur and his Transmitting Equipment.

include practically all the World's top-ranking professional radio men.

The Amateurs also list among their members men whose working hours are devoted to virtually every trade and profession known to man. Doctors and Lawyers, Merchants and Bankers, Mechanics and Musicians, all have succumbed to the lure of the mysteries of radio, and spend most of their leisure hours probing ever-deeper into its seductive secrets.

Radio Amateurs frequently build equipment with their own hands which enable them to talk with other Amateurs. There are few things in a man's life which will give him the same thrill he knows when a device of his own creation provides a medium of conversation with either friend or stranger out in the wide blue yonder. There is something uncanny in the thought that a few pieces of wire, a few vacuum tubes, and a few other pieces of relatively simple equipment, skillfully and expertly put together, can make possible the ability to talk with a distant person through no inter-connecting medium other than space itself. Once a man has experienced this thrill, it seems there is no power on earth which can break his interest in radio.

Is it any wonder we say that the man who decides to make radio and television his life's work is truly a fortunate individual?

Section 2. HOW CONDUCTORS HINDER CURRENT FLOW

We have already discussed in a limited way something of the manner in which electrical current flows through a conductor. Electrical conductors are always composed of materials which have plenty of free electrons. Such conductors include all metals, and it is of these that we intend to speak now.

While it is true that all metals can be classed as conductors of electricity, it should be carefully explained that electricity does not flow through all metals with equal ease. In other words, the flow of electricity meets with more opposition when trying to flow through some metals than when it flows through others. We call this opposition to electrical current flow *resistance*.

We have previously compared the flow of electricity through a metal conductor with the flow of water through a hose or pipe. If the hose, or pipe, is long, the water will not flow as freely as when the hose is short. Much the same thing is true with respect to the flow of electricity through a conductor.

It should be mentioned that while some conductors allow electricity to flow much more freely than others, *all conductors contain a certain amount of resistance.* There is no perfect conductor. Silver is the best conductor yet discovered, but it is not completely free from resistance. Copper is the next best conductor, and since it has only slightly more resistance than silver and is very much less expensive, it is used much more widely in electrical and radio work than silver.

Since every kind of conductor has a certain amount of resistance, it is reasonable to say that if a conductor of a given unit length has a certain amount of resistance, a similar conductor twice as long would have twice as much resistance. This is shown graphically by Fig. 2. If the conductor at the top of the illustration has a certain amount of resistance, the one at the center would have twice as much resistance since it is twice as long. This could be said another way by saying that the current would meet twice as much resistance in the longer conductor than in the shorter one because it had to travel through the longer conductor twice as far.

By the same line of reasoning there would be only half the resistance in the conductor at the bottom of Fig. 2 as in the one at the top. This is because the conductor at the bottom is only half as long.

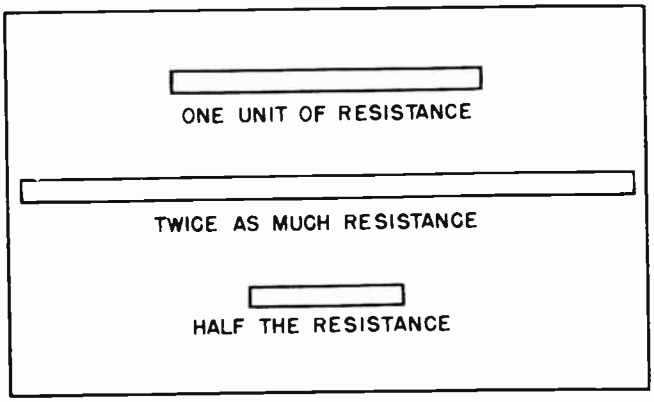

Fig.2. The conductor in the center will have twice as much resistance as the one at the top. The one at the bottom half as much as the top.

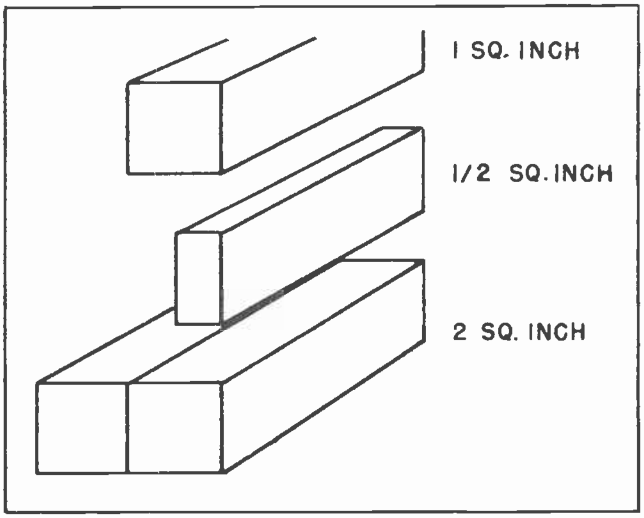

Fig. 3. Comparing the effect of the size of a conductor on its resistance.

And since the electricity would travel through it only half as far as in the conductor at the top, it would meet only half as much resistance.

This provides us with a handy rule. Electrical resistance is *directly proportional* to the length of a conductor when the whole length is of the same material and is the same size.

This rule means that if a wire is the same size over its entire length, and is made of the same material, the amount of resistance it would present to the flow of electricity would be entirely dependent upon its length. That is, if 100 feet of the wire presented so much resistance, 200 feet would present twice as much resistance, 300 feet would present three times as much resistance, and 1000 feet would present ten times as much resistance.

It can be readily seen that the length of a wire has an important bearing upon its ability to conduct electricity. The longer the wire is, the more difficult it is for current to flow through it.

The size of the wire also has a lot to do with the resistance. The larger the wire is, the less resistance it will present to the flow of electrical current. And on the other hand, the smaller the wire is, the more resistance it will have to the flow of electrical current.

Fig. 3 shows rather clearly the relationship of the size of the wire to the amount of its resistance. The conductor shown at the top of Fig. 3 is shown cut squarely across. The cut end, or cross-sectional area, measures exactly one square inch. The resistance of a conductor with one square inch of cross-sectional area will be exactly twice as much as a conductor which has two square inches of cross-sectional area, as shown at the bottom of Fig. 3.

Likewise, the resistance of a conductor which has one square inch of cross-sectional area will be only half as great as a conductor which has one-half square inch of cross-sectional area. To put all this in other words, we can say the larger the wire the lower the resistance, and the smaller the wire, the higher the resistance.

All of which gives us another useful rule to remember -- the electrical resistance of any conductor is *inversely proportional* to its cross-sectional area.

Section 3. MEASURING CROSS-SECTIONAL AREA

Because most electrical conductors are much less than one inch in diameter, the use of the inch as a unit of measurement is rather awkward. If the inch is used to calculate the area of the cross-section of a piece of wire, all the figuring must be done in fractions. And since the area of the cross-section of a wire has such an important bearing upon the value of its resistance, it is often convenient, even necessary, to calculate its exact size.

To overcome the necessity for working with very small fractions, electrical men measure the diameters of wires in a unit called a *mil*. A mil is equal to one-thousandth of an inch. Or an inch is equal to 1000 *mils*. Fig. 4 shows the cross-sectional area of a piece of wire one inch in diameter. The diameter of the wire can be measured in either of two ways. If it is measured in inches it will measure exactly one inch

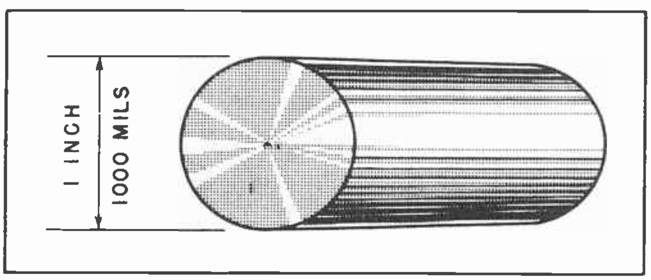

Fig. 4. One inch is equal to 1000 mils.

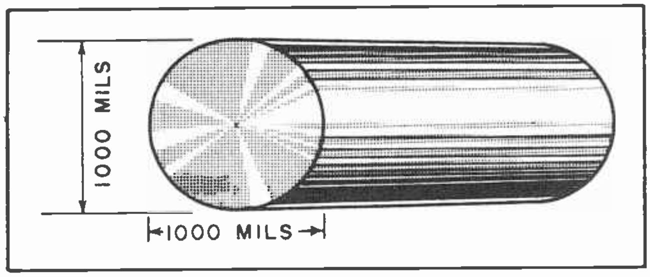

Fig.5. The cross-sectional area of the end of a wire is obtained by multiplying the diameter of the wire in mils in one direction by the diameter in the other. This is the same as squaring the diameter in mils.

in diameter, but if it is measured in *mils* it will measure 1000 *mils* in diameter. (Mil is pronounced as though spelled "Mill".)

Since the shape of most wire is round, or circular, the cross-sectional area of most wire is usually referred to as having a certain number of *circular mils* in extent. For example, the wire shown in Fig. 4 can be measured in the manner shown in Fig. 5 to obtain its cross-sectional area in *circular mils*. The area is found by multiplying the diameter in one direction by the diameter in the other direction. This would be the same as multiplying 1000 by 1000, which will, of course, give us one million. Therefore, a wire which is one inch in diameter would have a cross-sectional area of 1,000,000 circular mils.

One circular mil is a circle which is exactly one mil in diameter. A wire then, that is one inch in diameter would have a cross-sectional area exactly equivalent to one million wires which had a cross-sectional area of one mil each.

Nearly all larger wires have their size designated by the cross-sectional area in circular mils. It is frequently convenient to consider the cross-sectional area in circular mils of the smaller size wires also. Above all, it is important to know what electrical men and radio men are talking about when they speak in terms of circular mils.

Section 4. EFFECT OF CONDUCTOR MATERIAL ON RESISTANCE

It has already been mentioned several times that silver is the best conductor of electricity, but that it is seldom used in electrical work. This is true. However, it should be mentioned that there are some occasions when the extra expense of using silver conductors is warranted.

A good example of the use of silver as an electrical conductor is in the construction of cyclotrons and betatrons, the giant electro-magnetic machines which led to the splitting of the atom and the creation of the atomic bomb. Some of the cyclotrons used in atom-splitting experiments weigh several thousand tons and use enormous quantities of electricity. The necessity for obtaining the most nearly perfect electrical conductors far outweighs the extra expense involved. Some of the cyclotrons use many tons of silver as electrical conductors.

During the recent war, silver was used as an electrical conductor in the construction of several types of radar units. The delicate nature of the instruments required that the best electrical conductors obtainable should be used in certain places in their construction.

But on the whole, it is reasonable to say silver is seldom used as an electrical conductor, the reason being that it is so many times more expensive than copper. And copper is almost as good a conductor of electricity as is silver. It can be truthfully said that copper is the most widely used metal for conducting electricity.

Aluminum is also a good conductor of electricity, although not quite so good as copper. Fig. 6 gives a graphical illustration of the comparative ability of several metals to conduct electricity. Before the recent war aluminum was used relatively little in electrical work. This was partly because copper was inexpensive, and plentiful, and partly because aluminum was not quite so good a conductor. In more recent years, aluminum has been used much more widely in electrical work. The price

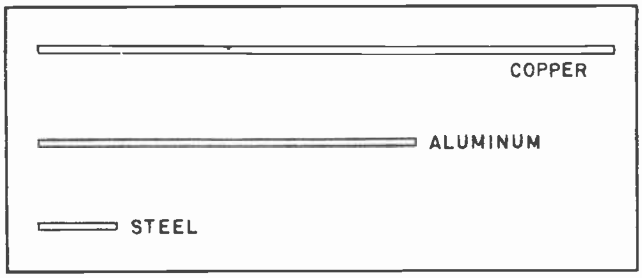

Fig.6. A comparison of the effect of the conductor material on its resistance.

of aluminum and that of copper is now practically the same. At some times aluminum has been much more plentiful than copper, which made it more readily available.

One of the principle assets of aluminum is that it is much lighter in weight than copper. In some places, such as aircraft work where weight is an item to consider, aluminum has been used more and more frequently. Although a wire made from aluminum must be made somewhat larger than one made from copper which will carry the same amount of current, the difference in weight is such that the aluminum wire will weigh less.

The use of steel for the primary purpose of carrying electrical current has almost ceased. There are, however, many places where the steel used in the manufacture of other devices is also used as a part of a general electrical circuit. There was a time when steel wire was used very widely in communications work such as telephone and telegraph lines. It is still used to a certain extent for that purpose, but not so much as was once the practice.

Section 5. EFFECT OF TEMPERATURE ON RESISTANCE

We have already discussed three things which affect the resistance of a conductor to the flow of electrical current. These were the length of the conductor, the size of the conductor and the material from which the conductor was made. We will now consider something else which affects the resistance of a conductor.

If you took two conductors made from the same material, and each was of the same size and the same length, it would still be possible to create conditions under which one would have more resistance to the flow of electrical current than the other. If one conductor was immersed in ice so that it remained at a constant temperature of 32° and the other was kept heated to the temperature of boiling water, about 212°, it would be found that much more current could flow through the conductor which was kept cold than the one which was kept hot. If the conductors were made from copper it would be found that the hot conductor would have more than 40% more resistance than the cold conductor.

It has been found that the resistance of outdoor lines used for the conduction of electrical current is often as much as 25% greater in summer time as in the winter.

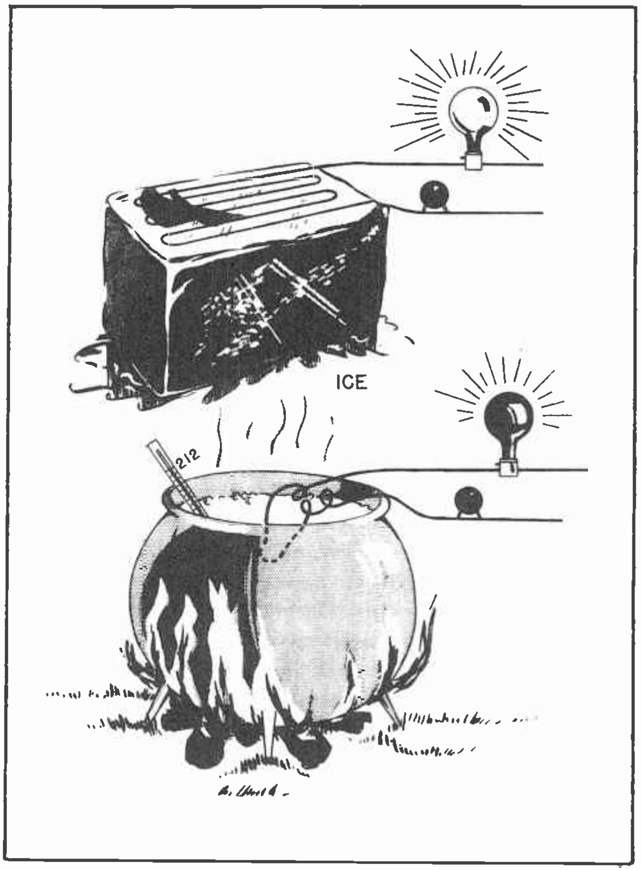

Fig.7. Comparing the effect of temperature on the resistance of a conductor.

The resistance of any conductor composed of a pure metal -- not an alloy -- increases and decreases at a constant rate with equal changes of temperature. If a 10° rise in temperature causes a certain increase in resistance, another 10° rise in the temperature will cause another increase in the resistance of an additional like amount.

Equal drops in the temperature causes similar equal drops in the resistance. It might be thought from this that if the temperature was dropped low enough, it would be possible to remove all resistance.

Back in 1914 several scientists determined to find out just what would happen to the resistance if the temperature was reduced to very low values. They started a current flowing in a ring made from lead. Then by the use of liquid helium they reduced the temperature to 455° below zero. At that temperature they removed the force which kept the current flowing. Sure enough, the current kept right on flowing and apparently would have gone on indefinitely, because the resistance had practically disappeared.

It is possible to mix certain metals in certain proportions -- to make alloys -- in which the change of resistance remains practically constant over very wide temperature ranges. Wire made from such alloys is quite useful in the manufacture of delicate instruments whose resistance must not change as the temperature changes.

While the resistance of most metals increases with the increase in temperature, the opposite is true with carbon and graphite. The resistance of carbon has a tendency to decrease as the temperature rises. Much the same is true of graphite, which is actually a form of carbon. The same thing is also true with liquid solutions, or electrolytes. Their resistance decreases as their temperature rises. On the other hand, their resistance increases as the temperature goes down. This is one of the reasons the storage batteries on automobiles do not work so well in the winter time as they do in the summer. On very cold winter mornings the batteries sometimes get so cold their resistance rises too high to allow enough current to get through to turn the engine over and start it.

Section 6. HOT RESISTANCE AND COLD RESISTANCE

Our studies so far have shown us that four things affect the resistance of any conductor: The length of the conductor, the size of the conductor, the material from which the conductor is made, and the temperature of the conductor. Since we encounter resistance in every conductor in ordinary use, and thus have to consider it when working with electrical, radio and television equipment, it is important that we remember the four things which affect a conductor resistance.

The matter of change of resistance with change of temperature is something requiring serious consideration in the design and operation of all kinds of electrical apparatus. We are not usually so much concerned with changes in outdoor temperatures, although these may be important at times, as we are with the fact that the flow of electricity heats the conductor through which it flows. Then the higher temperature of the conductor causes an increase in the resistance.

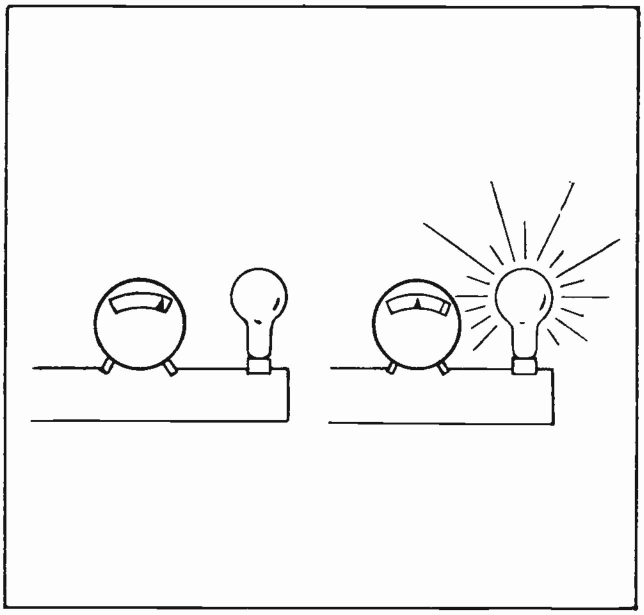

Fig.8. Resistance increases and current decreases with rise in temperature.

The larger the amount of the current, the higher the temperature becomes. When we are dealing with large machines, such as electric motors and heavy lifting magnets, the rise in temperature sometimes attains rather high values and seriously affect their operation. But even in radio and television work, where most of the currents involved are usually rather small, the change in the temperature of a conductor must quite often be taken into account. This is particularly true in the case of oscillators which create the extremely high frequencies so common to radio and television work. The exact frequency at which these oscillators operate depends upon several things, among them the resistance of the conductors through which the high frequency current flows. If there is a material change in the resistance of the conductor, a change in the frequency of the oscillator can be expected. The higher the frequency at which the oscillator works, the more important is the matter of any change in the resistance of any conductor.

An easy method of demonstrating this matter of resistance change with a change in temperature is to connect a current measuring instrument in the circuit leading to an electric lamp as shown in Fig. 8. When the current is first allowed to flow through the lamp, the filament of the lamp will be cold. At this time the filament will have a relatively low resistance. The result will be a sudden rush of current. But after the current begins to flow it will heat the filament until it becomes white-hot. When this happens, the resistance rises until it is several times as high as when it was cold. Then the current will fall to a much lower value than during the first instant it flowed.

Section 7. THE OHM

While it is readily apparent that the flow of water through a pipe or hose is restrained somewhat by the opposition it meets in the friction of the walls, there is no single definite unit by which to measure the amount of opposition. There is really no need for such a unit because the opposition to the flow of water is not a matter requiring frequent measurement or calculation. The resistance presented by a conductor to the flow of electrical current, however, is an entirely different matter. Resistance in an electrical circuit can never be neglected, nor ignored. It is a very important item for consideration.

We have learned that we have a unit by which we measure the electrical pressure in a circuit. It is the *volt*. Likewise, we have a very special unit for measuring the *rate of flow* of electrical current. That is the *ampere*. Now we come to another unit of measurement which is used by the radio and television technician during nearly every one of his working hours. The unit for measuring electrical resistance -- The *Ohm*.

The exact values of the volt, the ampere and the ohm are very closely linked together. Each depends upon the other, so to speak. The volt represents the pressure which tends to force the current through a circuit. The Ohm represents the opposition which tends to retard the flow of current.

This means that when a conductor contains a certain amount of resistance, the current will rise and fall in direct proportion to any rise or fall in the voltage, or amount of electrical pressure. If the voltage is increased, then the current will increase in direct proportion. If the voltage is decreased, then the current will fall, and will fall in exact proportion to the decrease in the voltage.

On the other hand, if the voltage is a constant value, the current will also rise or fall in response to any change in the value of the resistance. But instead of changing in direct proportion to any change in the resistance, as was the case in the change in voltage, the current will change *inversely* with any change in the value of the resistance.

To explain this a little more clearly, it should be remembered that any increase in the resistance means that there will be more opposition to the flow of current. It is only natural then that any increase in resistance in any circuit will mean that there will be a decrease in the amount of current which will flow. When one thing decreases by the same amount that something else increases, we say that they are *inversely* proportional. If two children are playing on a teeter-totter, it is readily apparent that one end of the teeter-totter will rise by the same amount as the other end moves downward. We could say that the height of one end above ground was always *inversely* proportional to the height of the other end.

From this it can be shown that the amount of current which will flow in any conductor at any time is always determined by the value of the voltage and the value of the resistance. It is not possible for just so much current to flow, and for that amount to be determined without any reference to the other circuit values. It can be truthfully said that the current is always dependent upon some force outside itself.

All of which means that if we desire a change in the value of the current we must change either the value of the voltage, or the value of the resistance, or change the values of both.

We have mentioned that the ohm is the unit of measurement in determining the value

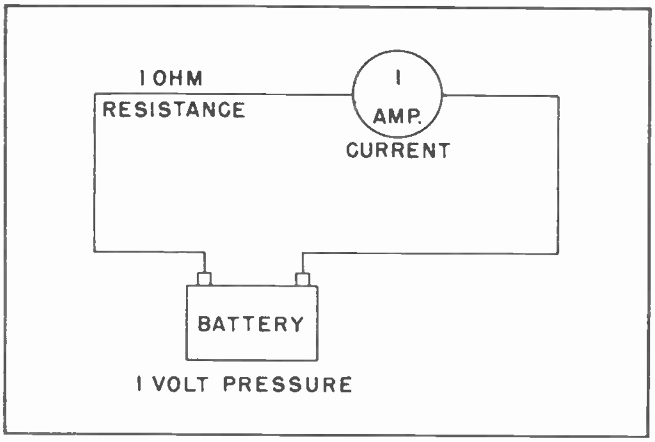

Fig.9. One volt will force one ampere of current through one ohm of resistance.

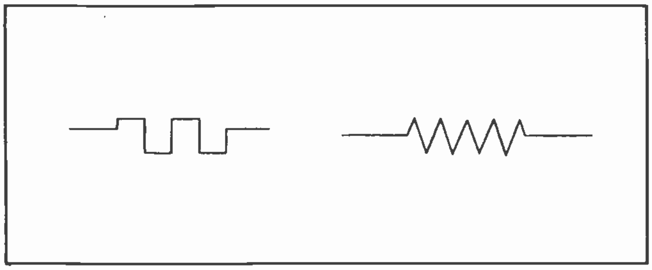

Fig.10. Symbol for Resistance.

of electrical resistance. It is important to know just how much resistance one ohm represents.

The ohm has been defined as being that amount of electrical resistance which will permit one ampere of current to flow in a circuit when an electrical pressure of one volt is applied.

To illustrate this, suppose we take an electrical generator, or battery, which is capable of producing one volt of electrical pressure. The one volt will cause an electrical current to flow in the circuit, but the value of the current will also depend upon the resistance present in the circuit. If we want exactly one ampere of current to flow, the conductor of the circuit must contain exactly one ohm of resistance. (See Fig. 9.)

An ohm, then, is that value of electrical resistance which will limit the flow of current to a value of one ampere when there is an electrical pressure of one volt applied to the circuit. The relationship of the ohm, the ampere, and the volt to each other becomes very important in all kinds of electrical work. We will devote an entire lesson to the discussion of this relationship.

In making electrical drawings, or diagrams, it is convenient to have some symbol which will represent resistance. Fig. 10 shows two symbols commonly used by electrical and radio men to represent resistance. The one at the left is used more commonly by men engaged in electrical power work, while that at the right is the one used most generally by radio and television technicians.

Section 8. ELECTRICAL SYMBOLS AND DIAGRAMS

We have mentioned before this matter of symbolic representation of the various elements we find in electrical and radio

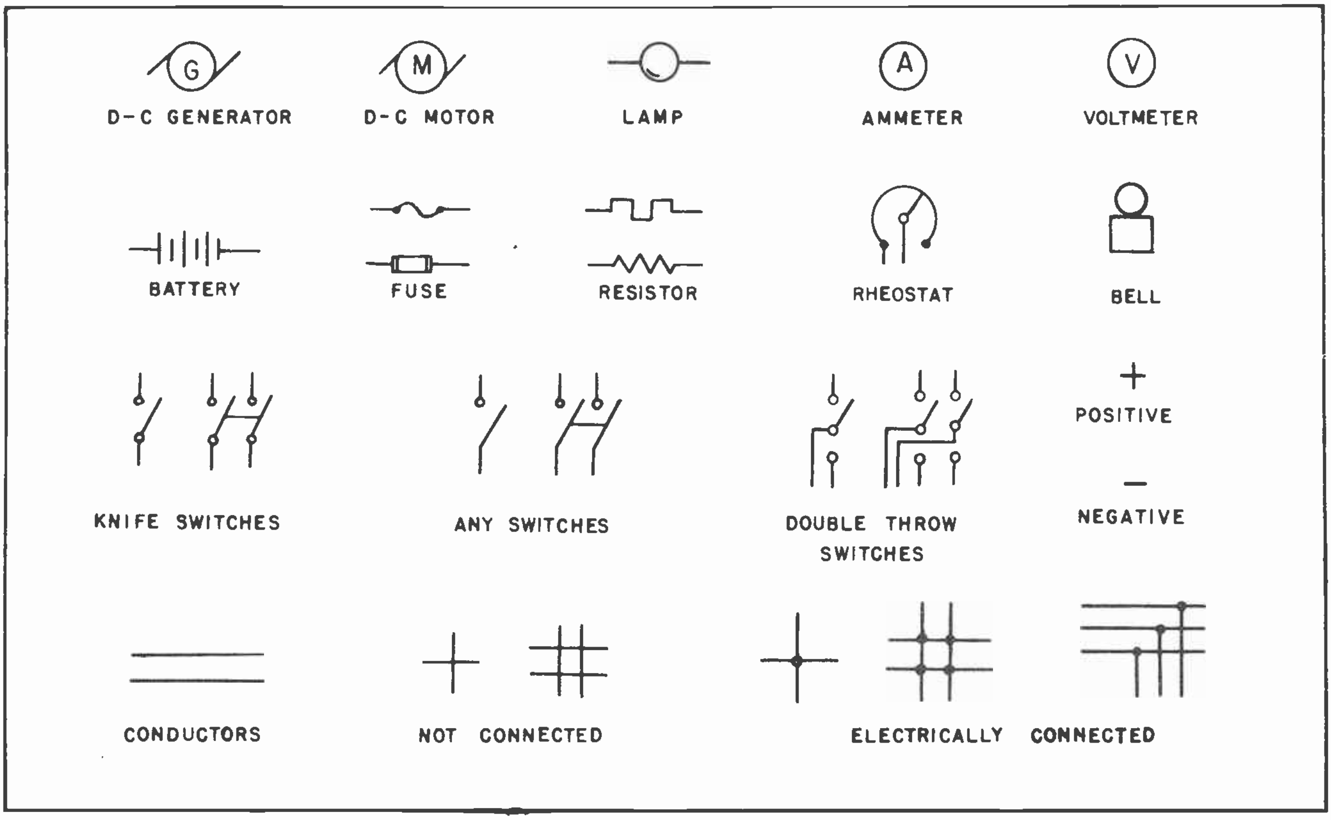

Fig.11. Some symbols used in electrical diagrams.

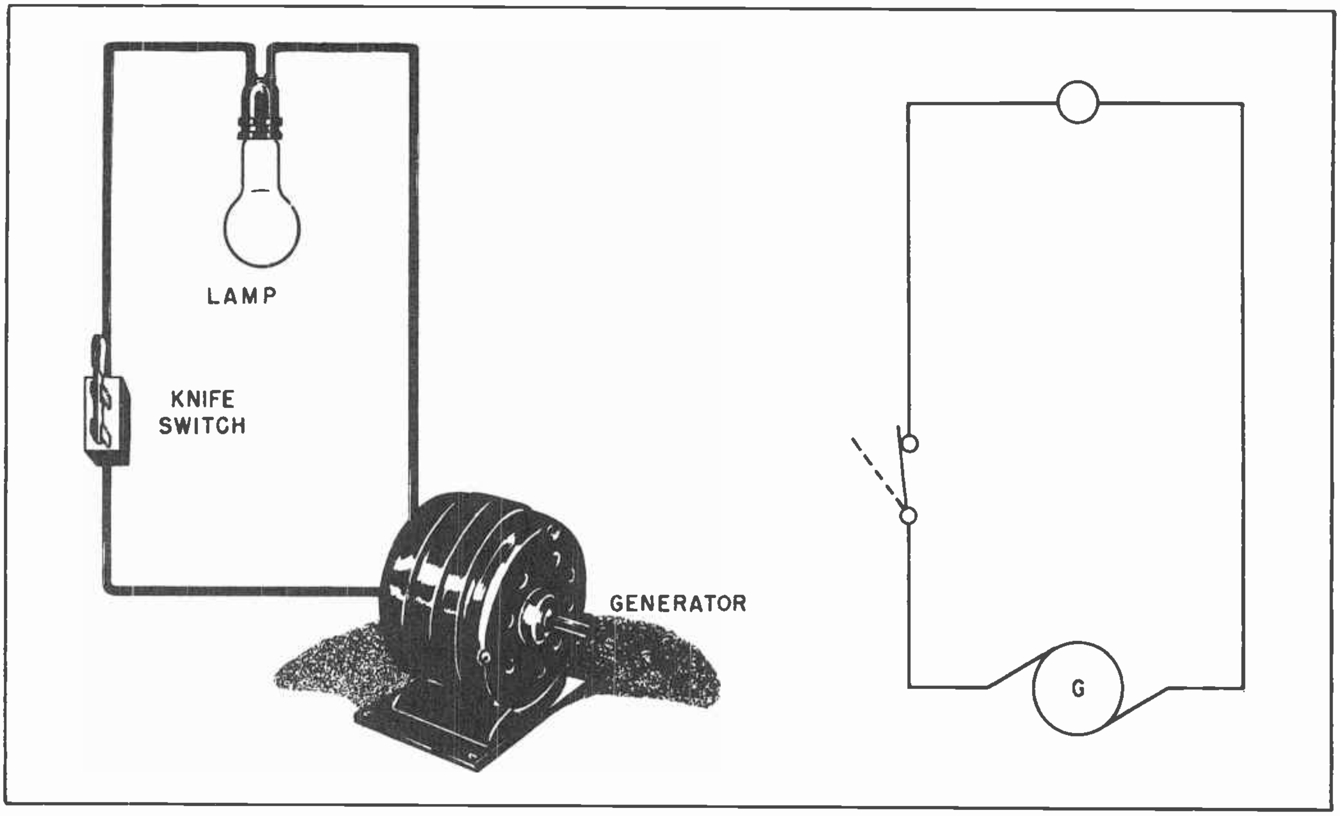

Fig.12. A Series Circuit.

circuits. It is well to explain why this should be. Pictures of the various components which are to be found in electrical circuits might be all right on the printed page where there is plenty of time to prepare understandable drawings. But the average technician, who is seldom an artist, would find it very difficult to describe the elements of a circuit by means of pictures. Furthermore, there are some things which enter into electrical work which would be very hard to describe pictorially. For example, how could any artist describe an intangible substance such as resistance by means of a picture?

To make it easier to describe the operation of electrical circuits, and electrical apparatus, a system of symbols have been worked out which are readily learned and understood. Many of the symbols bear a strong resemblance to the parts they represent, but their resemblance is purely elementary. Fig. 11 shows some of the symbols we will be using right along. From time to time we will add other symbols. It would be well to learn these symbols quite well so that our diagrams can be more easily understood.

Some of the things represented by the symbols of Fig. 11 have not yet been discussed in our lessons. But you will probably recognize many of them even though they have not been described. In the upper right hand corner is shown the symbol for a voltmeter. Although we have discussed volts we have not said much about the voltmeter. It is probable you have already decided that a voltmeter is an instrument which is used for the measurement of electrical pressure -- that is, for the measurement of voltage.

The symbol next to the voltmeter is the ammeter. This might have given you slightly more trouble, but probably not much more. The ammeter is an instrument which is used to measure the rate of flow of electrical current. It is a current measuring meter. An ampere meter. Since ampere meter is a bit of a tongue twister, general usage has shortened the name of this meter to *ammeter*. Much more will be said later on about the use of electrical measuring instruments.

Section 9. THE SERIES CIRCUIT

To begin our investigation of what happens when current moves in electrical conductors we shall use the simplest kind of a circuit. (See Fig. 12.) Here are shown pictorially at the left a generator, a switch and a lamp. The generator is a source of elec-

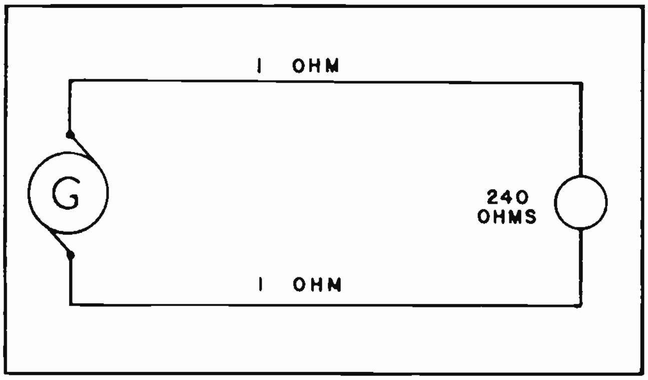

Fig.13. Resistance in a Series Circuit.

trical pressure -- electro-motive force -- voltage. Instead of a generator we could have used a battery. The effect on the operation of the circuit would have been the same. At the right are shown the same circuit elements drawn in symbolic fashion -- a schematic diagram.

The wire conductors between the generator, the switch and the lamp are covered with insulation or are surrounded with air. The supporting base of the switch is made of porcelain. The lamp-holder is made of hard rubber except for the parts which carry the electrical current to and from the lamp.

It might be noted that in the working, or schematic, diagram at the right of Fig. 12, none of these elements are shown. In our schematic diagram only the conducting path is shown.

Now assume that the system is in operation. The generator is producing a voltage, the switch is closed so that it makes a good electrical connection and there is current moving through the filament causing

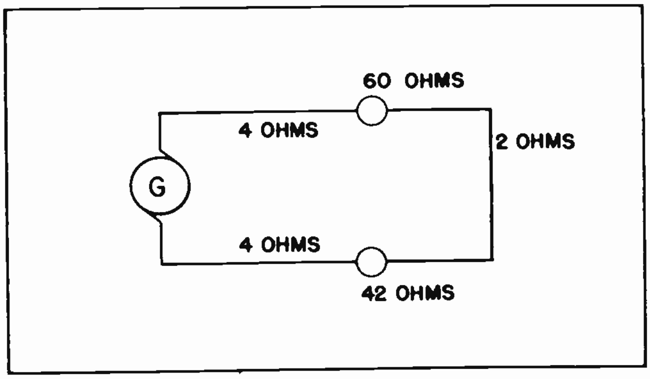

Fig.14. Resistance in a series circuit adds together to form the total resistance.

the lamp to light. How much current is flowing through the lamp, and how much is flowing through the switch, and how much through the generator?

Remember, electricity cannot be stretched nor compressed. Neither can any of it escape through the insulation nor out through the air. The answer to our question must be that the same amount of current must be flowing in all parts of the circuit. For example, if the lamp is taking one ampere of current, then there must be one ampere of current flowing through the switch, and one ampere flowing through the generator.

Any circuit in which all the current flowing through any one part must also pass through every other part, is called a *series circuit*. This is because each of the parts are connected in series with each other. There is one basic rule to remember when working with any series circuit:

The current is the same in every part of a series circuit.

Section 10. RESISTANCE IN A SERIES CIRCUIT

In Fig. 13 we have a diagram which shows a generator and a lamp connected together with two lengths of wire. There is one ohm of resistance in one wire, 240 ohms of resistance in the lamp and one ohm of resistance in the other wire. Now what would be the total resistance of this circuit from the generator through one wire to the lamp and back again to the other side of the generator? Well, let's look at this matter for a minute.

The current would meet a resistance of one ohm while moving from the generator to the lamp, it would meet 240 ohms of resistance in the lamp itself, and it would meet another ohm of resistance returning back to the generator. It would seem logical to conclude that the total resistance would include all the resistance which was met, both in the wires and in the lamp. This would be a total of 242 ohms. And this is the correct answer.

Which gives us another rule to remember in connection with series circuits:

The total resistance in a series circuit is equal to the sum of the resistances in all parts of the circuit.

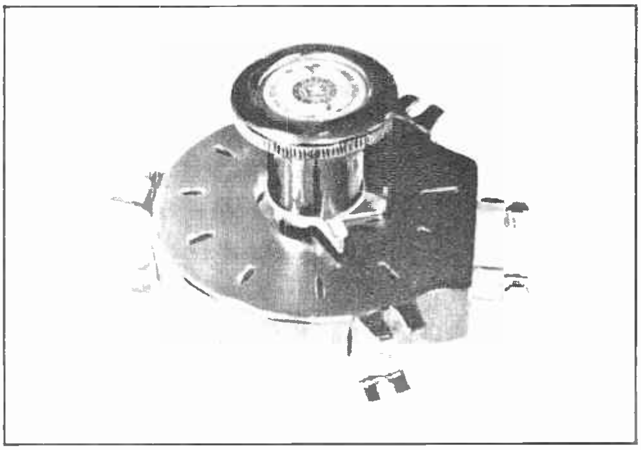

Fig.15. Variable resistor, called rheostat, used for controlling current flow.

Now suppose that in the circuit described in Fig. 13 we were to move the lamp twice as far away from the generator, and used the same size wire for conductors. We have already learned that if we double the length of a conductor we will double the resistance. So if we now double the length of the wire leading to the lamp we will increase its resistance from 1 ohm to 2 ohms. Likewise, the resistance of the wire returning from the lamp to the generator will be increased from 1 ohm to 2 ohms. If we continue to use the same size lamp, the resistance would now be 244 ohms instead of the 242 ohms we had before.

In these examples we had one large resistance represented by the lamp and two smaller resistances represented by the wires. The same principle holds true, however, where the values of the resistances are more nearly equal. In Fig. 14 is shown a generator, two lamps and the wires which will connect them together in series. There are 4 ohms of resistance in the wire leading from the generator to one of the lamps, two ohms resistance in the wire connecting the two lamps, and 4 ohms resistance in the wire leading back to the generator. One of the lamps has a resistance of 60 ohms and the other has a resistance of 42 ohms.

In determining the total resistance in such a series circuit we proceed in exactly the same way we did before. We merely add all the resistances together and that will give us the total resistance in the circuit. In this case we add 4 and 42 and 2 and 60 and 4, which gives us a total of 112 ohms of resistance in complete circuit.

Section 11. PUTTING RESISTANCE TO WORK

So far in our studies we have looked upon resistance as something which tries to prevent current from flowing in an electrical circuit. And this is correct. Furthermore, it could probably be figured that resistance can be pretty much of an unwanted problem, especially when it tries to prevent the

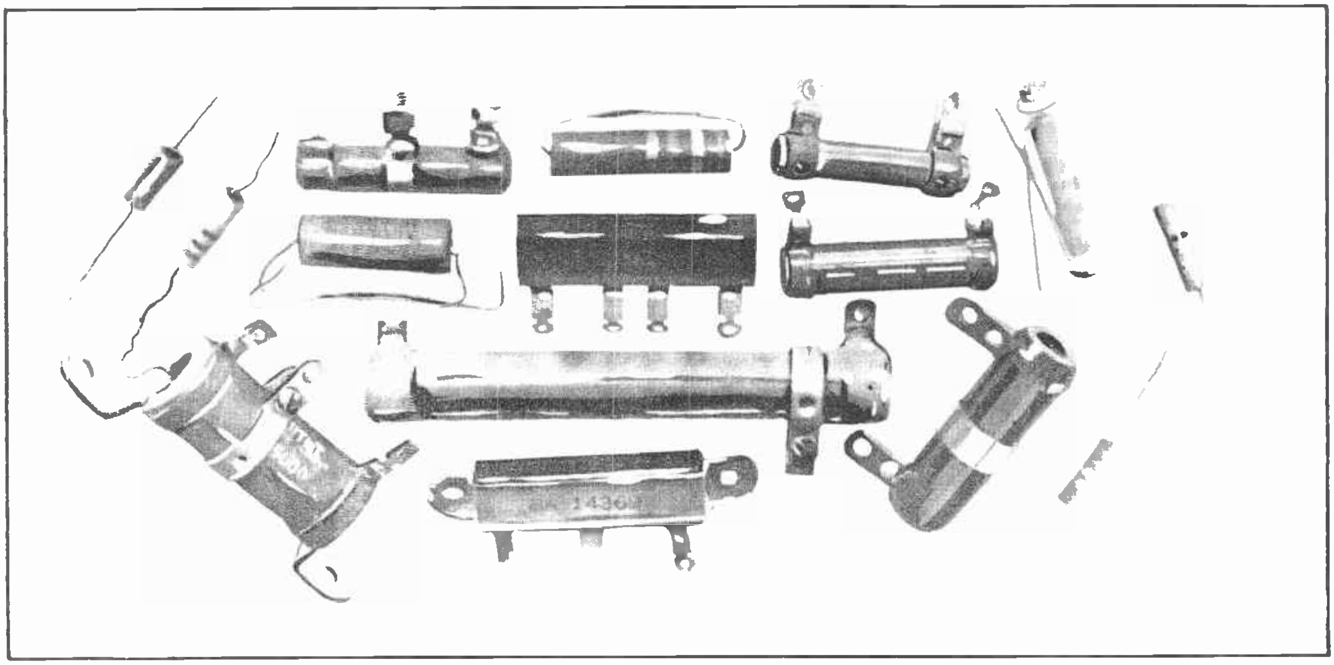

Fig.16. Types of resistors in common use in radio and television work.

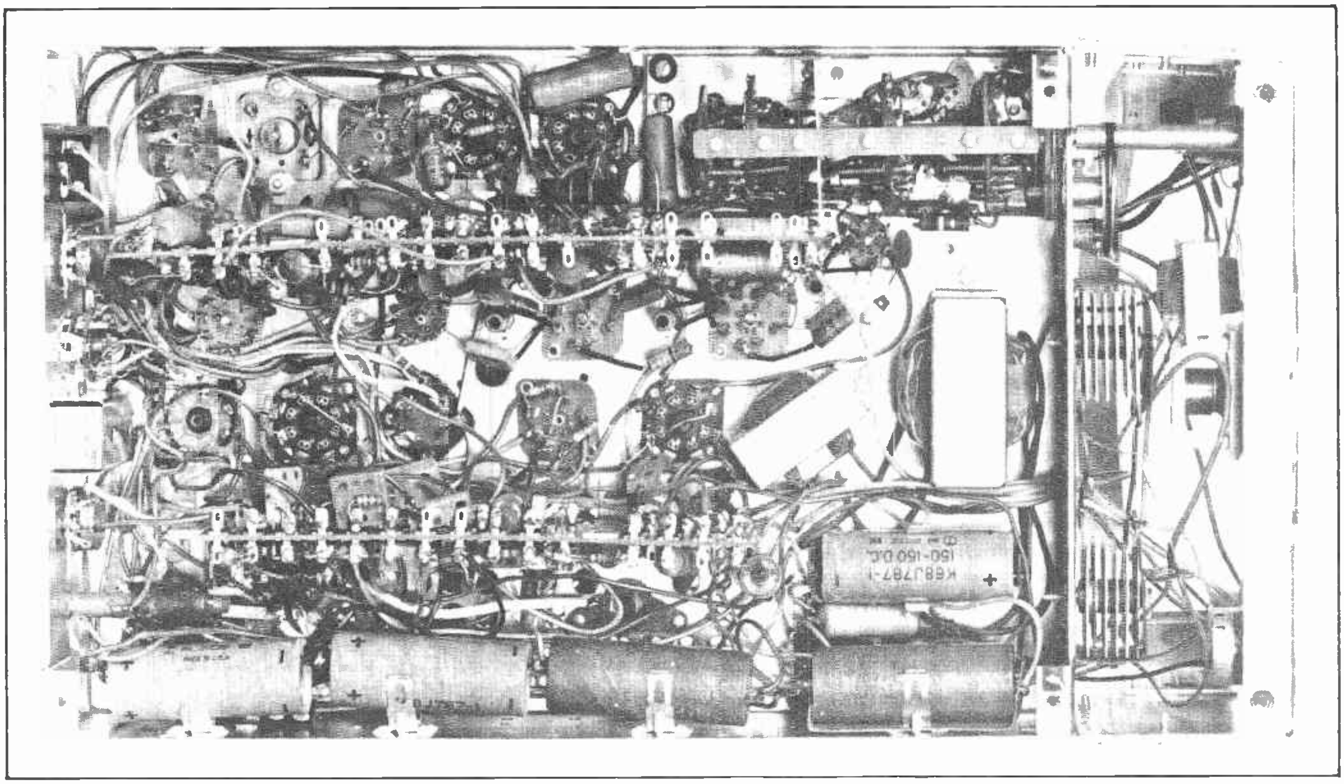

Fig.17. Photograph of the underside of a television chassis showing some of the resistors which are used. (Courtesy of General Electric.)

passage of current which is needed to light our lamps, run our motors, and operate our radio and television equipment. And all of this would also be a very correct deduction.

But it should not be thought that resistance is a completely useless evil. Nothing could be farther from the truth. We put resistance to work for us in many ways, and it is extremely useful. We use resistance in so many ways in radio and television receivers that one wonders how the equipment could be made to operate without it. Probably it couldn't.

Just as it is necessary to have brakes on automobiles to control their operation, so must we also have some means to retard the flow of electrical current and keep it under our control. It is for the purpose of controlling the electrical current flow that we put resistance to work for us.

To deliberately introduce resistance into an electrical circuit at whatever location meets our needs, we use a special type of conductor in which the value of the resistance is carefully controlled. Some of these are so constructed that the value of the resistance can be changed to suit our convenience. These are called *Rheostats*, and are illustrated by the picture in Fig. 15.

The type of rheostat which is shown in Fig. 15 is somewhat larger than is commonly found in radio and television work but it shows more clearly the way in which these parts are made than would be possible in a picture of the smaller types. These large types of rheostats will be found in the transmitter rooms of radio and television broadcast stations.

There are many occasions where it is desirable to introduce a resistance into an electrical circuit and have its value remain constant for the entire life of the circuit. There are scores of places in radio and television receivers where permanently fixed resistances are installed. To meet this need, wire having an especially high resistance is often wound onto a spool, or onto a piece of ceramic, and then connected into the circuit. Such a resistance element is called a *resistor*.

Many resistors are constructed of high resistance wire wound into the form of a spool as has just been mentioned. They are generally referred to as wire-wound resistors. Others are made of powdered carbon which has been specially mixed with clay and other materials. A connecting wire, called a pig-tail, is fastened to each end of the resistor to afford a means by which the resistor can be connected into the circuit. These resistors are used by the tens of thousands in radio and television work. The values of their resistance has now been pretty well standardized. It is possible to walk into any radio or television parts supply house and purchase a resistor of almost any needed value for a few cents.

To give an idea of the various values of resistors commonly used in radio and television work, it is possible to obtain resistors which have a resistance of only a few ohms. In fact, resistors with a resistance of less than an ohm are quite common. At the other extreme, there are resistors which have resistances running up into the tens of millions of ohms. Resistors which have resistance running over a million ohms are rated in *megohms*. A megohm is equivalent to one million ohms. Many radio receivers use resistors which are rated from possibly two or three megohms up to ten or twelve megohms.

It is worth mentioning at this time that it would be a good idea to become used to working with large numbers. In radio and television we regularly work with numbers which are very large and with other numbers which are very small. Upon first contact with these large numbers, some persons feel just a little bewildered. But that feeling soon passes and one becomes as accustomed to working with, and speaking of these large numbers, as with any other thing in everyday life. Within a few short weeks, working with these kinds of numbers becomes so much a matter of habit that it seems we have been working with them all our lives.

NOTES FOR REFERENCE

Resistance is affected by the length of a conductor. Doubling the length, doubles the resistance. Halving the length, halves the resistance.

Resistance is affected by the cross-sectional area of a conductor. Doubling the cross-sectional area, halves the resistance. Halving the cross-sectional area, doubles the resistance.

Material of which a conductor is made affects its resistance. Silver is the best conductor. Copper is almost as good. Aluminum, iron, steel, brass, zinc, lead, German Silver are all classed as conductors.

The temperature of a conductor affects its resistance. The higher the temperature, the higher the resistance in metals.

The cross-sectional diameter of a conductor is measured in *mils*.

A *mil* is equivalent to one-thousandth of an inch.

The cross-sectional area of a conductor is measured in *circular mils*.

One *circular mil* is the area of a circle one *mil* in diameter.

Resistances in a series circuit add together to form the total resistance.

The current is the same in all parts of a series circuit.

Resistors are used in electrical circuits to retard the flow of current.

Resistors can be either fixed in value, or variable.

Variable resistors are called *Rheostats*.

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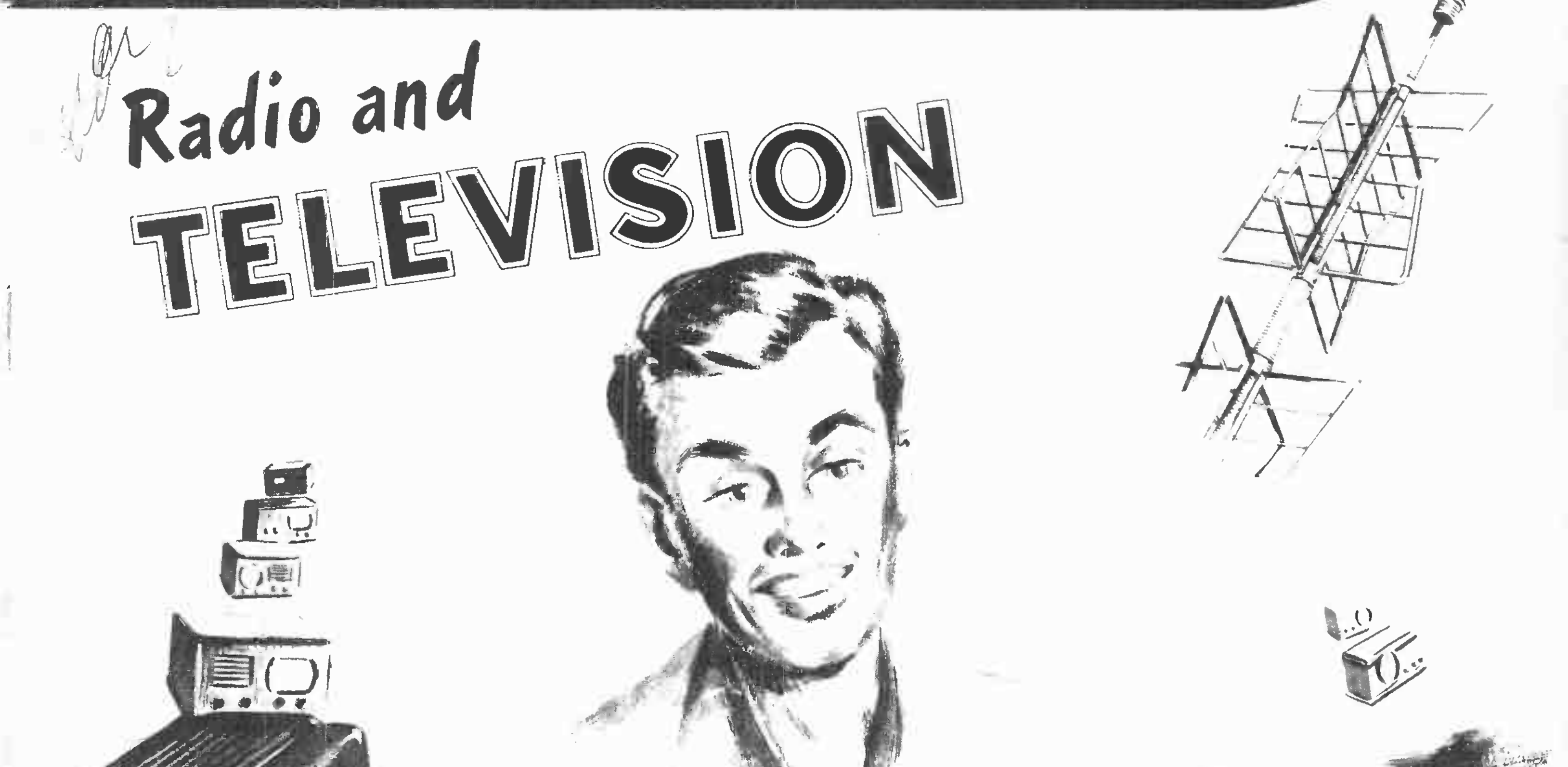

INDUSTRIAL TRAINING INSTITUTE

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TECHNICAL TRAINING SERVICE

RADIO TELEVISION

MAGNETISM

Contents: Introduction - Early History of Magnetism - Kinds of Magnets - Magnetic Lines of Force - The Earth as a Magnet - Why Iron Becomes a Magnet - Inducing Magnetism in Soft Iron - No Insulators for Magnetism - The Magnetic Field Around an Electric Current - Magnetic Field Around a Coil - The Electromagnet - Moving and Static Lines of Force - Magnetic Terminology - The Gauss - Permeability and Reluctance - Magnetomotive Force and Ampere-Turns - Notes for Reference.

Section 1. INTRODUCTION

The man who decides to become an expert in the field of radio and television has to acquire a seemingly boundless amount of technical knowledge. There are so many things to learn that it sometimes seems that no single man can know all there is to know about the subject.

From a strictly abstract point of view it is probably true that no man does know all there is to know about radio and television. There are so many new things being learned

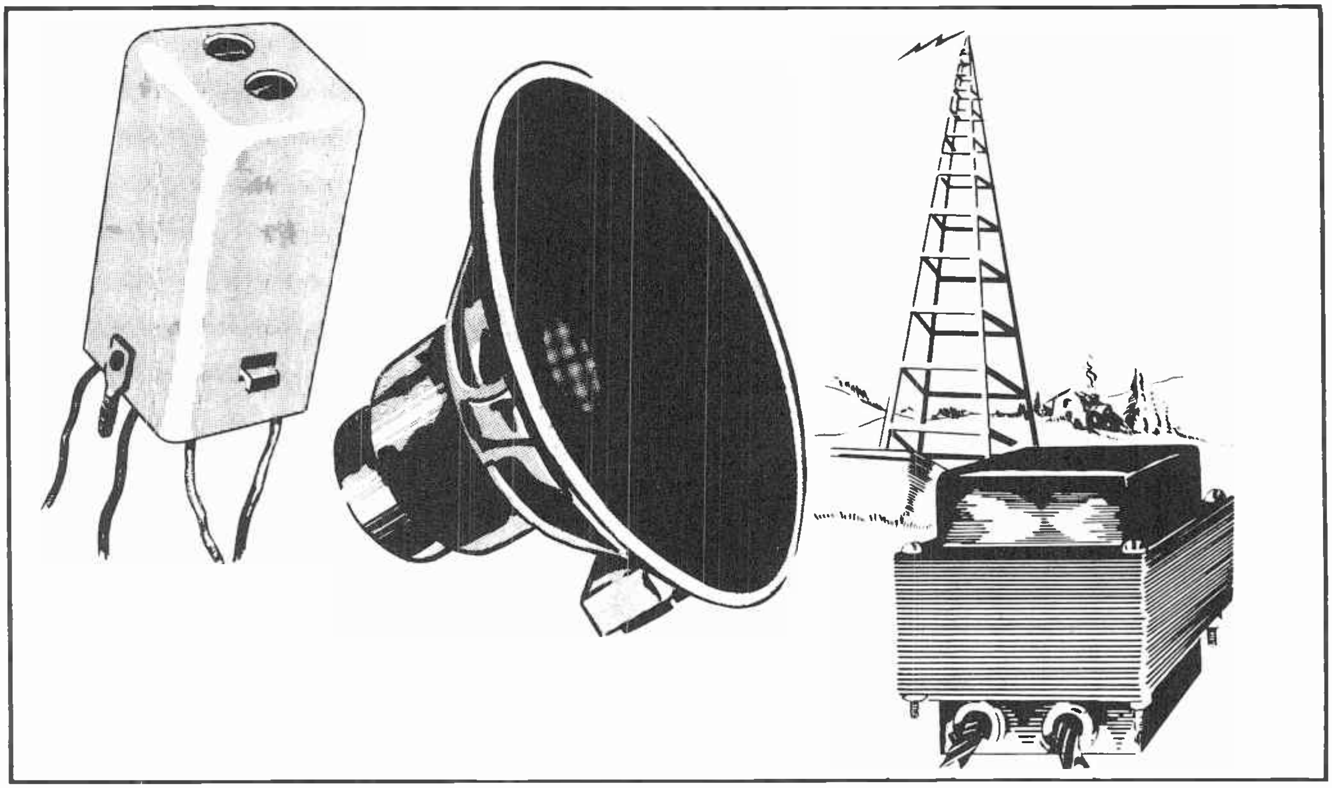

Fig. 1. Magnetism is used in many ways in radio and television.

everyday -- so many engineers, scientists, and amateurs are conducting endless experiments in search of new knowledge -- that radio and television is one field of endeavor which does not become passive. It has never reached the point where something new is not being constantly introduced to those working with it.

Probably this is what makes radio and television so fascinating to those who are working with it. When the worker knows that around almost every corner lies a vast expanse of unexplored knowledge, his interest is kept constantly alive and his ambition spurred by the thought that at any moment he too, might find his name listed with those immortals who have already contributed so much to science, to radio and to television.

When Thomas A. Edison was selling candy and fruit as a News Butch on a passenger train, his opportunity to become a great inventor was nowhere nearly so great as that of our modern young men. When he started his experiments he did not even know that the field of electricity actually had any future. Every young man today knows that electricity, radio and television have a great future -- most of them know that the discoveries and inventions which have been made in these fields, have done little more than to open a storehouse of limitless possibilities. The length to which any man can go in this field is limited only by his own ambition and by his abilities. All who are acquainted with this work are aware that the future will give us new things, many of which will probably dwarf in importance those things we know today.

No other line of endeavor offers the ambitious young man -- the adventurous young man with a thirst for scientific knowledge -- greater opportunity than he can find in the field of radio and television. While there is a lot to be learned about radio and television, it is the purpose of this series of lessons to set forth that knowledge so you too can be well trained in that specialized field. The information and training contained in this series of lessons is so arranged that any man with normal intelligence can learn all the essentials of this fascinating work with a minimum of effort. More than two thousand years ago a very learned man said, "There is no royal road to learning." That was true then, and it is true today. But in this series of lessons we have succeeded in making your road to the learning of radio and television as nearly a royal one as such a thing can ever be.

Some of the knowledge which has led to the development of radio and television was first acquired so many centuries ago, that one wonders sometimes, just why it was that so much time had to pass before that science was raised to the perfection we know today. A classic example of an element that plays an important part in radio and television work which was a familiar thing to the ancients, is that of magnetism. Every branch of electricity is so completely tied up with magnetism there is no separating one from the other. We could not generate power in the enormous quantities which are needed today were it not for the peculiar properties of magnetism. Neither would we be able to use electric power in many of the ways that we do use it.

Radio and television owe their very existance to the peculiar disturbances in the space which surround us -- the peculiar disturbances we call electromagnetic waves. There are many things right inside the radio and television receivers which also owe their operation to the strange phenomenon we know as magnetism. The action of the loudspeaker -- which is such an important part of both radio and television receivers -- depends entirely upon two magnetic fields operating upon each other. The functioning of the intermediate-frequency transformers, which are such a familiar part of the superheterodyne receiver, is completely dependent upon magnetic linkage between one of the coils within it, and the other. The power transformers and output transformers are other good examples of the properties of magnetism put to useful work. There are other examples -- many of them -- which could be cited. But these are enough to show that it would be well for us to acquire a good understanding of magnetism before going any further with our studies.

Section 2. EARLY HISTORY OF MAGNETISM

More than two hundred years before the birth of Jesus Christ, the ancient Greeks had discovered a form of magnetism. They discovered that a certain ore found in a district of Greece known as Magnesia, had the property of attracting and holding small pieces of iron. That ore is now called Magnetite.

For many centuries Magnetite remained an object of curiosity, but so far as history

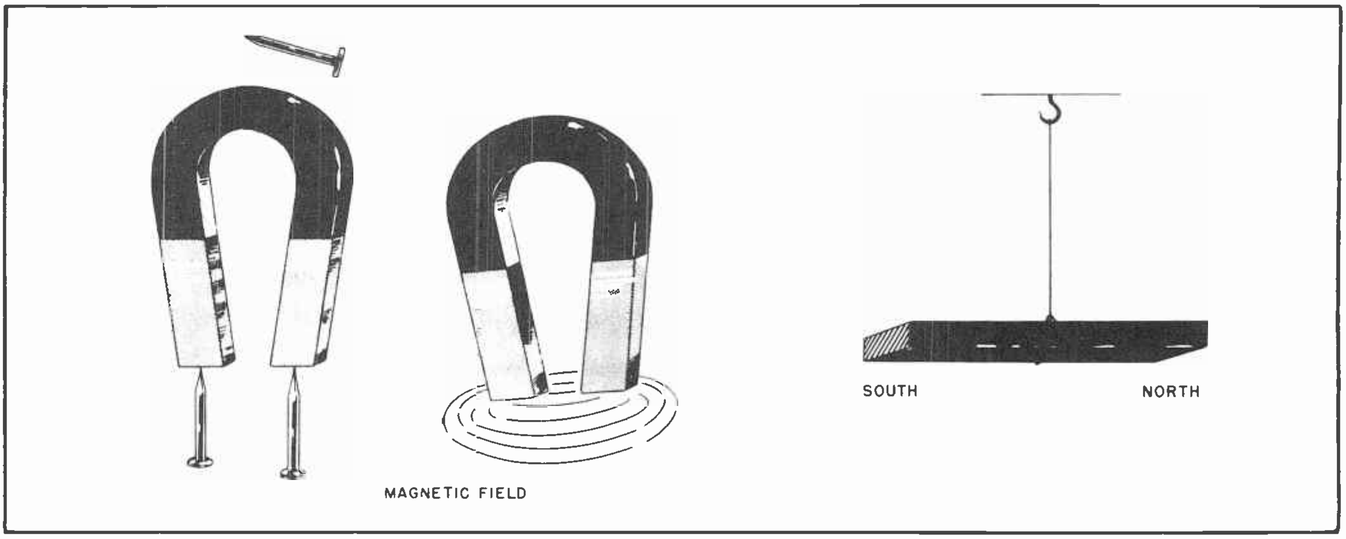

Fig.2. Properties of a Steel Magnet.

records, apparently nobody was able to figure out a practical use for it. Along about the year 1100, a Chinese experimenter discovered that if a piece of Magnetite was suspended by a string it would swing around until it assumed a position which pointed north and south. Mariners sailing their ships far beyond the sight of land soon came to depend upon pieces of Magnetite to point out to them the direction of North. They gave the name, "Leading Stone" to the bits of Magnetite which guided them across the trackless seas. This name was soon corrupted into "Lodestone", by which name the ore is still most widely known.

Today this same idea is still in quite common use. But instead of lodestone, the modern magnetic guide is the magnetic compass. Every ship on the ocean uses some form of compass to guide it when out of sight of land. Many hunters and fishermen also, use a magnetic compass when they venture into strange woods, or into places where roads and houses are few and far between.

The first link between magnetism and an electric current was discovered by a Danish teacher while teaching a science class in Denmark shortly after the close of the Napoleonic Wars. The Professor, named Hans Christian Oersted, made the discovery quite by accident in the year 1820. While teaching a class at the University of Copenhagen, he noticed that when a magnetic compass was brought close to a wire in which an electrical current was flowing, the needle of the compass was deflected. By continuing his experiments he discovered that the needle would be deflected one way if the current was flowing in one direction, but would be deflected in the other way if the current was flowing in the opposite direction.

The first practical use of this discovery was made thirteen years later, in 1833. An English scientist named Michael Faraday constructed a dynamo, or electric generator, by means of which it became possible to change mechanical force into electrical force for the first time. Michael Faraday continued his experiments with magnetism, and its relationship with electricity. Many of the things we know about electricity today were first discovered by Faraday. His name looms large in any discussion of the great men of the early electrical age. Much more will be said about him as we progress with our studies.

Section 3. KINDS OF MAGNETS

Most of us have seen the familiar horseshoe magnet such as is shown in Fig. 2. These can be purchased at any dime store or novelty shop. The horseshoe magnet will attract and hold small pieces of iron or steel which come into contact with it. If the magnet is strong enough, and the piece of iron or steel small enough, the magnet will actually cause the iron or steel to move toward it before they actually touch each other. The closer the pieces of iron or steel are to the ends, or *poles* of the magnet, the stronger will be the attraction. From this we can conclude that some invisible force exists around the poles. The space within which this force exists is called the *magnetic field.*

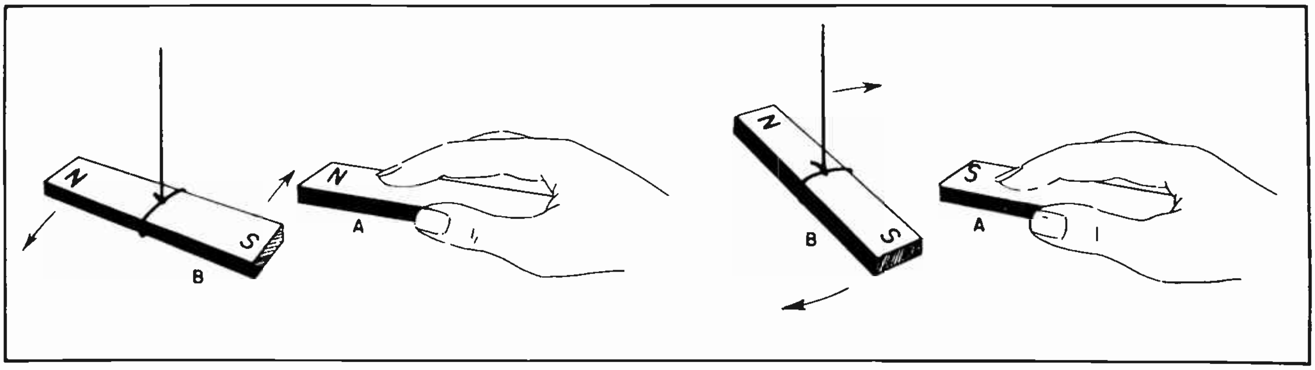

Fig.3. Magnetic attraction and repulsion.

When we suspend a straight magnet, or bar magnet, such as the one shown at the right of Fig. 2, the bar will swing around until it points north and south. We may then mark the north-seeking pole *N* and the south-seeking pole *S*. If we turn the magnet half-way around, so as to reverse the directions to which the poles point, then release the bar magnet so that it can swing freely, the two poles will return to their original positions. That is, the bar will swing around so that the north pole will again point toward the north, and the south pole of the magnet will again point toward the south.

Such a simple experiment shows that the two poles are not alike. This is true in spite of the fact that both ends of the magnet will attract pieces of iron or steel with equal force.

Since most magnets are made of iron or steel, it will be well to understand that iron which is one of the elements, is made commercially in forms called cast iron, wrought iron, and steel. Steel is merely iron prepared in a certain way by mixing with other substances in the form of alloys. Steel can be prepared so that it will have certain desirable qualities such as hardness and strength, or it can be made so as to be relatively soft and workable. There are certain other kinds of alloys which do not contain iron but which can be created to act as a magnet. Iron, however, is the only substance which is always magnetic in whatever form it is used.

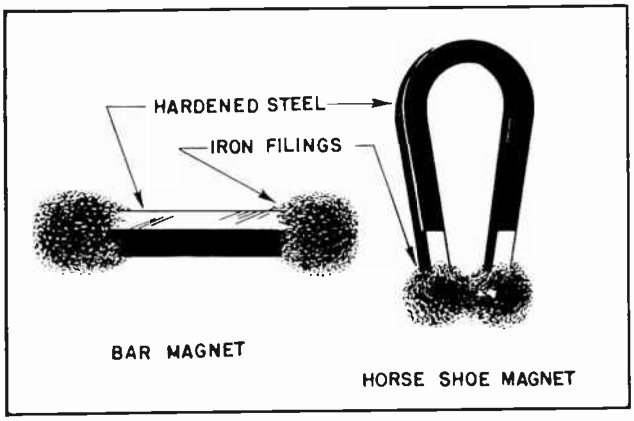

Fig.4. Iron filings show where the magnetic fields exist most strongly.

While the exact nature of magnetism is not fully understood, a careful and thorough study of magnets and their actions shows that all substances are affected to some extent when brought close to a strong magnet. Trying all of the known substances, we find that while iron and steel are affected very strongly, cobalt and nickel to some extent, the effect on most others is negligible. The effect on iron is so much greater than that on cobalt and nickel that, by itself, iron is the only element of commercial importance. However, certain alloys of iron, cobalt and iron have come into very common use because of their improved magnetic qualities. Another alloy, that of aluminum, nickel and cobalt, has also assumed considerable importance. This is especially true in radio work. The alloy is known commercially as Alnico, and is made in a variety of grades.

In Fig. 3 we have two similar bar magnets. Their north-seeking poles are marked *N*, and the south-seeking pole is marked *S*. At the left side of Fig. 3 the north pole of magnet *A* is brought near the south pole of the suspended magnet *B*. Note that these two poles have a strong attraction for each other. The attraction is so strong that if they are brought close together, they will actually pull into contact with each other.

At the right side of Fig. 3 the south pole of magnet *A* is brought near the south pole of the suspended magnet *B*. Now instead of the magnets being attracted to each other, they actually repel each other. If the two *north* poles are brought together there will be a similar repulsion between them. There is always repulsion between similar poles, and attraction between opposite poles.

This makes for a rule it would be well to learn -- and remember. You will use it often. *Unlike magnetic poles attract, like magnetic poles repel.*

Section 4. MAGNETIC LINES OF FORCE

The usefulness of a magnet in any of the purposes for which it is employed lies in the space surrounding the poles, within which is found strong evidences of attraction and repulsion. This is the space marked *magnetic field* in Fig. 2.

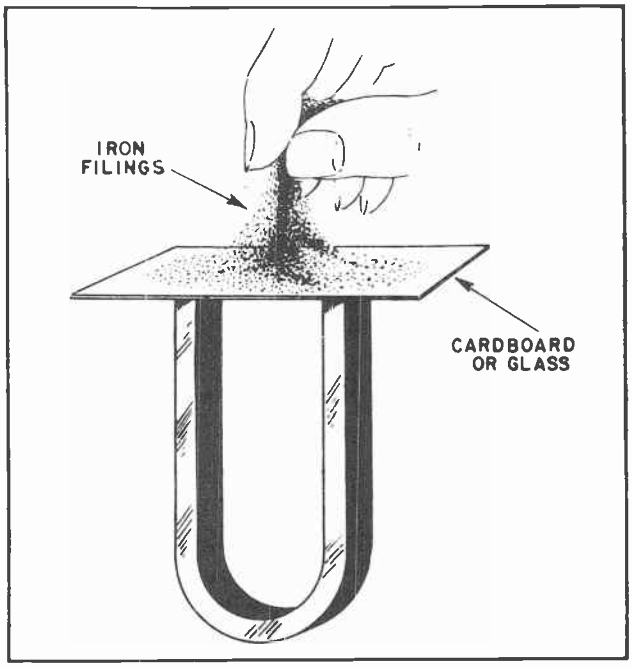

Fig. 5. Making a field pattern with iron filings.

We may gain a good idea of the strength and the extent of the force in a magnetic field by dipping the poles of a magnet into iron filings. The filings cling together and to the poles because of the magnetic attraction. The result is as that pictured in Fig. 4. There we may see that the magnetic force radiates from around the magnet ends, or poles. From both poles of the bar magnet the force extends chiefly in a direction lengthwise of the magnet, but also sidewise to some extent. By noting how the filings are held on the horseshoe magnet, we may see that the force exists in the entire space between the poles, extending from one pole to the other. The force also extends in a generally outward direction all around the two poles.

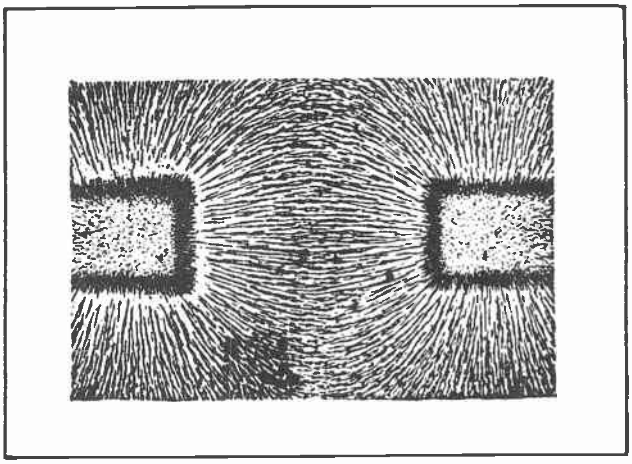

Fig. 6. The magnetic field pattern between unlike poles.

To better understand how the force extends between the poles of a magnet, we can take a piece of cardboard or glass and place it over the ends of the poles as is shown in Fig. 5. If we then sprinkle a small quantity of iron filings over the screen, the filings will form a distinct pattern as shown in Fig. 6. Immediately above the poles of the magnet the filings stand straight up in tiny lines extending away from the poles and into the space around them. In between the poles the filings arrange themselves in curved lines.

Because the force existing around the poles and extending between them appears to exist in definite lines, we speak of them as *magnetic lines of force*. In drawings or

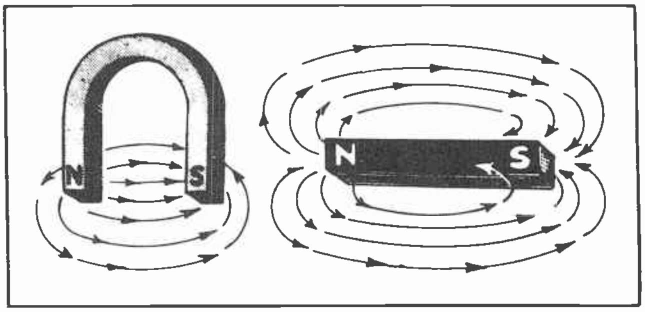

Fig. 7. The magnetic fields around steel magnets.

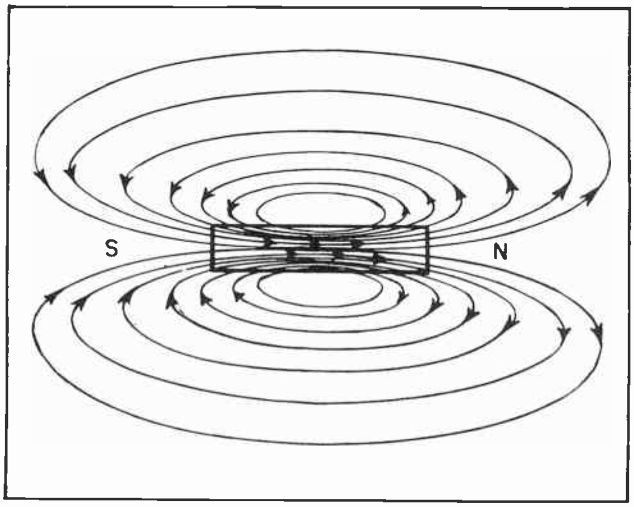

Fig.8. Lines of force inside and outside a magnet.

diagrams it is a common practice to represent the magnetic force as straight or curved lines such as is shown in Fig. 7.

In Fig. 7 the small arrowheads indicate that the magnetic lines of force come out of the north pole of the magnet, pass through the field and re-enter the south pole. Within the iron of the magnet the lines of force are from the south pole to the north pole as indicated in Fig. 8. The intensity of the magnetism is far greater within the iron than in the field surrounding the iron. This means there are more lines of force in any given cross-section of the iron than in the field which surrounds in the iron.

Another curious thing about magnetism is shown in Fig. 9. If two bar magnets are so placed that the south pole of one is a little distance apart from the north pole of the other, many of the lines of force which issue from the north pole of one magnet will re-enter the south pole of the other magnet. In the field between the closest points of the two magnets there will be a decided concentration of magnetic lines.

A study of Fig. 9 will also show graphically a common conception of magnetic lines of force. Many electrical and radio workers like to think of magnetic lines of force as acting much like rubber bands which are always trying to contract and shorten themselves. We have previously shown that unlike poles of two magnets will be strongly attracted to each other. Now imagine that all the lines of force shown in Fig. 9 are tiny rubber bands which are somewhat stretched. All are trying to contract -- that is, shorten themselves. The result will be that the two bars are pulled together. Thinking of magnetic lines of force in this manner makes it easier to understand the action of magnetism.

Magnetic lines will pass in only one direction at a time through iron, or through the external field. If we bring two north-poles together, as in Fig. 10, the lines from neither will enter the other magnet, but each field will be completed by itself. The same thing will happen when two south-poles are brought together. Sprinkling iron filings over a screen of cardboard or glass laid on top of the two like poles will produce a pattern such as is shown in Fig. 11. There we can plainly see the two groups of lines coming together, but they are not mixing.

Section 5. THE EARTH AS A MAGNET

We all know that the needle of a compass tends to point in a line which runs approximately north and south. The compass needle is a piece of steel which is highly magnetized, and which can swing freely. The reason the compass needle assumes a north and south position is that the Earth is an exceedingly large magnet whose poles attract the smaller magnet of the compass needle.

Considering the small magnet in the compass, we call the end which points north, the north pole, and the end which points south, the south pole. We have learned that

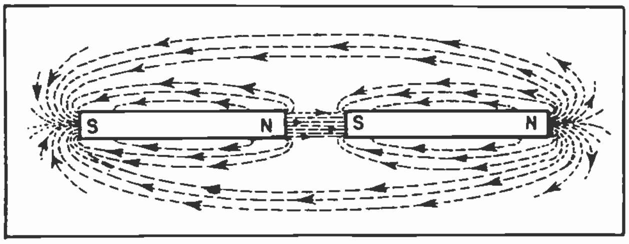

Fig.9. How fields join when unlike poles are brought close together.

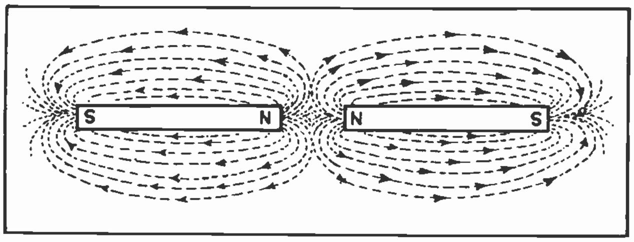

Fig.10. The fields remain separate when like poles are brought together.

the north pole of a magnet is attracted by the south pole of another magnet, consequently the north pole of the compass must point toward the south magnetic pole of the Earth, and the south magnetic pole of the compass must point to the north magnetic pole of the Earth. Thus we learn that the south magnetic pole of the Earth is near the north geographic pole and the north magnetic pole of the Earth is near the south geographic pole of the Earth. Fig. 12 shows these relationships.

Section 6. WHY IRON BECOMES A MAGNET

If you break a bar magnet, such as the one shown at the top of Fig. 13, into two pieces you will have two magnets as is shown at the center of the same illustration. If you break these two pieces each into two other pieces, you will have four magnets as shown at the bottom of Fig. 13.

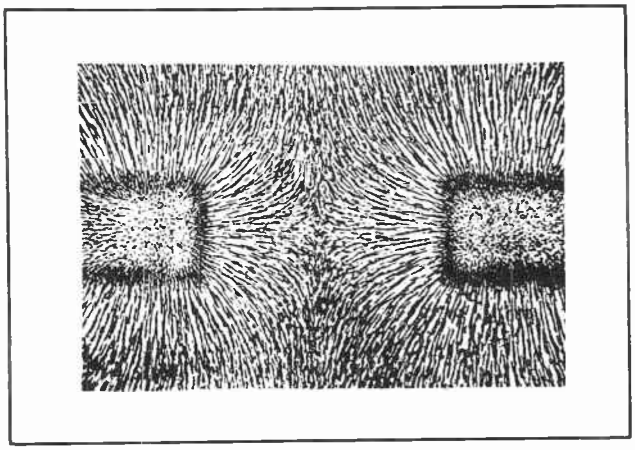

Fig.11. The magnetic field pattern between like poles.

It is generally believed that the reason why this is so is because each of the molecules of a piece of iron is itself a magnetic particle. Under normal conditions, the molecules assume a disorderly arrangement, some pointing in one direction, others pointing in other directions. This is much the same arrangement suggested by *A* in Fig. 14. The result is that the magnetism of one molecule is cancelled out by the magnetism of some other molecule, and the piece of iron as a whole apparently possesses no magnetism.

But if the piece of iron comes under the influence of a magnetic field, some of the molecules will tend to arrange themselves into a pattern so that more of them are lined up in the same direction, the magnetism of each being aided by that of some

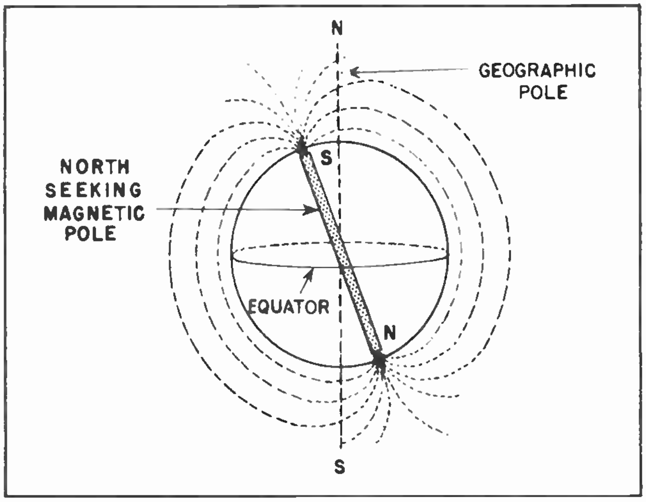

Fig.12. The magnetic poles and the geographic poles of the Earth.

of its neighbors. This is shown by the arrangement at *B* in Fig. 14.

If the piece of iron is placed in a still stronger magnetic field, even more of the molecules will line up with their individual magnetic poles pointing in the same direction. This arrangement is shown by *C* in Fig. 14.

Soft iron is easily magnetized. It becomes a magnet itself when placed in a rather weak magnetic field. This is as though the molecules were easily forced into line by the magnetic force. Soft iron loses its magnetism just as easily as it is acquired. As soon as the magnetizing force is removed, the iron loses most of its magnetism.

Hard steel, on the other hand, is much harder to magnetize. It would seem that

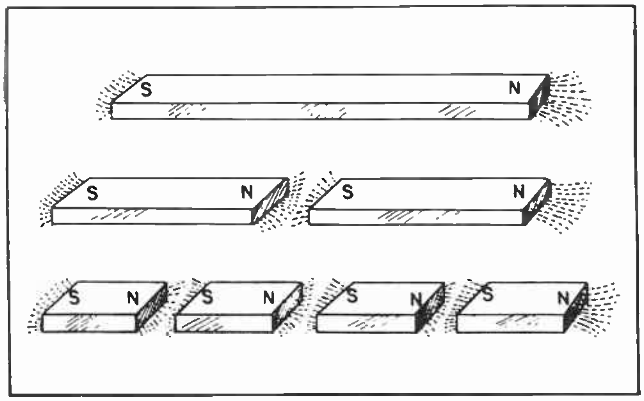

Fig.13. Breaking a magnet produces additional magnets, each having a north pole and south pole.

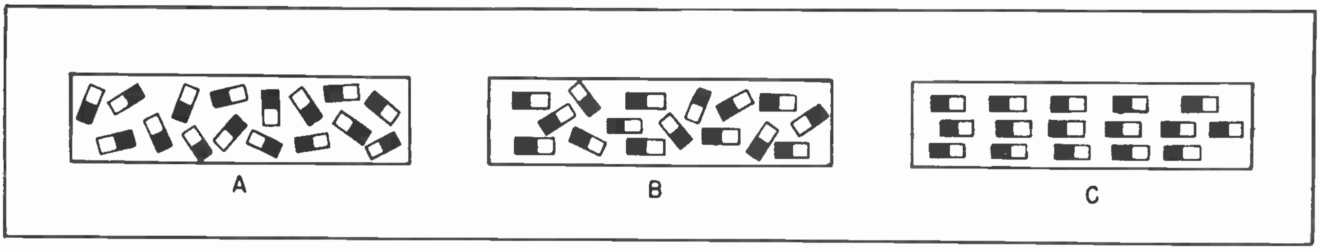

Fig.14. The arrangement of the molecules in an iron bar. "A" shows a random arrangement, not magnetized. "B" is partially magnetized. "C" is fully magnetized.

the molecules of the steel resist much more strongly any effort to rearrange them. But when once forced to become a magnet, steel will retain its magnetism for a long period of time.

For these reasons, soft iron is used when it is desired to create a magnet temporarily.

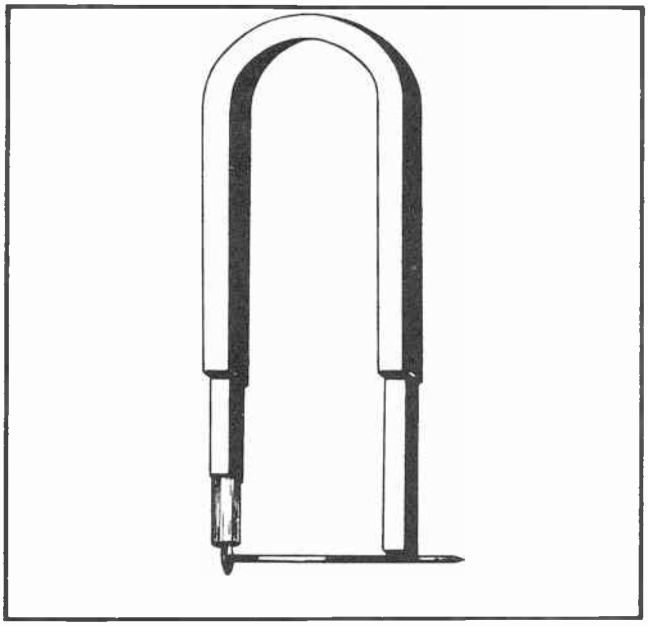

Fig.15. A magnet induces magnetism in other pieces of iron.

Soft iron is especially useful as the magnetic cores for electromagnets, where the magnetism is needed for short or irregular periods. Where it is desirable to maintain the magnetism for a long, or indefinite period, it is better to use steel or one of the special magnetic alloys such as Alnico. These are called *permanent* magnets.

Every magnet will lose its magnetism if the metal is heated red hot. For each kind of iron, steel or alloy there is a certain temperature above which all magnetic properties disappear.

Section 7. INDUCING MAGNETISM IN SOFT IRON

Either pole of a fairly strong magnet will attract and hold a piece of soft iron which is not itself a magnet. While this piece of iron is in contact with the magnet it will attract and hold another piece of iron. This shows that the first piece of soft iron has temporarily acquired the properties of a magnet. This is shown by Fig. 15. That illustration also shows that a number of pieces of iron may be hung on the poles of a magnet, each piece supporting one or more other pieces of iron.

Any soft iron which is placed in contact with, or close to, a pole of a permanent magnet becomes a magnet itself. It will remain a magnet so long as it touches, or is close to the permanent magnet. When the iron is moved away from the magnet, it loses nearly all its magnetism.

In order for a piece of iron to become magnetized it is not necessary that it actually touch the metal of the magnet. If one end of a piece of iron is held close to, but not touching the pole of a magnet, as is shown in Fig. 16, the iron will pick up iron filings or other small pieces of iron or steel. The reason is that many lines of force existing around the magnet

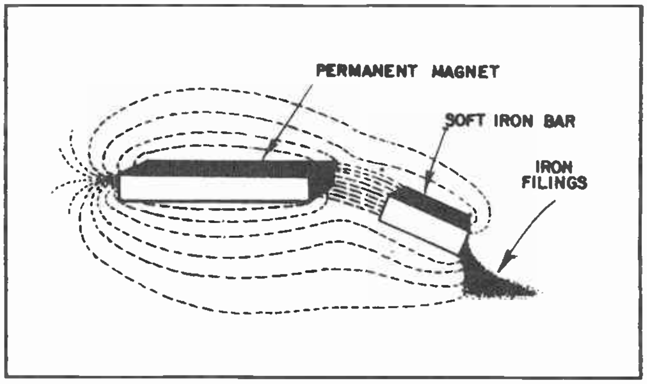

Fig.16. Iron may be magnetized when not touching another magnet.

will extend to the piece of iron. And so long as the lines of force pass through it, the iron will be a magnet.

Section 8. NO INSULATORS FOR MAGNETISM

Magnetism, or magnetic lines of force, pass through air quite easily, and will pass through a vacuum just as easily. This fact is taken advantage of in many of the larger television receivers. The deflection of the electronic stream within the cathode-ray tube, which creates the picture, is brought about by heavy magnets which surround the tube. The magnetic lines of force pass through the glass and the vacuum of the tube quite easily. The arrangement of such a magnet around one of the larger television picture tubes is shown in Fig. 17.

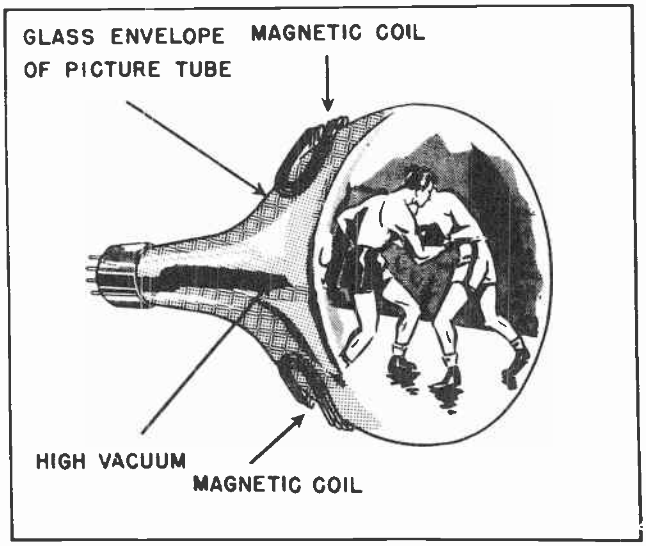

Fig.17. Magnetic deflecting coils on a television picture tube.

You can readily see for yourself that magnetism does actually pass through glass -- and quite easily too. Obtain a horseshoe magnet -- or a bar magnet for that matter -- and place a piece of glass over the end of the magnet poles as is shown in Fig. 18. On the other side of the glass will be a magnetic field sufficiently strong to attract and hold small pieces of iron or steel.

Section 9. THE MAGNETIC FIELD AROUND AN ELECTRIC CURRENT

We mentioned earlier in this lesson that a Danish science teacher had discovered a relationship between magnetism and an electric current. We can demonstrate for ourselves that there is always a magnetic field

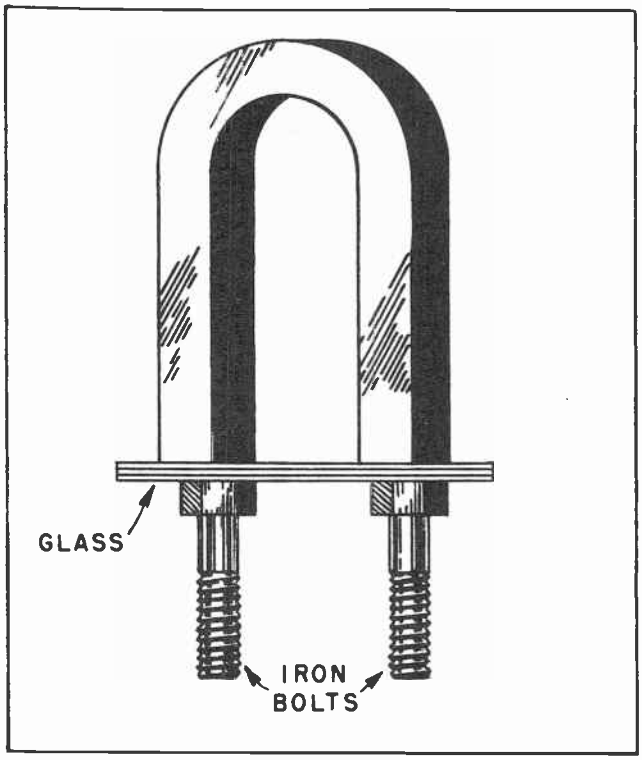

Fig.18. Magnetic lines pass through glass and other electrical insulators.

surrounding any conductor which is carrying an electric current. Fig. 19 shows four small magnetic compasses surrounding a wire which is carrying an electric current. In our illustration we show four compasses. In an actual experiment only one compass is really needed. It can be moved from one

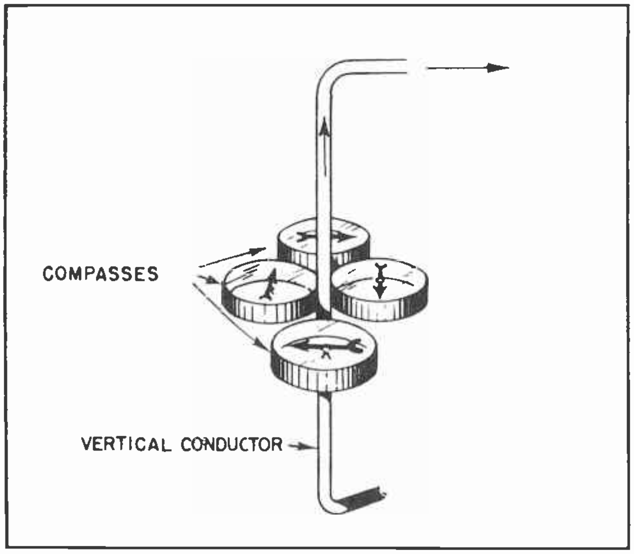

Fig.19. Compasses indicate lines of force around a conductor.

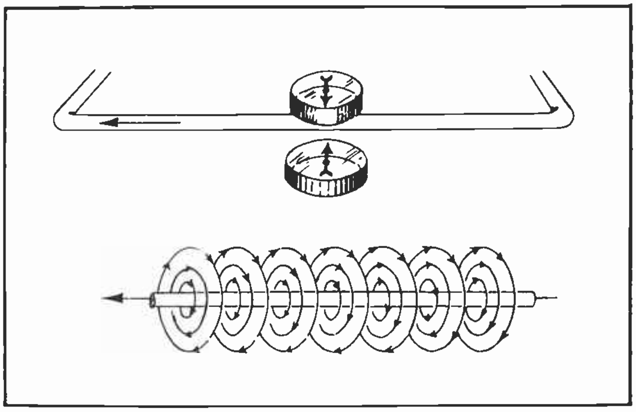

Fig.20. Direction of lines of force around a conductor.

position to the other as successive readings are taken. The action of the needle shows beyond any doubt that there is magnetism present around the wire.

To prove the point even further, the current can be turned off, at which time the compass will no longer be affected by the magnetic field of the electric current and it will then swing around in line with the magnetic poles of the Earth. Fig. 20 shows another experiment which can be conducted with the compass. Place the compass first above the horizontal wire of the conductor carrying the electric current and observe the action of the needle. Then place the compass below the conductor. Note the reversal of the needle. This indicates that the magnetic lines of force are moving around the wire in the form of circles, with the wire at the center of the circle. The current in the wire must be direct current. The experiment will not work with alternating current.

It has been mentioned previously that an electric current is nothing more than free electrons moving from one atom of a piece of metal to another atom. When there is current flowing in a conductor, the free electrons are all moving in the same direction at the same time through the conductor. The thought might occur to you that if electrons moving from atom to atom in a conductor set up a magnetic field around them, why wouldn't free electrons flying through space, or the vacuum of a vacuum tube or cathode-ray tube, also set up a magnetic field around them? The answer is, they do. Just as a moving stream of electrons, such as those in a cathode-ray tube, or television picture tube, are affected by an external magnet, so do the moving electrons themselves create a magnetic field around them which affect other substances. This will be discussed in more detail in a later lesson. We are not yet fully prepared to understand many of the things which goes on in a picture tube.

Section 10. MAGNETIC FIELD AROUND A COIL

If two parallel wire conductors were cut so that we could view the cross-section of their ends they would look like the cores of the patterns shown in Fig. 21. The left-hand part of the illustration represents the cross-section of a wire in which the current is moving toward the observer. The dot in the center of the wire represents the point of an arrow which is moving in a direction toward the observer, and is frequently used to represent the direction in which the electrons in the conductor are moving. The cross in the center of the wire at the right side of the illustration represents the crossed feathers on the tail of an arrow which demonstrates the direction of the electron flow in that conductor.

In other words the electrons in the wire to the left of the illustration are moving toward the observer. The electrons in the wire at the right of the illustration are moving away from the observer. The dot and the cross are quite widely used in electrical diagrams when it is necessary to show the direction of the electron flow in any conductor which is shown in cross-section.

The lines which ring the conductors represent the magnetic lines of force which surround the conductors when electrons are moving through them. When the electrons are moving through a wire toward an observer the magnetic lines will circle the conductor in a clockwise manner as shown at the left of Fig. 21. When electrons are moving away from the observer, the lines will circle the conductor in a counter-clockwise manner as is shown at the right of the same illustration.

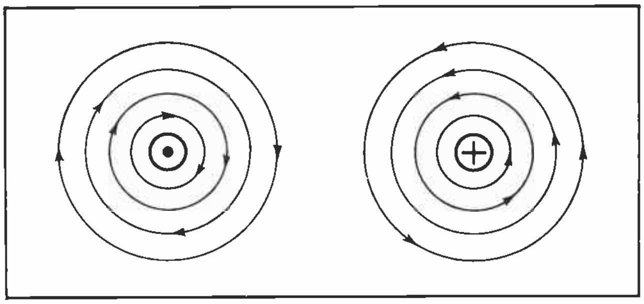

Fig.21. Lines of force around a conductor.

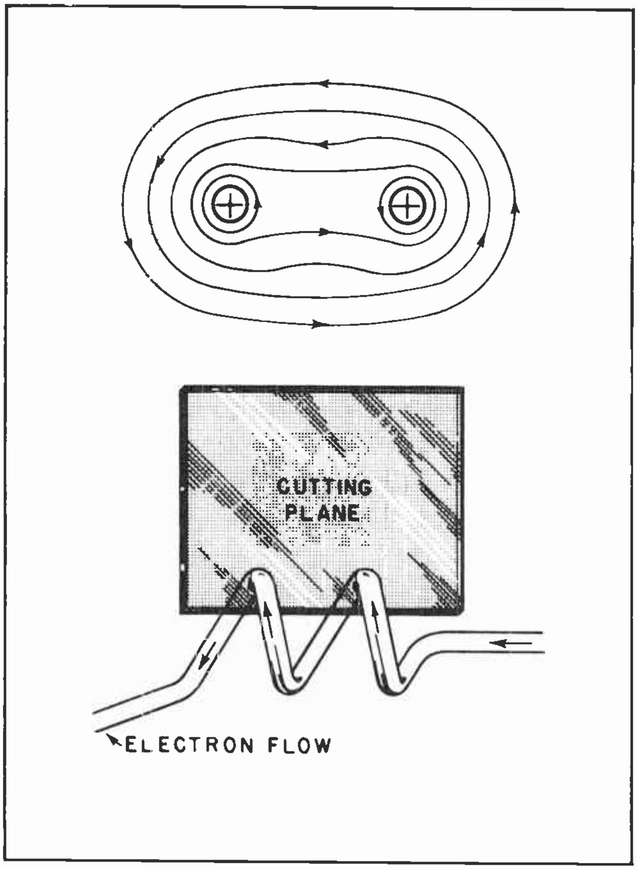

Fig.22. Lines of force around parallel conductors.

When two conductors are parallel with each other and have current flowing through them in the same direction, we have an effect such as that shown by the illustrations in Fig. 22. The upper illustration shows the cross-section of two conductors in which the electron current is flowing away from the observer. If we could imagine the cutting of the two wires at the top of the loop, or coil, shown in the bottom part of the illustration as shown by the imaginary cutting plane, we would have the cross-section of the two conductors bared to our view as shown at the top. In other words, if the two loops of the wire were cut at the point indicated by the cutting plane, that portion bared to our view would be the same as shown at the top of the illustration. The electrons would be moving away from us as is indicated by the crossed feathers of the two arrows in the cross-sections.

The important thing to observe, however, is that when two conductors are in parallel, their lines of magnetic force will link together in the manner shown at the top of Fig. 22. The lines will tend to surround both conductors.

In this illustration the conductor has been bent to form two loops of a coil. When a coil has been so formed into two loops there are approximately twice as many lines of force surrounding the two loops as there would be if there was only one loop in the coil. The importance of this fact is that by forming a conductor into a coil with many loops, or turns, we can concentrate the magnetic lines of force in one location.

Fig. 23 shows how the conductor has been formed into a coil of several loops. Note the concentration of magnetic lines of force in the hollow center of the coil.

As a general rule, the turns of any coil are wound close together, as illustrated in Fig. 24. Then nearly all the lines of force encircle all the turns, and practically the entire magnetic flux passes through the interior and back around the outside of the coil. If you compare Fig. 24 with Fig. 8 you cannot help noticing the similarity in the paths of the magnetic lines of force. The similarity exists because both diagrams illustrate magnets. In Fig. 8 we have a bar magnet. In Fig. 24 we have a *solenoid* magnet, meaning a coil of wire which has all the properties of a magnet while electrical current is passing through it. The solenoid has north and south poles just like the bar magnet. When you bring the north pole of a solenoid near the south pole of another solenoid, or the south pole

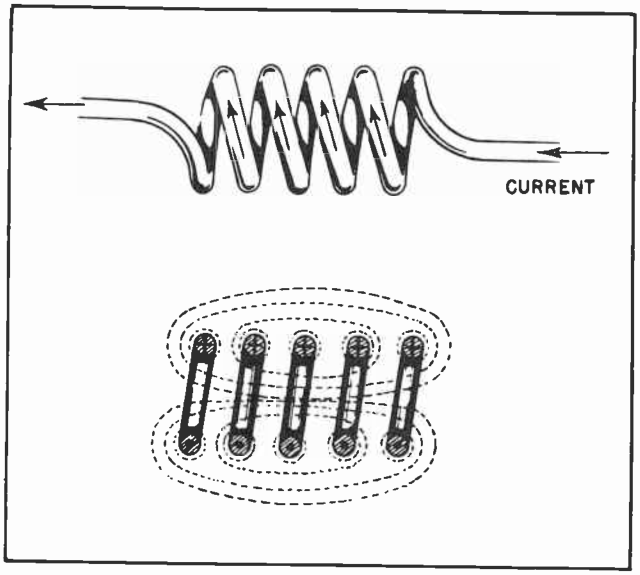

Fig.23. Magnetic lines link all the turns of a coil.

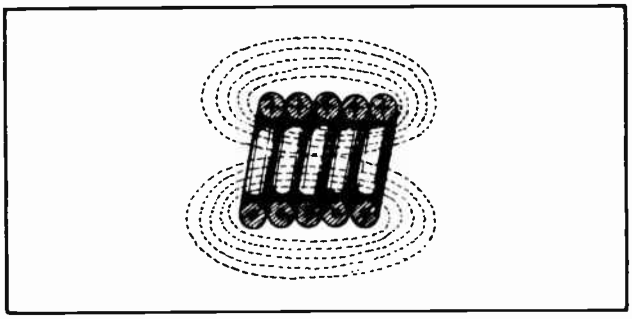

Fig.24. Linkage is more complete with turns close together.

of a bar magnet, the two will attract each other. If you bring like poles together, they will repel each other.

Section 11. THE ELECTROMAGNET

The magnetic properties of the solenoid are useful in many ways. The radio-frequency coils in nearly all radio and television receivers are wound in the form of a solenoid. Transmitter coils are also wound in the form of a solenoid. Such coils are absolutely indispensable in radio and television work. But they are by no means the only place solenoid coils are used.

But for use as a magnet, the solenoid is weak in proportion to the amount of current which flows in the winding of the coils. The reason is that the air within the core of the coil does not provide an ideal path for the magnetic lines of force.

In order to have more lines of force for a given amount of current in the winding we must provide a better path for the lines of force to follow. The best way to provide a good path for the magnetic lines of force is to make a path of iron. When we place an iron center, or an iron core, inside a coil of wire we have an *electromagnet.* The electromagnet is one of the most useful and important devices in the whole field of electricity. The reason is that so many things depend upon the principle of the electromagnet.

We may make an electromagnet by placing within a solenoid winding an iron core. Such an arrangement is shown in Fig. 25. The number of lines of force in the field, for the same current in the winding, is tremendously increased by inserting the iron core. Most electromagnets are made with cores of some kind of iron or steel which is easily magnetized, and which loses most of its magnetism when the current ceases to flow in the winding. So long as current flows in the winding, we have a magnet which will attract and hold anything made of iron or steel. *The electromagnet is a device in which a mechanical pull or force may be produced and regulated by control of current in a winding.*

Section 12. MOVING AND STATIC LINES OF FORCE

Earlier in this lesson we said that the exact nature of magnetism was not fully understood. This is true. Some of the things about magnetism which we generally accept as being facts are actually more in the nature of convenient theories. At the risk of possibly confusing you, we are going to mention some of these.

In Figs. 7, 8, 9 and 10 we show the magnetic lines of force emerging from the magnets at the north pole and re-entering the magnet at the south pole. This is the generally accepted theory among all electrical and scientific men. This theory fits all the facts known about magnetism.

While we do not want to say anything which might possibly confuse you, it is only fair to say that at this time no one actually knows whether the lines of force emerges from the north pole of the magnet or from the south pole. But since all the learned men act upon the theory that the lines do emerge from the north pole, and that theory has never been disputed, we will continue to assume that they do.

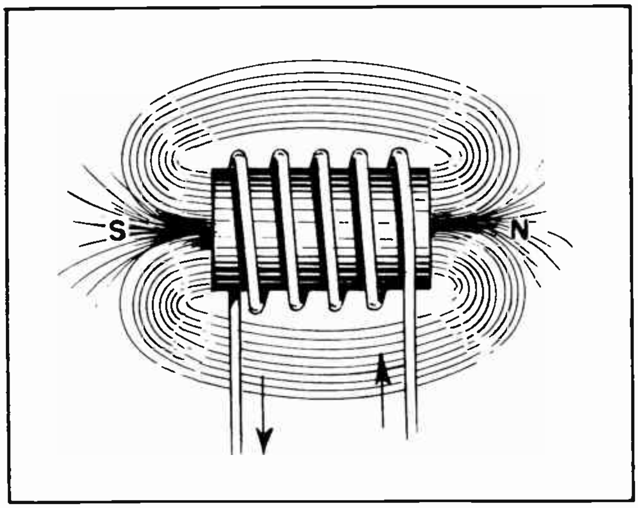

Fig.25. The field around an electromagnet.

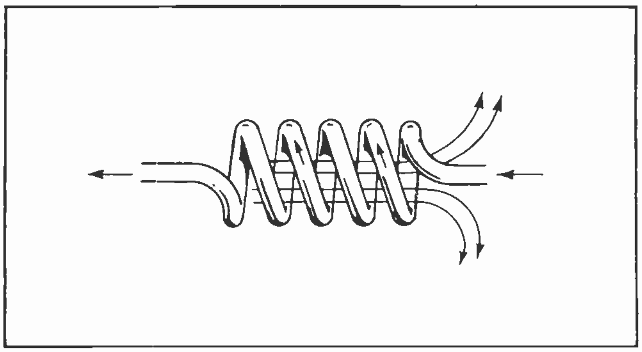

Fig.26. Lines of force emerging from the coil as current starts to flow.

Most of our illustrations indicate that the lines of force emerge from one pole and re-enter the magnet at the other pole. Most experiments with magnetism indicate that this is true. But it should not be thought that the lines are continually moving from the north pole to the south pole in the manner of an electric current in a conductor. Such is not strictly true.

To illustrate this situation, let us assume we have a coil of wire -- a coil in the form of a solenoid like that of Fig. 23. Until the coil is connected to a source of potential there will be no current flowing in the coil. At this time there will be no lines of flux surrounding the coil.

As current begins to flow through the coil, some lines of force will begin to emerge from the north pole end of the coil. While everything about electricity and magnetism seem to be instantaneous to the human senses, we have learned that actually it does take a certain amount of time for things to happen, even in electrical work. The emerging lines of force will resemble the situation portrayed in Fig. 26.

As the amount of current increases, the lines of force will reach around until they link in a complete circuit around the coil, as shown by Fig. 27. This is practically the same situation as that shown in Figs. 23 and 24. This brings us to a peculiar thing about magnetism. The flowing electrical current will push these lines of force out so that they surround the coil in the manner described. But the lines go out as though they were reluctant to do so, much in the manner of stretched rubber bands. They will collapse back into the coil the instant the current ceases to flow.

So long as the current flows at a steady value, the lines will continue to surround the coil. Though the lines surround the coil, the lines are not moving. They are static. Once they have assumed the position the current caused them to take, they stay there. So long as the value of the current does not change, the lines will not move.

Now if the amount of current through the coil is increased, the lines will be pushed out somewhat further from the coil, and there will be more of the lines. This is shown in Fig. 28.

The point to remember is this: so long as the current remains steady, the lines remain fixed and motionless in the space surrounding the coil. The lines move only during the time the value of the current is changing. If the current increases, the lines will expand. If the current decreases, the lines will contract toward the coil in much the same manner a group of stretched rubber bands will contract when the tension which has stretched them tends to relax.

This matter of static lines of magnetic force, and moving lines of magnetic force will assume considerable importance in later lessons. The problem at this time is to explain the difference between them to you, and show how each condition is brought about.

Section 13. **MAGNETIC TERMINOLOGY**

The ordinary electrical worker frequently finds it necessary to calculate the values concerned in the construction of magnets. This requires that he know and understand the various magnetic units. Fortunately, the radio and television technician is not often concerned with the construction of electromagnets. His knowledge of magnetism

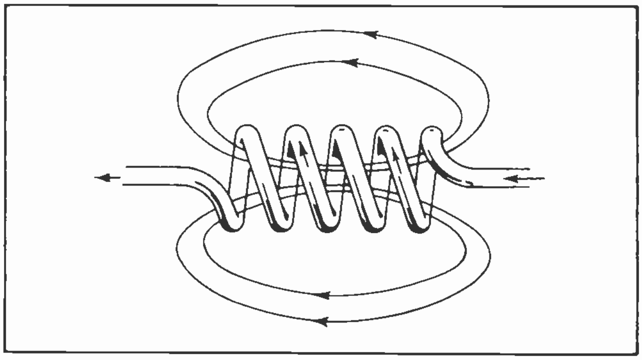

Fig.27. A small current creates a few lines of force near the conductor.

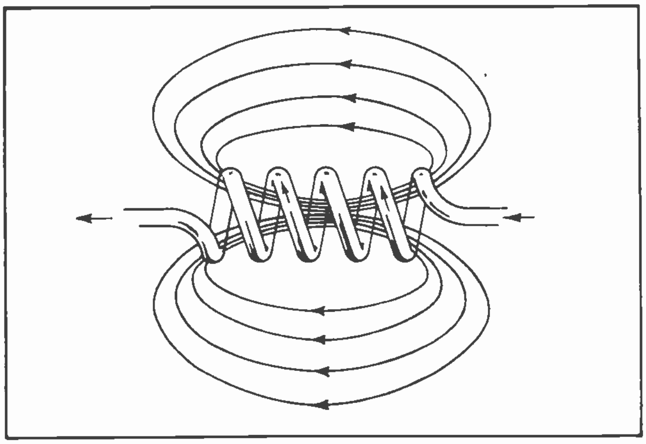

Fig.28. A larger current creates more lines of force and they move farther from the conductor.

can be more generalized than detailed. Nevertheless, it is often convenient for the radioman to be familiar with the various terms used in connection with magnetism.

Generally speaking, the electronic technician is not usually concerned with the individual lines of magnetic force in a magnet. It is usually more convenient to consider all the lines of force as one group, and to refer to them as "magnetic flux."

You may occasionally run across the term "Maxwell" in connection with magnetic fields. The Maxwell is simply the name of a unit of measure. One Maxwell is equal to one line of force. Instead of describing a magnetic circuit as having so many lines of force per square inch, it can be said that the circuit has so many Maxwells per square inch.

Since the metric system is used very extensively in technical work, the size of the magnetic field may be measured in square centimeters. In this case the magnetic flux will be stated as being so many Maxwells per square centimeter.

Section 14. THE GAUSS

Because a magnetic flux of any given number of lines of force may be spread over a comparatively large magnetic field or compressed into a relatively small field, it is necessary to know both the number of lines and the size of the area through which they pass. For this reason the number of lines of force passing through a given area is known as the "density" of the field.

To combine the number of lines and the area into a single unit of measure, one Maxwell per square centimeter is referred to as a "Gauss." The gauss was named for a famed German mathematician and astronomer, Karl Friedrich Gauss. He became much interested in the Earth's magnetism and invented apparatus necessary to measure it. His work resulted in a number of important contributions to the knowledge of magnetism. He was Director of the Gottingen Observatory from 1807 until his death 48 years later in 1855.

Since a Gauss is equivalent to one line of force per square centimeter, a magnetic field with a strength of 10,000 Gausses would have 10,000 lines of force per square centimeter. Like electrical energy, magnetic energy cannot be seen. It is necessary to base all measurements on the effects which are produced.

Section 15. PERMEABILITY AND RELUCTANCE

Because its molecules respond readily to any applied magnetizing force, the magnetic flux in iron will be comparatively strong. Since this action varies with different materials, the ratio of the magnetic flux density to the value of the magnetizing force is known as the "permeability" of a substance. In general, it is possible to think of permeability as being the *ease* with which magnetic flux may be developed within a material.

Reluctance is just the opposite of permeability. Reluctance is the opposition which a material offers to the passage of magnetic flux. Reluctance in a magnetic circuit can be compared to resistance in an electrical circuit.

Section 16. MAGNETOMOTIVE FORCE AND AMPERE-TURNS

The force which creates magnetism in a magnetic circuit is referred to as the *magnetomotive* force. In an electromagnet the magnetomotive force is created by passing electrical current through a coil of wire as has been previously discussed. The amount of magnetomotive force, and thus the amount of magnetism in a magnetic circuit, will depend upon two things. The number of turns in the coil and the amount of the current flowing through the coil. Thus, the magnetomotive force is dependent upon the *Ampere-turns* of a coil. The number of ampere-turns is arrived at by multiplying the number of turns of wire in the coil by the number of amperes of current through the coil.

NOTES FOR REFERENCE

Unlike magnetic poles attract; like poles repel.

The Earth's magnetic north pole is near its geographical south pole, and its magnetic south pole is near its geographical north pole.

Soft iron is easily magnetized and easily demagnetized; harder grades of steel are more difficult to magnetize, but retain their magnetism longer.

There is no such thing as an insulator for magnetism.

Parallel conductors in which the current flows in the same direction tend to pull together. When the currents flow in opposite directions the conductors tend to be pushed apart.

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ELECTROMAGNETIC INDUCTION

Contents: Introduction - Factors Affecting the Induced Voltage - How Lines of Force Move - Induced Voltage from Moving Lines - Causing the Lines to Expand and Contract - Varying the Primary Current - Mutual Induction - Direction of Current Flow in the Primary and Secondary - Self-Induction - Measuring the Effect of Self-Induction - Eddy Currents - Notes for Reference.

Section 1. INTRODUCTION

As you have progressed with your studies you have become aware of the fact that there is a definite link between electricity and magnetism. In this lesson we will take up in detail the study of that link.

Induction is the essential link between electrical energy and nearly all the other forms of energy which produce electrical power. All electrical energy which is economical enough to be useful must come, originally, from some natural source. The natural energy of coal, oil, waterfalls,

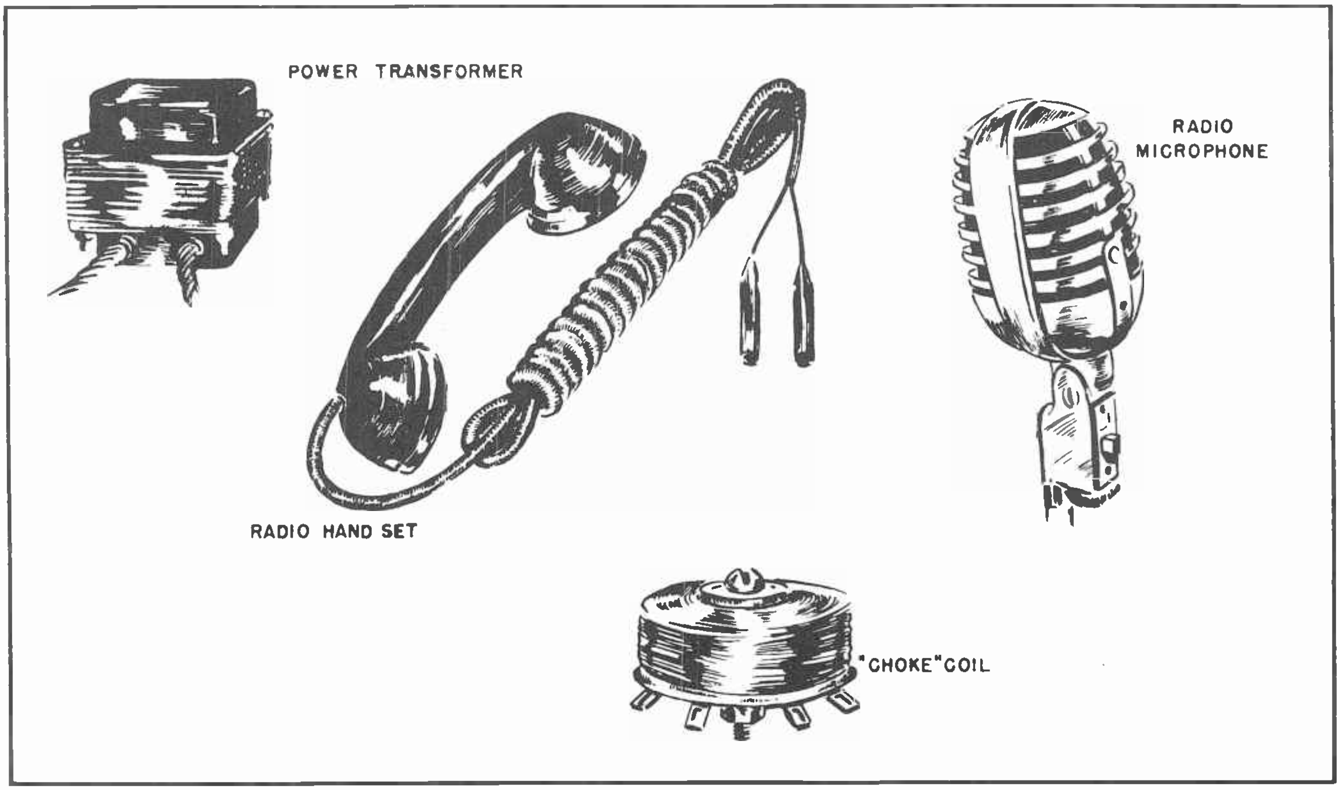

Fig. 1. Typical electrical apparatus which are dependent upon electro-magnetic induction for their operation.

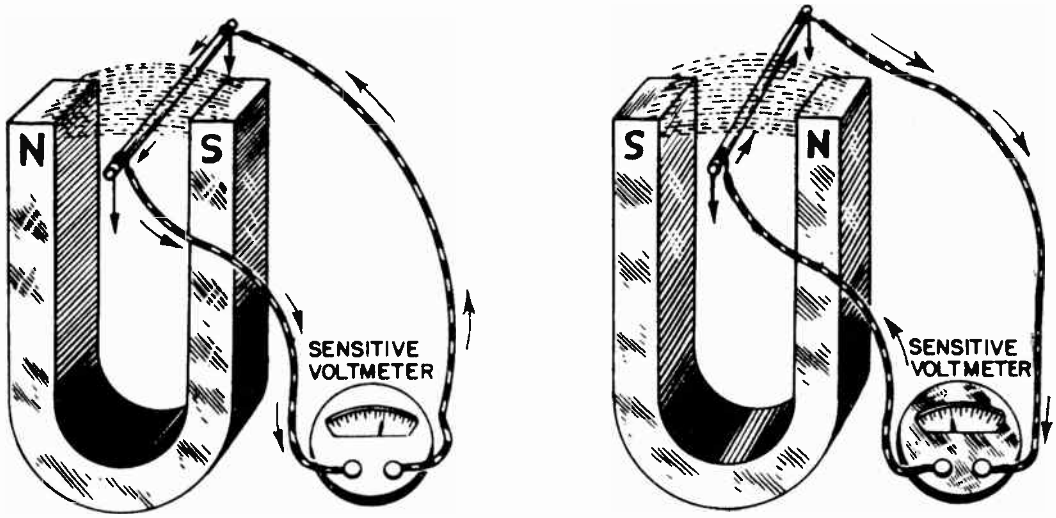

Fig.2. How Voltages are Induced.

windmills and the like must be transformed into electrical energy before it can be used to operate electrical devices. This transformation of energy is brought about through the phenomenon of induction -- electromagnetic induction.

We have previously discussed how Hans Christian Oersted, the Danish teacher discovered by accident that a moving electrical current produced magnetism. It was Michael Faraday, the English scientist, while continuing Oersted's experiments, who proved that the reverse was also true. He showed that magnetism is capable of causing an electrical current to flow. He was the first to show that whenever a conductor is moved through a magnetic field so as to cut across the lines of force, a voltage will be created, or *induced* in the conductor.

Fig. 2 shows how a voltage will be created in a conductor when it is moved across the lines of force which exist between the poles of a magnet. The direction in which the current will flow through the conductor will depend upon which direction the conductor is moved, and the position of the poles of the magnet. Note that the poles of the magnet at the left are in one position while the poles of the magnet at the right are in the opposite position. When the conductor is moved downward in such a way as to cut across the lines of force, a current will move in one direction. But at the right where the poles are in another position, the current will move in an opposite direction.

The meter used to record the presence of the current is one which has its zero point in the center of the scale. If the current flows through the meter in one direction, the meter needle will be deflected in one direction. But if the current flows through the meter in the opposite direction, the meter needle will be deflected in the other direction.

Such a meter is commonly called a *galvanometer*. (See Fig. 3.) It registers not only the amount of current which flows, but also the direction in which it is flowing. Most generally this type of meter is so designed that it will measure the current, but it can be so designed that it will measure the voltage instead. The meter used in Fig. 2 is a voltage type galvanometer.

The mere fact that a conductor is present in a magnetic field is not enough to induce a voltage in the conductor. Before a voltage will be induced in the conductor, the conductor must be moving so it will cut across the lines of force. The same effect, however, can be produced by allowing the conductor to remain stationary and then moving the magnet so the lines of force will cut across the conductor. Perhaps the best way to say this would be to emphasize the fact that there must be *relative movement* between the conductor and the magnetic lines of force.

If the conductor in Fig. 2 is moved rapidly up and down through the magnetic field between the poles of the magnet, the needle of the meter will swing rapidly from side to side. The movement of the needle will coincide with the up and down movement of the conductor. Every time the conductor moves downward, the needle will swing in one direction and every time the conductor moves upward, the needle will swing in the other direction.

If the conductor were held stationary and the magnet moved up and down so its lines of force could cut across the conductor, the effect on the needle of the meter will be the same.

Section 2. FACTORS AFFECTING THE INDUCED VOLTAGE

If the conductor is moved through the field of the magnet quite slowly, the needle of the galvanometer will not swing nearly so far as it does when the conductor is moved rapidly. This means the induced voltage is much smaller when the movement is slow than when the movement is fast. The voltage depends directly on the speed at which the conductor moves through the magnetic field.

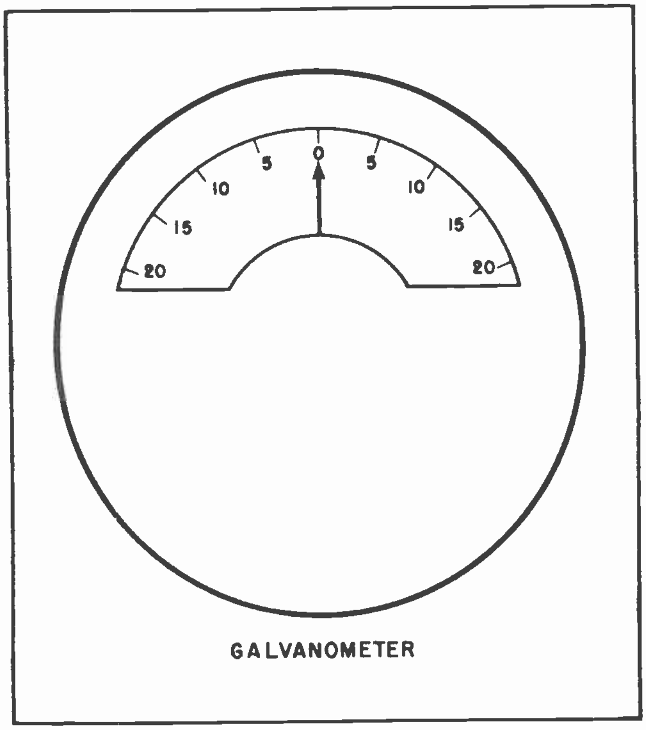

Fig.3. A Galvanometer.

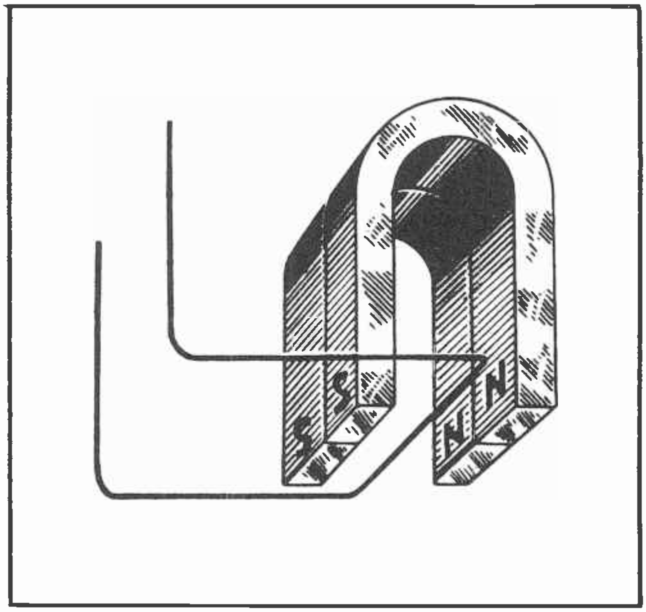

Fig.4. Lengthening the magnetic field by placing two magnets side by side.

In Fig. 4 two similar magnets have been placed side by side. The illustration shows how the conductor could then be moved through the magnetic field. It will be noted that a longer portion of the conductor will now move through the magnetic field This will have the effect of doubling the voltage induced in the conductor. The length of the conductor which cuts across the lines of force directly affects the value of the voltage which will be induced in the conductor.

Instead of using two magnets so that a longer portion of the wire can move through a magnetic field, the same effect can be obtained by arranging the wire so that more of it will cut across the same lines of force. Such an arrangement is shown in Fig. 5. Instead of the conductor cutting across the lines of force once, the conductor has been so looped that it will cut across the same lines of force twice. Note that the loop of wire has been so arranged that the voltage induced in one wire will be in the same direction as the voltage induced in the other wire. Because of this arrangement, the voltage induced in one part of the wire adds to the voltage induced in the other part. Since, in this case, the voltages will be equal in each of those

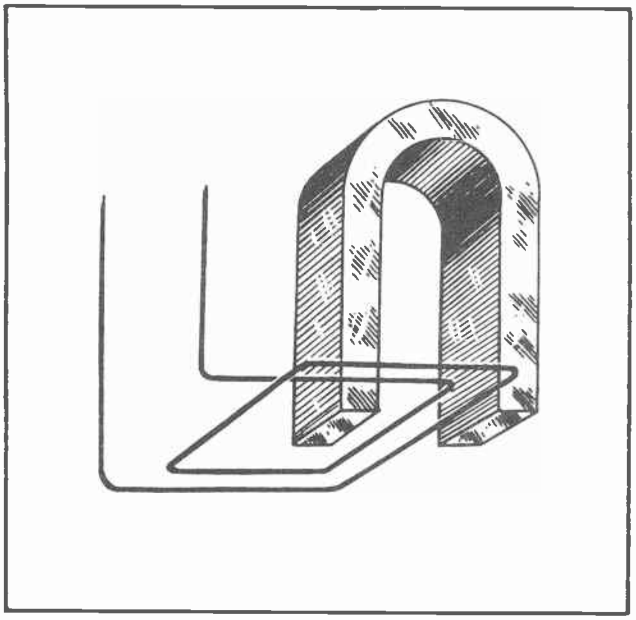

Fig.5. Increasing the length of the conductor cutting the magnetic lines of force by passing two loops of the conductor through the field instead of one loop.

portions of the conductor which cuts the lines of force, the total voltage in the entire conductor will be twice as great as it would be if it was passed through the magnetic field as a single loop.

Had the conductor been passed through the magnetic field twice in an arrangement similar to that shown in Fig. 6, the total voltage induced in the conductor would have been zero. The reason is that the voltage in one part of the conductor as it cuts across the lines of force would buck, and cancel out the voltage which was induced in the other part of the conductor which was also passing through the magnetic lines of force.

From our discussion of induction, so far as we have gone, it becomes evident that the amount of voltage which is induced in any conductor by a magnetic field is going to depend upon several things. One important factor is the speed with which the conductor cuts the lines of force. Another factor is the length of the conductor which cuts the lines of force. This is virtually equivalent to saying the number of turns, or loops, in the conductor where it cuts across the lines of force. Another important factor is the strength of the magnetic field The more lines of force the conductor cuts, the higher will be the voltage.

So far we have assumed that the conductors will cut straight across the lines of force. That is, that the conductor will move at right angles to the lines of force. Such, of course, would always be the ideal situation, but it is not the one we always find in actual practice.

At *A* in Fig. 7, we find the conductor cutting across the magnetic lines of force at right angles. When this situation occurs the voltage induced in the conductor will be the maximum possible value. But sometimes the conductor must cut across the lines of force diagonally as at *B* in Fig. 7. When this occurs, the conductor will cut fewer lines of force for any given distance of movement. As a result, the smaller voltage will be induced.

Should the conductor move in the same plane with the lines of force; that is, should the conductor move parallel with them as shown at *C* in Fig. 7, no voltage at all will be induced. The reason is that no lines of force will be cut by the moving conductor. The conductor must cut across lines of force in order to induce a voltage. No matter how fast the motion, and no matter how strong the field, so long as the conductor is moved parallel with the lines of force, no voltage will be induced.

It may occur to you to wonder whether in the act of producing an electromotive force

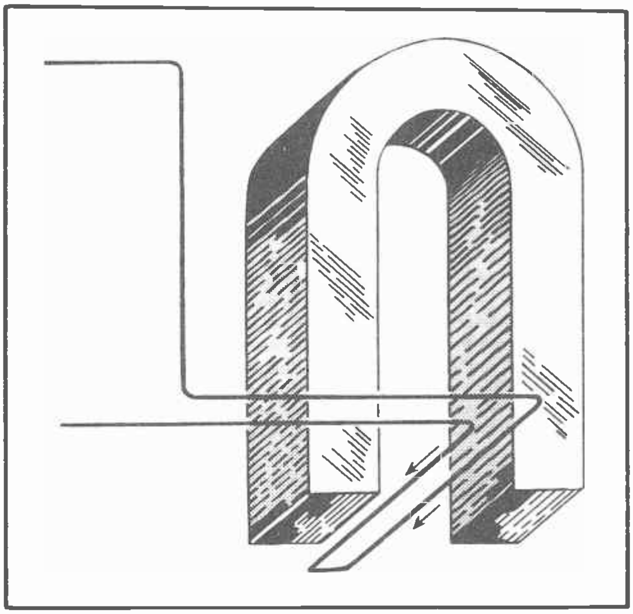

Fig.6. No voltage is induced when two sections of the same conductor is passed through the field in this manner.

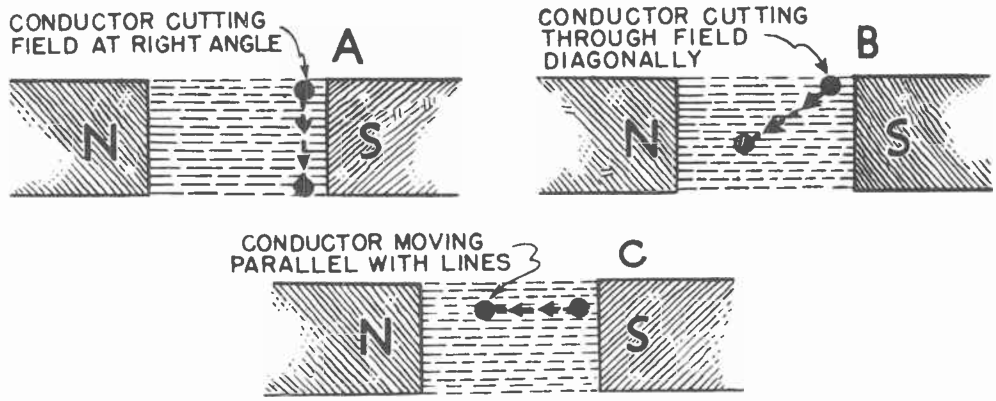

Fig. 7. Relations between field direction and conductor travel.

in a moving conductor, there will be any weakening of the magnetic field. You may also wonder, if there is not, just what is the source of the energy which produces the voltage and current in the conductor.

There is no weakening of the field. The source of the energy is the muscular, or other mechanical energy which moves the conductor through the field.

Section 3. HOW LINES OF FORCE MOVE

We have learned that a voltage is induced in a conductor when either of two things happen. First, when a conductor is moved through a magnetic field so as to cut the lines of force in the field. Second, when the magnet itself is moved so that its lines of force will cut across the conductor. This means that we can induce a voltage in a conductor by moving the conductor, by moving the magnet, or by moving both.

Some generators of electrical power are built so that the conductors move through a magnetic field. Most of the larger, and higher voltage generators are so constructed that the magnets move. There is a mechanical advantage in keeping the conductors of the larger machines stationary and causing the magnets to move so the lines of force will cut the conductors.

There are other kinds of electrical equipment which are so constructed that both the magnet and the conductors are stationary but the lines of force alone are caused to move. An example of this are the ignition coils in automobiles where the six volts from the battery are "stepped up" to possibly the 8000 to 12,000 volts which are needed to overcome the resistance of the air in the gap in the spark plug. The various kinds of transformers constitute another example. There are many kinds of apparatus in telephone, radio and television work which have no moving parts, but in which voltages are induced by the action of moving lines of force.

To provide the necessary moving lines of force in such apparatus, an electromagnet is used instead of a permanent magnet. You will recall from an earlier lesson that when current first begins to flow through the coils of an electromagnet, lines of force will start building up around the magnet. Then as more current flows through the coils of the magnet, the lines expand still farther around the magnet. Although the lines will remain stationary so long as the strength of the current remains the same, every change in the value of the current will cause the lines of force to expand or contract. (See Fig. 8.)

When the lines of force expand or contract they are actually moving in space. If another conductor is so placed that it will be cut by the expanding or contracting lines of force, a voltage will be induced within

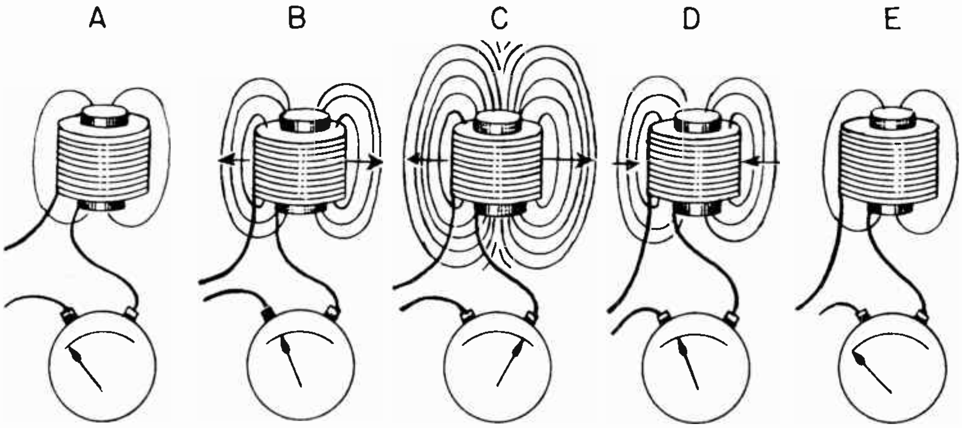

Fig.8. A moving field from a stationary magnet.

the conductor just as though the conductor was moved through them.

Fig. 8 shows how the lines of force build up around an electromagnet as a current first begins to flow through the coils of the magnet, then as the current continues to increase, next as the current reaches maximum and finally as the current decreases. At *A*, as shown by the meter, the current through the coils of the electromagnet is relatively small. At that instant there are few lines of force around the magnet, and they do not extend very far. At *B* more current is flowing through the coils and there are more lines of force around the magnet. The arrows extending from the coils show the direction in which the lines of force are expanding. At *C* the current has reached its maximum value. The lines of force have expanded until they have reached their greatest extent. The arrows here show how the lines have moved to reach this position. At *D* the current has decreased somewhat. The current is smaller so the lines of force have contracted toward the coils of the magnet. The movement of the lines of force is indicated by the small arrows which show them moving toward the coils of the magnet. At *E* the current has decreased almost to zero. At this instant there are very few lines of force and they do not reach very far beyond the magnet itself.

If a conductor was so placed that it would be cut by these lines of force as they expanded and contracted around the electromagnet, a voltage would be induced within that conductor.

Section 4. INDUCED VOLTAGE FROM MOVING LINES

We will now see just how we can arrange things so as to take practical advantage of this situation. The first thing we will do is place a second coil around the original coils of the electromagnet. This second coil will not be connected electrically in any way with the conductor in the first coil. They will be electrically insulated from each other. Next we will insert a meter in the circuit to each coil. This arrangement is shown in the upper illustration of Fig. 9.

When current begins to flow through the first, or original coil of the electromagnet, magnetic lines of force will build up around the magnet in the manner previously explained. As the lines of force build up, they cut across the turns of the conductor of the second coil. As they cut across the conductor, a voltage will be induced within it. This voltage will cause a current to flow in the second coil as is indicated by the movement of the meter needle to the right.

If the current in the first coil was allowed to build up to a maximum value, then remain steady, the lines of force would become static as soon as the current ceased increasing. If the lines of force stopped moving they would no longer be cutting across the conductor of the second coil, with the result that a voltage would no longer be induced in the second coil. This condition could be brought about by connecting the first coil to a battery. The instant the switch was closed, current would begin to flow in the first coil, causing lines of force to expand around the magnet, and inducing a voltage in the second coil. But the voltage in the second coil would be only a momentary one. As soon as the current in the first coil reached a maximum, the voltage in the second coil would be decreased to zero. In other words, if we connected the first coil to a battery and closed the switch, there would be a momentary deflection of the needle in the secondary circuit, indicating a momentary voltage, then the needle would return to zero.

The needle of the meter in the secondary circuit would remain at zero so long as the current in the first coil remained steady. But suppose we open the switch to the battery and stop the current from flowing in the first coil. When this happens, the lines of force around the electromagnet will collapse back into the coil. This means the lines of force will again be moving. And in moving, they again cut across the conductors of the second coil. But note this: Where the lines of force moved *outward* before, they moved *inward* now. In other words, they will move across the conductors of the second coil in the opposite direction to that in which they moved before.

From what we have previously learned about moving a conductor across the lines of force of a magnetic field, it might be suspected that the voltage in the second coil will now be in a direction opposite to what it was when the field was first built up. This is exactly what will happen. Whereas the meter needle was deflected to the right when the switch to the battery was closed, it will now be deflected to the left when the switch is opened. Such a condition is indicated by the illustration at the bottom of Fig. 9.

It is not necessary for the second coil to be wound immediately around the first coil as is shown in Fig. 9, and described in the preceding paragraphs. It will be remembered that when an iron core is inserted within the turns of a coil, the entire iron core becomes magnetized. Therefore, if the second coil is placed around this iron coil at any point, a voltage will be induced within it by the lines of force which expand and contract at all points around the iron core as the current in the first coil is varied. Fig. 10 illustrates two ways in which the first coil and the second coil can be coupled together *magnetically* without actually touching each other.

Section 5. CAUSING THE LINES TO EXPAND AND CONTRACT

Anything which causes a change of current in the first, or primary coil will induce a voltage in the second, or secondary coil. Thus it is easy to see that any change in

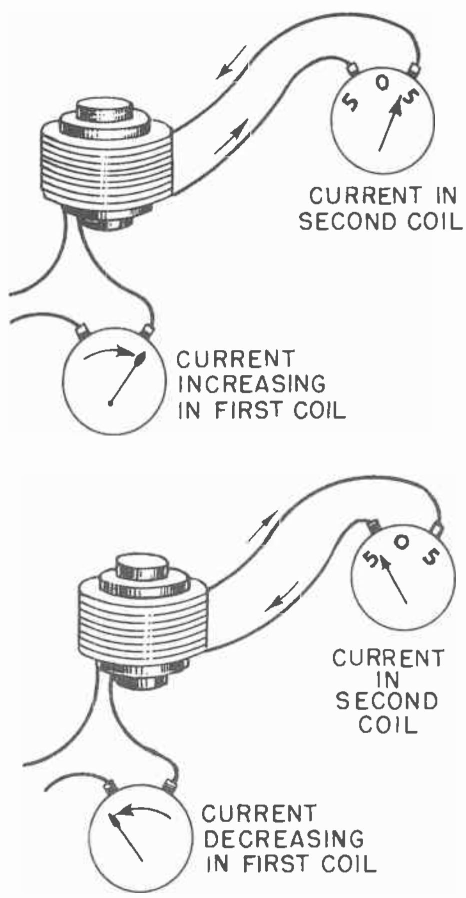

Fig.9. How induced current changes its direction.

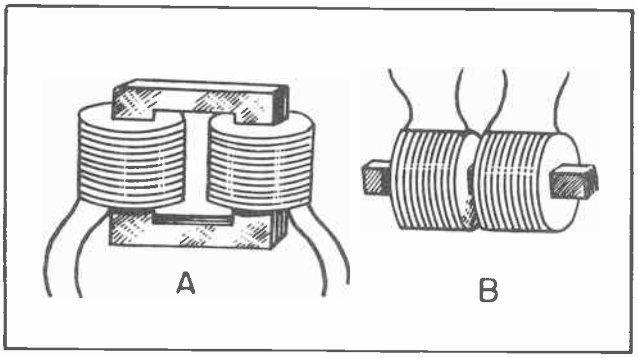

Fig.10. Two coils on the same iron core.

the current of the primary circuit will be instantly reflected by a change in the voltage of the secondary circuit.

We have just discussed how a voltage could be induced in the secondary circuit by making and breaking the current in the primary circuit. One of the best examples of a practical application of this principle is the ignition system in an automobile. Such a system is illustrated diagrammatically in Fig. 11.

In Fig. 11 the primary winding of the ignition coil is part of a series circuit which includes a battery for the source of current, an interrupter having a pair of contacts which act as a switch to open and close the primary circuit, and the primary coil itself. The secondary circuit consists of the secondary winding on the iron core of the ignition coil and a spark plug having an air gap across which the current is forced, and which provides a hot spark.

While the contacts are closed, battery current flows through the winding of the primary coil and creates a magnetic field around the core of the coil. When the cam rotates and separates the contacts, the current ceases to flow. When this happens the magnetic field collapses, and as the lines of force cut across the conductors of the secondary coil, a high voltage is induced in it. This voltage is great enough to force the current to jump across the gap in the spark plug.

If you have been following the lesson quite closely you will probably be inclined to ask at this point whether or not there are *two* sparks created -- one when the contacts are closed and the other when the contacts are opened. After all, you might say, there will be a voltage induced when the current builds up and again when it stops.

Since it is not desirable to have two sparks each time a contact is made and broken in the ignition system of an automobile, steps have been taken to prevent the creation of a spark at the instant the con-

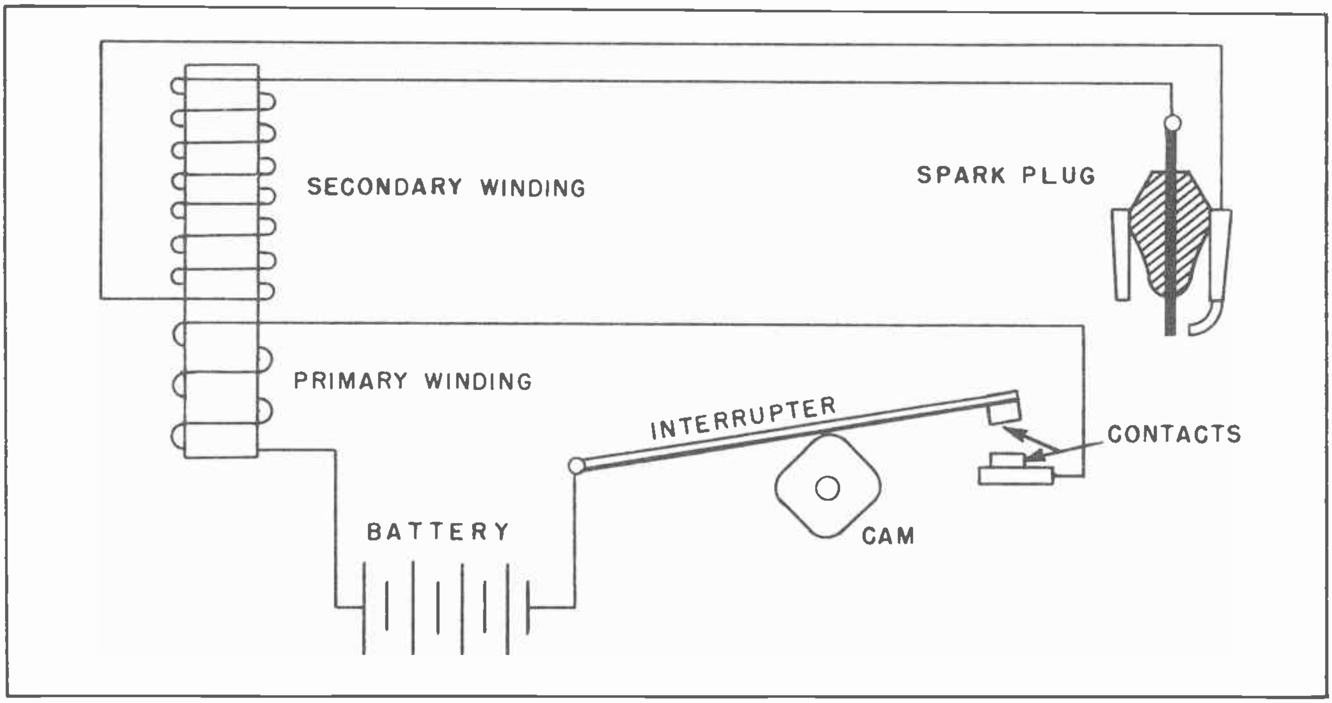

Fig.11. Automobile Ignition Principles.

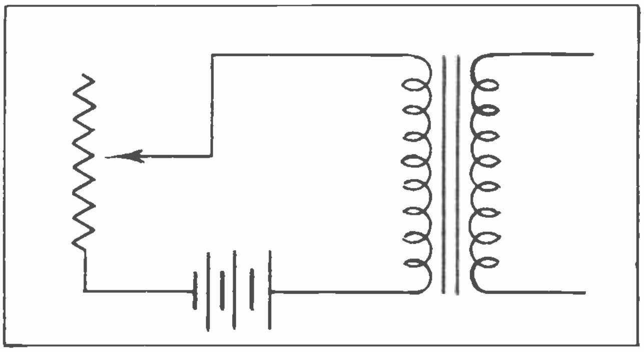

Fig.12. One method of varying the current in the primary.

tact is made and the current starts flowing in the primary of the ignition coil. First, and this is something worth remembering, the magnetic field cannot build up from zero to maximum as quickly as it can drop from maximum to zero. Since the value of the voltage depends upon the speed with which the conductors are cut by the lines of force, and the lines of force do not cut across so quickly when the current is building up as when it is decreasing, the voltage at the instant of making the contact is not so great as that at the instant of breaking the contact. To further increase this difference between the speed with which the current builds up and that with which it dies out, automotive engineers have added another element to the ignition system called a "condenser", or capacitor. We have not as yet, studied capacitors, but in this case it has the ability to greatly slow down the time it takes the current to build up in the primary of the ignition coil and the further ability to make the current stop flowing almost instantly when the contact is broken. For these reasons there is only one spark when the contact "points" open and close; it occurs when the contacts are opened.

Section 6. VARYING THE PRIMARY CURRENT

Instead of completely stopping the primary current, then starting it again, to obtain voltage and current in the secondary circuit, we may merely increase the current and then decrease it. We must keep in mind that any *change* of primary current causes a secondary voltage, and of course we have *changes* when the primary current rises and falls.

The primary current might be varied as in Fig. 12, with a rheostat or variable resistor in series with a battery and the winding of the primary coil. Moving the rheostat in one direction would cause the primary current to increase, while moving the rheostat in the other direction would cause the primary current to decrease. While the current in the primary coil was either increasing or decreasing, the magnetic lines of force around the coil would be either expanding or contracting. And as the lines of force move outward or inward, they would cut the conductors of the secondary coil. This would induce a voltage in the secondary.

It probably would not serve any practical purpose to set up a circuit such as the one we have just described. But the principle which we have been describing is used constantly in radio and television work. A very practical application with which most everyone is familiar is the telephone transmitter which changes the sound waves of our voices into electrical impulses. Fig. 13 shows the basic elements of such a transmitter. The carbon particles act as a variable resistance. As the sound waves strike the diaphragm, the carbon particles are alternately compressed and relaxed. When the particles are compressed, they have less resistance than when they are more loose. The varying resistance causes a varying current to flow in the primary circuit, which includes a coil. The moving lines of force set up about the primary coil induces a voltage in the secondary coil.

Section 7. MUTUAL INDUCTION

We have looked at a number of combinations of two conductors, or of two conductors and

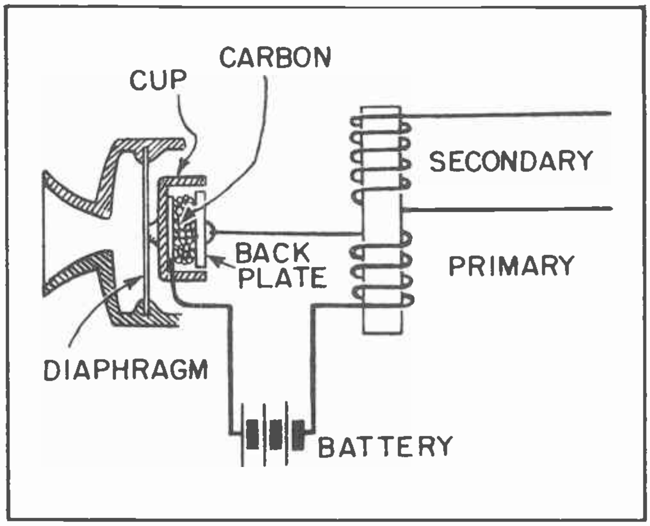

Fig.13. Basic principles of a telephone transmitter.

a common magnetic core, where a change of current in the primary circuit causes a voltage in the other circuit. It should be remembered that if the secondary circuit is closed -- that is, is a complete circuit -- a current will flow in it as a result of the induced voltage. The current which flows in the secondary circuit also sets up magnetic lines of force of its own. These lines of force react back upon the primary coil. This mutual action of two circuits upon each other is called *mutual induction.* The word "mutual" means some effect which is exerted by each of the two parts on the other part. With mutual induction we have two conductors or circuits, either of which will induce a voltage in the other one when there is a change of current in the first one.

It is not our intention to go very deeply into the technicalities of mutual induction at this time. Mutual induction will come to our attention many times during our study of radio and television It is well that you become familiar with the term at this time.

Section 8. DIRECTION OF CURRENT FLOW IN THE PRIMARY AND SECONDARY

While the current in a primary coil is increasing in value, the voltage which is induced in the secondary will be opposite to the direction of primary current. This means that the current in the secondary will flow in the opposite direction from that of the primary current. This is shown diagrammatically in Fig. 14.

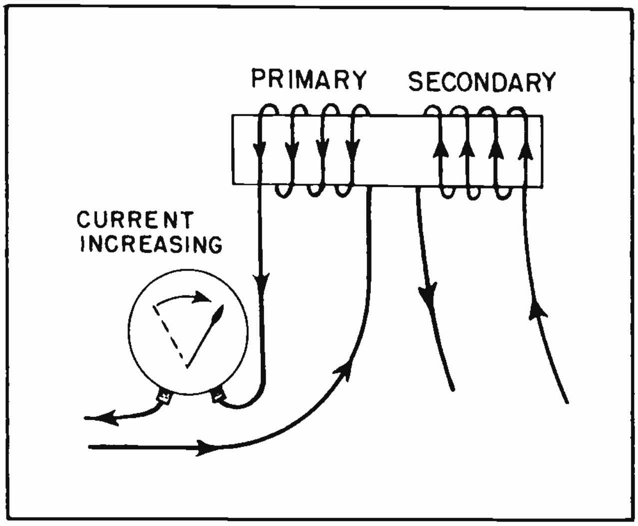

Fig.14. Current direction in the two coils when current is increasing in the primary.

If the primary current is reversed, then the secondary current will also be reversed.

Section 9. SELF-INDUCTION

Self-induction is defined as "that property of an electrical circuit which tends to prevent any change in the flow of the current". When a switch is closed and current starts to flow in the circuit, any induction in that circuit will try to prevent the current from flowing. Later, after the current has attained its maximum value, any attempt to stop the flow of the current will be opposed by the action of any inductance in the circuit.

Induction has also been compared with mechanical inertia. It has often been called the "fly-wheel" effect in an electrical circuit. Just as a fly-wheel is hard to start moving, but when once moving is hard to stop, so it is with the current in a circuit which contains induction.

Now let us see just why this is so. Look at the two coils wound on the iron core in the left-hand illustration of Fig. 15. One of these coils can be called the primary and the other the secondary. If we start a current to flowing in the primary, there will be lines of force moving out from the coils while the current is increasing. These lines of force will cut through the coils of the secondary, inducing a voltage in the secondary circuit. As was mentioned previously, the voltage induced in the secondary will act to cause the current to flow in the opposite direction from that of the current in the primary.

Again, as the current in the primary decreases, the lines of force will collapse back into the primary coil. The collapsing lines of force will again cut the coils of the secondary, but this time will be in the opposite direction from what it was before. The voltage induced in the secondary will be, as a result, in the opposite direction. Thus the voltage induced in the secondary will be in one direction when the current is increasing in the primary, but will be in the opposite direction when the primary current is decreasing. Further than this, the *voltage* induced in the secondary while primary current is increasing, will cause the *secondary current* to flow in the opposite direction to the *primary current.* We may then state that the voltage induced in the secondary coil is in the opposite direction from that in the primary coil.

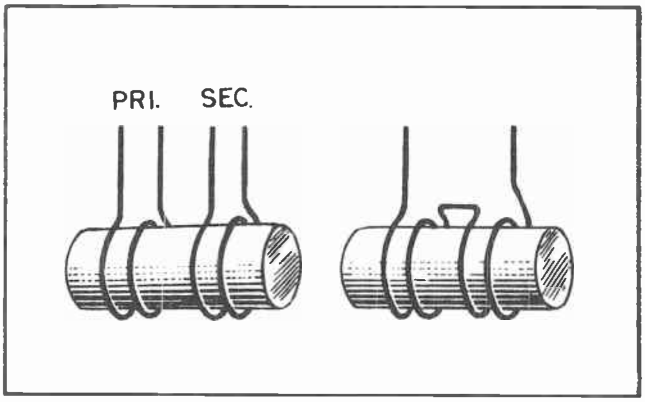

Fig.15. The primary and the secondary coils combined.

Now look at the right-hand illustration of Fig. 15. Here we have connected the two coils together. They now form one continuous winding. It is neither primary nor secondary. It is both together. Once more we shall increase the current in the coils. This increasing current causes lines of force to expand just as before and to pass through the various turns of the coils also, just as before. We have the same movement of lines of force which with two separate coils caused a voltage to appear in the turns through which the lines moved. And just as before, there is going to be a voltage induced in the coils of the conductor. Instead of actually causing a current to flow, this voltage is going to oppose the original voltage which causes the primary current to move.

When current *increases* in a conductor magnetic lines move outward. When the current *decreases* the lines move inward. Thus, as the current builds up in a conductor a second voltage will be induced in the same conductor to oppose the current which produces it. (See Fig. 16, left.) If the current *decreases* the moving lines of force will *reverse* just as though the current was reversed. This peculiar action is called *self-induction.* It does not contradict the statement secondary current is opposite the primary current because now there is only one coil.

Fig. 17 shows how the voltage acts in the secondary of a separate coil as the current increases and decreases. If the two coils were linked together as in Fig. 15, it can be seen how the action of inductance would tend to retard the flow of current during the time the current was building up, and would tend to keep it flowing after it had reached maximum, thus retarding any tendency of the current to decrease in value.

Examination of Fig. 16 shows that while current is increasing, the induced voltage opposes the current, or opposes the increase of current in the conductor, or coil. While the current is decreasing, the induced voltage acts in the same direction as current flow and helps to keep the current going. While we are increasing the current, self-induction works against us and makes it more difficult to obtain a given increase. Then, when we want the current to drop off, or to stop altogether, the voltage of self-induction again works against us by trying to keep the current going.

One of the first places where you will find this action put to practical use in radio circuits is in the filter circuits of rectifiers. Rectifiers are quite commonly used in the power supplies for radio and television equipment. It is usually desirable to maintain the voltage of the power supplies as nearly constant as possible. Any unevenness, or ripples, should be ironed out, so that the voltage will remain at a constant level at all times. The effect of inductance is brought into play here and serves as a balance wheel, or flywheel, to keep the voltage stable. If the voltage and current tries to decrease, the inductance tends to raise it to the normal value. If the voltage and current tries to go higher, the inductance steps in to hold it

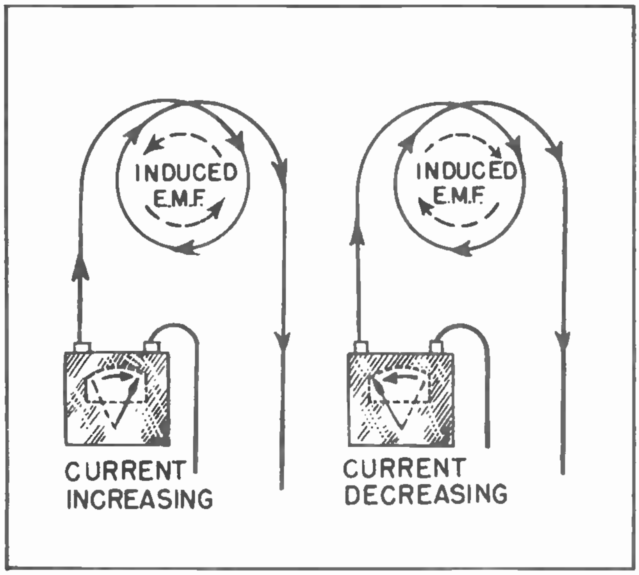

Fig.16. The direction of the voltages of self-induction when the current is increasing and when it is decreasing.

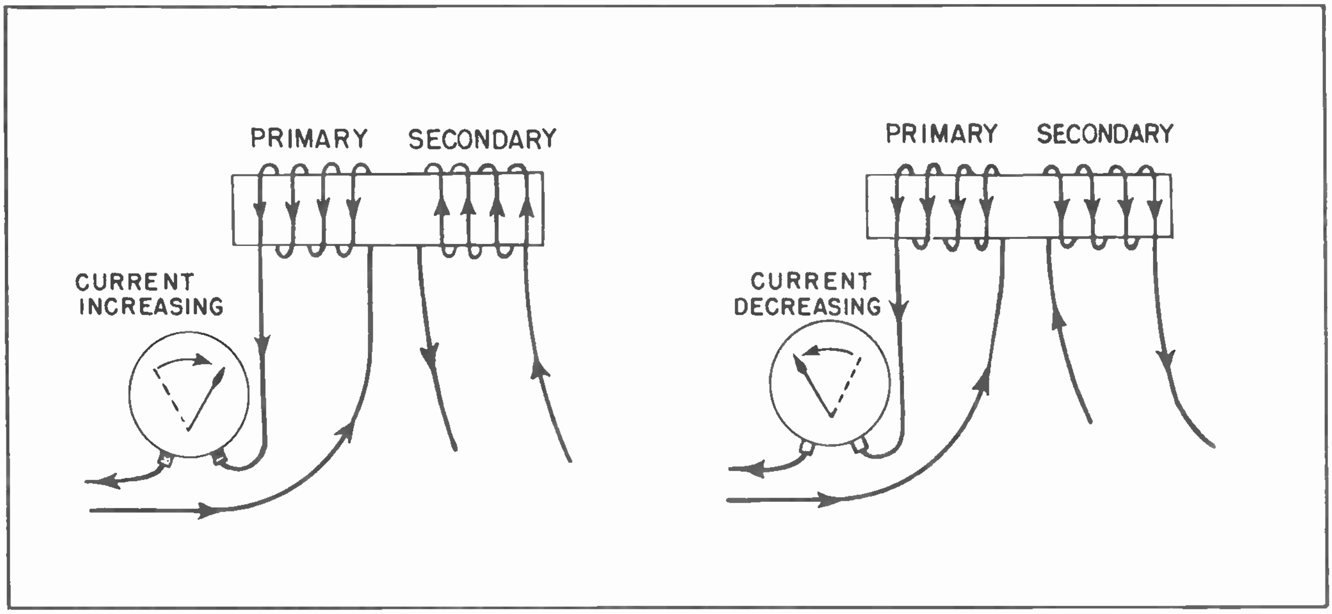

Fig.17. Secondary voltage opposes any change in the primary current.

down to its proper value. But that is by no means the only place induction is put to work in radio and television work. In conjunction with capacitance, which we will be studying shortly, induction is one of the most important things we will encounter in our work.

Section 10. MEASURING THE EFFECT OF SELF-INDUCTION

From what we know about magnetic circuits and about electromagnets, it is apparent that the ability of a circuit to oppose any increase of its own current and to oppose any decrease of its current will depend upon several factors. The voltage of self-induction, which acts first in one direction and then in the other as the current rises and falls, will depend upon the number of lines of force which cut through the turns of the conductor. This flux will depend on the permeability of the magnetic circuit, because the greater the permeability, the more lines of force we will have for any given current in the winding. The number of lines of force will depend also upon the number of turns in the coil, for the greater the number of turns, the greater the number of cuttings.

The ability of a coil or a circuit to oppose increase and decrease of its own current is called the *self-inductance* of the coil or circuit. Self-inductance is measured in a unit called the henry, named for the great American scientist who invented the electromagnet, Joseph Henry. While teaching mathematics at Albany Academy, Joseph Henry made many improvements in electromagnetic apparatus, invented the electromagnet, and prepared many learned scientific papers on the subject of electromagnetism. In 1832 he became a professor of Natural Philosophy at Princeton University, and fourteen years later, in 1846, he became Secretary and Director of the Smithsonian Institute in Washington D.C. It was while teaching

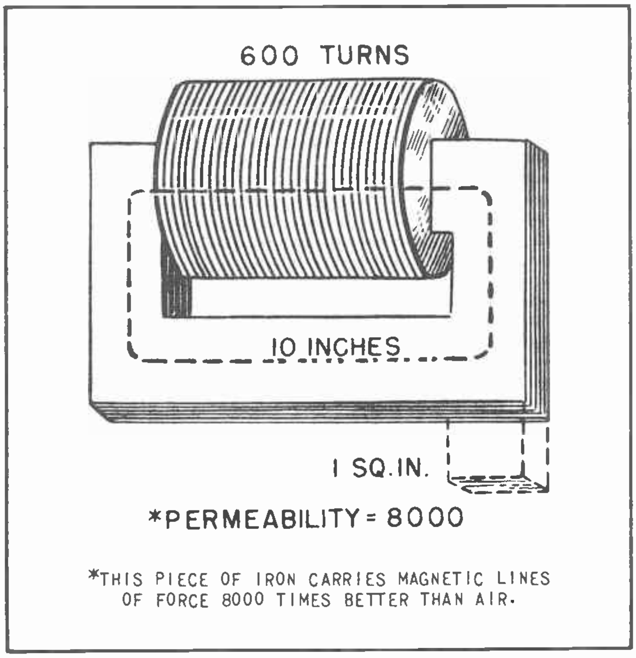

Fig.18. A circuit having self-inductance.

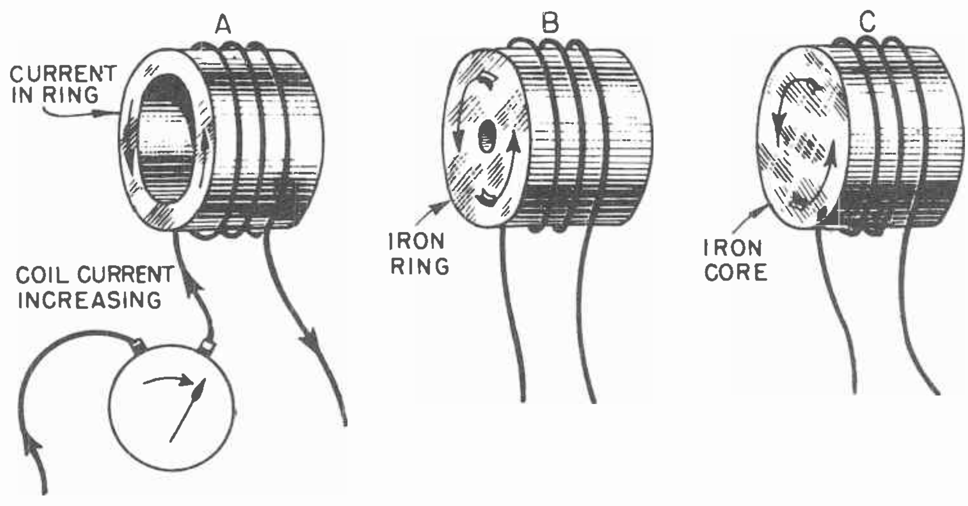

Fig. 19. Production of Eddy Currents.

at Albany Academy that he invented the electromagnet.

If we wish to know the inductance of a coil and core, we multiply together the square of the number of turns, the permeability, and the inches of cross-section of the magnetic circuit. Then we divide all that by 100,000,000 times the length of the magnetic circuit in inches. Written as a formula:

$$\text{Self-inductance in henries} = \frac{(\text{Number of turns})^2 \times \text{Permeability} \times \text{Sq. Inch Cross-section}}{100{,}000{,}000 \times \text{Circuit length in inches}}$$

Fig. 18 illustrates an inductance coil, called a "choke" coil. It has 600 turns wound on an iron core. The iron core has a cross-section of 1 sq. in. and is 10 inches long. Suppose we put that information in the formula and determine the self-inductance of the coil in henries. We would set the problem up in this manner:

$$\text{Self-inductance in henries} = \frac{600^2 \times 8000 \times 1}{100{,}000{,}000 \times 10} = \frac{2{,}880{,}000{,}000}{1{,}000{,}000{,}000} = 2.88 \text{ henries}$$

Section 11. EDDY CURRENTS

In speaking of induction we have always spoken of the coil, *or* the conductor which was being cut by the lines of force. This was done intentionally. While it is usually the wire in the form of a coil with which we are most concerned, it should not be forgotten that *any* conductor which comes under the influence of magnetic lines of force will have a voltage induced in it.

At *A* in Fig. 19 is pictured an iron ring, or a short open cylinder, around which are turns of wire forming a coil. If current in the coil is flowing in the direction indicated, and is increasing, there will be a voltage induced in the ring, and a current will flow in it in the direction indicated by the arrows.

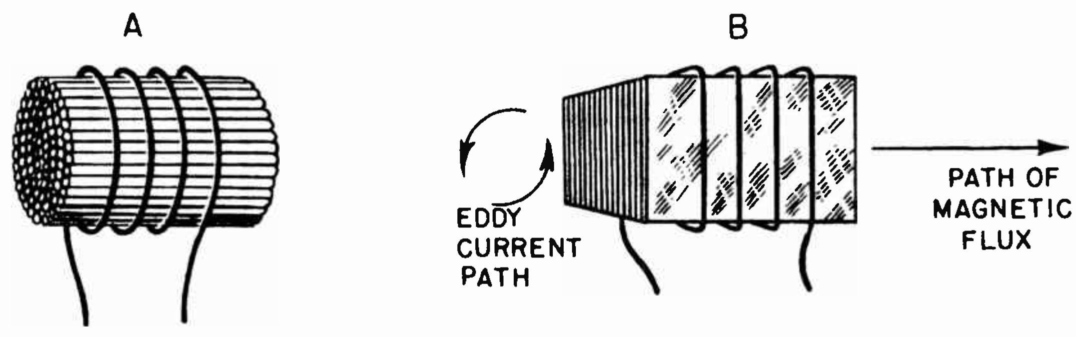

Fig.20 Using laminated cores to reduce eddy currents.

When current decreases in the coil circuit, there will be a voltage induced in the opposite direction in the iron ring. The ring forms a closed secondary circuit, and since iron is a fairly good conductor, and the cross-section is large, the induced current will be large.

At *B* in Fig. 19 we have reduced the opening through the center of the iron ring. Since we have still further increased the cross-section of the ring and thereby lessened the resistance, the current flowing in the ring will be even larger than before. At *C* we have eliminated the hole altogether and find the iron to be the same as that commonly found as a core for so many of our electromagnets. Any change in the current in the coil of wire surrounding the iron core will thus induce a voltage within the iron of the core, with the result that a current will flow through the iron. Any current thus produced within the iron of a magnetic core of iron is called an *eddy current*.

As a general rule, eddy currents are undesirable. They tend to use electrical power, which is thus wasted, and the core of iron will become heated as the result of the heavy currents flowing through it. If the current rises and falls quite fast, as in the case of alternating current which is constantly changing, the iron can become unbearably hot. This has a disastrous effect on many kinds of electrical insulation, not to mention the other things which might be damaged by the heat.

To prevent this situation becoming unreasonably bad, it is the standard practice to break the iron core up so as to present a good path for the magnetic flux, but a poor path for the electrical eddy currents. Usually the iron core is built up of many thin sheets of iron, called laminations, similar to that shown at the right of Fig. 20. Sometimes, however, iron wire is bound together to create the magnetic core, as shown at the left of Fig. 20.

The eddy current can still form in the smaller laminated sheets, but due to the oxides and varnish which separates the sheets the voltage cannot build up to any sizeable value. The result is that the eddy currents are kept to negligible values. Nearly all power transformers, output transformers, choke coils, and other kinds of electrical apparatus which use iron cores have the core built up from the thin laminations.

NOTE FOR REFERENCE

Induced voltage is increased by *(a)* more rapid relative movement of conductor and field, *(b)* greater flux density, *(c)* cutting more nearly at right angles, and *(d)* greater length of conductor or more turns cutting the field.

Mutual induction is the production of an electromotive force in one circuit, and current if the circuit is closed, when lines of force due to change of current in another circuit cuts through the conductors of the first circuit.

Self-inductance is a measure of the ability of a circuit to oppose either increase or decrease of its own current, this opposition being due to the voltage of self-induction, which may be called *counter electromotive force*.

The unit of self-inductance is the *henry*.

Both self-inductance and induced voltage increase *(a)* with more turns, *(b)* with greater permeability, *(c)* with greater cross-section of iron, *(d)* greater change of current, *(e)* quicker change of current, *(f)* shorter magnetic path.

Eddy currents are produced within the mass of the iron which is cut by changing the magnetic field.

Eddy currents can be reduced by the use of laminated sheets to build up the iron core.

NOTES

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OHM'S LAW

Contents: Introduction - Ohm's Law - Other Uses for Ohm's Law - What Ignorance of Ohm's Law Can Do - Ohm's Law and Voltage Drop - Short Forms of Ohm's Law - More About Resistors - Wire Wound Resistors - The Resistor Code - Notes for Reference.

Section 1. INTRODUCTION

Most skilled trades require that a man have a strong back in order to perform his work properly. The brick mason for instance, is a highly paid skilled worker, but he has to put in years of hard work as an apprentice before he can qualify as a full-fledged mason. Even then the work he performs is hard physical labor. Plumbers, carpenters, steam fitters, and most other skilled workers also find this to be true. Not one of these trades is any place for the man who is physically handicapped.

Radio and television, on the other hand, is a good paying profession where a good physique is of little importance. While it is true that most men in this field could have gone into almost any line of endeavor insofar as their physical ability was concerned, there are also many physically

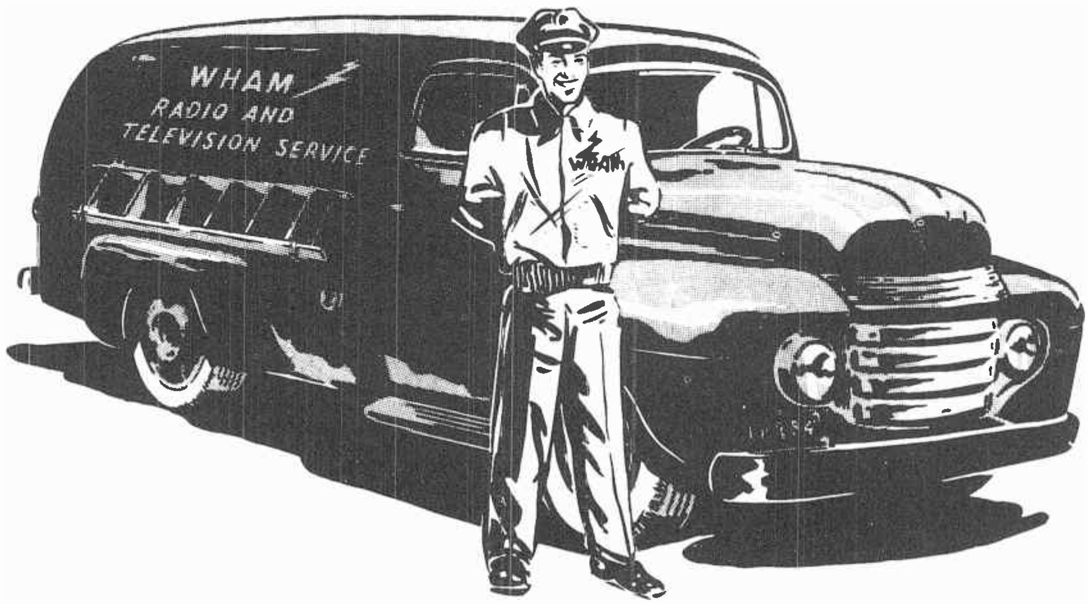


Fig.1. Television technician and his truck.

Fig.2. All other skilled laborers envy the radio repairman.

disabled men doing radio and television work who could not have qualified for any of the other skilled trades. No other skilled trade or profession seems to offer so many opportunities for the man who is physically handicapped as does that of radio and television.

The reason for this can be found in the fact that a radioman's skill lies in the training of his mind rather than being dependent upon any manual skill. This is because his skill lies in his knowledge and understanding of various intangible factors, rather than in his ability to do something skillfully with his hands. By intangible factors we mean things which cannot be seen, or felt, or otherwise perceived by the human senses.

In dealing with electricity we are constantly dealing with intangibles. For example, we cannot see electricity as it moves through a wire. Yet the trained radioman is able to detect currents of almost unbelievably small values -- and make them do things for him exactly as he wants them done. He becomes so skillful at doing this that he frequently does his work without conscious thought.

But to attain such skill a man must learn many things about electricity, and how it works in radio and television circuits. He must be thoroughly familiar with the various natural laws which govern the flow of electricity, and be able to apply them to any set of conditions. But it should not be thought that the learning of these laws involves a lot of grueling mental labor over dry, musty rules which some long-bearded thinker worked up for the sole purpose of making things harder for the newcomer. Nothing could be farther from the truth. Most of the natural physical laws dealing with electricity, radio and television are just as natural as the law of wave-motion which we discussed earlier -- and usually even more interesting.

Section 2. OHM'S LAW

In this lesson we are going to take up the natural physical law which involves the relationship of electrical pressure, current flow and resistance. It is considered the basic law for electrical workers regardless of which of the many fields of electricity the worker intends to enter.

In calling this rule a "law" it should not be thought that a group of scientists sat down -- in the manner of a legislative body -- and decided among themselves that electricity was going to flow in a certain manner, and then created a law to govern that flow. It just wasn't done that way. Back in the year 1826, only a few years after the close of the War of 1812 between the United States and England, a German scientist named George Simon Ohm was experimenting with the then little known curiosity called electricity. (Ohm's name is pronounced to rhyme with foam.)

George Simon Ohm had built himself some voltaic cells and had fixed up some wires for the electricity to flow through. In the course of his experiments he discovered that sometimes more electricity would flow, and at other times less would flow. After a seemingly endless series of experiments he discovered that the flow of electrical current was always proportional to the electrical pressure which caused it to flow, and then discovered that the current was also adversely affected by the amount of resistance in the circuit. He continued his experiments until he had proved that the current was always proportional to the voltage, and was inversely proportional to the resistance.

He then published the results of his experiments. His proof of the interdependent relationship of voltage, current and resistance upon each other came to be known as *Ohm's Law.* It continues to be recognized as the fundamental rule for the determination, and prediction, of how the change in any one of the three basic elements found in all electrical circuits affects the others.

Ohm presented his law in three forms:

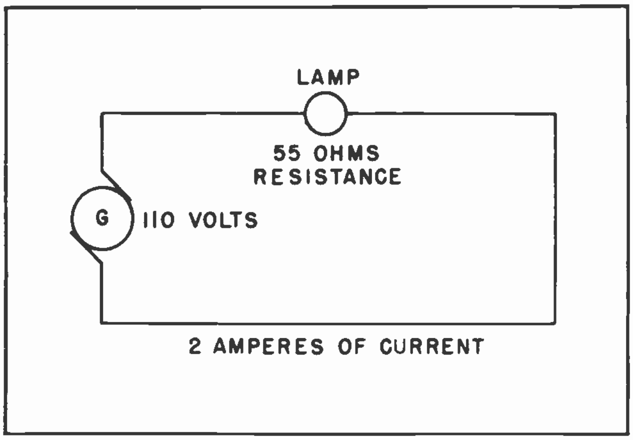


Fig.3. 110 volts of pressure will force 2 amperes of current through 55 ohms of resistance.

> The current in amperes is always equal to the voltage in volts divided by the resistance in ohms.
>
> The voltage in volts is always equal to the current in amperes multiplied by the resistance in ohms.
>
> The resistance in ohms is always equal to the voltage in volts divided by the current in amperes.

Now let's take up these three forms one by one and see just exactly what they mean in ordinary, everyday language. The first form says that the current in amperes is always equal to the voltage divided by the resistance. This can be written in the form of a mathematical equation:

$$\text{Current} = \frac{\text{voltage}}{\text{resistance}}$$

Such an equation indicates that for any given value of voltage and resistance there is only one definite value for current. It does not make any difference what the values might be. When the values of voltage and resistance are known, or can be determined, it will be found that the value of the current is always equal to the value of the voltage divided by the value of the resistance.

To use actual figures we can substitute 110 for the voltage and 55 for the resistance. Then the equation would look like this:

$$\text{Current} = \frac{110}{55}$$

Then by actually dividing the 110 by the 55 we will come up with the figure 2. This means that whenever we have 110 volts across a circuit in which there is 55 ohms of resistance there will be 2 amperes of

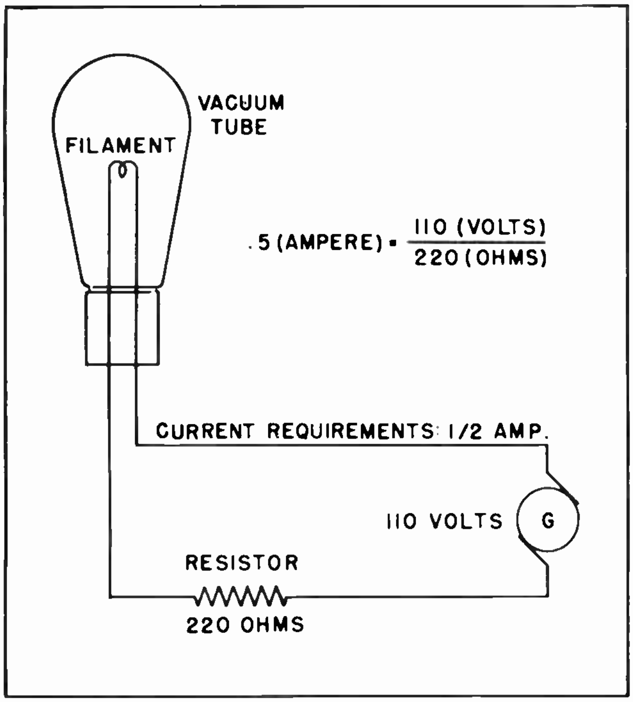


Fig.4. The 220 ohm resistor limits the current to the tube filament to a safe value.

current flowing through the circuit. This might apply to an incandescent lamp which is placed across 110 volts of ordinary household power. If the lamp had only 55 ohms of resistance in the filament a current of 2 amperes would flow through the lamp. This is an example, but is by no means the only place where the first form of Ohm's Law would be useful. In fact, Ohm's Law might not be needed in a situation such as the one described, but it could be used there.

In radio and television work there are many places where it is vitally necessary to know how to use the first form of the Law. When working with vacuum tubes the manufacturer gives instructions as to how much current can be allowed in certain parts of the tube. For example, it might be that the current through the filament would have to be limited to ½ ampere. If the voltage available for forcing the current through the filament was regular 110-volt, or 120-volt household voltage, the trained radioman would know immediately that he would have to do something to limit the current through the tube.

Suppose the radioman happened to have a 220 ohm resistor handy. If he knew nothing about the first form of Ohm's Law he would not know whether the resistor could be used to limit the current. But since all radiomen do know Ohm's Law he would immediately apply it to the solution of his problem. He would set up his equation like this:

$$\text{Current (through the tube filament)} = \frac{110}{220}$$

Dividing 220 into 110 gives him .5, which is equivalent to ½. He would know immediately that the resistor could be used to limit the current to the value he needed.

If the radioman had not happened to have had the 220-ohm resistor handy he might have approached his problem from a slightly different angle. He could have used the third form of Ohm's Law: *The resistance is equal to the voltage divided by the current.*

He knew what his voltage was: 110 volts. He knew the amount of current which had to flow through the tube filament: ½ ampere. What he had to determine was the value of the resistor he must use to limit the current. He would set up his equation like this:

$$\text{Resistance (in ohms)} = \frac{\text{voltage}}{\text{current}}$$

For the voltage he would substitube 110:

$$\text{Resistance (in ohms)} = \frac{110}{\text{current}}$$

The next step is to substitute the value of his current. He knows the current must be ½ ampere, but since it is easier to work with decimals than with fractions he will change the ½ to .5, and substitute that into the Ohm's Law formula:

$$\text{Resistance (in ohms)} = \frac{110}{.5}$$

By ordinary arithmetic it is quickly determined that 110 divided by .5 is 220. The solution to the problem then becomes:

$$220 \text{ ohms} = \frac{110 \text{ volts}}{.5 \text{ amperes}}$$

Ohm's Law is most commonly used to *predict* what will happen in an electrical circuit when certain factors, or values, are known. It might be that the radioman knows there must be a certain value of current flowing in a certain circuit, and that a resistor of a certain value is needed at that point for some purpose. His problem then is to determine the amount of voltage he must have to drive the needed current through the resistor. It might be that he needs 2 amperes of current for some purpose, and must also have a 25 ohm resistor at a certain location for some reason. He then must determine the amount of voltage to place across the resistor. Here he would use the second form of Ohm's Law: *The voltage is equal to the current multiplied by the resistance.*

He sets up his equation like this:

It is then up to the radio technician to determine the value of resistance to use.

As an example suppose a small gas-filled tube is to be used to operate a relay. The manufacturer may specify that the tube can be used continuously if the current does not exceed ½ ampere, that it will handle up to one ampere for a period not to exceed one second, but must never attempt to handle more than 2 amperes for even the shortest possible fraction of a second.

Voltage (in volts) = Current multiplied by resistance.

His next step is to substitute his known values into the equation. He knows the current which is needed, 2 amperes. He also knows the value of the resistor he must insert into the circuit, 25 ohms. He now substitutes the 2 amperes and the 25 ohms into the Ohm's Law formula:

Voltage (in volts) = 2 x 25

By ordinary arithmetic he multiplies the 25 ohms by the 2 amperes and comes up with his solution, 50 volts. His solution of the problem would then look like this:

50 (volts) = 2 (amperes) x 25 (ohms)

This would mean that he would have to provide 50 volts of electrical pressure if he is to force 2 amperes of current through the 25 ohms of resistance he wants to place in the circuit.

Section 3. OTHER USES FOR OHMS LAW

A common use for resistors is as a protective device for other electrical equipment. In working with electronic tubes which contain a small amount of gas, the current through the tubes can attain a very high value if there is not something to limit it. To protect the tubes from damage, and probable destruction, it is necessary to limit the current to reasonable values. Resistors are used for this purpose. But not all tubes of this type will handle the same amount of current without damage. Some might handle many amperes, while others would be seriously damaged by less than one ampere. Therefore, it is not possible to say that a resistor of any one value will provide protection for every type tube. The manufacturers provide the information as to how much current the tube can handle safely.

If the relay will operate satisfactorily on less than ½ ampere it would be wise to insert a resistor into the circuit to limit the current to that value. The problem then is to determine the value of resistance which must be connected into the circuit in order to provide the necessary protection.

Let us say the tube and the relay are to be operated from a voltage source which provides 240 volts. The tube itself has a very low resistance, and will be of little

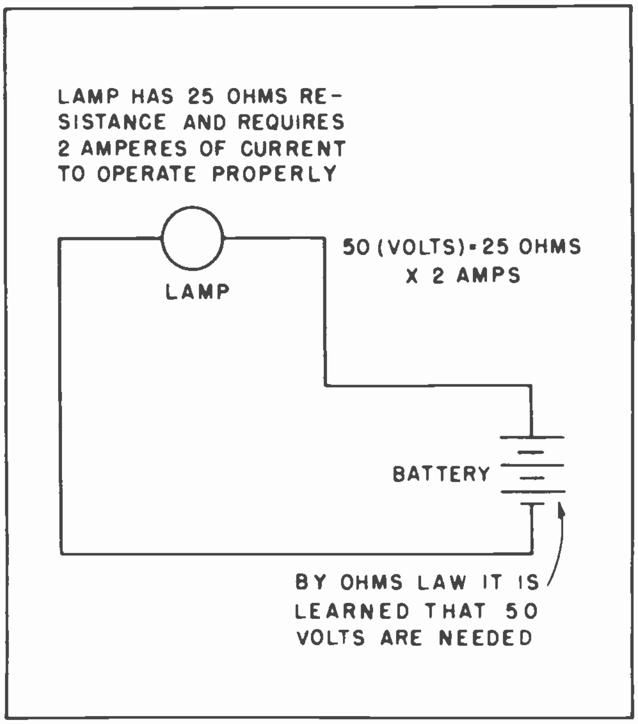


Fig.5. A circuit which needs 2 amperes of current and a resistance of 25 ohms can be represented by an incandescent lamp. The proper voltage for the circuit would be 50 volts.

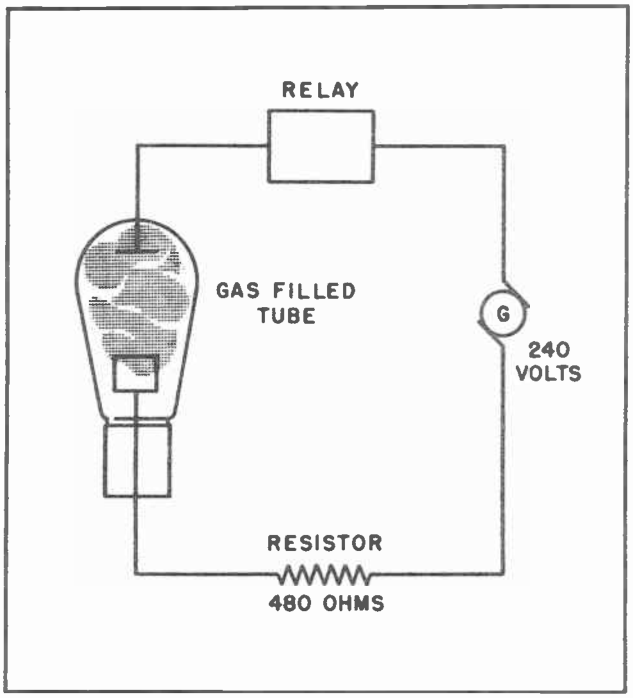


Fig.6. The 480 ohm resistor limits the current to a safe value for the gaseous type tube.

help in limiting the current to a safe value. If the relay is of the low-resistance type it will not add very much resistance to the circuit either. Thus both of them together provide so little resistance to the circuit they can be ignored for the moment while we work out our problem.

Our problem now is a simple one of applying Ohm's Law to the known factors, and by its use learn the thing we want to know. We take the known voltage and the known current limitations, and use them to learn the value of the resistance:

$$\text{Resistance (ohms)} = \frac{240 \text{ volts}}{.5 \text{ amperes}}$$

By simple arithmetic we divide the 240 volts by .5 amperes and obtain the figure 480. The solution to the problem would then look like this:

$$480 \text{ ohms} = \frac{240 \text{ volts}}{.5 \text{ amperes}}$$

This means that we would have to insert 480 ohms of resistance into the circuit to limit the current to a value which would not damage the tube, and incidentally, the relay. Fig. 6 shows the resistor inserted in the circuit between the generator and the tube. Since this is a series circuit it could be inserted in the circuit at any point.

A little earlier we said the tube itself had very little resistance and could be ignored for the moment, and so could the relay. As a matter of fact, both the tube and the relay do have some resistance, even though it might not be very much. A common value of resistance for a tube of this kind would be about 15 ohms, and the resistance of the relay might be on the order of about 25 ohms.

Now suppose we take these two resistances into account and then figure out how much resistance we would have to add to the circuit as protection for the tube and the relay. The total resistance of the circuit would still have to be 480 ohms, since that is the amount of resistance which is needed to limit the current to the proper value. We have already learned that resistances in a series circuit add together to give us the total resistance. Since this is true, and we already know that the total resistance needed is 480 ohms, it would seem to be reasonable to deduct the resistance of the tube and that of the relay from the total amount needed. If we did this it would seem logical that that would give us the amount of additional resistance

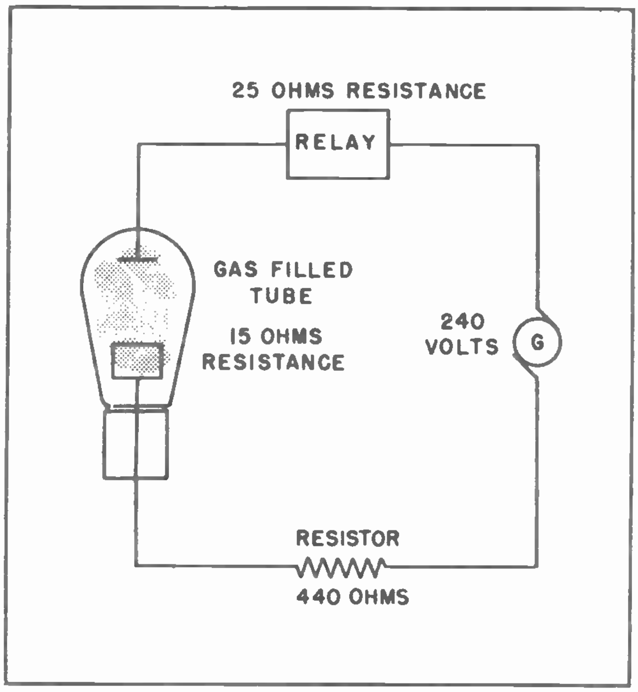


Fig.7. The resistance of the tube and relay should be considered when determining the value of resistor to use.

we would need in the circuit in the form of a fixed resistor.

And such, indeed would be the case.

We take the 480 ohms we have determined that we need in the circuit. From that we deduct the 15 ohms resistance of the tube and the 25 ohms resistance of the relay. This leaves 440 ohms. This means that we must add 440 ohms resistance in the form of a fixed resistor if the circuit is to operate properly.

Section 4. WHAT IGNORANCE OF OHM'S LAW CAN DO

This example is one which shows that the radio man must know his business, and do the right thing the first time. Suppose the radioman knew nothing about Ohm's Law and was confronted with the problem of protecting the tube and the relay from the damaging current which would flow if the proper resistor was not in the circuit. Not being able to determine the value of resistor needed by calculation, he would be forced into the position of trying one blindly. Since there are well over a hundred standard values of fixed resistors, the chance of him selecting the correct resistor by chance would be considerably less than 1 in 100.

Suppose that in his ignorance he decided to try a resistor of 50 ohms and take a chance on it working. The resistance of the 50 ohm resistor added to the 15 ohms of the tube and the 25 ohms of the relay would amount to only 90 ohms.

240 volts divided by 90 ohms gives a little more than 2½ amperes. Such a current would cause the tube to destroy itself -- almost in a flash. With the tube destroyed he would not be able to experiment again until he obtained a new tube. He might destroy a dozen tubes before hitting upon a resistor of the right value. With such tubes costing from $2.00 each to over $20.00 his experimentation would be extremely costly.

But suppose he was more cautious. Instead of choosing a resistor of 50 ohms he might have chosen one of 100,000 ohms. Such a resistor would present so much resistance in the circuit that neither the relay nor the tube would operate. If he then substituted one resistor after another, each with a little less resistance than the one before, he might try 50 or more resistors before hitting on the one which would work.

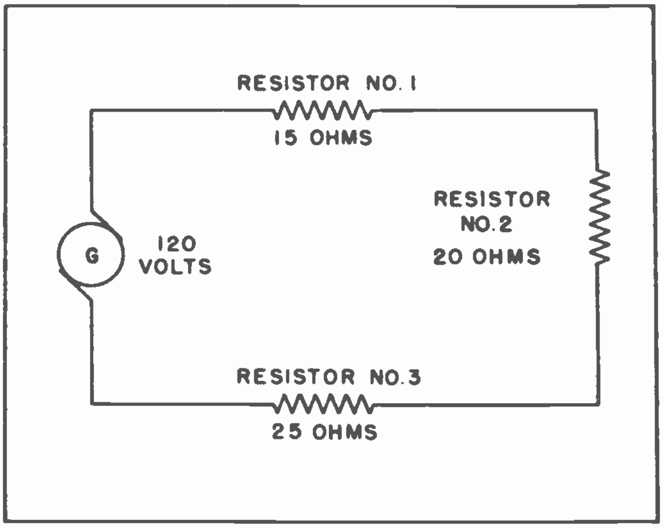


Fig. 8. Resistance in a series circuit.

The skilled radioman has no time for such guesswork. There is no need for guesswork when a man knows how to use Ohm's Law. And since it is so easy to learn, and to work with, there is little excuse for a man not knowing it.

Section 5. OHM'S LAW AND VOLTAGE DROP

We have previously mentioned that voltage drops will occur at various parts of a circuit. We have also said that the voltage drops in a circuit will always exactly equal the voltage of the source. We will now learn that Ohm's Law can be used to determine the value of the voltage drops anywhere in a circuit.

Fig. 8 shows a series circuit containing a voltage source of 120 volts and three resistances. Resistor No. 1 has a resistance of 15 ohms, resistor No. 2 has a resistance of 20 ohms, and resistor No. 3 has a resistance of 25 ohms. Adding the 15 ohms, the 20 ohms and the 25 ohms together we obtain a total of 60 ohms. This means there are a total of 60 ohms resistance in the circuit. Now to set up our Ohm's Law equation and find out how much current is flowing in the circuit.

$$\text{Current (amperes)} = \frac{120 \text{ volts}}{60 \text{ ohms}}$$

By simple arithmetic we can divide the 60 ohms into the 120 volts and come up with the answer. There are 2 amperes of current flowing in the circuit.

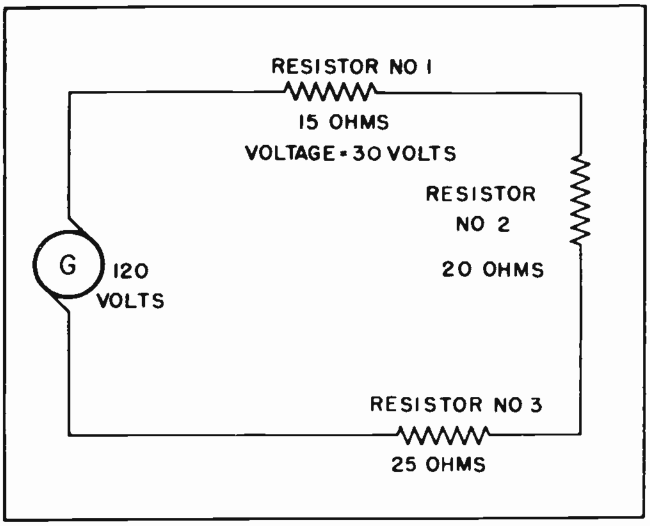


Fig.9. Voltage drop across a resistor.

We have already learned that the voltage drops in a series circuit always add up to equal the original voltage source. Our problem now is to find out just where the voltage drops occur in this circuit, and how much they are.

Before beginning our investigation of this problem it would be well to get one thing firmly fixed in mind. *Whenever current flows through a resistor there will be a voltage drop across that resistance.*

The voltage drop across any resistance can be determined by Ohm's Law. All that is necessary is to multiply the resistance by the value of the current through it.

The circuit of Fig. 8 has been redrawn in Fig. 9. Here is shown the voltage across resistor No. 1. The value was found by multiplying the 15 ohms resistance by the 2 amperes of current. We had already found the amount of current in the circuit, and since the current is the same in all parts of a series circuit it is bound to be 2 amperes through the resistor. Thus, 15 ohms multiplied by 2 amperes gives us 30 volts.

Fig. 10 shows the voltages across each of the resistors. The current through each of the resistors is 2 amperes. The voltage across resistor No. 2 is found by multiplying the 20 ohms resistance by the 2 amperes of current which gives a total of 40 volts. The voltage across resistor No. 3 is found by multiplying the 25 ohms of resistance by the 2 amperes of current. This gives a voltage drop across resistor No. 3 of 50 volts.

The accuracy of our calculations can be determined by adding all the voltage drops together to see if they equal the original voltage of the source. Adding 30 volts, 40 volts and 50 volts together gives a total of 120 volts. Since this is the same as the source voltage it shows that our calculations have been correct.

While Ohm's Law is being continually used for finding all kinds of values in electrical circuits, in radio work it is probably used to calculate voltage drops more frequently than for any other purpose. The determination of the value of voltage drops is encountered at nearly every step of the radioman's work.

He must learn to calculate the voltage drop across the load resistor in a vacuum tube circuit. He must learn to calculate the voltage drop across the *cathode bias* resistors, of which much more will be said later. He must be able to calculate and set up voltage divider networks so as to be able to tap off whatever voltage his needs call for. The places where he must determine the voltage drops are almost endless. The point is that he must be able to figure out ahead of time exactly what values of resistors will be needed to give him the voltage drops he needs. Cut and try methods have no place in most radio work.

All of this may seem rather complicated and difficult. Actually it is not. Only a very little experience is needed, once a man understands the basic principles of Ohm's Law, to become a genuine expert at working with voltage drops and the predetermining of values needed in radio circuits.

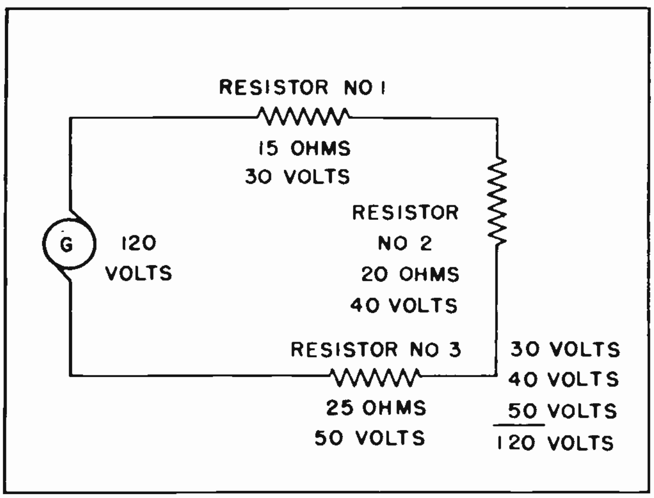


Fig.10. Voltage drops around a series circuit.

It can be truthfully said that Ohm's Law is probably one of the most useful things a radioman works with. If he knows any two of the values to be found in a radio circuit he can quickly find the third one. Very often he will encounter a situation where he knows one existing value. He knows what he wants for a second value, and wants to learn what he must use for a third value in order to obtain the second. This situation occurs over and over. Ohm's Law is the perfect solution for such a problem.

Section 6. **SHORT FORMS OF OHM'S LAW**

It would be rather awkward to write out the entire equation "Voltage is equal to the current multiplied by the resistance" every time a person wanted to use Ohm's Law. To make the formula much less cumbersome, radio and electrical men have substituted letters of the alphabet in place of the names of the various circuit elements. Because voltage is the measurement of Electromotive force they have chosen to use the first letter of the word "Electromotive" to represent the voltage in the formula. That substitution would make the formula look like this:

$$E = \text{current} \times \text{resistance}$$

Even this is too long. Since the measurement of current is actually the measurement of the *Intensity* of electron flow electrical men have mutually agreed to use the letter *I* to represent current. The letter *I* is used to represent current everywhere in electrical work, not merely in Ohm's Law. Furthermore, it is the most natural thing in the world to use the letter *R* to represent resistance. This makes it possible to write the formula for Ohm's Law in a much more simplified manner than we have been doing. It is commonly written in this manner:

$$E = IR$$

Although the average radioman seldom thinks of the use of letters to represent the elements found in an electrical circuit as being anything other than a handy form of shorthand, such use does set up the equations in a manner which makes their solution easy through the application of the rules of algebra. It is not essential that a radioman know algebra, but if he does know it, such knowledge is a great help.

The short method of writing Ohm's Law for voltage can be readily changed to fit the law for current or the law for resistance. The form of the law for current in the short form would read:

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

And the short form of the law for resistance would read:

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

For the man who is familiar with algebraic equations all it is necessary to remember is the first form: $E = IR$. Then by simple algebraic operations the other two forms can be readily found. The man who does not know algebra will have to rely a little more heavily on his memory. He will have to remember the first form also, but in addition will have to remember the other two forms. One thing to remember is that the *E* of the formula is never below the fraction line. It is either by itself on one side of the equal sign, or is above the fraction bar. If this can be remembered it will be easy to remember exactly how the various forms of Ohm's Law is written. Fig. 11 shows a handy method of remembering the arrangement of the letters in the short form of Ohm's Law.

To use the method shown in Fig. 11 all that is necessary is to cover the letter representing the value that is unknown. For example, if the voltage is unknown, cover the *E* in the circle at *A*. This is shown at *B*. Then it will be seen that to obtain the voltage you multiply the current by the resistance.

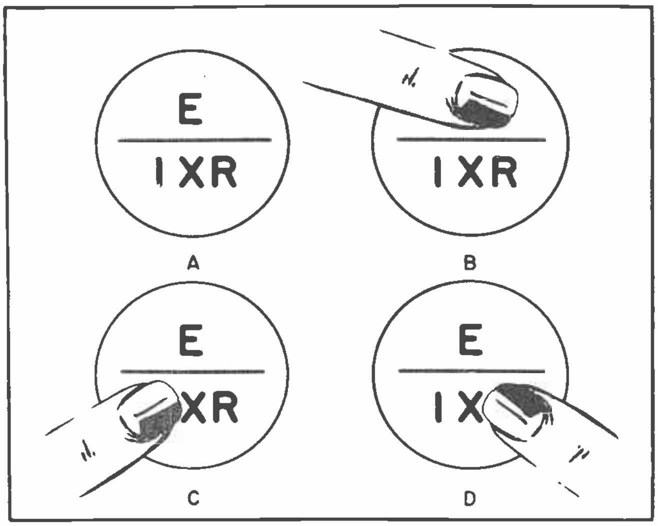


Fig. 11. A Handy Device for Remembering Ohm's Law.

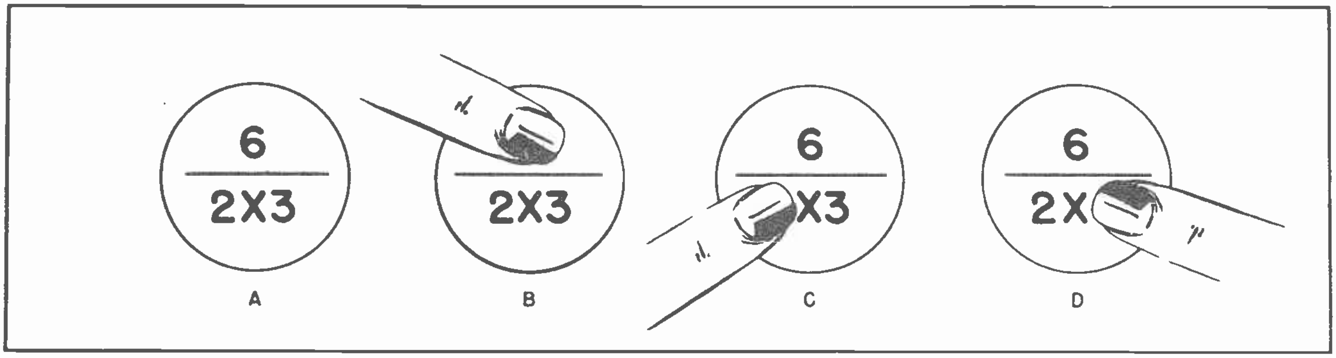


Fig.12. Using actual figures instead of letters.

If the current is unknown cover the *I* as shown at *C*. Then it will be seen that the voltage must be divided by the resistance in order to obtain the value of the current.

And if it is the resistance that is unknown cover the *R* as shown at *D*. That leaves the *E* and *I* exposed in such position to indicate that the voltage is divided by the current in order to obtain the value of the resistance.

Fig. 12 shows how actual figures can be substituted for the letters of the Ohm's Law formula, and the solution to a problem obtained.

Section 7. MORE ABOUT RESISTORS

We have made considerable mention about resistors but have avoided going into too much detail about them, or their construction. It is time now to learn a little more about resistors; how they are made, what they look like, and how some kinds differ from other kinds.

The most common type resistor found in radio and television work is the so-called "carbon" resistor. The conducting material in a carbon resistor is either carbon or graphite. The powdered carbon, or graphite, is mixed with some type of insulating material. Usually the insulating material is some type of clay, or is bakelite or rubber. By combining the correct amount of the insulating substance with the conductor material it is possible to obtain virtually any value of resistance which might be desired.

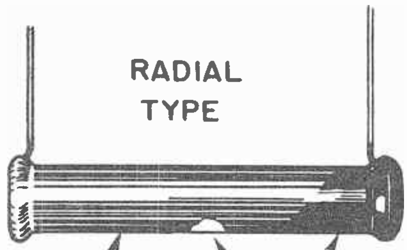
After the mix has been made it is molded into the form of a solid rod and given a heat treatment. The rod is then cut into suitable lengths and connecting wires are attached to the two ends of the various lengths.

There are two general positions in which the connecting wires, called "pig-tails", are attached to the resistors. The "radial" type as shown at the top of Fig. 13 has the connecting wires attached at right angles to the body of the resistor. Some years ago nearly all resistors were of this type. More recently the radial type seems much less popular than formerly.

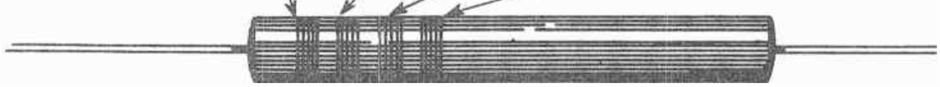
The connecting wires of the "axial" type, shown at the bottom of Fig. 13, has the wires extending straight out from the ends of the resistor. The axial type resistor is now the much more common of the two types.

The physical size of carbon resistors is quite small. The smallest ones are no larger around than a wooden match, and not so long. The larger sizes seldom exceed 2¼ inches in length, nor the size of a lead pencil in diameter. Their resistance in ohms may range from a very few ohms up to several million. Fig. 14 shows a comparison in the physical size of several radial type resistors.

In addition to the resistance of resistors in ohms they are also rated in "watts". We have not yet gotten into a discussion of the meaning of watts, so we will merely mention that, in general, the larger the physical size of a resistor the larger its wattage. This can be said another way, that the larger the resistor the more current it can carry safely. You will learn later that there will be a dissipation of heat from a resistor at any time there is current flowing through it. So, the larger the resistor the more current it can handle and the more heat it will dissipate without burning up.



CODE	BODY	END	DOT	TOLERANCE
BLACK	0	0	NONE	
BROWN	1	1	0	
RED	2	2	00	
ORANGE	3	3	000	
YELLOW	4	4	0000	
GREEN	5	5	00000	
BLUE	6	6	000000	
VIOLET	7	7	0000000	
GREY	8	8	00000000	
WHITE	9	9	000000000	
GOLD				5%
SILVER				10%
NONE				20%
	BAND 1	BAND 2	BAND 3	BAND 4



AXIAL TYPE

Fig.13. Two types of resistors and the resistor color code.

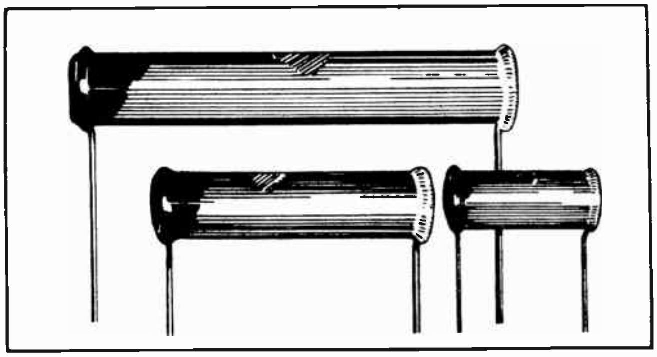


Fig.14. Radial type carbon resistors.

Fig. 15 shows three sizes of resistors of the axial type. The top one is a ½-watt resistor, the middle one is a 1-watt resistor and the bottom is a two watt resistor. It might be wondered why it is necessary to have such a variety of sizes for resistors. The fact is there are many cases where it is necessary to have resistors large enough to carry a large current and dissipate a lot of heat. Such resistors are quite large physically, and cost a lot of money. On the other hand there are dozens of places where a resistor will carry only an extremely small current, and the resistor must fit into a very small space. In this case the larger resistor would not be practical.

From a strictly electrical standpoint if a circuit called for a resistor of a certain resistance in ohms it would make no difference whether the resistor was large in physical size, or small. But there are other considerations. A carbon resistor rated at ½-watt can be purchased from a radio wholesale house for approximately 5 cents. So far as the price is concerned it makes little difference whether the resistance is 10 ohms or 100,000 ohms. A 1-watt resistor would cost about 8 or 9 cents. But a 20-watt resistor might cost upward of a dollar. If a ½-watt resistor will suffice it would be economic foolishness to use the larger and more expensive size.

There is still another reason for using the smaller resistor besides that of cost. It might be difficult to fit the larger physical size of the higher wattage resistor into the position where the smaller resistor would go easily. The underneath part of a radio or television chassis is usually quite crowded with wires, resistors and other components which make the set operate. If very many of the resistors were over size there simply would not be room for them all.

When several carbon resistors are closely grouped together under a radio chassis there is danger that they will shift their position and touch one another. When a contact of this kind occurs an unwanted electrical path is provided. To prevent such things a resistor like the one shown in Fig. 16 was created. The conductor rod is in the center of a ceramic sleeve. The connecting wires are imbedded in a bakelite cap at each end of the conductor rod. Both the bakelite and the ceramic are insulators, which prevent the conducting part to come into contact with any other conducting material. These types of resistors have become quite popular.

Section 8. WIRE WOUND RESISTORS

We have previously mentioned that not all kinds of metal will conduct electricity with equal ease. Some metals have a resistance which is quite high. Combining two or more of these metals into an alloy can provide a special type of wire which has a higher resistance than either of the metals which are used to make the alloy.

A combination of chromium and nickel and iron is alloyed by various companies and formed into special types of resistance wires. These are sold under such trade names as "Nichrome" and "Chromel". This is the kind of wire which is used in the heating elements of electric irons, toasters, soldering irons and other heating apparatus.

In radio and television work resistance wire is used to make resistors which are somewhat similar in appearance to those resistors we have been discussing. In general, "Wire wound" resistors have lower

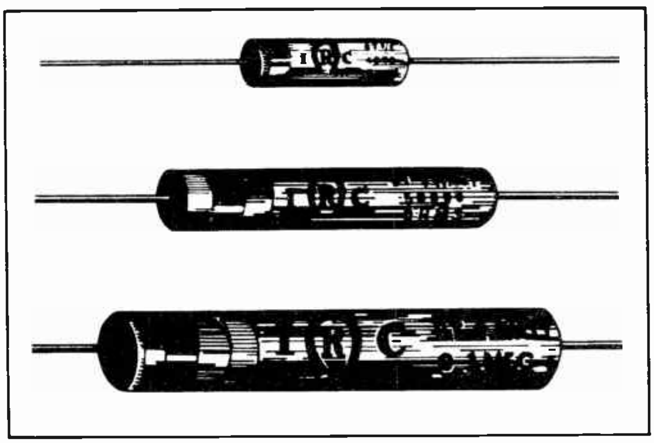


Fig.15. Axial type resistors.

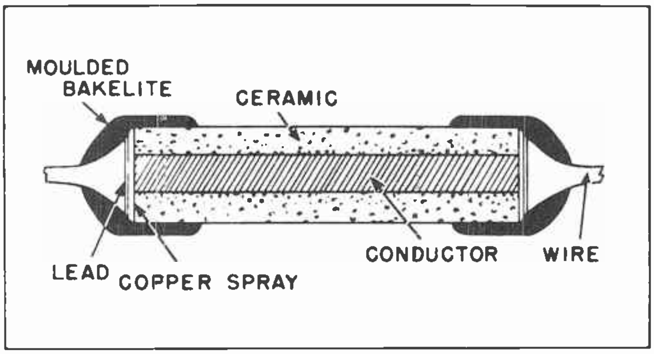


Fig. 16. Construction of the ceramic insulated resistor.

values of resistance than carbon resistors, but they can carry much larger currents.

Fig. 17 shows the construction of a wire wound resistor. The resistance wire is wound on an insulating form. Each end of the resistance wire is attached to connecting wires which are used in the same manner as the "pig-tails" of the carbon resistors. Then the entire assembly is covered with a ceramic insulating material. The completed resistor is sturdy, well insulated, moisture proof, and will stand reasonably heavy overloads.

In Fig. 18 are shown two types of wire-wound resistors. It will be noted that they closely resemble the carbon resistors. In general, however, the wire-wound resistors are usually larger in physical size than carbon resistors, and they are usually considerably more expensive. They have the advantage of carrying heavier currents, and usually their resistance is more accurately calibrated than that of carbon resistors.

Section 9. THE RESISTOR CODE

If you will turn again to Fig. 13 you will note that various colors are used to designate various numbers. This is called the "Resistor code". The code is used to mark the values on the resistors by the manufacturers. The larger wire-wound resistors often have their values stamped onto the body of the resistor in numerals. But many of the smaller resistors have such high resistance values and such small physical size on which to write the number that it was found much more convenient to use a system of color codes to mark the values on the resistors.

It is not deemed necessary nor desirable that you attempt to memorize the color code at this time. Trying to commit it to memory without some resistors to work with could be an exceedingly difficult task. Once you are working with resistors regularly you will find that it will then be a very simple thing to learn and remember the code.

As a hint it might be worth mentioning that only the first six colors are generally used. That is black, brown, red, orange, yellow and green. The other four are used occasionally, but not nearly so frequently as the first six. In fact, you might work for weeks and never see the last four colors.

It is easier to read the code on the axial type resistor than on the radial type. There are four bands on the axial type resistor. Only the first three have to do with the value of the resistance. The fourth band designates how nearly accurate the designated value is to the actual value.

In evaluating the amount of resistance in a resistor only two *significant* figures are used. This is somewhat like estimating how much money an automobile is worth. Since it is practically impossible to exactly evaluate every item which enters into the value of an automobile it is the practice to "round" the price off to some convenient figure. It might be possible to scientifically determine the exact condition of every working part in an automobile, and then from that figure out exactly what the whole automobile was worth. But from a practical standpoint that is not done.

For example it might be possible, after much time and effort, to figure out that an automobile is worth exactly $553.25. Considering all the time it would take to

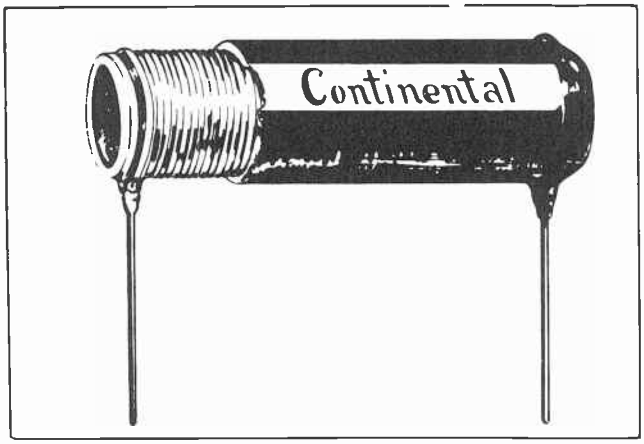


Fig. 17. Construction of a wire-wound resistor.

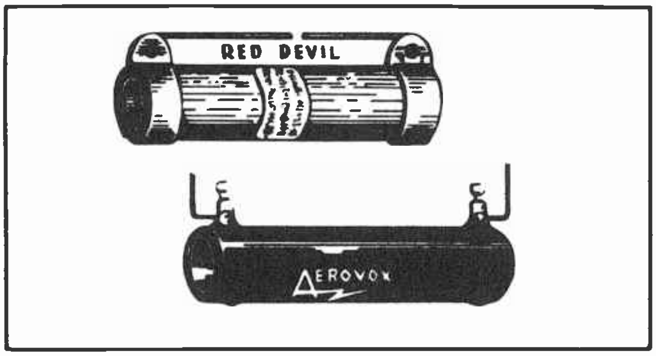


Fig. 18. Outward annearance of wire-wound resistors.

figure out the exact value it would be better to say the car was worth $550.00, and let it go at that. We could then say the value of the car had been determined within two *significant* figures. The two first figures are the two significant ones.

And so it is with the matter of fixing the value of a resistor. The value is determined to within two significant figures. The color of the first band on the axial resistor in Fig. 13 gives the first significant figure of its value. The color of the second band gives the second significant figure of its value. And the color of the third band determines how many zeros to add after the first two figures.

As an example suppose the color of the first band of the axial resistor is red, the second band is green, and the third band is yellow. Looking this up on the color code we find that red stands for 2, green stands for 5, and yellow stands for 4 zeros.

The first two colors are red and green. This means that the first two figures of the resistor's value will be 25. The third color, yellow, stands for 4 zeros, so then we must add four zeros after the 25. This makes the value of the resistor 250000, or 250,000 ohms.

This matter of the use of the color code will be gone into much more thoroughly when we actually begin working with resistors with our hands. At that time it will be found that the color code is a simple, easy-to-use tool to have around.

NOTES FOR REFERENCE

Ohm's Law is the rule which governs the flow of current through all electrical circuits.

There are three forms of Ohm's Law:

$$E = IR$$

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

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

Ohm's Law is used to *Predict* what will happen in an electrical circuit under any given set of conditions.

Knowledge of how to use Ohm's Law prevents costly experimentation, and waste of time.

NOTES

Ohms Law

The current is always equal to voltage divided by Resistance

E = Electromotive force

NOTES

NOTES

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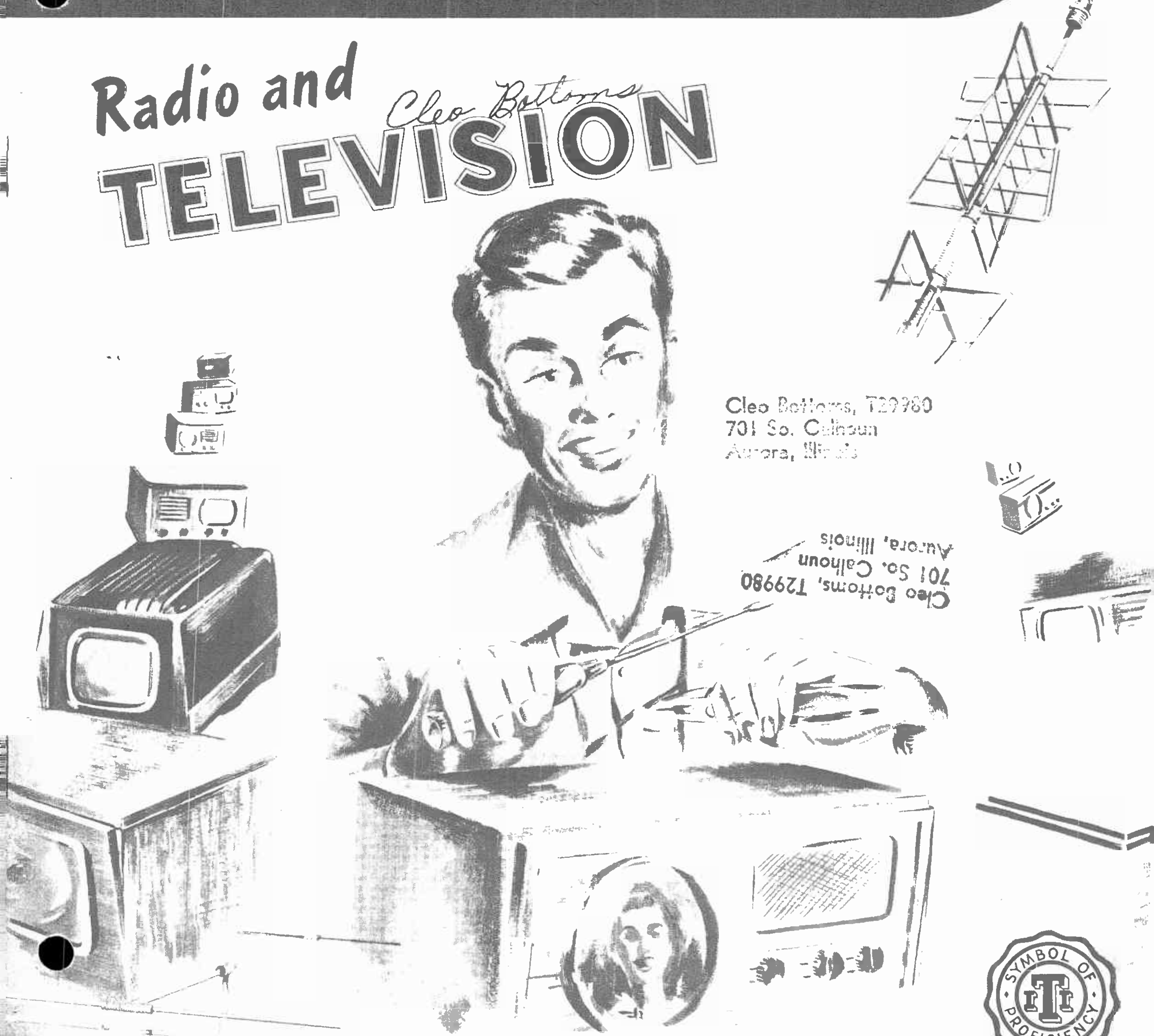

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TECHNICAL TRAINING SERVICE

ELECTRICAL POWER

Contents: Introduction - Power - Work - Work and Power - Measuring Mechanical Power - Energy - Power in Moving Electricity - Voltage, Amperes and Power - The Unit of Electrical Power - Power Consumed in Electrical Devices - Measuring Electrical Power - Large and Small Units - Converting Electrical Power into Mechanical Power - Reference Notes.

Section 1. INTRODUCTION

The carpenter and cabinetmaker work with wood. Their ability as craftsmen depends very largely upon how neatly they can join two or more pieces of wood together to make a finished object. It takes months, even years, for their hands to acquire the high degree of skill necessary to turn out work which meets the standards of their trade. Their skill lies in the training of their hands. Theirs is a manual skill.

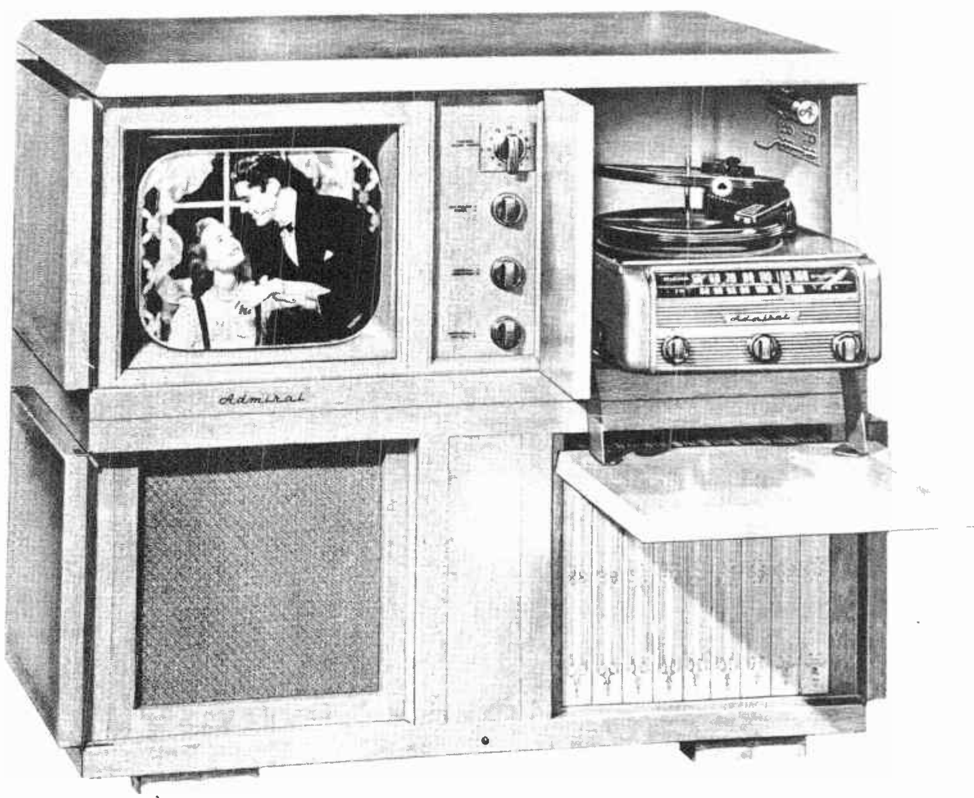

Fig. 1. A Combination Radio-Phonograph-Television Console. (Courtesy of Admiral Corp.)

Fig.2. A man does work in shoveling coal.

Much the same thing is true with the machinist, except that he works with steel and metal rather than with wood. But to be able to form metal into shapes of intricate design, and hold it to dimensions which are measured in thousandths of an inch, requires the development of great skill over a period of many months or years. The machinist is a highly skilled worker, and his, too, is a skill of the hands -- a manual skill.

And so it is with the mason. To be able to lay a course of bricks which is perfectly straight, weaving neither in nor out, nor up or down, calls for a skill which can be acquired only after much practice. The mason's skill lies in the ability of his hands to do the thing he wants them to do -- and do it right. Here again, the skill is a manual one.

Virtually unique among the skilled trades and professions is that of the radio and television technician. He is called upon to acquire virtually no skill with his hands. Except for the development of a skill in the proper use of the soldering iron -- and that is easily acquired -- radio and television places little demand upon a man's manual dexterity. The radio and television technician is not required to develop a high degree of manual skill.

The skill of the radio man lies in the training of his mind -- his intimate knowledge of the functions performed by intricate electrical circuits. It lies in his seeming uncanny ability to quickly put his finger on the source of trouble in a bewildering maze of wires, resistors, capacitors and other things which go to make up the modern radio or television receiver. His skill lies in his knowledge of just what each of the various parts in a receiver does -- what part it plays in keeping the receiver operating properly.

In building up his knowledge of exactly how a radio or television receiver operates, the technician must first learn all there is to learn about the various parts which go into the receiver. He must learn what each part does, and just how it contributes to the proper functioning of the receiver as a whole.

The proper functioning of a receiver can be compared in one way with a steel chain. It has been said that no chain is stronger than its weakest link. Should any link fail, the chain can no longer perform its intended function. In the same manner, if the tiniest -- and apparently most insignificant -- resistor or capacitor should fail in a radio or television receiver, then the receiver can no longer perform its intended function. It is his knowledge of just what each little part in a receiver is intended to do that makes it possible for the radioman to go straight to the cause of trouble when anything goes wrong. Therein lies his skill.

Without the special knowledge of the radioman an untrained man might look for months for trouble in a radio or television receiver -- and still not find it. Such an unskilled person would be lucky to escape electrocution. But the trained man usually knows exactly what is wrong -- or is quickly able to determine it. He does not guess. He does not fumble blindly in the intricate maze of circuits. He knows how to systematically check for the trouble, find it, then correct it.

Section 2. POWER

In previous lessons we have discussed electrical pressure, or voltage; rate of electrical current flow, or amperage; and the opposition presented to the flow of electrical current flow, or resistance. We have shown how each of these elements in an electrical circuit is very closely dependent upon the others. We have explained how important it is for the radioman to understand their relationships as they are stated in Ohm's Law, and how necessary it is to become so familiar with Ohm's Law that it's principles can be applied to a problem without conscious effort.

Now we introduce a new factor in electrical work which is scarcely less important than the ones we have previously mentioned. This is electrical *power*. As a matter of fact, the term *electrical power* probably is not so new to you at that. You have probably heard it many times. The large companies which supply electrical energy to their customers usually refer to themselves as *power* companies. The huge hydro-electric dams which now confine the water in so many of our rivers are quite commonly referred to as *power* dams. In short, the product which the electrical utilities companies sell to their customers is electrical *power*.

Although we use the term *power* quite frequently, even in everyday conversation, it so happens that we often do not completely understand the exact meaning of power. Power and work and energy are terms which are frequently used interchangeably with each other. But the fact that they are so used does not mean that they all mean the same thing. They do not. Each has a definite meaning of its own, and in electrical work it is wise to make certain that we know exactly what each means.

Section 3. WORK

We will first take up the discussion of the meaning of the word "work". This is a word we all use every day. It is a common word. It is so common that we take it for granted that we all know exactly what it means. But all too often, we do not.

Since we are talking about work, and intend to talk about electricity at work, it is wise to look into the exact meaning of the word. As an illustration, suppose we take the familiar situation of the coal truck which dumps a ton of coal on the sidewalk or street in front of a building. Before it can be used, the coal must be moved into the basement. A man with a large scoop shovel can shovel the coal into the basement in perhaps half an hour. In shoveling the coal into the basement the man has done a definite amount of work.

A small boy with his much smaller shovel can also shovel the coal into the basement. It might take the boy three hours to shovel the coal where it took the man only half an hour, but he has done exactly the same amount of work as the man. It would take the boy a much longer time to do the work, but the *amount* of work done would be exactly the same.

Most kinds of work mean the moving of something from one place to another. Such work may be measured by stating the quantity, such as the weight of the thing to be moved, and the height to which it is raised, or the force against which it is moved.

When a given quantity is moved a certain distance, a definite amount of work will be done. It will make no difference whether it takes a long time or a short time to do the work, the amount of work done will be the same. As an example, a man with rope and pulleys can hoist a barrel of tar onto a roof. In doing so he will do a certain amount of work. An electric hoist can do the same job in a fraction of the time, but the machine does neither more nor less work than the man.

To cite an electrical example: One of the many things electricity can do is the electroplating of metals. Suppose a certain job requires the depositing of half an ounce of silver on an ornamental tray. To take that much silver out of the electroplating solution and place it on the surface of the tray requires that a certain quantity of electricity flow through the apparatus, and that a certain amount of work be done. The plating might take a few minutes or several hours, but the work done would be the same in either case.

Section 4. WORK AND POWER

The man and the boy who shovel the coal into the basement do the same amount of work, but the man exerts several times as

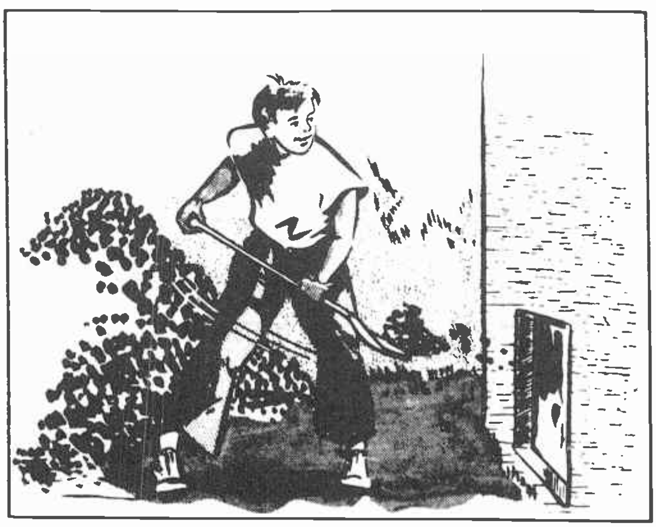

Fig.3. The boy does the same work as the man, but takes more time.

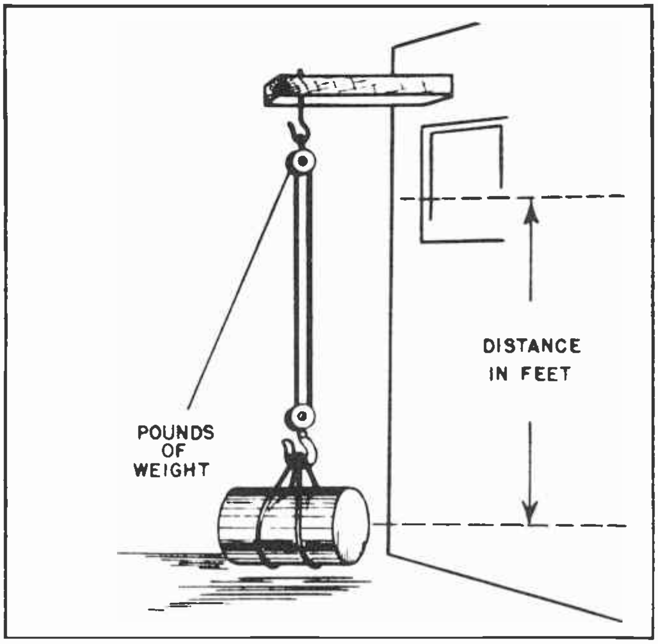

Fig.4. Work is measured in weight and distance. Time makes no difference.

much power as does the boy. It takes much more power to do the plating job in a few minutes than in an hour or two. The electric hoist puts forth much more power than the man with the rope and pulleys, in spite of the fact that the same work was done by each. Power is a measure of the speed with which work is done. The greater the speed, the less the time for a given amount of work, and the greater the amount of power being used. Power measures the rate at which work is done, but does not measure the quantity of work unless you know how long the power is used.

Mechanical work which involves the lifting of some object or material can be measured by stating the number of pounds which are raised and the number of feet through which they are raised. An example would be the raising of a 400-pound barrel of tar to a height of 20 feet. The amount of work done can be found by multiplying the weight of the barrel by the distance it is raised. In this case we would multiply the 400 pounds by the 20 feet. This would give us 8000 foot-pounds. 8000 foot-pounds is the amount of work done in raising the barrel of tar 20 feet.

If it is necessary to know the power used to raise the barrel, then we would need to know the time which was required to raise it. Power always involves the element of time. It is the measure of how much work is done, or how much work can be done, in some specified length of time. The faster the work is done, the greater is the power required. By the same reasoning, the slower the work is done, the less power is required.

A low-powered engine might move an automobile 40 miles in one hour. If it was desired to make it possible for the automobile to move the 40 miles in one-half hour, it would be necessary to use a much more powerful engine. Most modern American automobiles have very powerful engines which are capable of moving them from one point to another at very high speeds.

Much the same thing is true with airplanes. Many private planes use low-powered engines which are capable of moving them from place to place at relatively slow speeds. Military planes, on the other hand, which must be capable of blinding speeds, use engines which are capable of developing 50 times the power of the private planes.

Section 5. MEASURING MECHANICAL POWER

The most generally used unit of mechanical power is the *horsepower*. This is a unit which was determined by James Watt to measure the power developed by his newly invented steam engine. James Watt invented the steam engine back in 1768, a few years before the American Revolutionary War. It was the first time man had ever been able to create power mechanically, and it became necessary to devise some method of measuring the power delivered by the engine in order to compare its ability with that of animal power. Previous to the invention of the steam engine, animals were man's most important source of power other than his own brute strength.

In casting about for some unit by which to measure the power of his new engine, James Watt hit upon the idea of measuring the amount of water a good draft horse could pump out of the mines, and then comparing that with the amount his engine could pump. As far back as men could remember, the water was kept from flooding the underground mines by means of pumps which were kept in continuous operation by patiently plodding horses. It was Watt's idea to use his new engine as a source of power for the pumps instead of the horses. But before he could convince the owners of the mines of the value of his new engine, it was necessary

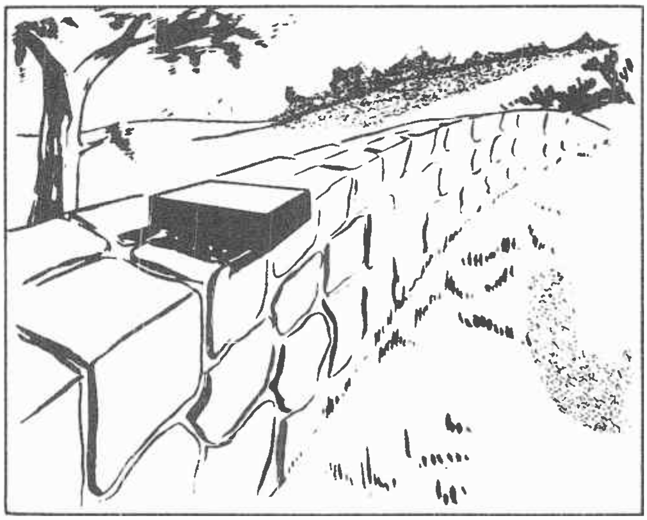

Fig.5. The brick, while at rest, has energy. It is energy due to position.

for him to create some unit of measurement by which he could compare the ability of the engine with that of a horse.

By actual measurement he found that a good draft horse could raise 330 pounds of water 100 feet a minute. By multiplying 330 pounds by the 100 feet, he determined that 33,000 foot-pounds was the amount of work done by a good horse in a minute. Thus he created a new unit of measurement -- the horsepower. The value of the horsepower remains unchanged until this day; one horsepower is equal to 33,000 foot-pounds.

If your weight is 150 pounds, and you climb a flight of stairs 14 feet high in 15 seconds, you have done 14 x 150 = 2100 foot-pounds of work in 15 seconds. Dividing 2100 foot-pounds by 15 seconds shows you have done work at the rate of 140 foot-pounds per second. Since one horsepower is equal to 33,000 foot-pounds per minute or 550 foot-pounds per second, you would have exerted 140/550 horsepower, which is equivalent to about one-quarter horsepower, in climbing the stairs.

If you climb the same flight of stairs in 30 seconds, you will have done exactly the same amount of work, but at only one-half the speed. Thus you would exert only half the power in climbing the stairs in 30 seconds that you would in climbing them in 15 seconds.

If you race up the stairs in 5 seconds, you will do no more work than before, and no less. But the power you exert would be much higher. The 2100 foot-pounds of work divided by 5 seconds shows that you would be working at the rate of 420 foot-pounds per second. This is equivalent to about three-quarters of a horsepower. A man is capable of exerting more than one horsepower for a very short period of time.

Section 6. ENERGY

"Energy" is another word we often use without being completely sure of its exact meaning. There are many kinds of energy. But in a mechanical sense, anything has energy when it has ability to do work. Energy, then, is the *ability* to do work.

Energy is usually divided into two general classes. One is called "potential" energy. The other is "kinetic" energy. It would be well to remember these two names because you will encounter them quite frequently in your study of radio and television. Kinetic energy is a very important factor in the study of vacuum tubes.

"Potential" energy is energy due to position. "Kinetic" energy is energy which is in motion. To explain this a little more fully we can take the example of a brick resting on top of a wall. To look at the brick you would not be able to detect any energy, but it has "potential" energy due to its position on top of the wall. If the brick should be pushed off the wall and fall to the ground, it could exert quite a force when it hit. So long as the brick rests on top of the wall its energy is potential. It has energy of position. The instant the

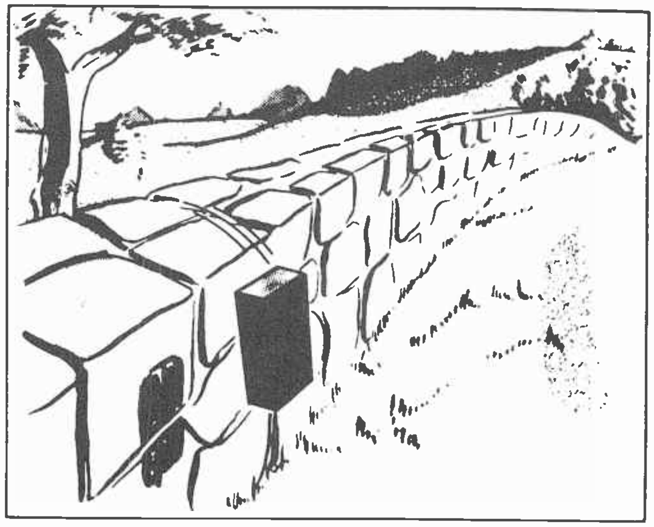

Fig.6. In falling, the brick's energy becomes kinetic.

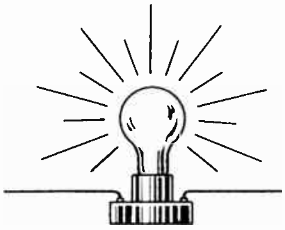

Fig.7. 200 watts power is consumed in the lamp when 2 amperes flow through it under a pressure of 100 volts.

brick left the top of the wall and started to fall, it was in motion. Its energy was then changed from potential energy to kinetic energy.

Another good example of the difference between potential energy and kinetic energy is that demonstrated by the action of a pile driver. A pile driver is a huge machine which is used to drive long piles into the ground for use in the building of bridges and trestle work, and in preparing foundations for large buildings. Essentially, a pile driver is a machine which lifts a heavy weight, then allows it to fall and strike the end of the pile which is being driven. When the heavy weight, or hammer, is raised and is at rest, its energy is potential. It is energy due to position. It is in position to strike a heavy blow. The instant the hammer begins moving downward, the potential energy of the hammer is changed into kinetic energy.

Section 7. POWER IN MOVING ELECTRICITY

In electricity which is moving we have a force capable of doing many kinds of work. It also does work at varying rates of speed, which means at varying powers. When electromotive force changes into heat we have accomplished one kind of work: electrical energy is changed into heat energy, or thermal energy.

If electromotive force changes the chemical make-up, or arrangement of substances in which it acts, we have accomplished another kind of work: the electrical energy has been changed into chemical energy.

If the electromotive force causes a motor to run, we accomplish still another kind of work: the electrical energy is changed into mechanical energy, or into motion of machinery. In every case we find that the electromotive force or electrical energy, does work only when it changes to some other form of force or energy. So long as it remains electromotive force, no work is done.

Since work can be done only when there is a change from electrical energy to some other form, it follows that we must introduce into the path of moving electricity something which causes a change of energy, or something which changes the electromotive force into some other kind of force. If we place resistance in the path of the electricity, or in the electrical circuit, the resistance is the thing that makes the moving electricity do work. In this case, the work generates heat. There are many other ways in which electricity can be made to do work, but for the moment we will confine our studies to this one.

Section 8. VOLTAGE, AMPERES AND POWER

We have already mentioned that mechanical work can be measured by multiplying the number of feet an object is raised by the number of pounds the object weighs. This gives us the amount of work in foot-pounds. We have also shown that mechanical power can be measured as so many foot-pounds of work per second of time. This is the same as saying that mechanical power can be measured as the number of feet of elevation times the number of pounds raised to that elevation per second.

Now we want a similar measure for electrical power. This means a unit to measure the rate at which the electrical current will do work.

First we must find some quality of electricity which is similar to the number of feet through which a weight is lifted. This, of course is not hard to do. We have already seen that electrical pressure is similar to the weight of water which has been raised to a height. Instead of measuring the number of feet through which an object is raised, as in the case of mechanical power, we can substitute the difference of electrical potential -- the voltage.

Next we must find some electrical quantity which is similar to the pounds per second in mechanics. A pound of any material in mechanics is considered a definite quantity of that material. In electricity we already have such a ready made quantity. The *ampere*. The ampere is the rate of current flow. It represents a definite amount of electricity which passes any given point in a second of time.

In mechanics we multiply the distance in feet by the weight per second of time to obtain the power. In electrical work we do exactly the same thing. We multiply the potential difference of the rate of current flow. In other words, we multiply the voltage by the amperes to obtain the power.

Here is a comparison of our definitions for mechanical power and for electrical power:

current and the letter *R* for resistance when writing down anything about an electrical circuit. We also use one of the letters of the alphabet as a symbol for power. As you have probably anticipated, we use the letter *P*. Since the power in watts in an electrical circuit is equal to the voltage in volts times the current in amperes we can shorten the formula by substituting the letter symbols. The formula would then be like this:

$$P = EI$$

Of course, we could change the formula to look like this:

$$P = IE$$

Mechanical power = Feet of difference in height x pounds per second.

Electrical power = Volts of difference in potential x current per second.

Electrical power = Volts x Amperes.

Section 9. THE UNIT OF ELECTRICAL POWER

We have a unit for measuring the difference of potential between any two points in an electrical circuit. We have a unit for measuring the rate of current flow. And we also have a unit for measuring the resistance which any conductor presents to the flow of electrical current. Now we need a unit for measuring electrical power.

The unit of electrical power is based on the amount of power which will keep one ampere of current flowing at a potential difference of one volt. In any part of an electrical circuit which carries one ampere at a potential difference of one volt we will be using eleetrical power at this unit rate. The name given to this unit of electrical power is the *watt*. It was named in honor of James Watt, the inventor of the steam engine.

We may say that one watt is the power which must be used continuously to keep current flowing at the rate of one ampere through a part of a circuit where one volt of electromotive force is changing to some other kind of force and where the current is one ampere.

We have already seen how we substitute the letter *E* for voltage, the letter *I* for

and it would mean exactly the same thing. It makes no difference whether we multiply the voltage by the amperage, or the amperes by the volts. The result is the same in either case.

When we know the number of amperes of current and the number of volts of voltage we merely multiply the two together and that gives us the number of watts of power being used. In Fig. 7 we see an electric lamp through which is flowing 2 amperes of current under a pressure of 100 volts. This can be said another way. The resistance of the lamp is such that it takes 100 volts of pressure to force 2 amperes of current through it. It takes electrical power to force the current through the resistance. The power it takes is determined by multiplying the voltage by the amperes, in this case, multiplying 100 by 2. This gives us a total of 200 watts. In other words, 200 watts of electrical power are being used when it takes 100 volts to force 2 amperes of current through the resistance of the lamp.

There is a voltage *drop* across the lamp. We have mentioned before that whenever current flows through a resistance there is always a voltage drop. This means that electrical power is being used. In the case of the lamp, the energy of the electromotive force is changed into another kind

100 VOLTS X 2 AMPERES = 200 WATTS

100 VOLTS ÷ 2 AMPERES = 50 OHMS

Fig.8.

of energy -- it is changed into heat. It is not necessary to go into a discussion at this time of the changing of energy from one form to another, but this is mentioned in passing in case you should wonder what physical action was taking place when the voltage was *dropped*, or lost.

Now before we go any further, we will pause briefly and make certain we fully understand the entire electrical action which is taking place in the lamp when current is flowing through it. We can determine everything we want to know about the electrical action by using Ohm's Law (E = IR) or the Power Formula (P = EI).

We do not yet know the resistance of the lamp. Should we need to know that, it can be found by dividing the 100 volts by the 2 amperes, in which case we come up with the answer: 50 ohms. Now we know all the essential facts about the lamp, and the electrical elements which concern it.

Volts	=	100
Amperes	=	2
Watts	=	200
Ohms	=	50

These four electrical units are present in every electrical device when current is flowing through it. If we know any two of them we can use either Ohm's Law or the Power Formula to find the other two.

If we know the voltage and current we can find the wattage, or power, by multiplying the two together. We can find the resistance by dividing the voltage by the current. (See Fig. 8.)

If we know the resistance and the current we can find the voltage by multiplying the two together to learn the voltage. In this case we would multiply 2 by 50 and obtain 100. Then when we knew the voltage we could multiply that by the current and obtain the power. (See Fig. 9.)

But, you might say, suppose we knew the value of the power and the value of the current. How, then, could we obtain the other values?

This is almost as simple. Just as in the case of Ohm's Law, which could be written in three forms, so we can also write the Power Formula in three forms. If you are familiar with algebra you have probably figured this out for yourself long ago. You merely rearrange the various values to suit your needs. But if you do not know algebra we will give you the other two forms, which you can easily remember.

$$P = EI$$

can also be written:

$$E = \frac{P}{I} \quad \text{and} \quad I = \frac{P}{E}$$

In Ohm's Law we said that an easy way to remember the various forms was merely to remember that the *E* was either by itself to one side of the equals sign, or was above the division line on the other side of the equals sign. In the case of the Power Formula the *P* is either by itself on one side of the equals sign, or is above the division line on the other side of the equals sign.

We will again take the case of our lamp and see how our formulas work out for us when we know the value of the power and that of the current. Since we know these two values, the next thing we should try to find out is the value of the voltage. To do this we merely divide the value of the power by

50 OHMS X 2 AMPERES = 100 VOLTS

100 VOLTS X 2 AMPERES = 200 WATTS

Fig.9.

200 WATTS ÷ 2 AMPERES = 100 VOLTS

100 VOLTS ÷ 2 AMPERES = 50 OHMS

Fig. 10.

the value of the current. (See Fig. 10.) This gives us the voltage, 100 volts. The next step is to find the resistance. By using Ohm's Law we merely divide the voltage by the current and obtain the resistance in ohms, 50 ohms.

If, instead of knowing the value of the power and the value of the current, you know the value of the power and the value of the voltage, you will solve your problem in very much the same way. The only difference is that you will divide the power by the voltage to obtain the current rather than dividing the power by the current to obtain the voltage. (See Fig. 11.)

Now you may say that so far everything is fine, and not too difficult. But suppose both the voltage and the current is unknown, which is often the case. All that is known is the value of the power and the value of the resistance.

If you are familiar with the rules of algebra you will be able to quickly answer this question for yourself. The problem can be readily worked out by simple rearrangement. But it would not be fair to you for us to assume that you know algebra and let it go at that. All too often, algebra as it is taught in many of our schools, is made so dry and uninteresting that many students simply never understand it. This is very unfortunate. Especially for the technical man. Algebra can be extremely useful to any man in technical work, particularly radio and television, and there is no excuse for any teacher making it a dull subject. Actually, algebra is, or should be, a live and intensely interesting subject. It deals with natural physical laws -- rules laid down by Mother Nature herself, and the only reason it is ever uninteresting is because it is so often taught by persons who do not themselves fully understand what it is all about.

It is not absolutely essential for you to know algebra to understand this course. But if you do know it, the course will be much easier for you.

Let us see now just how we go about the problem if we know only the values of the power and the resistance. There is another form of the power formula which is obtained by combining the Ohm's Law formula and the Power Formula. It is written:

$$I^2 = \frac{P}{R}$$

This means that if we divide the value of the power in watts by the value of the resistance in ohms we will come up with a quantity which is equivalent to the square of the current. That is, we will come up with a value which is equal to the current multiplied by itself.

Let us see just how we do this. We already know that the power is equal to:

$$P = EI$$

More than this, by Ohm's Law, we know that *E*, or the voltage, is also equal to the current multiplied by the resistance, or by the formula:

$$E = IR$$

Since *E* is equal to *IR*, suppose we substitute for the *E* in the power formula its equivalent *IR*. Then the power formula would look like this:

$$P = (IR)I$$

What this means is that the power is equal to the current multiplied by the resistance,

200 WATTS ÷ 100 VOLTS = 2 AMPERES

100 VOLTS ÷ 2 AMPERES = 50 OHMS

Fig. 11.

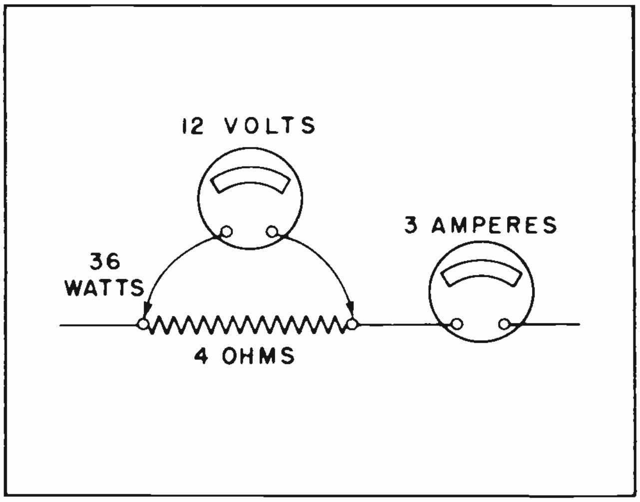

Fig.12. The relationship among volts, amperes, ohms and watts.

and then again multiplied by the current. In the case of our lamp we could show how this is true by:

P (200 watts) = I (2 amps) x R (50 ohms) x I (2 amps)

This could then be written:

$$200 = 2 \times 50 \times 2$$

And by common arithmetic, we know this is true. We can go a step further. When any quantity is multiplied by itself we say it is *squared*. We could show the square of the current like this:

$$I \times I = I^2$$

Now we can again rewrite our power formula:

$P = (IR)I$ is also equal to:

$P = IRI$, which is also equal to

$P = I^2R$.

This last form of the formula is one that is very, very frequently used in electrical work. It means that the power is always equal to the square of the current multiplied by the resistance. The reason it is used so often is that so frequently we know the value of the resistance and the current, and by using this formula we can find the value of the power directly without the necessity for also calculating the value of the voltage.

It would be a very smart thing to obtain a little notebook and jot down in it these various formulas so you will have them handy when you want them. You can use the notebook until you know the formulas so well that you can throw the notebook away. You will be using the formulas so much in your work that you will soon know them without any conscious effort at memorizing them.

Now let us see just how we obtain the formula

$$I^2 = \frac{P}{R}$$

which we need to know in order to obtain the value of the current when we know only the values of the power and the resistance.

We start with $P = I^2R$, which we have just learned how to obtain. Like any other formula which is divided by an equals sign it can assume several forms. We have already seen how the Ohm's Law formula can assume three forms, and the power formula $P = EI$ can assume three forms. In the same manner the formula $P = I^2R$, which actually is another form of the power formula, can assume three forms.

$P = I^2R$ can also be written

$R = \frac{P}{I^2}$ and $I^2 = \frac{P}{R}$

It is this last form that we would use to learn the value of the current when we know

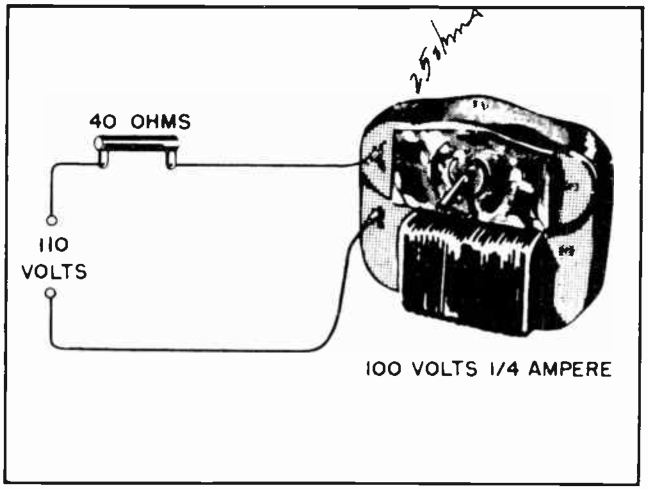

Fig.13. Power is consumed in every part of a circuit.

the power and the resistance. We will now see just how it fits our problem. We know the value of the power used by the lamp is 200 watts and the resistance is 50 ohms. We could set this up in the formula like this:

$$I^2 = \frac{200}{50}$$

Then by simple arithmetic we determine that I^2 is equal to 4. All we have to do now is find the *square root* of 4, which is 2.

So we find again that by use of the various forms of the formulas we can find all the values; power, resistance, voltage or current, if we know any two of the values.

All these formulas, and the various forms of the formulas, may seem a little bewildering to you at this time. Actually they are by no means as bewildering as they seem. It is not at all essential that you know, or remember, all the various forms we have shown you. We have merely gone through them step by step so you will be familiar with them all. Then you can select the particular one you need to use in the situation where you need to use it. At the end of this lesson is shown the various forms of the formulas which should be noted down for future reference.

There is another form of the power formula which should be mentioned. It is obtained from the basic Power Formula and Ohm's Law in much the same manner as the form we have just mentioned. This is used to obtain the voltage when only the values of the power and resistance is known. It is written:

$$E^2 = PR$$

Section 10. POWER CONSUMED IN ELECTRICAL DEVICES

Power is consumed in every part of an electrical circuit. We have already mentioned that resistance is present in some measure in every electrical conductor. And whenever current flows through a resistance, power will be consumed. The amount of power consumed will depend upon the values of the current and the resistance. The power will be equal to the square of the current multiplied by the resistance. From this it can be seen that doubling the amount of current through a resistance will increase the power consumption four times. But doubling the value of the resistance merely doubles the power consumption, provided the current remains the same.

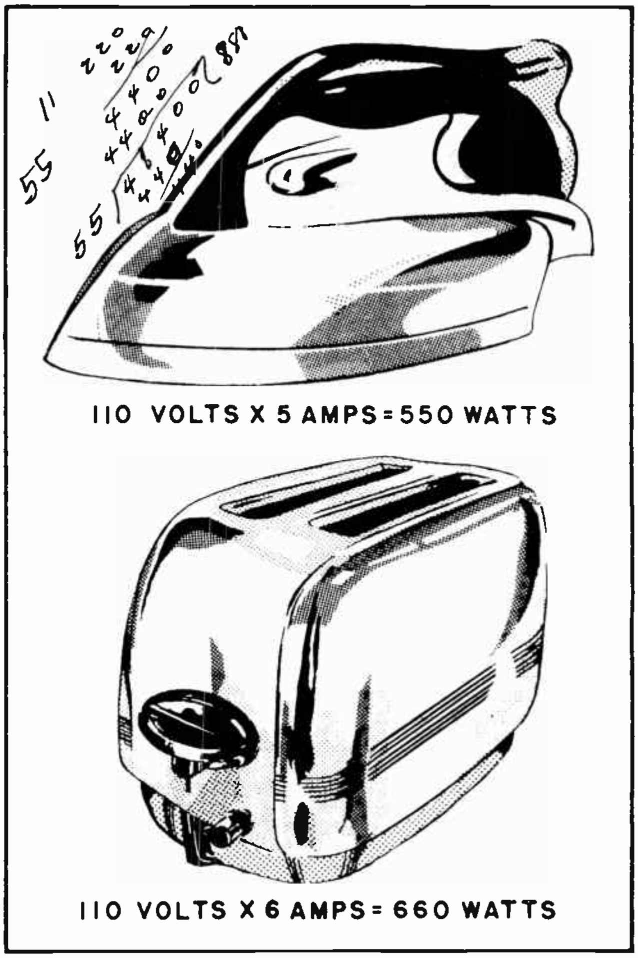

Fig.14. Power in watts is equal to volts times amperes.

Fig. 12 shows graphically the relationship among the four main elements of an electrical circuit. It shows the voltage which is dropped across a resistor, the current which is flowing in the circuit, the resistance in ohms of the resistor, and the power consumption in watts. It would be a good exercise for you to use your knowledge of Ohm's Law and the Power Formula to check these values and see if they are correct.

Fig. 13 shows that power is consumed in more than one part of a circuit. There is a voltage drop across the resistor, and another voltage drop across the motor. It would be a good problem for you to find the value of the resistance of the motor, the amount of power consumed in it, the voltage drop across the resistor and the power consumed in the resistor. As a hint it should be remembered that the current is the same in all parts of a series circuit.

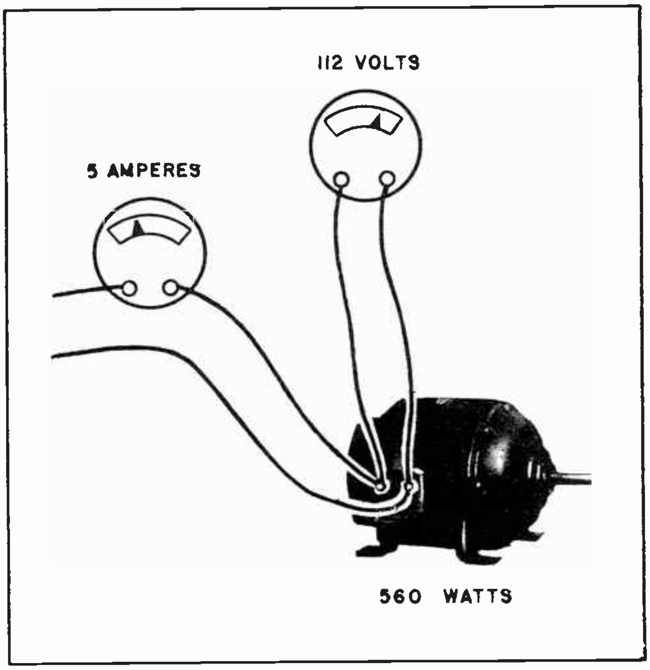

Fig.15. Measuring power with an ammeter and a voltmeter.

Fig. 14 shows two very common types of household appliances, an electric flatiron and a bread toaster. The wattage values are typical for appliances of these kinds. To exercise your knowledge of Ohm's Law, it would be a good idea for you to figure out the resistance of each of these appliances. If you feel up to tackling a little more difficult problem it might be a good idea to see just how much current would flow through each of these appliances if the voltage should be raised to 125 volts. If you tackle this problem you should also calculate the amount of power which will be consumed in each appliance when the voltage is raised 15 volts. You will probably be a little surprised at your answer. You can determine the correctness of your answer by cross checking.

Section 11. MEASURING ELECTRICAL POWER

The power consumed in any electrical device, or in any part of an electrical circuit is measured by determining the voltage across that part of the circuit and the current through it. In Fig. 13, for example, we could not find the power consumed in the motor by multiplying the current through the motor by the voltage from the source (110). The power consumed in the motor is found by multiplying the voltage across the motor itself (100 volts) by the current through it.

In the same manner, the power consumed in the resistor of Fig. 13 is found by multiplying the voltage across it by the current through it, not by the voltage from the source multiplied by the current through it.

It can be readily seen that we would come up with some absurd figures if we multiplied the current through a device by the voltage of the source. This can be clearly seen by referring back to Fig. 13 again and seeing what would happen there should we try to determine the power consumption by multiplying the voltage at the source by the current through the device. There we have a series circuit. We know the current is the same in all parts of a series circuit. Suppose we multiply the 110 volts of the source by the 1/4 ampere current through the motor. We would come up with the figure 27.5 watts of power consumed in the motor.

Now we will take up the case of the resistor. Since it is in series it will have the same current through it, 1/4 ampere. Multiplying this by the voltage of the source we again come up with the same amount of power, 27.5 watts. This is obviously incorrect because we cannot make our figures check by using the other forms of Ohm's Law and the Power Formula.

To repeat: The power in any device is determined by using the values applying to

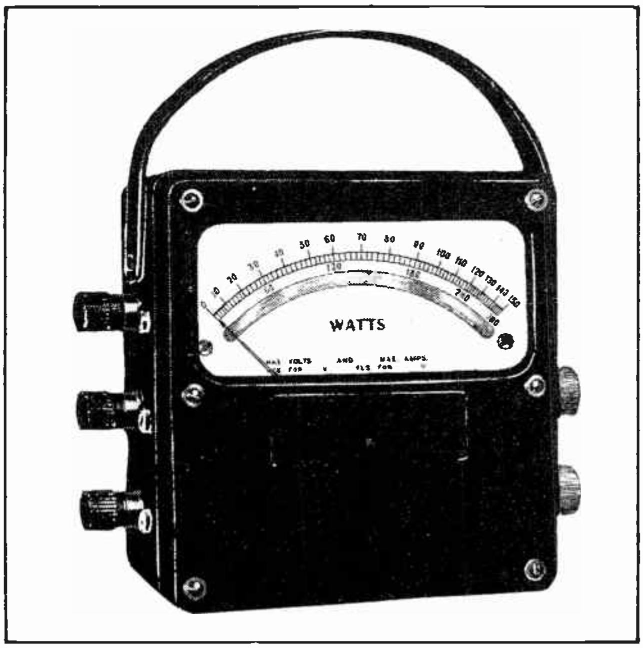

Fig.16. A Wattmeter, used for direct measurement of power.

1/1,000,000	1/1000	Unit	1000 times	1,000,000 times
Microwatt	Milliwatt	Watt	Kilowatt	Megwatt
Microampere	Milliampere	Ampere		
Microvolt	Millivolt	Volt	Kilovolt	
		Ohm		Megohm
		Cycle	Kilocycle	Megacycle

that particular part of the circuit, without reference to any other part of the circuit.

Fig. 15 shows one method for determining the amount of power used in an appliance of any kind. There we see an ammeter used in series with the motor to determine the value of current flowing in it, and a voltmeter connected across the motor to measure the voltage across it. The readings of the ammeter and the voltmeter are then multiplied together to give the value of the power consumed.

Instead of using a separate voltmeter and ammeter as in Fig. 15 to measure the watts used in an appliance we could use a single instrument called a wattmeter to read the power. There are several types of wattmeters in common use. Each manufacturer has his own idea of exactly how they should look. Fig. 16 illustrates one type.

Section 12. LARGE AND SMALL UNITS

So far we have discussed ohms, volts, amperes and watts. In the case of ohms we have mentioned that the values of resistance frequently are so high that it is much more convenient to use a large unit, the megohm. The same thing is true with ampere, volts, and watts. In radio and television work it is a very common practice to work with units much larger than the standard ones, and also much smaller. For the larger units it is the standard practice to prefix the unit with kilo- for 1000 times, or meg- for 1,000,000 times. The standard practice is to prefix the smaller units with milli- for one-thousandth, and micro- for one millionth. This can be understood a little more clearly by a study of the table above.

Section 13. CONVERTING ELECTRICAL POWER INTO MECHANICAL POWER

It is often convenient to know just how much mechanical power is equivalent to any given amount of electrical power. And, of course the reverse is also true.

It has been determined that one horsepower of mechanical power will do work at the same rate as 746 watts of electrical power. This means that 746 watts is equal to one horsepower so far as ability to do work is concerned. The power equivalents can be shown in this manner:

746 watts = 1 horsepower

1 horsepower = 0.746 kilowatt or 746 watts

1 kilowatt = $\frac{1000}{746}$ or 1.34 horsepower; approx. 1-1/3 hp.

(*Reference Notes on the page following*)

NOTES FOR REFERENCE

Work usually consists of moving something from place to place. It is measured by the quantity moved, and by the height to which it is raised, or the force against which it is moved.

Power is a measure of the speed with which work is done, but not of the quantity of work unless the time is specified. For any given amount of work done, the power increases as the time decreases, and vice versa.

Work may be measured in foot-pounds.

One horsepower is equal to work done at the rate of 33,000 foot-pounds per minute, or 550 foot-pounds per second.

Electromotive force does work only when it changes to some other form of energy.

Some useful formulas to remember:

$$E = IR \qquad P = EI \qquad P = I^2R \qquad E^2 = PR$$

$$I = \frac{E}{R} \qquad E = \frac{P}{I} \qquad I^2 = \frac{P}{R} \qquad P = \frac{E^2}{R}$$

$$R = \frac{E}{I} \qquad I = \frac{P}{E} \qquad R = \frac{P}{I^2} \qquad R = \frac{E^2}{P}$$

1 HP = 746 watts.

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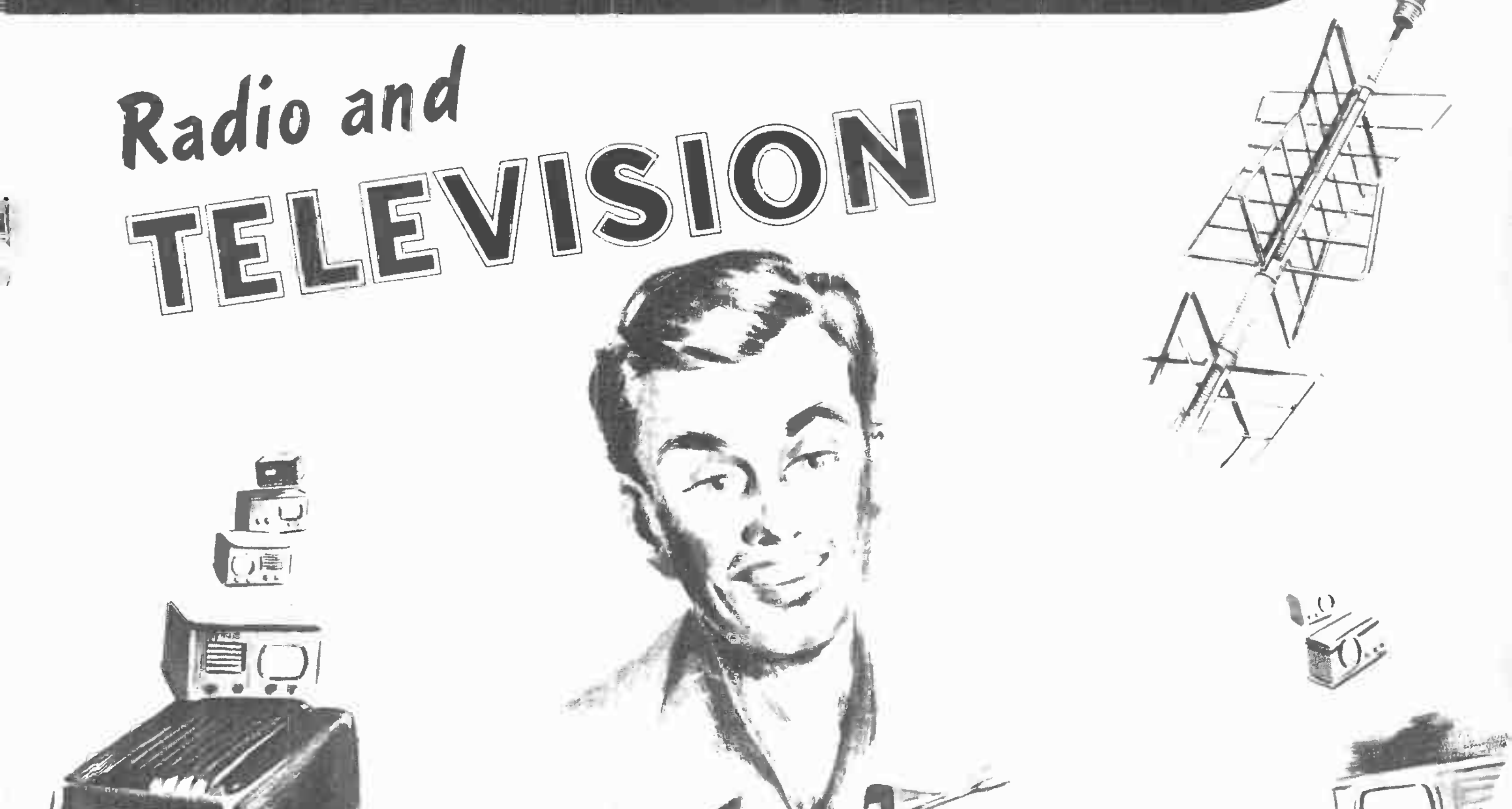

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TECHNICAL TRAINING SERVICE

REVISED 1952

RADIO TELEVISION

DIRECT CURRENT AND ALTERNATING CURRENT

Contents: Introduction - Currents in Radio and Television - Direct Current - Direction of Current Flow - The Dry Cell - Dry Cell Construction - Dry Cell Performance - Connections of Dry Cells - Other Sources of Direct Current - Alternating Current - The Sine Wave - Opposition to the Flow of Alternating Current - Notes for Reference.

Section 1. INTRODUCTION

In most of the discussions so far in our studies we have treated electricity as though it flowed through a conductor in the same direction at all times. There are many electrical circuits where this is true. Typical of these are the electrical systems commonly found in automobiles.

The storage battery is the heart of the automotive electrical system. Because the storage battery raises the electrical potential at one terminal to a value somewhat above the other, and maintains this potential difference, the current will always flow from one terminal, through the entire electrical system, then back to the other terminal of the battery. Since this current flows in the same direction at all times, it is called *direct current*.

But there is another kind of electrical current -- one which we have mentioned

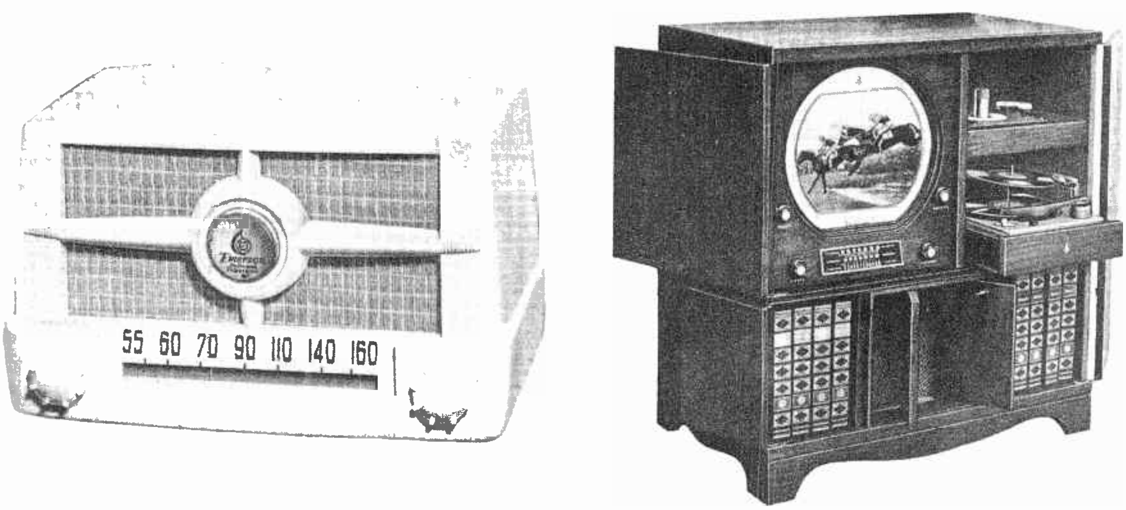

Fig. 1. Every type of radio or television uses both direct current and alternating current. (Courtesy of Emerson Radio and Phonograph Corporation.)

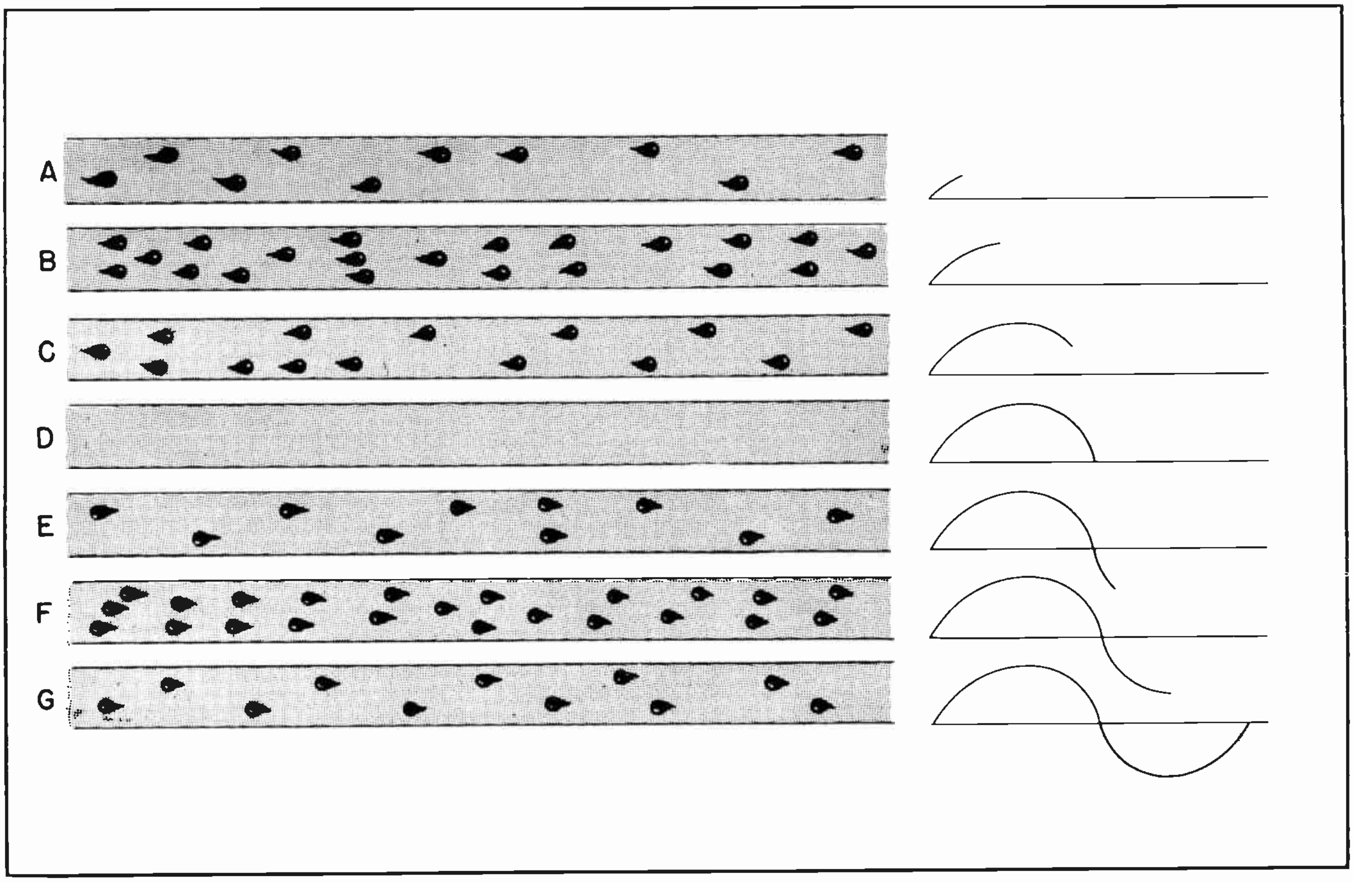

Fig.2. Alternating current flows first in one direction, then in the other. The value of the current is constantly changing.

several times during the course of our studies. This other kind is called *alternating current.* Alternating current is current which flows in one direction for a period of time, then reverses itself and flows in the other direction. Alternating current is continually reversing itself. Moving first in one direction, then in the other.

Some alternating current reverses itself at relatively long intervals. The alternating current which is used for power in some of the steel mills, and at a few other places, reverses itself only 50 times each second. This means that it goes through 25 complete cycles each second. The current will start from zero and build up gradually to a maximum value in one direction, then diminish until it ceases to flow in that direction. Then it will reverse and move in the opposite direction. Again it will build up to a maximum value, then diminish to zero. Then again reverse itself.

This action is shown graphically in Fig. 2. At *A* there is a small movement of the electrons toward the right in the conductor. A graph at the extreme right shows the rise of the current. At *B* the number of electrons which are moving toward the right has increased. The increase in the movement of electrons is also shown by the graph at the extreme right which has become higher as the electron movement increased. The graph of *B* shows the movement of electrons to be maximum at that instant. At *C* the movement of electrons through the conductor toward the right has decreased. There are not so many moving at *C* as were moving at *B*. The decrease in the movement of electrons is also shown at the right by the moving graph. The curve of the graph has turned downward, signifying a smaller movement of electrons.

At *D* there are no electrons moving through the conductor in either direction. This condition is also shown by the graph. The curve has now reached the "Zero" line, or "Zero Axis".

At *E* the direction of electron movement has been reversed. The electrons are now moving toward the left. This condition is also shown by the graph at the right. The curve of the graph has continued downward so that it is now below the "zero" axis. At *F* the movement of electrons toward the left has continued, and has increased. This also is indicated by the curve of the graph which continued downward until it has reached the maximum position in that direction. We could say that it has reached the maximum point in the "negative" direction. In this case, "negative" means the opposite of the original direction.

At *G* the electron flow toward the left has decreased. This condition is reflected in the upward turning of the curve of the graph. The next condition would be a repeat of the situation at *D* where there was no movement of electrons in either direction. Then following that, the electrons would again start moving toward the right. This would be repeated over and over.

Section 2. CURRENTS IN RADIO AND TELEVISION

The importance of thoroughly understanding both direct current and alternating current cannot be over-emphasized. There is no such thing as a radio receiver, or a television receiver, which has only direct current circuits. Neither is there such a thing as a receiver which has only alternating current circuits. Every radio or television in existance uses both direct current circuits and alternating current circuits, and usually uses a lot of different circuits of each.

As an example of this, let us look for a moment at a typical table model radio receiver similar to the one shown in Fig. 1. The receiver will receive the power for its operation from the power lines of the local utility company. In most localities within the United States this power will be in the form of alternating current which is going through 60 complete cycles each second. About the only place in the radio receiver that 60-cycle A-C power can be used is to light up the filaments in the tubes and to light the pilot lamp. In many cases it will be necessary to change the voltage of the power before it can be used for either of these purposes.

Before the power from the utility company can be applied to any part of the vacuum tubes except the filaments, the alternating current must be changed into direct current. This is accomplished by a rectifier circuit such as we will be studying in a later lesson after we take up the actual study of vacuum tubes. So already we have found two kinds of current present in every radio receiver, even the small, so-called simpler types.

But this is not all. The radio frequencies which are picked up by the receiver are actually alternating currents with frequencies running up into the thousands of cycles each second. This is a different kind of alternating current from that which was received from the power company.

In the superheterodyne type of radio receiver, and that is the type which will be found in most common use, it is the practice to create another alternating current within the receiver itself. To do this, a special device called an "oscillator circuit" is brought into play. By the means of this special circuit, part of the direct current is again changed, this time into alternating current again, but with a frequency far higher than that supplied by the power company.

In this brief discussion, in which some new terms have been introduced, it has not been the intention to bewilder you with what might seem to be a complex maze of circuits. At first glance they will seem somewhat bewildering, but that is merely because you have not yet been prepared for them. To understand them, you must know something more about direct current and alternating current than you do now. It was to point out to you the importance of studying electrical currents and their particular peculiarities, that we have mentioned these things.

Section 3. DIRECT CURRENT

The first source of a continuous flow of direct current was the "voltaic pile" built by Volta in Italy shortly after the year 1800. It consisted of alternate layers of copper and zinc plates which were separated by an insulating substance soaked in sulphuric acid. The chemical action between the acid and the metal created a difference of potential between the two kinds of metal. This provided a continuous flow of electricity in an external circuit.

The old "Gravity" cell, or "crow's foot" battery, as it was much better known, was a modification of Volta's original "pile". It became the standard source of power in telephone and telegraph work, and continued

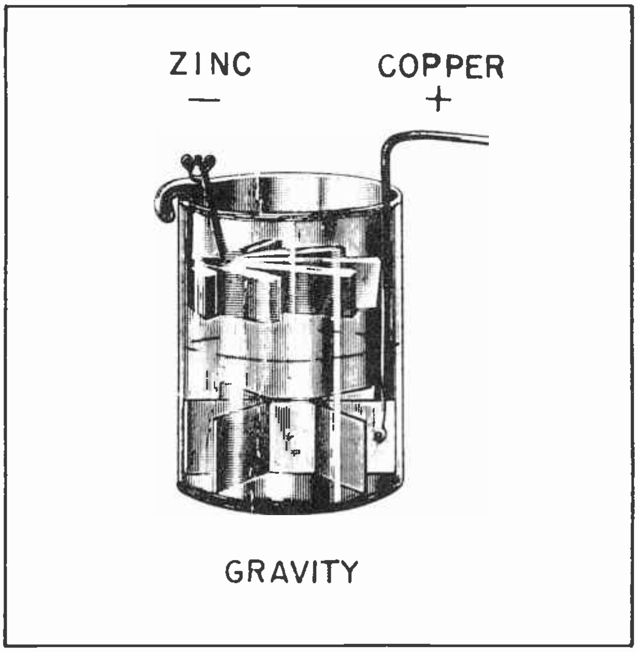

Fig.3. Gravity Cell.

to be an indispensable part of such systems until recent years. (See Fig. 3.)

The gravity cell consisted of a piece of heavy zinc built in such a form that it could rest securely on the top of an open glass jar while several thick fingers of zinc spread out in a symmetrical horizontal position. This arrangement would immerse the major portion of the zinc in the upper part of the electrolytic solution. In the bottom of the jar was a copper plate made of much thinner material.

The electrolytic solution might be any one of several materials. Originally the solution consisted of a diluted mixture of sulphuric acid and water. Later the use of copper sulphate, or "blue vitriol", became more common.

In making such a cell, a glass jar some six or seven inches in diameter and about eight or nine inches deep was secured. Then the copper plate was placed in the bottom of the jar. Any kind of copper would do, but for many years a piece of fabricated copper made into the shape shown in Fig. 3 could be readily obtained from a number of sources. It was preferred because of the large area of copper exposed to the action of the electrolyte. After the copper was placed in the bottom of the jar a small handful of copper sulphate crystals would be dropped into the jar. The crystals of copper sulphate would partially cover the copper plate. Then water would be poured into the jar until the level reached within an inch and a half of the top of the jar. Finally the "crow's foot" of zinc was placed on the upper edge of the jar so that the spreading fingers were immersed in the electrolytic solution.

The usefulness of such a cell lies in the fact that it is quite inexpensive and will last for months. In most telephone and telegraph work the circuits are "closed". This means there is current flowing in the circuits at all times. Most battery cells lose their strength very quickly under such conditions, but the gravity cell retains its full usefulness for several months. When it does become worn out it is only necessary to renew the crows foot, and possibly the electrolytic solution. The copper plates will last almost indefinitely, frequently for periods of more than a year. The jars, of course, can be used over and over for years if protected from breakage.

In the earlier days of telephone and telegraph communication, gravity cells were depended upon exclusively to furnish the electric power needed. Every railroad office, where there was a telegraph station, had its bank of gravity cells. All the local telephone offices likewise had their bank of cells. The main offices also had their main banks. In the earlier days, the telephone and telegraph lines led into many parts of the country where regular electrical power was not available locally, and the communication companies had to depend upon their own sources of power.

The gravity cells are still used in many places, but their use has declined in recent years. Electrical power is available nearly everywhere and it is possible now to obtain the power more cheaply from the power companies than from the cells.

Where the battery cells can remain in the same position and do not need to be moved around, the gravity cell provides an ideal source of electric power. It will continue to deliver a voltage and current for an extremely long period of time. Furthermore, even today, it is quite inexpensive to construct. But it has the disadvantage that it cannot be moved around. The electrolyte is corrosive, and if spilled on anything will eat into that substance. For this reason its use has declined. In most localities today, utility power is available at even lower cost than it can be obtained

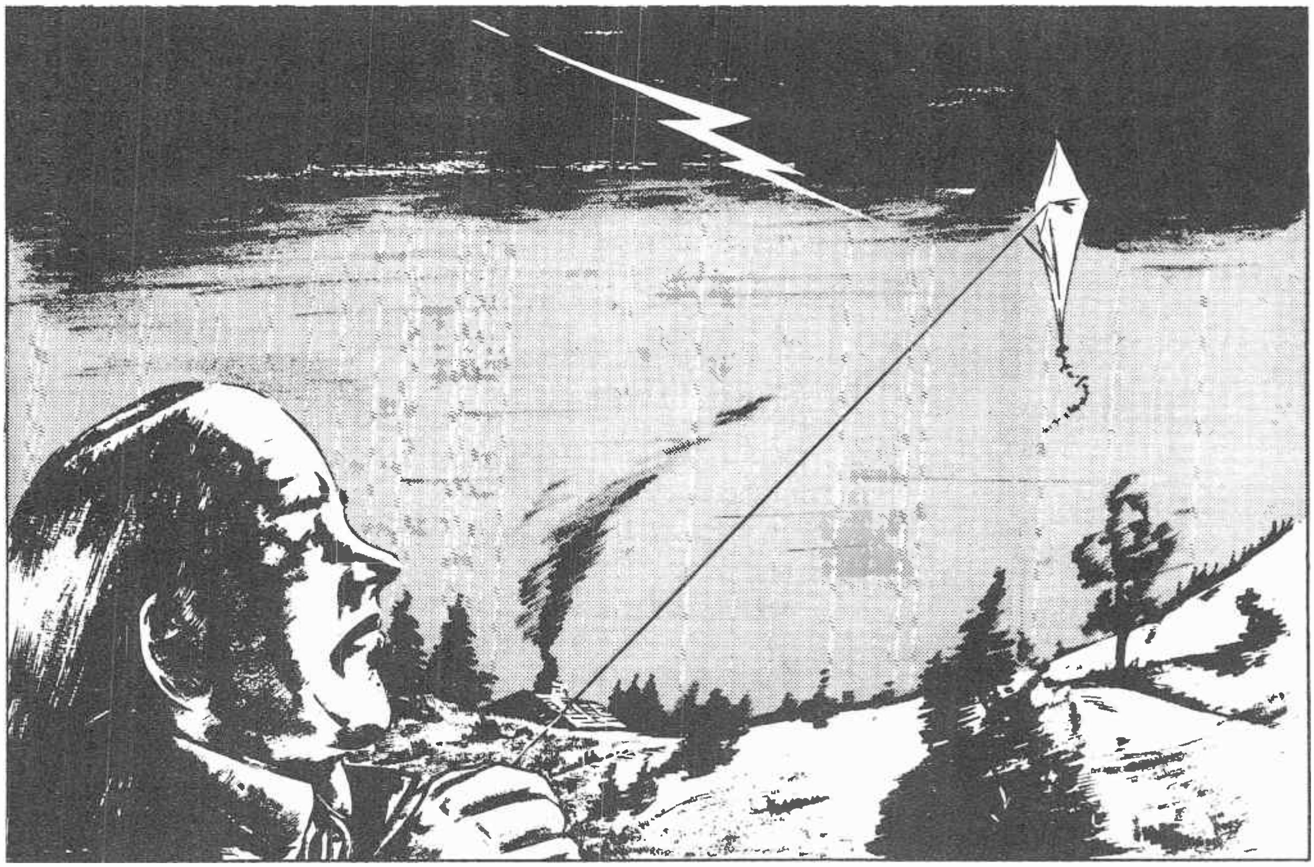

Fig.4. Benjamin Franklin proved that the lightning in the sky was a form of electricity.

from the gravity cell, and thus the need for a stationary source of battery cell power is not so great as it once was.

Section 4. DIRECTION OF CURRENT FLOW

In Fig. 3 it will be noted that there is a plus sign near the wire leading to the copper plate and a minus sign near the connection to the zinc plate. This means that the voltage at the copper plate will be "positive" with respect to the zinc plate. The difference in potential between the two plates is such that the copper will be positive and the zinc is "negative". The electrons will flow from the negative terminal of a battery cell, through the external circuit, and return to the positive terminal of the battery cell.

If you have had previous electrical experience, or have studied some of the older electrical books, you might be inclined to disagree with the assertion that electrical current flows from the negative to the positive. To avoid any confusion, it is well that we clear up this little point now before we go any further.

In the earlier days of electricity the experimenters became convinced that something was moving in the copper conductors which carried the electricity. But they did not know exactly what it was. Benjamin Franklin pictured electricity as being some kind of a fluid, but a kind that he was unable to describe precisely. Other experimenters had still other ideas. But all were agreed that something was moving, and moving in the form of a current.

Even after they were all agreed that something was moving they could not agree as to which direction the current was moving. No experiment which they could devise gave them any clue which could serve as a basis for determining definitely which direction the current was moving. These learned men knew that if they, with all their knowledge, could not determine which way the mysterious substance within the wires was moving to form a current, it would be very difficult to explain electrical current flow to others who did not have their knowledge.

Finally the learned men agreed among themselves that even though they could not prove

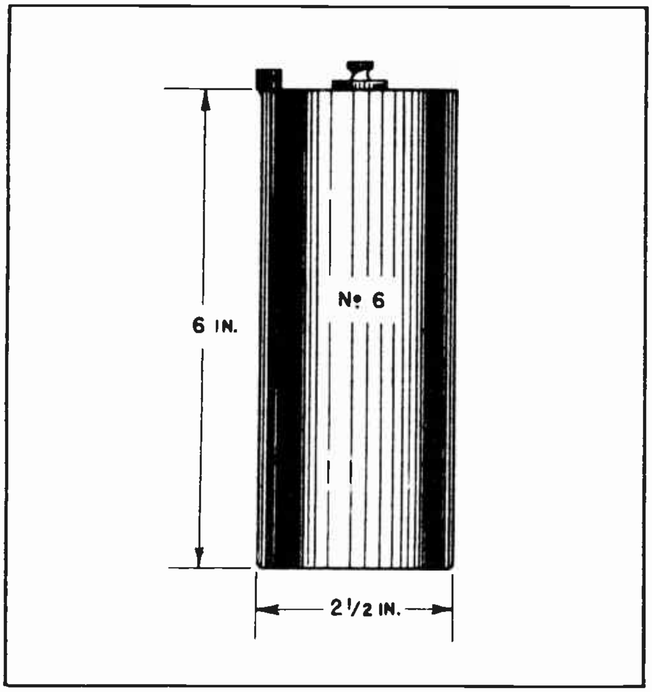

Fig.5. A No. 6 Dry Cell.

which way the current flowed, they would for convenience sake, assume that the electrical current flowed from the positive terminal of a battery, through the external circuit, and back to the negative terminal of the battery. For all practical purposes this assumption worked out all right. Many rules were formulated using this assumption. Hundreds of books were written -- yes, even thousands of them -- on the various phases of electrical work, and in all of them the assumption was that electrical current flowed from the positive to the negative. Everything in the electrical world was serene so far as current flow was concerned.

It was not until after the invention of the vacuum tube that electrical men discovered that the assumption of the earlier experimenters was wrong. Electrical current did *not* flow from the positive to the negative. Instead, it flowed in the opposite direction. Even so, they did little about it at the time. Too many books had been written, and were still in existence, which spoke of current flowing from positive to negative.

And so the situation remained for many years. Even the more learned electrical men, and physicists, who knew that the earlier assumption was wrong were forced to go along with the misconception because of the apparent inability of ever making any change. In every field, except that of radio, the older conception worked all right. And for many years radiomen were men apart from the other electrical workers. Because of their work with vacuum tubes, the radiomen were forced to accept the newer knowledge that electrical current actually flowed from negative to positive rather than the reverse.

After the beginning of the recent war, radiomen and other electrical workers were thrown together more and more frequently. Industrial uses of electronics came into existence. So did radar, sonar and several other electronic devices. No longer was it possible to pretend that electrical current flowed in the opposite direction from what was actually true. The electrical engineering societies, the radio engineering societies, the American Standards Association, The National Electrical Manufacturers Association, and the Army and Navy Technical staffs got together and decided it was time for a change. At first they decided that it was time to admit that electron flow was from negative to positive but that "conventional" current flow would be from positive to negative. This was admittedly a compromise to make it possible for the older electrical men and radiomen to work side by side in harmony without their conflicting training affecting their work.

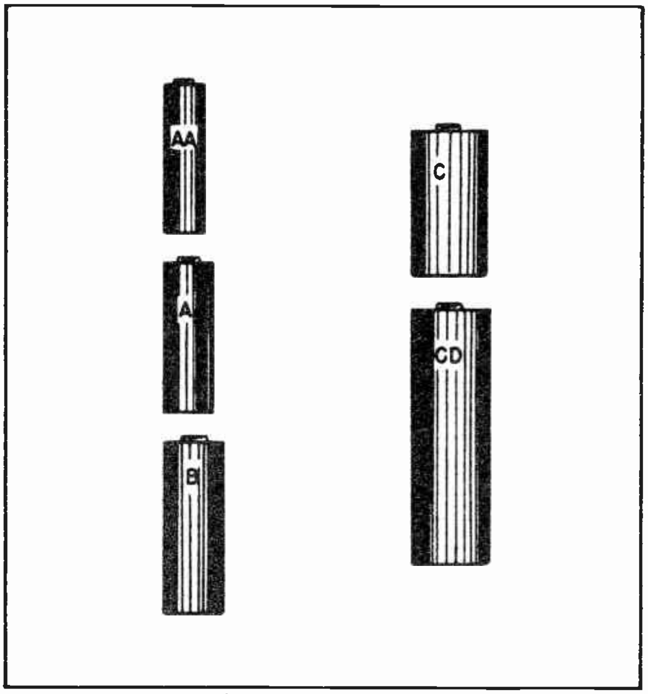

Fig.6. Relative sizes of dry cells.

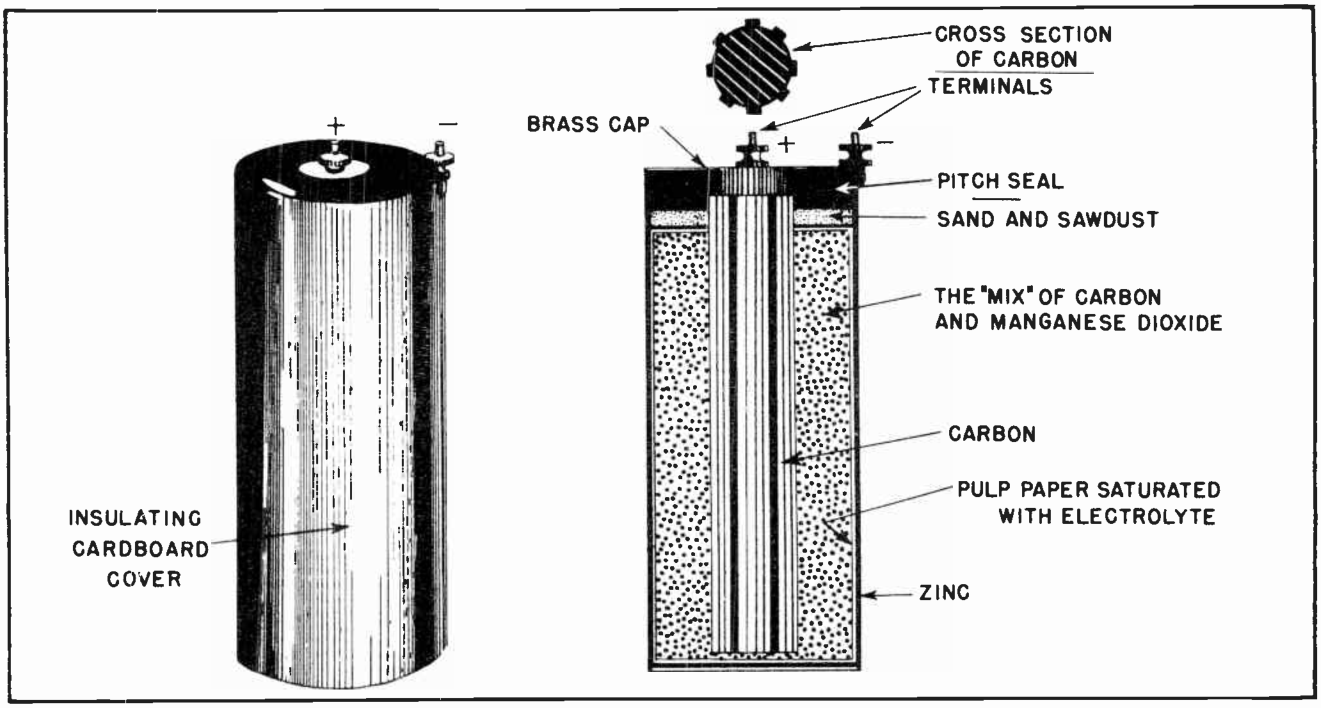

Fig. 7. Construction of a No. 6 Dry Cell.

This dual conception of electron flow and "conventional" current flow did help smooth things during a transition period when thousands of men new to electrical work were coming into the field. But it was not long before it was realized that some more permanent action would have to be taken. One by one the various engineering and technical societies have decided to drop all reference to "conventional" current flow, and admit that current flow and electron flow are one and the same thing, and that the flow is from the negative to the positive.

Section 5. THE DRY CELL

Electrical cells are still used in a number of ways in radio and television work. The most important from the standpoint of radio reception is the *dry cell*. Most of us are quite familiar with the use of dry cells in flashlights, and the lanterns used by railroad men for signaling.

In radio receivers they are commonly used to furnish the power to light the tube filaments and the voltage for the anode, or "plate" circuits of the tubes. The use of dry cells makes the receiver independent of the power company's power lines. Thus it can be carried anywhere -- on picnics, to the beach, the baseball park, the zoo, or anywhere else it strikes the user's fancy, and all the favorite programs can be brought in. Television receivers are also on the market which obtain all their power from self-contained dry cells.

A single dry cell provides an open-circuit voltage of 1.55 volts. But due to the internal resistance of the cell, the potential drops as soon as any current flows. Cells of various sizes are assembled into batteries whose voltage ratings are in multiples of 1½ volts. Common examples of such batteries which will be found in use in radio work are 4½-volt, 22½-volt, 45-volt, 90-volt and 135-volt. Since the advent of portable television receivers on the market, other special batteries of much higher voltage are being built. Probably the most common dry cell to most persons is the No. 6 cell shown in Fig. 5. This cell is cylindrical, measures 2½ inches in diameter and is 6 inches long. It weighs just under 2½ pounds. The dry cell is also made in many other physical sizes and shapes. But regardless of how long it is, or how big around it is, whether quite large or very small, its voltage is always the same. For all practical purposes the voltage output of a dry cell is always 1½ volts.

Section 6. DRY CELL CONSTRUCTION

Fig. 7 shows the details of the construction of a dry cell. The No. 6 dry cell is shown externally and internally in

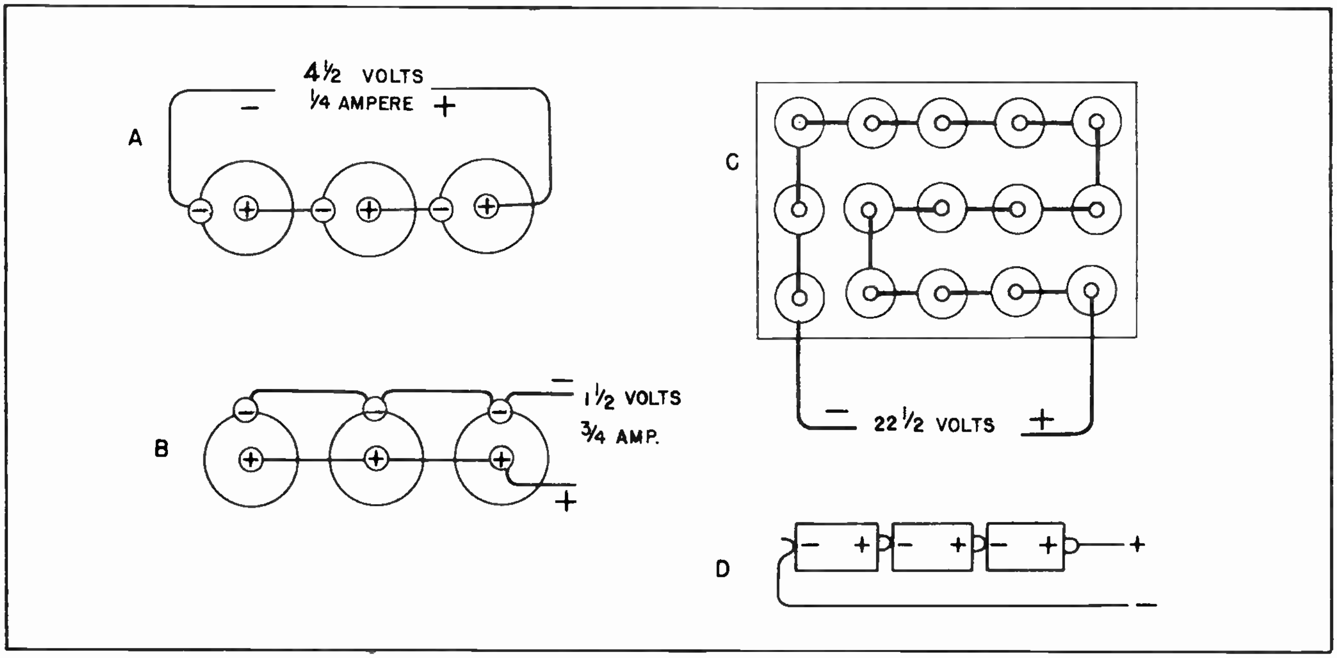

Fig.8. Series and parallel connected dry cells.

that illustration. The positive terminal consists of a carbon rod which extends almost all the way through the center of the cell. At one end of the carbon rod is a brass stud which is threaded. A knurled nut screws onto the threaded stud providing a means of connecting the external wires to the cell.

Around the carbon rod is a mixture of powdered carbon and black oxide of manganese. Black oxide of manganese is also called manganese dioxide. This "mix" is enclosed within a soft, absorbent pulp paper similar to blotting paper. The paper is wet with electrolyte. The electrolyte is a solution of sal ammoniac in water. Added to the electrolyte solution is some zinc chloride. The solution permeates both the paper and the mix. Around the outside of the paper is a zinc can. The zinc can forms the negative terminal of the dry cell. To the upper rim of the zinc can is attached another screw and knurled nut to which is attached the connecting wire to the outside circuit.

Construction of the smaller dry cells is quite similar. Instead of paper, many of the smaller cells use a cloth bag. Other slight changes are also made which will lighten the weight. Usually the smaller sizes are used where weight is an important item, especially in applications such as the portable radio.

Section 7. DRY CELL PERFORMANCE

The working ability of dry cells can be measured in ampere-hours. But the capacity measured in this manner is not a fixed quantity for any particular cell. The ampere-hours of a cell varies greatly, being largely dependent upon the circumstances under which the cell is used.

There is a difference in the number of ampere-hours a cell will deliver when it is used intermittently and when it is used continuously. By the same token, the number of ampere-hours a cell will deliver in intermittent service is no guide to the number it will deliver if used continuously. One cell might be better for intermittent service and another one might be better for continuous duty. For any dry cell there is one best rate of discharge in amperes at which it will deliver the greatest number of ampere-hours.

The open-circuit voltage of a new dry cell is approximately 1.5 volts. The open-circuit voltage drops during the life of the cell. When the capacity of the cell is about half gone, the voltage will drop to about one volt. As the cell is used still more, the voltage will drop to about 3/4 volt at the time when the cell is no longer of commercial value. When the open-circuit voltage has dropped to 3/4 volt, the voltage of the cell when it is connected to a load will be quite low. This is because the internal resistance of the cell increases as the cell becomes old, and as current tries to flow through the cell to a load the voltage will drop to a negligible value -- much lower than the open-circuit voltage when no current is flowing through the cell.

Section 8. CONNECTIONS OF DRY CELLS

Dry cells can be connected in either series or in parallel. The manner in which they are connected determines what the voltage and the current output of the connected cells will be. If the cells are connected in series, that is, the positive side of one cell to the negative side of the adjacent cell, the total voltage output of the connected cells will be equal to the number of cells multiplied by 1.5 volts. For example, if two cells are connected in series the total output voltage will be 2 x 1.5, or 3 volts. In like manner, if five cells are connected in series, the total output voltage will be 5 x 1.5 or 7.5 volts.

When dry cells are connected in series the total current which they will deliver will be no greater than that which could be delivered by one dry cell by itself. From this comes the saying that when dry cells are connected in series the voltage increases according to the number of cells, but the current remains the same.

The dry cells can be connected in parallel instead of being connected in series. An example of this is shown at *B* in Fig. 8. When dry cells are connected in parallel, all the positive terminals are connected together, and all the negative terminals are connected together. The output voltage of dry cells connected in parallel is no greater than that of a single cell, but the output current capacity has been increased according to the number of cells. There are a few places where primary cells are connected in parallel -- where the demand for current happens to be quite heavy for a short period of time. But in radio and television work dry cells are usually connected in series. Normally in this type of work it is desirable to obtain voltages which are as high as possible, and to meet this requirement it is imperative that the series connections be used.

Section 9. OTHER SOURCES OF DIRECT CURRENT

Probably 95% of all commercial electrical power is generated and distributed in the form of alternating current. But there are a few localities where the power companies still supply electrical power in the form of direct current. The central "Loop" district

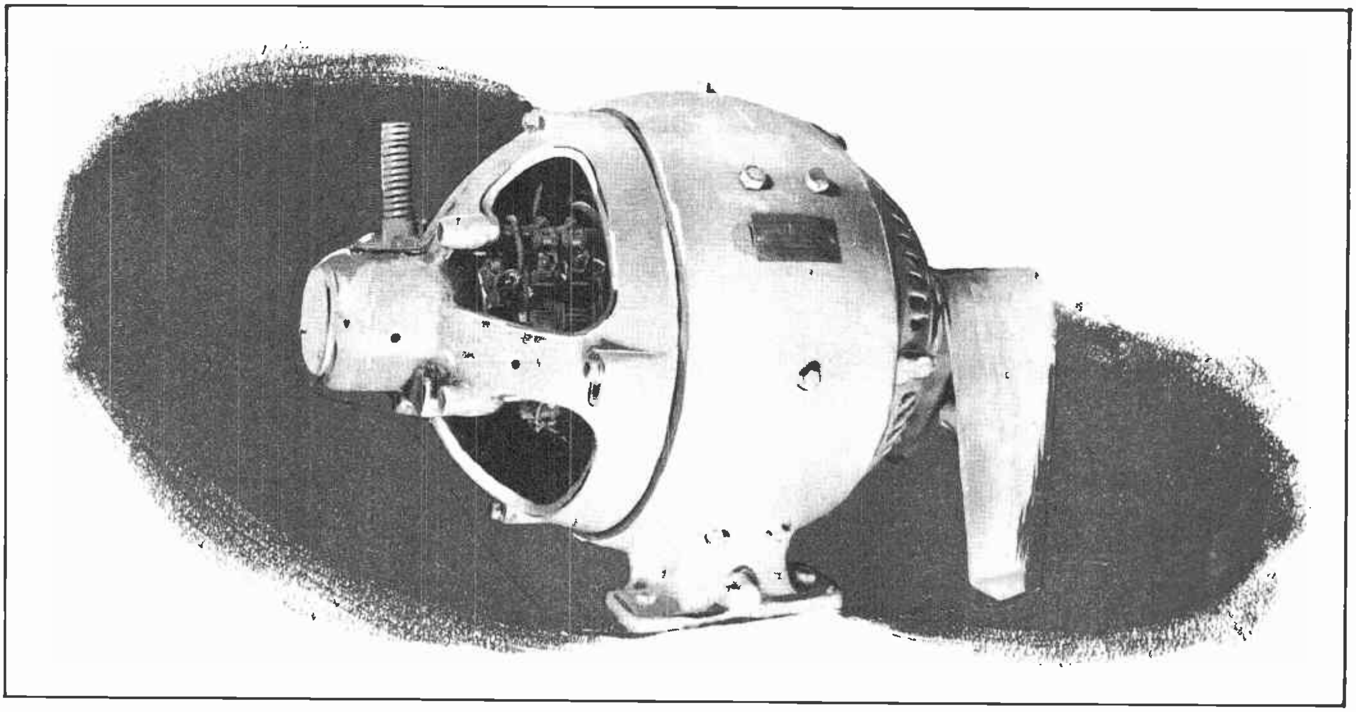

Fig.9. A Direct Current Generator.

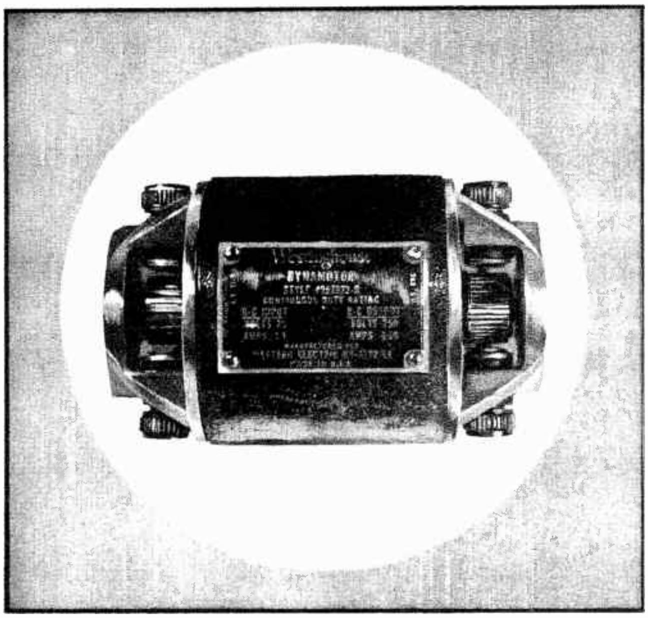

Fig.10. A Dynamotor.

of Chicago for example, is supplied with direct current. The same thing is true in the downtown business district in New York City. The reason is that these places were supplied with direct current very early -- even before it became practical to generate alternating current -- and because of the enormous amounts of money invested in direct current machinery, the power companies must continue to supply the direct current power to operate the machinery.

Because direct current has certain advantages over alternating current for a few specialized purposes, some factories manufacture their own direct current electricity or "convert" the power company's alternating current into direct current. Many municipal traction systems use direct current as a source of power for their trolley cars. Direct current has an advantage over alternating current for this purpose.

Where direct current is used in large amounts such as these, the power is generated by huge machines rather than by dry cell batteries. A picture of one of the large machines used to generate direct current power is shown in Fig. 9.

A direct current generator is essentially a machine which causes loops of wire to pass between strong magnets. The loops of wire passing through the magnetic lines of force will have induced within them electrical voltages. The value of the voltages will depend upon several things; the speed at which the wires are cutting across the lines of magnetic force, the number of loops in each wire, and the strength of the magnetic field.

Certain kinds of radio equipment depend for their power upon machines which are variously called "Dynamotor", "Genemotor" and "Motor-generator". Mobile radio units such as those used in police patrol cars, fire trucks, public utility emergency trucks, aircraft, motorboats, and similar moving vehicles, frequently depend upon such equipment for their power.

A dynamotor is essentially a machine with a rotating armature which carries a few turns of fairly heavy wire. These turns of wire are connected through a rotating device on one end of the armature, called a commutator, to the storage battery of the moving vehicle. These storage batteries usually deliver power at approximately 6 volts, which is far too low to operate most radio and television equipment.

The current from the storage batteries flows through the heavy winding on the dynamotor, and due to interacting magnetic forces, causes the armature of the dynamotor to rotate. In this respect, the dynamotor operates very much like a direct current motor.

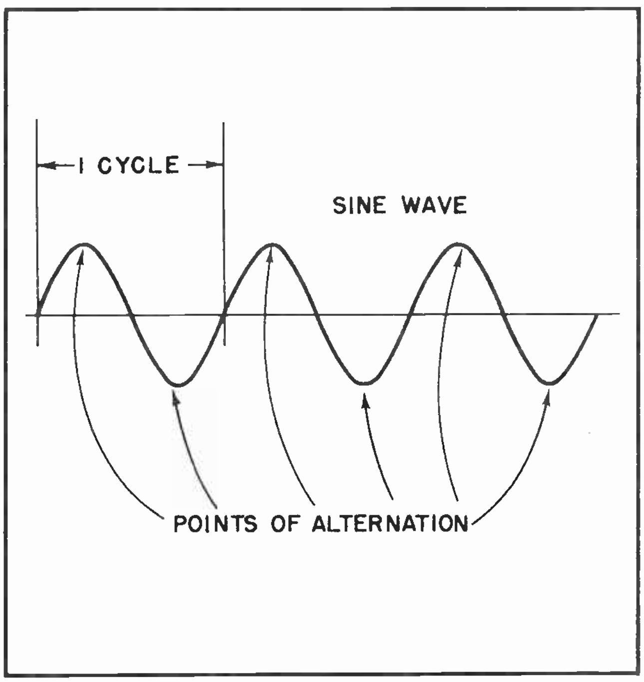

Fig.11. A graphical representation of alternating current flow.

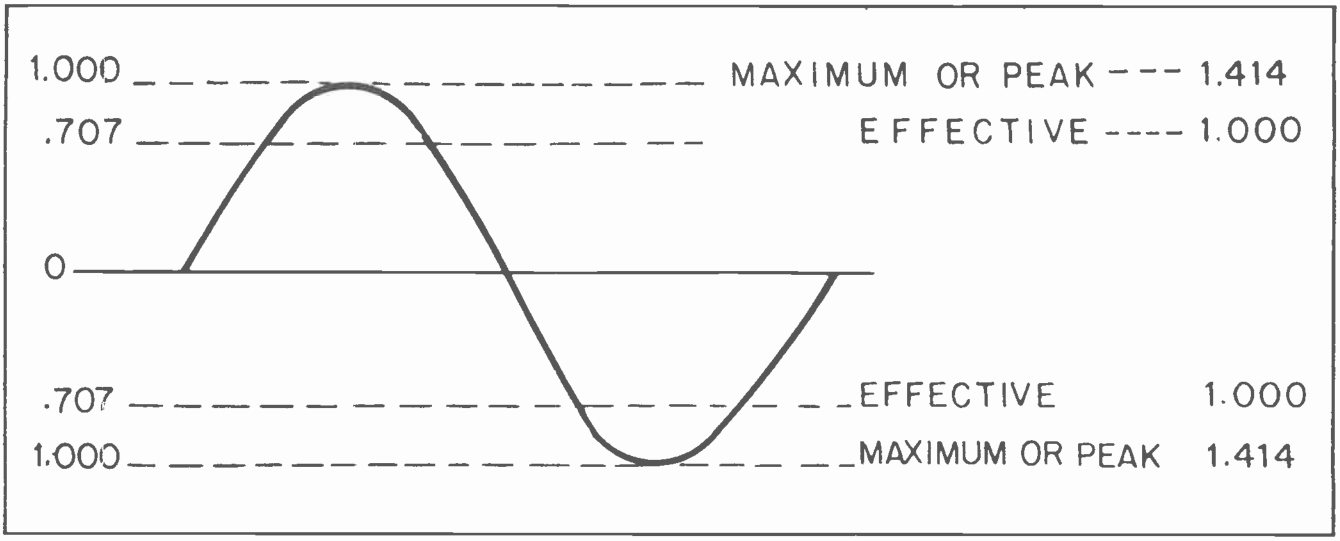

Fig.12. Relationship between effective and maximum values.

The armature of the dynamotor also has many turns of fine wire wound on it which are connected to another commutator on the opposite end from that where the current from the storage battery is received. Since there are many turns of this fine wire on the rotating armature cutting across the magnetic lines of force, a voltage will be induced in this wire which is much higher than that received from the storage battery. This high voltage can then be used to operate radio or television equipment. Many of the mobile television units which pick up sports events and other special events at places remote from the television studio, use dynamotors as the source of their power.

Dynamotors can be built to deliver almost any desired voltage. Common types deliver 300 volts, 500 volts, 750 volts and 1000 volts. But there are many special types in addition to these. Some aircraft dynamotors operate from 24 volts to 28 volts and deliver any value voltage which is desired. The subject of dynamotors will be gone into much more thoroughly later.

Section 10. ALTERNATING CURRENT

Interesting as direct current might be, the peculiar phenomena which surround the flow of electric current when it is moving back and forth in a conductor provides us with phases of study which are more interesting than almost any other branch of science. Many, many things have been learned about alternating current, but new and even more wonderful things are being discovered almost every year.

Nearly all the power supplied by the large public utility companies is in the form of alternating current. If you will look on your washing machine motor, your refrigerator, your automatic toaster, or your automatic electric iron, you will see a little name-plate which gives important information about the operation of the device. But in nearly every case, you will find that it has been designed to operate on alternating current. In some cases the device will not operate on direct current at all, and will bear a warning to that effect.

The current in an alternating current circuit is constantly changing. This was indicated in Fig. 2, where the electrons were shown moving first in one direction and then in the other. Because the current is constantly changing, and does not remain at any one value in either direction for more than an instant at a time, we are presented with the problem of measuring the value of the current and the value of the voltage. It can be seen from a study of Fig. 11 that the values of the current and the voltage are constantly changing in alternating current, and to say that the voltage is 110 volts, it would seem that one would also have to designate what particular instant the voltage was at that particular value.

Fortunately a method of measurement has been devised for calculating alternating currents and voltages which is quite simple. We have already learned that when direct current flows through a resistor, heat will be developed. For example, one ampere of current flowing through a 10-ohm resistor

Fig. 13.

will dissipate 10 watts of power. This comes from the formula $P = I^2R$. Likewise, 5 amperes of current through a 15-ohm resistor would use 375 watts.

Alternating current will also give off heat when it flows through a resistor. If an alternating current through a 10-ohm resistor gives off 10 watts we would say that one *effective* ampere of alternating current was flowing through the resistor. This is because electrical men have agreed that alternating currents shall be measured according to their effectiveness in creating heat as compared with direct current. This value has been determined to be .707 times the maximum value of the current which flows through the circuit.

For example, if electrons in an alternating current circuit were moving through the conductor at the rate of 100 amperes at the instant when they reached their maximum rate of flow, they would do the same work as 70.7 amperes of direct current flowing at a steady value. Likewise, if alternating current reached a maximum of 10 amperes at each of its peaks, the current would do the same work as 7.07 amperes of direct current flowing at the same rate continuously.

Fig. 12 shows a comparison of the maximum and effective values of alternating current. These same comparisons also hold true for measuring alternating voltages. It will be noted at the left side of Fig. 12 the maximum is shown as 1.000 and the effective value is shown as being .707 times that. This is the same thing we have just discussed.

Where the maximum value of the current or the voltage is known and it is desired to find the effective value, all that is necessary is to multiply the maximum value by .707 and the effective value can be obtained.

But there are many cases where the effective value is known and it is desired to determine the maximum value. Then it is better to use the figures shown at the right side of Fig. 12. If the effective value is known, then you multiply the known value by 1.414 to obtain the maximum value.

Nearly all alternating current meters for measuring either current or voltage are calibrated to read effective values. Usually we are more concerned with effective values than we are with maximum values. But there are times when it becomes imperative to know the maximum values of voltage as well as the effective values. An example is that of selecting a replacement capacitor for a radio receiver. A meter reading shows there are 300 volts of alternating current across the circuit. A capacitor capable of withstanding 400 volts D-C is available. An untrained man with no knowledge of alternating current could be easily misled, and figure he had a wide margin of safety. But the trained radio man would apply the formula to the problem to see if the capacitor really would work.

The meter shows there are 300 volts of alternating current across the circuit where the capacitor is to be placed. Applying the formula: Maximum voltage equals effective voltage times 1.414. In this case, 300 x 1.414 = 424.2 volts. This means that twice each cycle the voltage across the capacitor will reach maximum values of 424.2 volts, and in all probability will puncture the capacitor and ruin it.

Section 11. THE SINE WAVE

The curves shown in Figs. 2, 11 and 12 are commonly known as "sine waves". This comes from the fact that a curve of the shape followed by alternating current or voltage can be created by graphing a trigonometric sine through one or more complete cycles.

The creation of a sine wave is shown in Fig. 14. At the left hand side of that figure a conductor is shown cutting across lines of force between the poles of a magnet. The conductor moves in a circle at a uniform rate of speed. The direction of movement is clockwise as indicated by the small arrows adjacent to the conductor. The conductor starts from the center line at the point marked 0° degrees. It moves toward the point marked 90°, then to 180°, and finally back to the starting point by which time it will have gone through 360°. Every circle, as you undoubtedly know, is divided into 360°.

When the conductor is at 0° it is moving parallel with the magnetic lines of force.

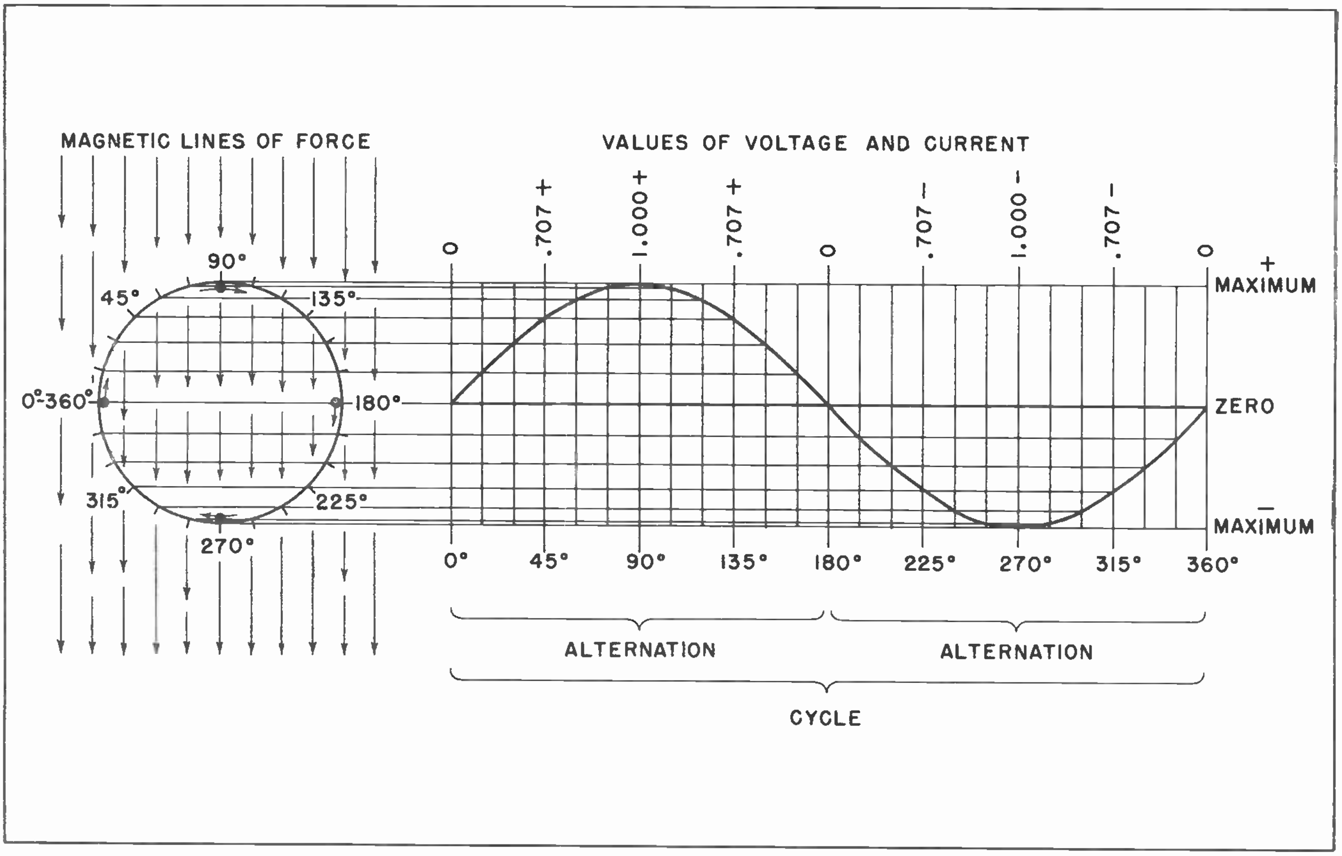

Fig. 14. How a sine wave is produced.

At that instant it will be cutting no lines of force, and as a result no voltage will be induced within the conductor. As the conductor travels around the circle it will cut across more and more lines of force and a voltage will begin building up within the conductor. By the time the conductor reaches the point marked 90°, it will be cutting across the lines of force at a maximum rate. At this instant it will be developing a maximum voltage. After passing 90°, fewer and fewer lines of force are cut. The voltage begins decreasing until at 180° the conductor will again be cutting no lines of force for an instant. At this instant, no voltage will be induced within the conductor. After passing 180°, the conductor

Inductive Reactance (in ohms) = 6.28 x Frequency (cycles) x Inductance (in henries).

will begin cutting across the lines of force again, but in the opposite direction to that when it was moving from 0° to 180°. As a result, the voltage will be induced in the opposite direction.

At the right side of Fig. 14, a line, or "graph" has been drawn to show the rise, fall and reversal of the voltage in the moving conductor as it moves around the circle. The length of the curve is divided into degrees in the same way as the circle. We speak of these as *electrical degrees*.

Section 12. OPPOSITION TO THE FLOW OF ALTERNATING CURRENT

The flow of alternating current is opposed by resistors in exactly the same way as the direct current is opposed. So long as the load is such things as incandescent lamps, toasters, soldering irons, heating elements and similar devices, it makes no difference whether the power is in the form of alternating current or direct current. Both meet the same opposition in the form of resistance.

We have previously studied the phenomenon of inductance. In the case of direct current, the presence of any inductance is of little importance. The direct current will flow through the inductance without any trouble, being opposed only by the resistance of the wires which compose the conductor of the inductance.

But the situation is vastly different in the case of alternating current. Alternating current meets additional opposition in the inductance entirely aside from its resistance. This additional opposition is called reactance. In some cases the opposition of the reactance may be many times greater than the opposition of the resistance of the conductors.

The amount of opposition presented by the inductance depends upon two things -- the frequency of the alternating current, and the value of the inductance. The greater the value of the inductance the greater will be the opposition, or reactance. And the higher the frequency, the greater will be the opposition, or reactance. The exact value of the reactance can be determined by the formula:

Reactance is generally represented by the letter *X*.

Inductive reactance is generally represented by the same letter with the letter *L* as a subscript: X_L. This is pronounced "X subscript L", or more generally "X sub L".

Frequency is always represented by the letter *f*. Inductance is represented by the letter *L*.

This makes it possible for us to rewrite the formula:

$$X_L = 6.28\ fL.$$

Since 6.28 is equal to two times π, we can rewrite our formula again and make it more simple. The figure 6.28 will keep bobbing up all the time you are working with radio. You might just as well get used to it now. It is directly related to the same π you became acquainted with in school when you were working with circles, and areas, and circumferences, and such like. Instead of using 3.1416 as is usually customary in school, in radio work we use only the first three figures: 3.14. Also in radio work we are usually concerned with two times π rather than π itself. For this reason we will have many occasions to use the figures: 6.28.

To simplify the formula still further it can be written in this form:

$$X_L = 2\pi fL.$$

note

This formula should be noted down in your note book until you get used to it. You will be using it so many times in your radio work that you will soon find yourself remembering it without having to look at your notes. The reason it is used so much is that nearly every coil of wire has some inductance in it, and nearly all our circuits will have some kind of alternating current flowing through them. These two circumstances make it necessary to frequently use the formula to determine the opposition the alternating current will meet while flowing through the coil.

NOTES FOR REFERENCE

Direct current flows in only one direction.

Alternating current is continually reversing its direction of flow.

Both alternating current and direct current can be converted into heat.

The *effective* value of alternating current is the measure of comparison with the effectiveness of direct current.

The effective current is equal to .707 times the maximum value of alternating current.

The maximum current is equal to 1.414 times the effective value of alternating current.

Inductive reactance is the opposition presented by the inductance of a coil to the flow of alternating current.

The formula for inductive reactance is $X_L = 2\pi fL$. note

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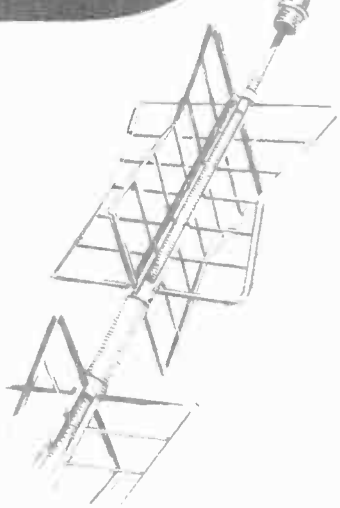
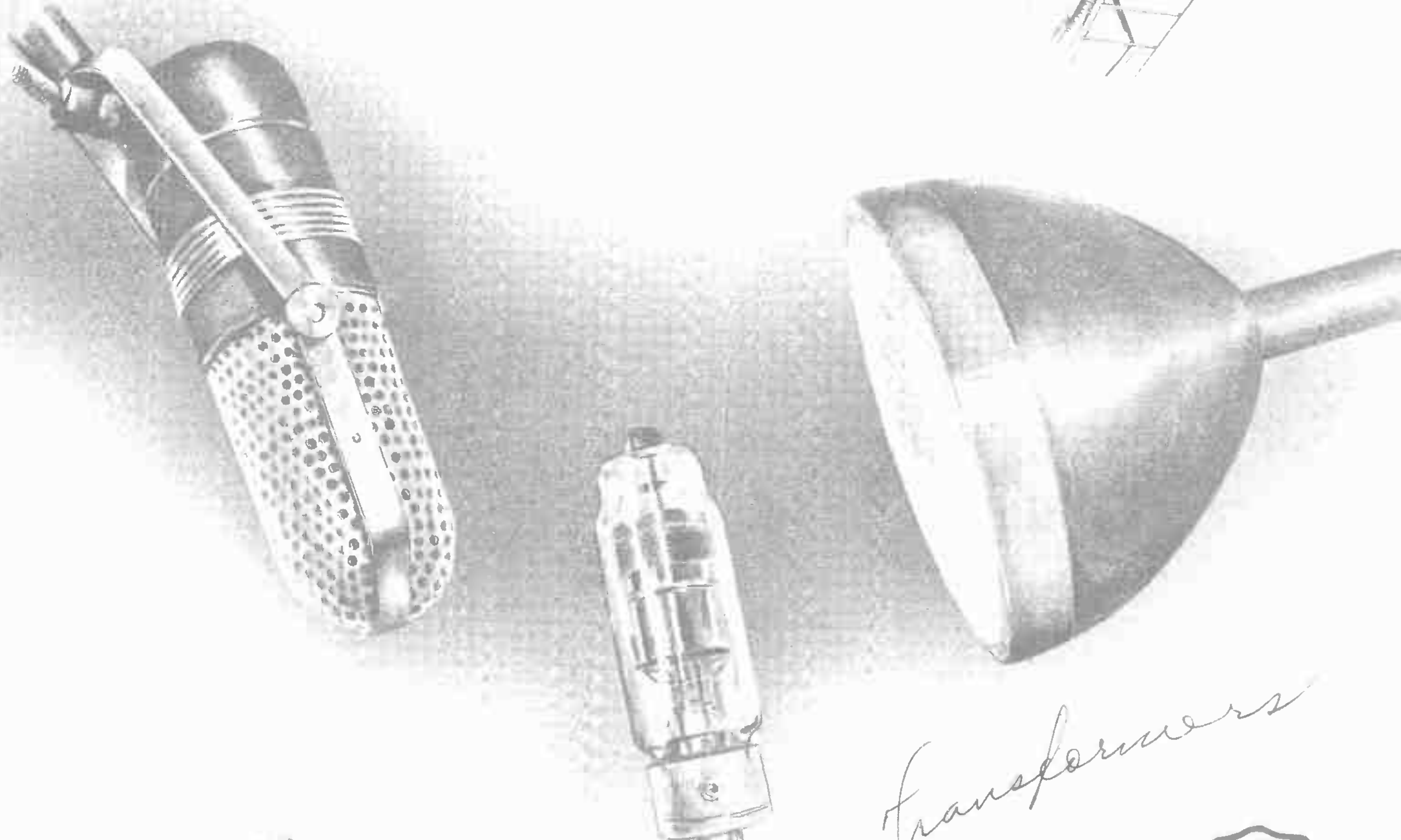
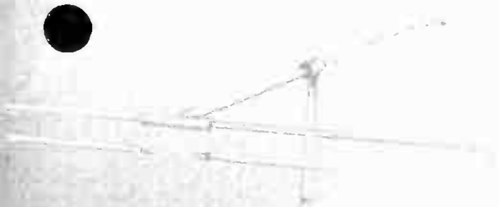
Transformers





Transformers



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TECHNICAL TRAINING SERVICE

RADIO TELEVISION

TRANSFORMERS

Contents: Introduction - Where Transformers are Used - Types of Transformers - Direction of Induced Voltage and Current - Strength of Induced Voltage - Secondary Current - Television Power Transformers - Audio Frequency Transformers - Intermediate Frequency - Intermediate Frequency Transformers - Notes for Reference.

Section 1. INTRODUCTION

Television is today so interwoven with the everyday affairs of most Americans it is hard for us to realize that as recently as the end of the second World War few persons other than radio laboratory technicians had ever seen a television receiver. When we take the time to think about it, we wonder just how we got along in the years before the wonders of television were unfolded to us.

Even yet, with most of us thinking of television solely as an entertainment medium, we are prone to forget there are other sides to television. With the possible exception of moving pictures, no other educational

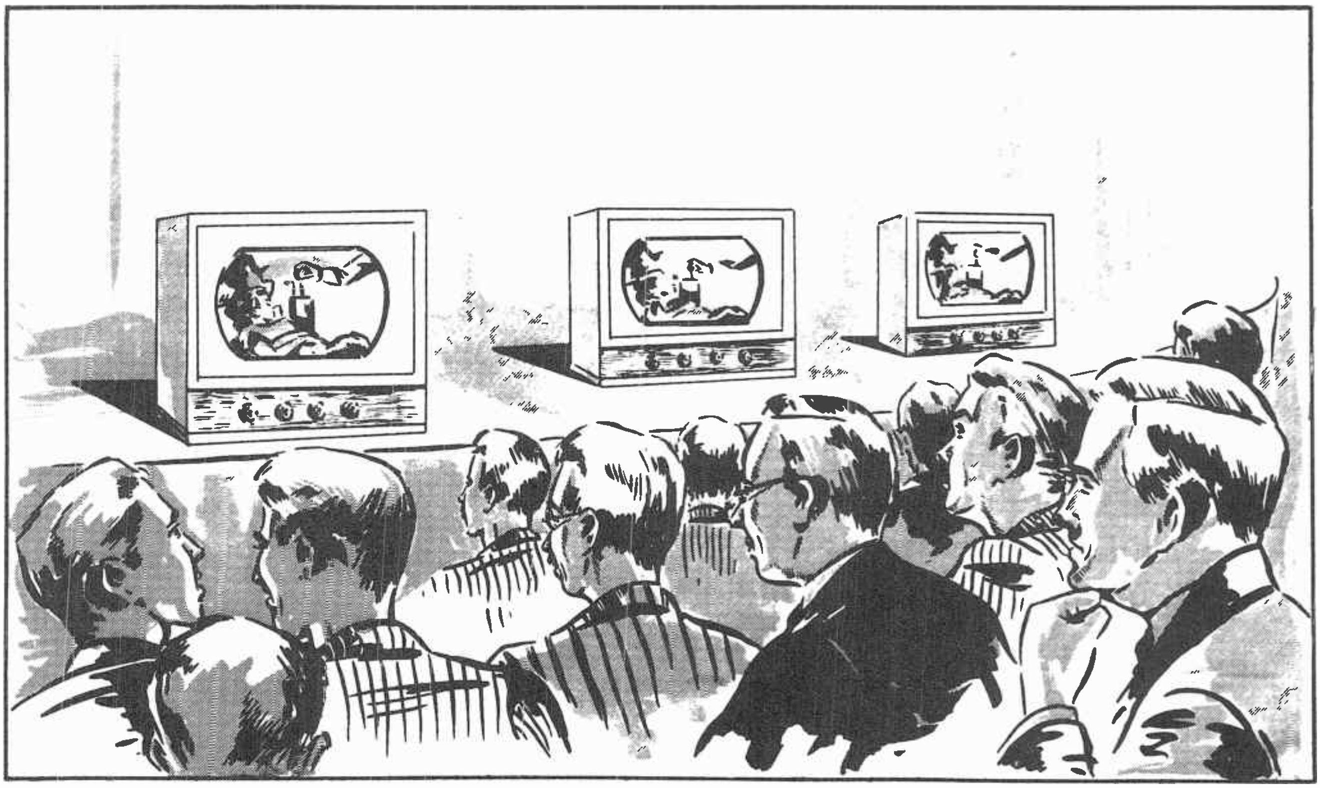

Fig. 1. Television is One of the Greatest Things in Surgical History.

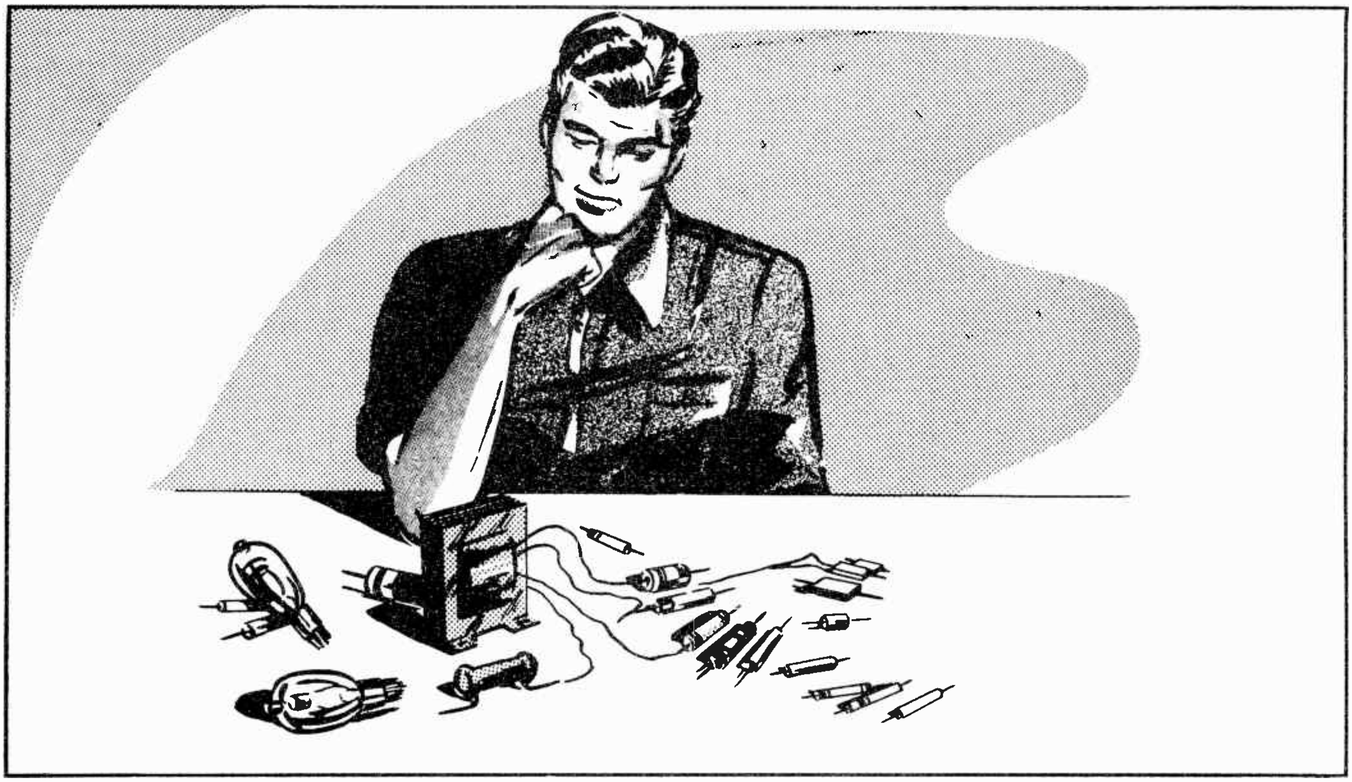

Fig.2. Resistors, Capacitors, Tubes, Transformers and Wire by Themselves do not make a Television Receiver.

medium is so valuable as the television receiver. Its use in demonstrating new techniques in surgery is proving to be one of the greatest boons the medical profession has ever known.

A few years ago many of the most delicate operations could be performed by only a handful of surgeons. This was because it was so difficult for them to demonstrate their techniques and knowledge to their fellow surgeons without endangering the lives of the patients. Even when they could show other surgeons how to perform certain rare and delicate operations, they could seldom demonstrate the methods to more than one surgeon at a time. Thus the spreading of medical and surgical knowledge was a painfully slow matter.

With the modern wonder of color television, a great surgeon can demonstrate certain skills he has acquired over the years to hundreds of other surgeons eager to learn. Color television often makes the details of such operations much clearer to the watchers than would be the case if they were actually at the side of the operating table. Best of all, there is not the slightest hazard to the patient other than would be present in any surgical operation. Delicate, and formerly dangerous, operations which were attempted by a small number of surgeons only a few years ago are now becoming medical commonplaces. Many skilled surgeons hesitated to perform certain operations which they knew could be performed, simply because they had never seen such an operation. None knew better than they that the slightest slip or mistake would mean death for the patient. And because they had never had the opportunity to watch such an operation, they were unwilling to take the risk. Now it is a regular practice in many of our great hospitals to televise rare and dangerous operations so that hundreds of other surgeons can themselves acquire the necessary skill by watching the famed surgeons at work, and listen to their comments as the operation progresses.

Truly television is a wonderful thing. It is giving us many things that its most avid boosters scarcely dreamed about only a few short years ago. The man who decides to make television his life's work, should certainly have a full life. The compensation is as profitable as can be found in any line of endeavor. But its additional rewards in the satisfaction of bringing a better and fuller life to one's fellow man is something which cannot be measured in dollars and cents.

Section 2. WHERE TRANSFORMERS ARE USED

Rudyard Kipling once described a woman as being "a rag, a bone and a hank of hair." Perhaps the description is apt. In a like manner, a television receiver could be described as a bunch of resistors, some capacitors, a lot of tubes and a few transformers all tied together with a few hunks of wire. All these things, and more, go to make up a television receiver.

But all the resistors, capacitors, transformers, tubes and wire in the world would not make a television receiver without the one priceless ingredient necessary to imbue these items with life -- the knowledge, the brain, the skill of a trained television man. Without his specialized skill they are inert, lifeless things. But when connected together in one definite, specific way -- a way he is able to determine through his own specialized knowledge -- they become almost as something alive. They become sensitive to things in the air which are not perceptible to human senses and convert these things into live pictures and vibrant sound.

It would be hard to point out any one type of component part which goes to make up a television receiver and say that that part was more important than another. Probably it is no more possible to say that a capacitor is more important than a resistor, or a tube is more important than a capacitor, or a transformer is more important than a tube, than in the case of the human body it could be said that the lungs are more important than the stomach, or the heart is more important than the lungs, or the brain more important than the heart. The human body could not function if any of these parts were missing. In a like manner resistors, capacitors, tubes and transformers are all vitally necessary to the operation of a television receiver. And in order for the television expert to know how to make a television receiver operate, and keep it operating, he must first know exactly how all the parts which go into it operate.

We have mentioned transformers before but have actually done little more than touch on the subject. It is time we examined

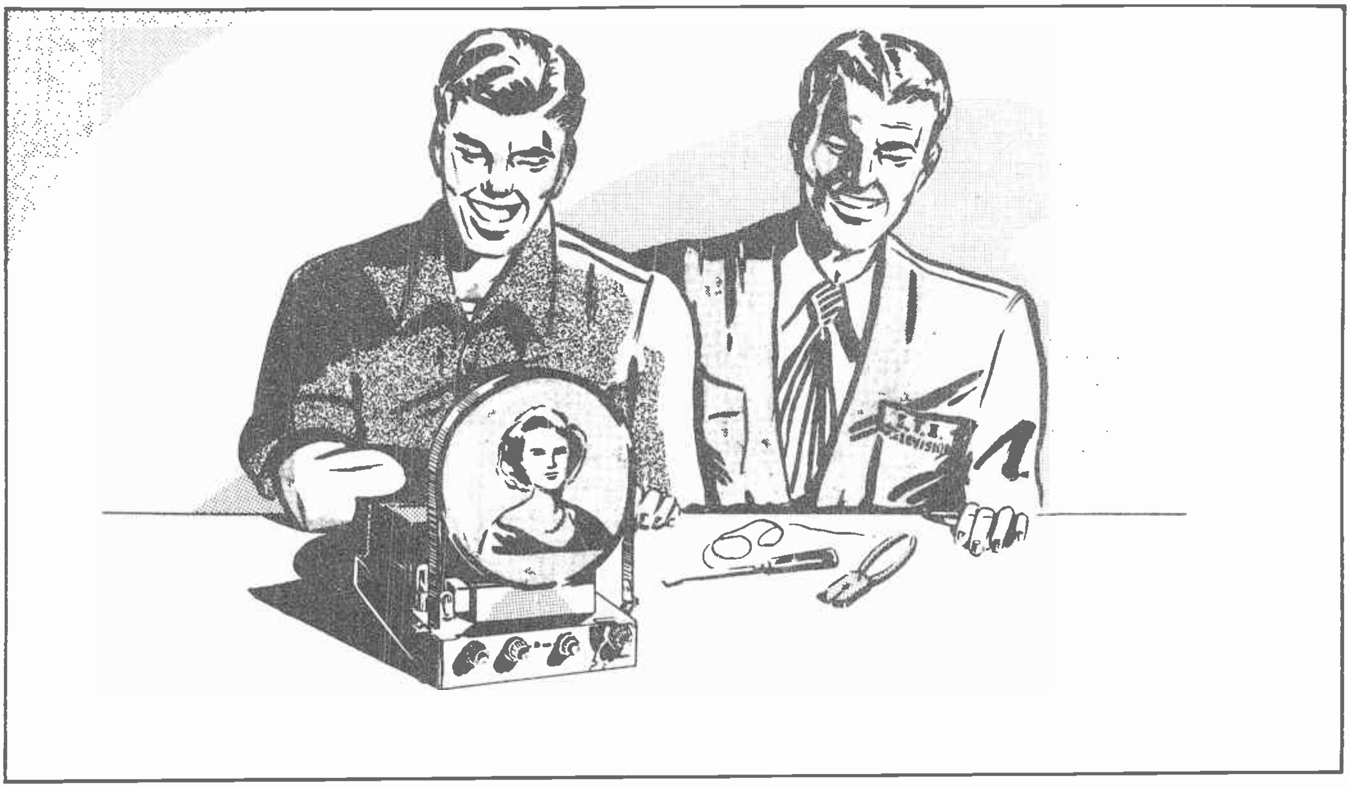

Fig.3. It takes the Knowledge and Skill of a Trained Television Man to Make a Television Receiver come to Life.

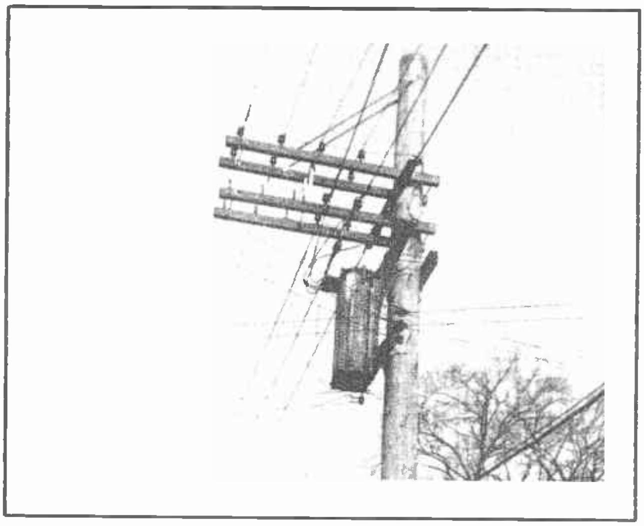

Fig.4. Power Transformer on a Rural Electric Line.

this peculiar, but extremely valuable, electrical device a little more carefully.

The underlying theory of the operation of transformers has been known since the days of Michael Faraday. But for many years little was done to put this knowledge to practical use. During the early days of commercial electricity, Direct Current was the type commonly used; the use of transformers with Direct Current is extremely limited.

As the trend gradually changed from Direct Current to the use of Alternating Current, the value of transformers became more apparent. It is the peculiar properties of transformers which makes Alternating Current the dominant type of electrical power. Power transformers are common sights on the electrical power poles along the back alleys of our cities, and on power line poles in the rural areas as well. The transformer, in its special steel "bucket", is a familiar sight along the power lines in the country. One can be seen at nearly every point where electric service wires for the individual farm leaves the "high-line".

The many transformers which are to be found in nearly every television receiver are merely "little brothers" of the larger outdoor-type power transformers. The operation of the various types of radio and television transformers are identical. The only difference is in the size.

Transformers are used in radio and television receivers to change the voltage from the commercial power lines to other voltages which are needed within the receiver. Output transformers are used to supply the power to drive the loudspeakers of the "audio", or sound, section of the receiver. Other transformers, called intermediate frequency transformers, or "I-F" transformers, are used in several stages through

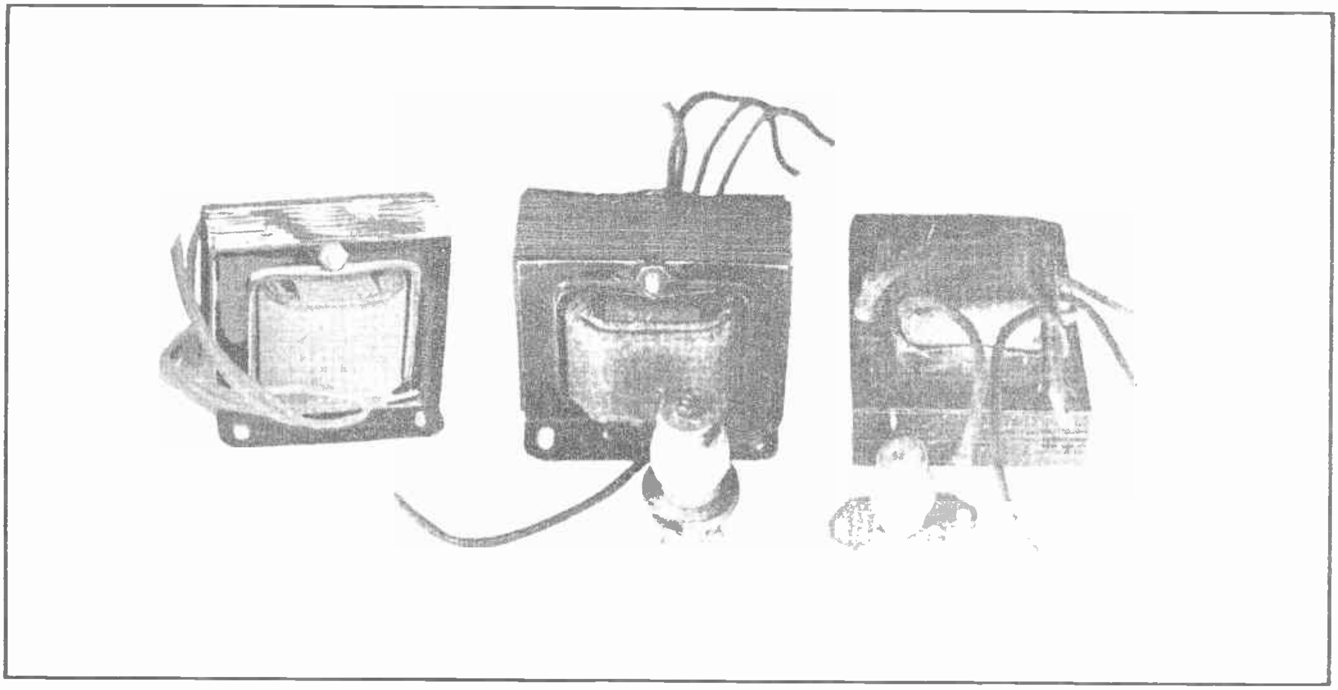

Fig.5. Radio and Television Transformers.

which both the sound and the "video" portions of the television signal passes. The video section of the receiver is that part which passes the signal which carries the picture. There are two distinct channels through every television receiver. One channel carries the "video", or picture, portion of the radio signal wave. The other channel carries the "audio", or sound, portion of the signal. These two terms will be used over and over many times. It would be well to become accustomed to them at this time. Other transformers are used for many other purposes.

Section 3. TYPES OF TRANSFORMERS

A transformer consists, essentially, of two or more coils wound on a single core. Sometimes the coils are wound on cylindrical pieces of insulating material such as bakelite, micarta, polystyrene or even waxed cardboard. Other times the coils are wound on iron cores.

Sometimes the coils are placed so that one is outside the other -- that is, one coil is wound over the other. This is the common practice when the coils are wound on an iron core. Sometimes the coils are wound on the core so that neither coil touches the other -- one being wound on one end of the coil form and the other coil being wound on the other end of the coil form. The exact construction of the transformer depends entirely upon the purpose for which it is to be used.

If the transformer is to be used with low frequencies, such as the common 60-cycle frequency generally found on commercial power lines, an iron core is almost universally used. The presence of the iron aids the magnetic linkage between the coils at the lower power frequency. It also increases the inductance. The symbol generally used for an iron-core transformer is shown in Fig. 6 along with an illustration of a transformer of the type commonly found in television receivers.

When the alternating current frequency is of the order of many thousands of cycles per second, as in the case of radio and television signals, transformers with iron cores cannot be used. Transformers for use at radio frequencies are called air-core transformers. Illustrations of such transformers are shown in Fig. 7. The symbol generally used to designate an air-core transformer in a schematic drawing is also shown in Fig. 7. It will be noted that

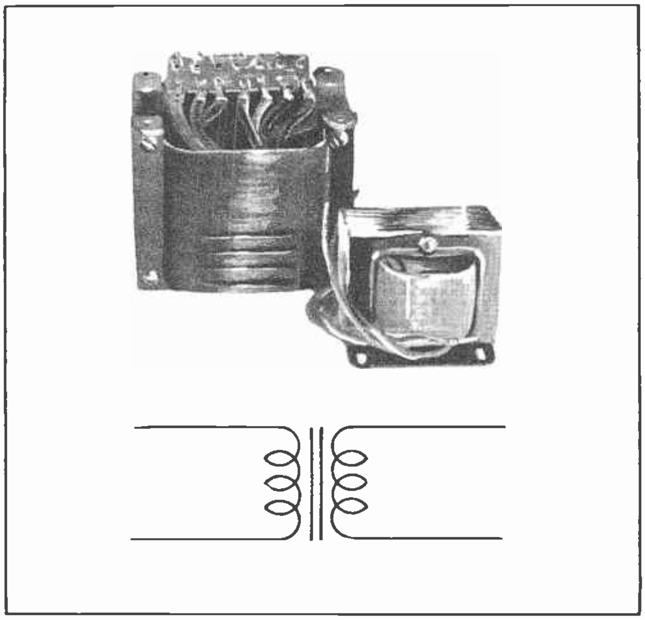

Fig.6. Iron Core Transformer.

the symbol is the same with the exception that the straight lines are omitted from between the coils.

A transformer transfers power from one winding to the other, and from one circuit to another, by induction. Every change of current in one winding induces a voltage in the other winding. It should be remembered that a voltage is induced in the second winding only during the time the current is *changing* in the first winding.

If the second winding forms a part of a closed circuit, current will be caused to flow in that circuit and in that winding. This is nothing new to you. It is merely repeated here by way of review, and to lend emphasis to this fact. It is a fact which is sometimes forgotten or overlooked.

Since a voltage is induced in the second winding only while the current is changing in the first winding, and since no voltage is produced in the second winding during any time the current in the first winding is of a steady or constant value, transformers are generally useful only in those circuits where the current is constantly, or frequently, changing. In a practical manner of speaking, transformers are useful only in connection with alternating current.

Section 4. DIRECTION OF INDUCED VOLTAGE AND CURRENT

We know that any induced voltage acts in such direction as to oppose the change of

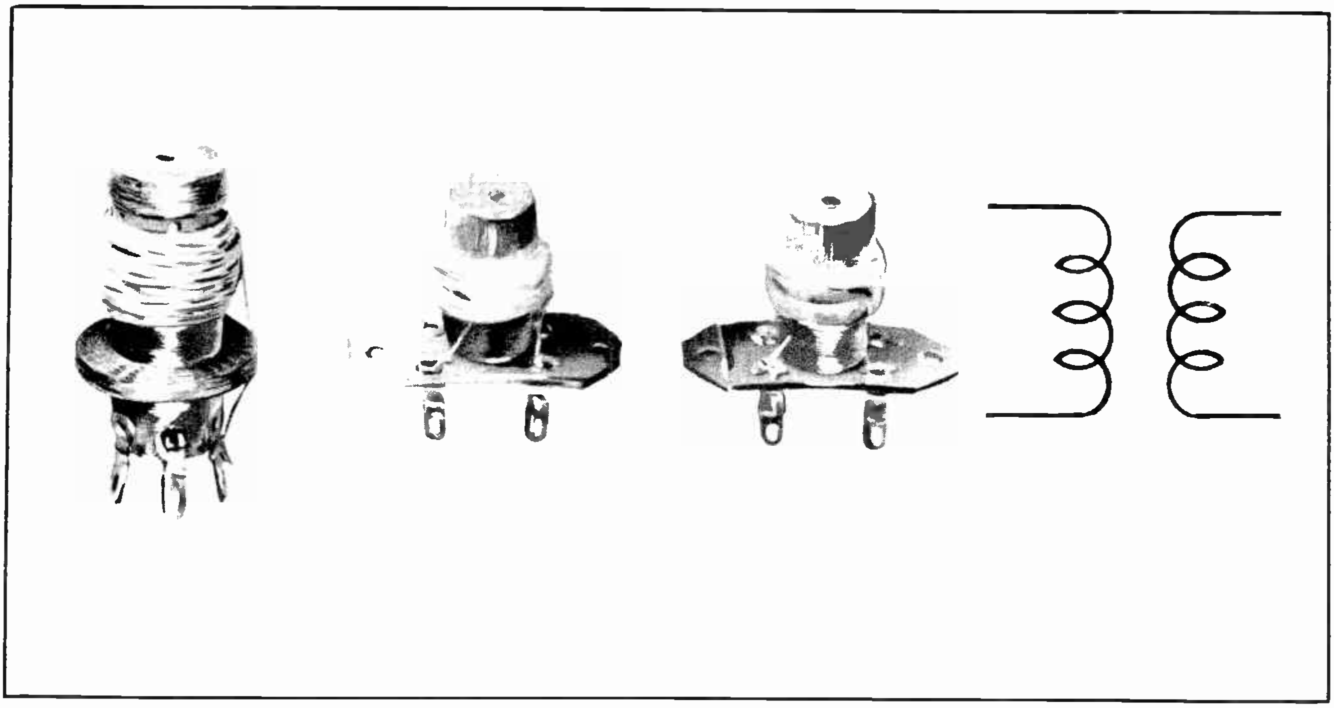

Fig.7. Air Core Transformers.

current which induces the voltage. As a result of this it follows that while current is increasing in a positive direction in the primary winding, the strength of the induced voltage in the secondary will be increasing in a negative direction. This action will be noted by studying the graphs in Fig. 8.

This means that the voltage and current in the secondary winding will be opposite to that of the voltage and current in the primary winding. This is a point well worth remembering, because it is something which must frequently be considered. The direction of the currents and voltages are shown by the use of arrows in Fig. 9. It is worth noting and remembering too, that the current is in the opposite directions in each of the two windings.

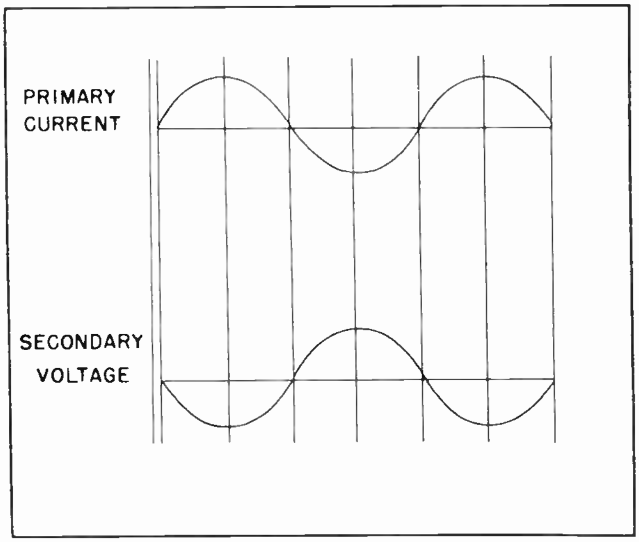

Fig.8. How Secondary Voltage is Directly Affected by Primary Current.

Section 5. STRENGTH OF INDUCED VOLTAGE

One of the most useful features of the transformer arises from its ability to change voltages from one value to another. This can be readily understood when it is remembered that each ampere of alternating current in one turn of a winding will produce a certain number of flux lines rising out of the turn of wire while the current is increasing. The same number of flux lines will collapse back into the wire when the current ceases. Furthermore, two amperes will produce twice as many lines from the one turn of wire; or one ampere in two turns will produce twice as many lines as one turn. To put this in other words, the number of lines of magnetic flux will be proportional to the number of amperes multiplied by the number of turns. This is called *the number of ampere-turns.*

If we consider a primary winding as existing alone, we know the rise and fall of the alternating current will induce an opposing voltage in the primary that is almost as strong as the applied voltage which sends the current through the winding. This is the action we call *self-induction.*

To illustrate this point, suppose we take an actual example. In Fig. 10 are shown the primary and secondary windings of a transformer. There are 100 turns on the primary and 100 turns on the secondary. Suppose 100 volts of alternating current are applied to the primary winding. The opposing voltage, which is caused by the magnetic lines of flux cutting through the turns of the coil will likewise be almost 100 volts. If the secondary winding is closely wound around the primary winding so the same lines of flux also cut through the secondary winding, a similar voltage will be induced in that winding. If there are the same number of turns, and the coils are so wound that the magnetic flux cut both coils simi-

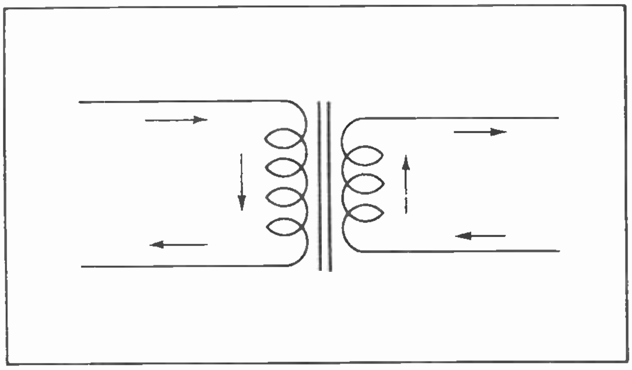

Fig.9. Coil Current in the Primary and Secondary of a Transformer.

larly, the voltage induced in the secondary will be the same as that of the primary: 100 volts.

But suppose the secondary winding had had 200 turns instead of 100 turns. This situation is shown diagrammatically in Fig. 11. We have not changed the number of lines of flux which are cutting through the two coils. The lines of flux cut through twice as many turns on the secondary as before, and twice as many as are on the primary winding. The result is exactly what would be expected. The voltage in the secondary winding is now 200 volts instead of 100 volts as it was when there were only 100 turns on the secondary winding.

If the number of turns on the secondary had been reduced to 50 turns instead of being increased we would have had still another situation. There would have been no change in the number of flux lines, but

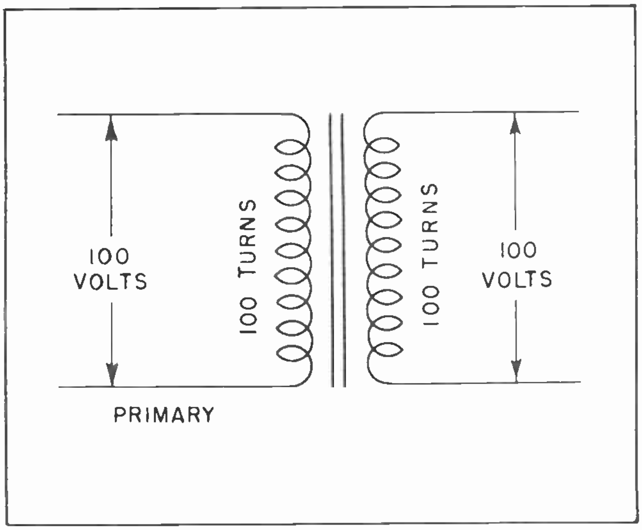

Fig.10.

the lines would have cut less turns in the secondary. The result is that only 50 volts would be induced in the secondary. This is shown in the diagram of Fig. 12. This can all be summed up in a rule which is well worth jotting down in your little notebook and remembering: The secondary volts of a transformer are to the primary volts as the number of turns on the secondary are to the number of turns on the primary. It can be set up in the form of an equation:

note

$$\frac{\text{Secondary volts}}{\text{Primary volts}} = \frac{\text{Secondary turns}}{\text{Primary turns}}$$

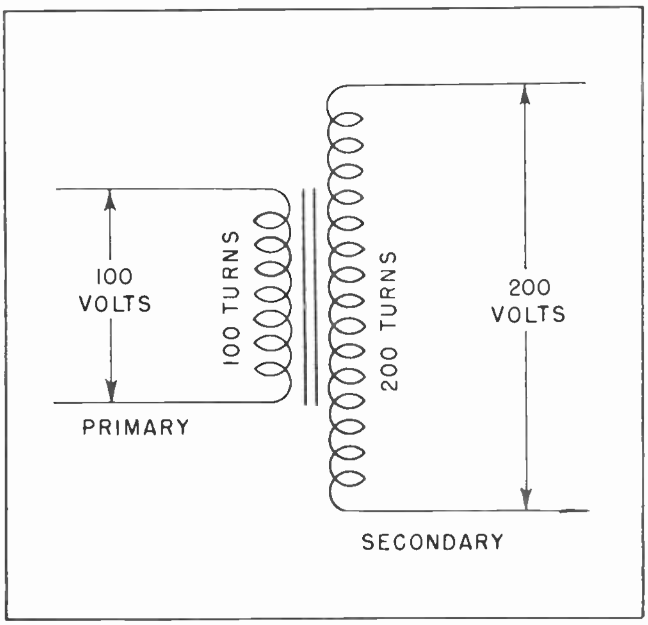

Fig.11.

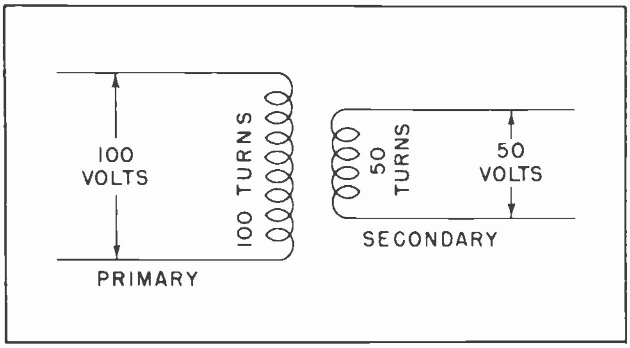

Fig. 12.

Section 6. SECONDARY CURRENT

We have just seen that it is easily possible to increase or decrease the secondary voltage of a transformer by merely changing the number of turns on the secondary. Or to be more exact, by changing the *ratio* of turns between the primary winding and the secondary winding. Our next investigation naturally leads us to see what effect this has on the secondary current.

In Fig. 13 we have a circuit quite similar to that of Fig. 10 with the exception that in Fig. 13 we find 10 amperes of current flowing in both the primary and secondary windings. The secondary current is also flowing through a 10 ohm load. The primary line is feeding 1000 watts to the transformer and the secondary winding is delivering 1000 watts to the load. In other words, the transformer is receiving 1000 watts at the primary and delivering 1000 watts at the secondary.

Now suppose we increase the number of turns on the secondary from 100 turns to 200 turns as in Fig. 14. If we want to continue to deliver only 1000 watts to the load, we must increase the resistance of the load. When the voltage increases from 100 volts to 200 volts we must increase the resistance of the load from 10 ohms to 40 ohms to hold the power consumption to 1000 watts. This means decreasing the current from 10 amps to 5 amps.

The net result is that if the voltage is doubled, the current will be cut in half. A moment's reflection will show us that this is what we should have expected. The transformer can readily increase or reduce the output voltage. But it cannot create power.

Now instead of increasing the resistance of the load from 10 ohms to 40 ohms at the same time the secondary voltage was raised from 100 volts to 200 volts, suppose we had allowed it to remain at 10 ohms. What would have happened? This situation is shown in Fig. 15. If the load resistance remains at 10 ohms a current of 20 amperes will flow in the secondary circuit. This means that the transformer will be delivering 4000 watts of power into the secondary circuit (20 x 200). Since the transformer cannot create power -- it merely changes electrical energy from one value to another -- it must receive 4000 watts at the primary. The primary voltage will not change. What will change is the current. Instead of drawing 10 amperes as before, the primary of the transformer will now draw 40 amperes instead.

It will be noted in both of these cases that while the *secondary voltage* is twice as great as the *primary voltage*, the *primary current* is twice as great as the *secondary current.*

This, too, can be set up as a rule: The secondary amperes are to the primary amperes as the primary turns are to the secondary turns. It can also be set up in the form of an equation:

$$\frac{\text{Secondary amperes}}{\text{Primary amperes}} = \frac{\text{Primary turns}}{\text{Secondary turns}}$$

This rule should also be noted down in your notebook for ready reference until such time as you think you can remember it without referring to your notebook.

It might occur to you to ask how the transformer could know to draw the additional

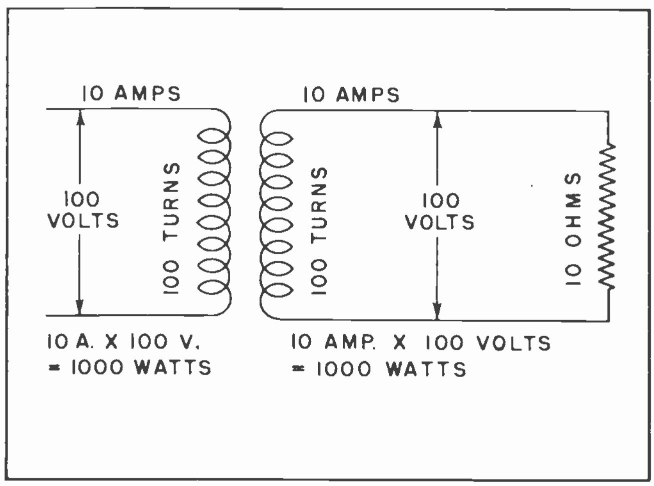

Fig. 13.

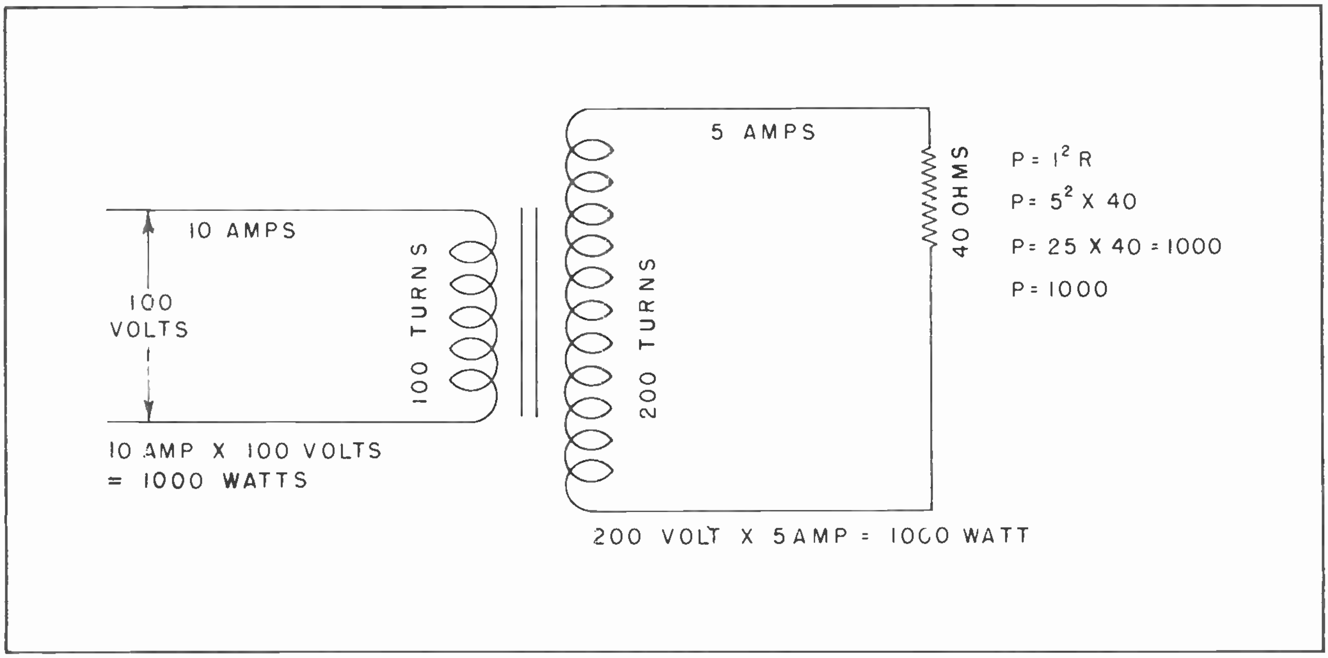

Fig. 14.

current to make up the necessary power input. While this cannot be fully and completely explained at this time in a manner which is likely to be understandable to you, it can be mentioned that the action comes about as a result of *mutual induction.* Mutual induction was mentioned briefly before, and will be discussed in greater detail further along.

Essentially the action of the transformer is automatic. As the load on the secondary draws more current, and thus more power, mutual induction automatically transfers this demand to the primary circuit, and it in turn, will call for more power to meet the demand. As more current flows in the secondary circuit this current will create magnetic lines of flux of its own, entirely separate from those of the primary current. These lines of flux tend to oppose the lines of flux created by the primary current. And where the lines of flux created by the primary current tends to oppose the flow of the primary current, the lines of flux from the secondary current tends to aid the flow of primary current.

The situation might be described as this: As the secondary load calls for more current, this current will flow through the secondary winding. As the increased current flows through the secondary winding it sets up lines of flux which tends to cancel out some of the flux lines of the primary winding, and thus reduces the opposition to the flow of primary current. The net result of the action is that as the load calls for more current, the transformer will automatically draw more current from the primary circuit.

Section 7. TELEVISION POWER TRANSFORMER

Almost every television receiver, and about half of all radio receivers, have power transformers. Some television receivers

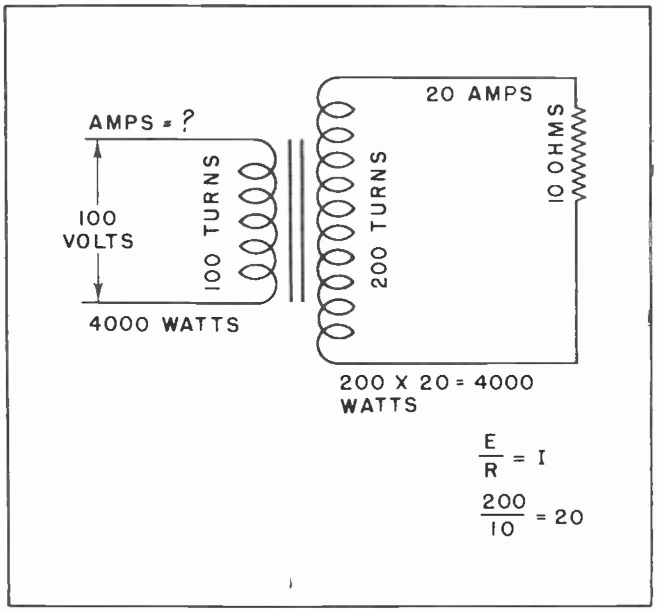

Fig. 15.

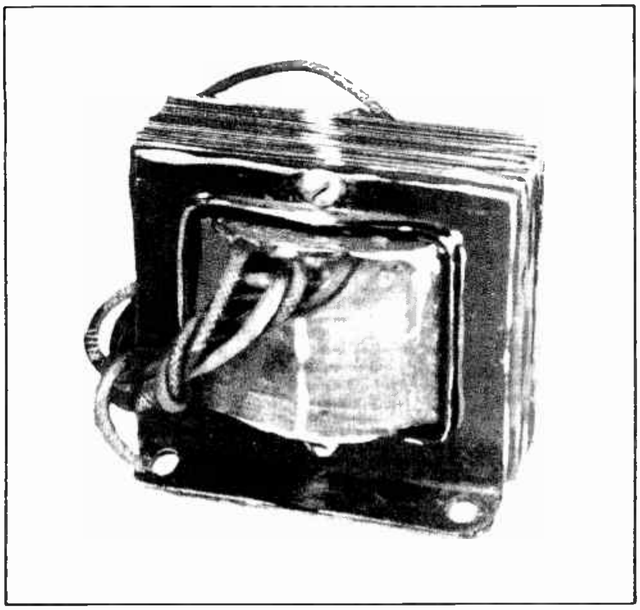

Fig. 16. Typical Power Transformer such as is used in Radio and Television Receivers.

have two or more power transformers. These transformers are used to change the commercial power voltages into values more suitable for the special needs of the receivers.

Some of these power transformers are relatively simple, having only one or two windings on the secondary. Others are considerably more complex. Some of them have a multiplicity of windings for the secondary, each serving its own particular purpose.

A typical power transformer designed for the purpose of supplying the anode voltage to a group of amplifier tubes, plus the filament voltage for the same amplifier tubes, plus the filament voltage for one or two rectifier tubes is shown in Fig. 16. This transformer has three secondary windings, one of which has a special connection to the center of the winding which is called a "center tap". The winding with the "center tap" connection is called the "high-voltage" winding. In this particular transformer the voltage between the two ends of the high-voltage winding is approximately 750 volts. The voltage between each end and the center tap is approximately 375 volts.

The schematic diagram of the windings on this transformer is shown in Fig. 17. The 6.3-volt winding is designed to supply the voltage for the filaments, or cathode heaters, of the amplifier tubes. The amplifier tubes are the ones which take the very tiny voltages which are picked up from the air and magnify them to values which are useful. Most television receivers have more than a dozen amplifier tubes of various kinds. Some are used to amplify the video signal; others are used to amplify the sound signal; while others are used to amplify the combined signal before the sound is separated from the video.

The 5-volt winding supplies the voltage to the filaments of the rectifier tubes. The rectifier tubes take the 750 volts of alternating current from the high-voltage winding of the transformer and change it into high-voltage direct current for use on the anodes of the various tubes.

The transformer illustrated in Figs. 16 and 17 is designed to operate from 120-volt commercial power. Some transformers have taps on the primary making it possible to operate at top efficiency from 115-volt power, or from 110-volt power. Still other transformers have a split primary so it can be operated from either 120-volt power or from 240-volt power. These are all merely variations from the standard type shown in Figs. 16 and 17.

In addition to the power transformer which supplies the power to the amplifier tubes,

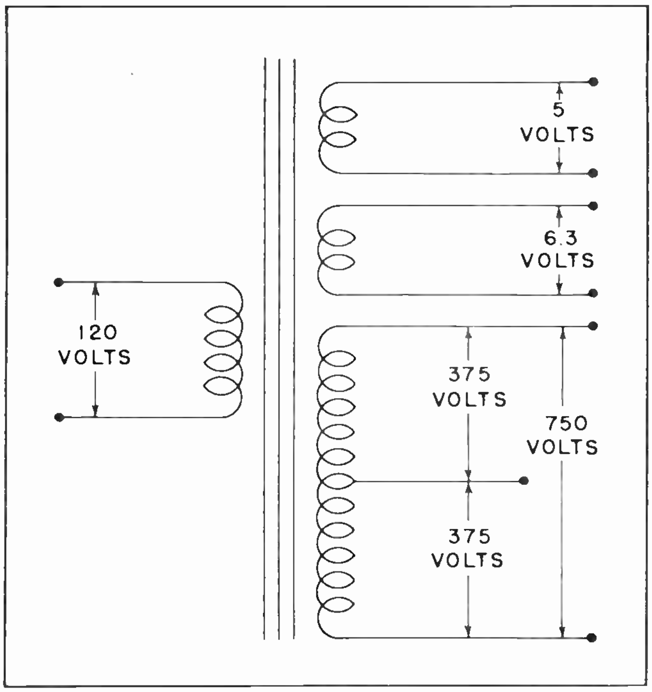

Fig. 17. Schematic Diagram of Power Transformer.

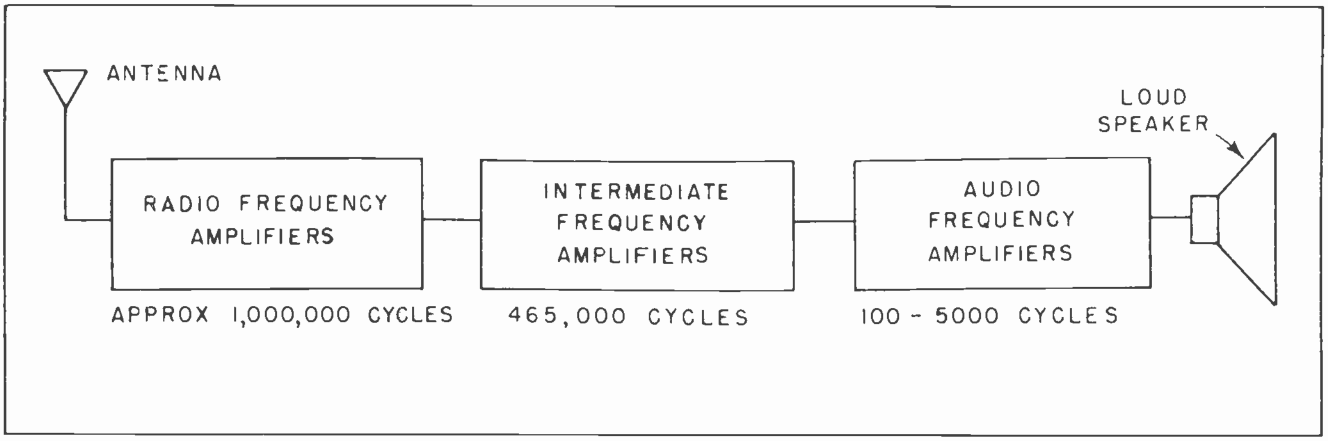

Fig.18. Block Diagram of a Radio Receiver.

some television receivers also have a separate transformer to supply the power to the sweep-circuit tubes, or the output power tubes, or to some other section of the receiver. But the operating characteristics of such transformers are not greatly different from the one described here.

In addition to the power transformers already described here, many television receivers - probably the majority of them - have still another power supply designed to supply the high voltage needed for the operation of the picture tube. The voltages needed by the tubes are extremely high, the exact value depending upon the size and type of the tube, and the ideas of the manufacturer. Even the smaller 7-inch tubes which are now largely obsolete required anode voltages running upward of 2500 volts. It is not uncommon to find voltages exceeding 25,000 volts on the anodes of some of the larger picture tubes.

The transformers which supply this high voltage must be well insulated to avoid breaking down the dielectric of the insulation. Great care must be observed in the manufacture of these transformers so they can hold up under the severe service to which they are subjected.

Section 8. AUDIO FREQUENCY TRANSFORMERS

An audio-frequency transformer, as its name suggests, is used to connect two circuits in the audio-frequency section of a receiver. The audio-frequency section is that portion of the receiver through which the sound signal travels at electrical frequencies which are audible to the human ear. Normally these frequencies lie in the region between 100 cycles and 5000 cycles per second, although the human ear is capable of detecting frequencies both above and below these two.

Audio-frequency transformers consist of a primary and secondary winding which are wound on an iron core built up from pieces of laminated steel. Because of the relatively high frequencies involved, it is the general practice to use special grades of steel for this purpose. Special silicon steel as well as several kinds of alloys which have very low losses are used. Normally these transformers have a greater number of windings on the secondary than on the primary. The ratios generally are about 2 to 1, or 4 to 1. Very rarely will the ratio exceed 5 to 1.

Of even greater importance than the ratio of turns is the *impedance* of the primary and secondary windings. We have not discussed impedance to any great extent and will pass over it at this time to come back to it later. Suffice it to say at this time that impedance in an alternating current circuit consists of a combination of resistance and reactance. The impedance of the transformer windings should match that of the circuits to which they are connected. Audio-frequency transformers do not occupy the important place in radio and television they once did. Improvement by manufacturers of amplifier tubes have made circuit designers much less dependent upon audio transformers than they once were.

Section 9. INTERMEDIATE FREQUENCY

Radio and television travels through space in the form of electromagnetic waves. These electromagnetic waves have a very high frequency. In the case of radio the frequency may be almost any value from about 50,000 cycles per second up to many hundreds of millions of cycles per second. Television uses frequencies from a little under 100,000,000 cycles per second up to many hundreds of millions of cycles.

When the electromagnetic waves passing through space strike, and cut across, a certain specially arranged part of a receiver called an antenna, they create tiny electrical voltages within the receiver. By the use of amplifying vacuum tubes these tiny voltages are "amplified", or increased, to higher values.

The electromagnetic waves which pass through space, and the tiny voltages they create in the antenna of a receiver, are called "signals". The word "signal" has, through usage, come to mean any voltage change impressed upon a vacuum tube which can be detected by human senses or by electrical or electronic instruments.

Because the electromagnetic waves passing through space vibrate at extremely high frequencies, the voltages they create within the receiver are extremely high frequency voltages and currents. These high frequency voltages can be amplified by the means of vacuum tubes, and the first few tubes in a receiver are generally used for this purpose. But unfortunately, the amplifying efficiency of vacuum tubes is not nearly so great at high frequencies as it is at somewhat lower frequencies. To avoid the need for an unnecessarily large number of amplifying tubes, manufacturers of receivers usually design them so the extremely high frequencies of the radio or television signal is changed into a much lower frequency within the receiver. Then this lower frequency "signal" can be amplified much more efficiently by means of fewer tubes. The lower frequency signal is passed from one tube to another by means of special transformers called "intermediate frequency" transformers. These are more commonly referred to as "I-F" transformers, or merely "I-F's". 13

The lower frequency itself is referred to as the "intermediate frequency". The reason for this name is that the voltages and currents of the signal passing through these transformers are much lower in frequency than the radio frequency signal received at the antenna, but are much higher than the "audio" frequencies which reach the loudspeaker or the "video" frequencies which paint the picture on the picture tube. In other words, they are *intermediate* between the high frequencies which first enter the receiver and the much lower frequencies which emerge at the output of the receiver in a form which are perceptible to the human senses.

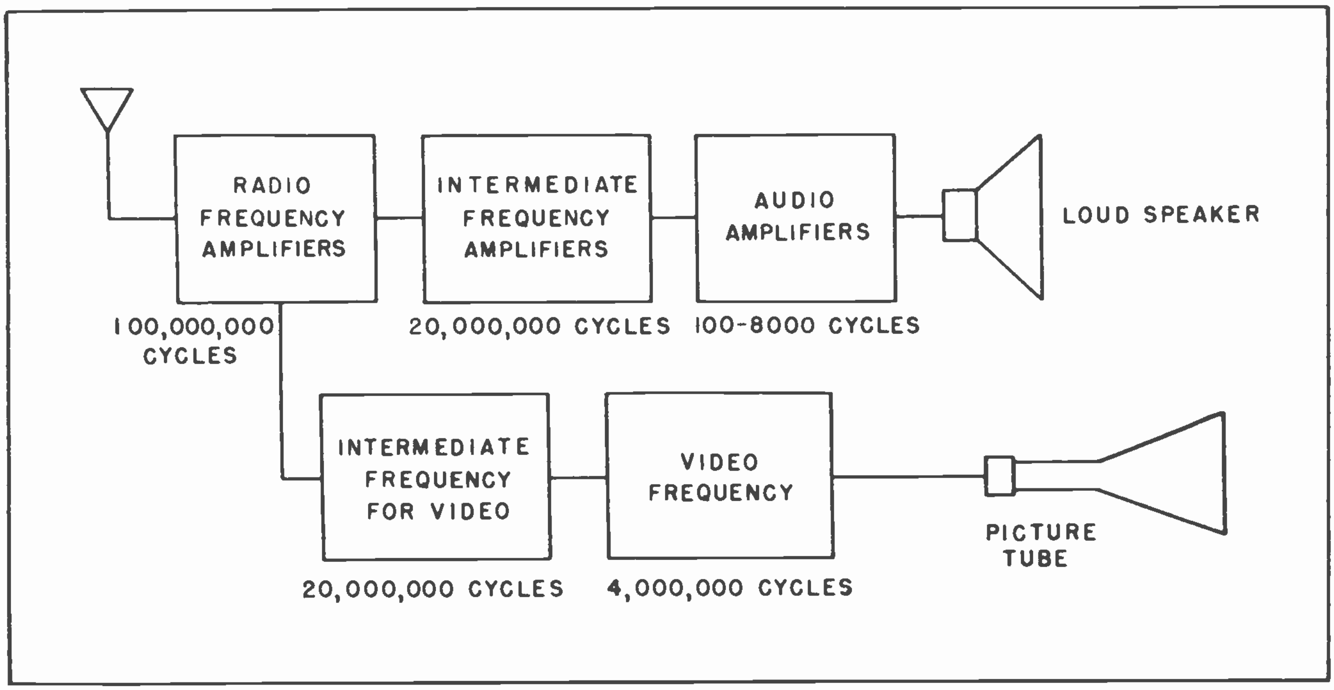

Fig.19. Block Diagram of a Television Receiver.

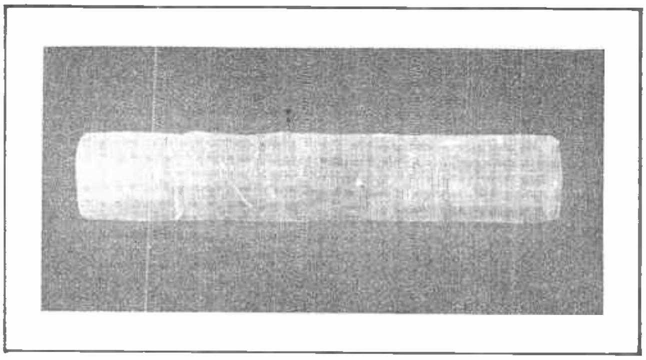

Fig.20. I-F Coil Forms.

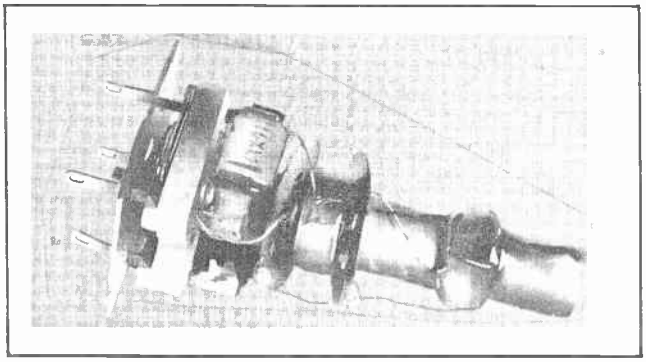

Fig.21. I-F Transformers.

In order to establish an understandable relationship among the several types of frequencies it can be mentioned that in a common radio broadcast receiver the radio signal which enters through the antenna will be between 550,000 and 1,600,000 cycles per second. The intermediate frequency signal will be approximately 465,000 cycles per second, which of course is much too high to be perceptible to the human ears. The audio frequencies will range between approximately 100 cycles per second and about 5000 cycles per second. Fig. 18 shows a "block" diagram of a radio receiver which locates the several frequencies.

In the case of a television receiver the radio frequency may be on the order of 100,000,000 cycles per second. The intermediate frequency would depend on the manufacturer's ideas, but would probably be in the neighborhood of 20,000,000 cycles per second. The video signal would be in the neighborhood of 4,000,000 cycles per second while the audio signal would not be greatly different from that of a radio.

Fig. 19 shows a block outline of the relationship of the various frequencies to each other in a television receiver. Block outlines do not generally give any specific information about the thing under discussion, but such diagrams do serve to place the general relationship in positions where they are more easily understood.

Section 10. INTERMEDIATE FREQUENCY TRANSFORMERS

The intermediate transformers generally consist of a coil form two to four inches in length and approximately 1/2 inch to 3/4 inch in diameter. The form itself can be made from a ceramic material, or from micarta, polystyrene or hard-pressed cardboard covered with wax. The primary coil of the transformer is wound on one end of the coil form, and the secondary coil is wound on the other end. The number of turns on each winding and the distance between them is determined by a number of factors such as the exact size of the coil form, the frequency at which the transformer is to be used, and the type of service for which it is intended.

The construction of an I-F transformer is a precision operation and calls for all the skill of an experienced radio engineer. These transformers are generally manufactured by companies who specialize in that one thing. It is not usually desirable nor practical for the average service man to attempt to build one for his own use. They can be purchased for less than they can be built, and the purchased ones will generally give better service.

The coil form, with the coils wound upon it, is firmly anchored within a metallic "can", or shield. The shield serves two purposes. It protects the coil from physical damage and makes it easy to fasten the transformer to the receiver's chassis; and it provides an electrical and magnetic shield

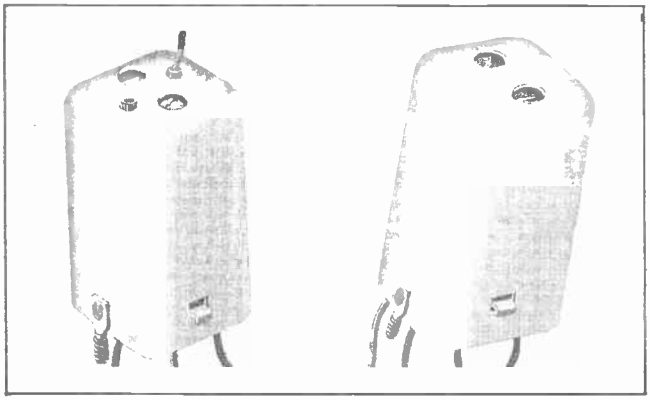

Fig.22. Complete I-F Transformer with Shield.

around the coils themselves. The shield prevents the high-frequency electromagnetic waves around the coils from radiating out into space where they might interact with other circuits of the receiver, and further prevents stray electromagnetic waves from other circuits striking the coils and thus setting up interference.

Intermediate frequency transformers are usually designed to pass one certain frequency, or band of frequencies. In the case of an I-F transformer for use in a radio receiver it would probably be designed to pass the frequencies at or near 465,000 cycles per second, but refuse to respond to frequencies higher than about 470,000 cycles or lower than about 460,000 cycles. Such a transformer would readily pass frequencies near 465,000 cycles, and possibly even step up their voltage. But the transformer would not be affected by signal frequencies differing greatly from that value. Such a transformer is said to be "tuned" to that particular frequency. We have not discussed "tuning" yet, but we will be studying that fascinating subject very soon.

NOTES FOR REFERENCE

Transformers can be used to "step up" the voltage between two circuits, or to "step it down".

The voltage in the primary and the secondary of a transformer is directly dependent upon the ratio of the turns on the two windings.

The voltage in the secondary of a transformer is directly proportional to the ratio of the turns on the secondary winding to the primary winding.

The current in the secondary of a transformer is inversely proportional to the ratio of the turns on the secondary to that of the primary.

Radio and television power transformers frequently have two and more windings on the secondary.

Some television transformers step up the voltage to extremely high values. THESE TRANSFORMERS ARE HIGHLY DANGEROUS. ALWAYS USE CARE.

NEVER WORK WITH A TELEVISION TRANSFORMER UNLESS YOU ARE ABSOLUTELY CERTAIN THE POWER IS TURNED OFF.

Intermediate frequency transformers serve to link together the various stages in the intermediate frequency section of a radio or television receiver.

Intermediate frequency transformers can be pre-tuned to one certain frequency, in which case it will pass no other frequency. This is a common practice.

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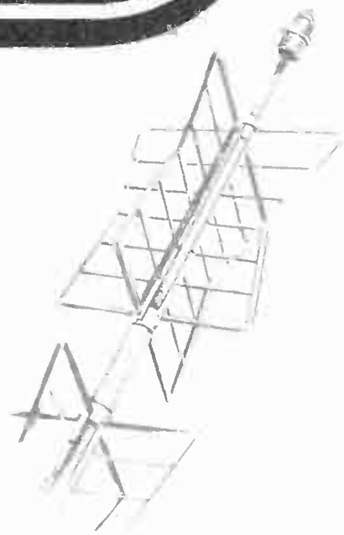

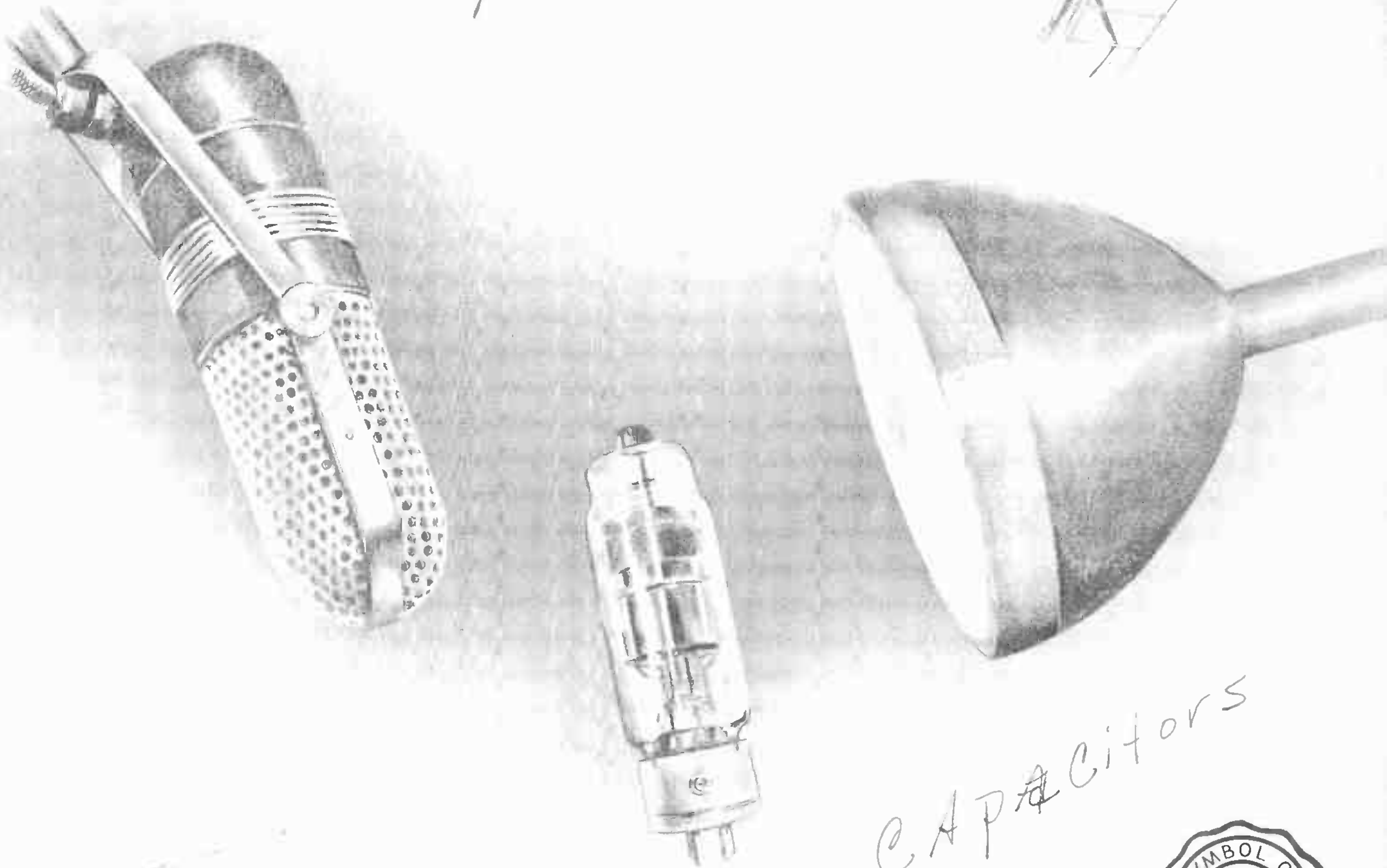

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RADIO TELEVISION

CAPACITORS

Contents: Introduction - Construction of a Capacitor - Where Capacitors are Used - What Capacitors Do - How Capacitors Operate - Action of Capacitors in Alternating Current Circuits - Capacity - Capacitive Reactance - Color Code for Capacitors.

Section 1. INTRODUCTION

There are recorded instances of men experimenting with the electrical properties of certain substances almost as far back as there is any recorded history. It is interesting, almost startling, to note that a student in ancient Greece performed some experiments more than 600 years before the birth of Jesus Christ which involved the electrical properties of amber and fur. The student was named Thales. He lived in the city of Miletus. He demonstrated how amber could be rubbed by fur and then would attract and hold light substances such as thread.

Thales did not know just what caused this action. Like many other men of his day, when he discovered something he could not explain he attributed the action to one of the pagan gods. He attributed the action of the amber to a god which lived within the amber. It was due to Thale's experiments with amber, that electricity obtained its name. The word "electricity" is derived directly from the Greek word meaning "amber".

Some thirty-five years before the outbreak of the American Revolutionary War, in about the year 1740, a European scientist got an idea that electricity was some kind of liquid. He conceived a plan for dissolving electricity in water.

Part of the apparatus designed for the experiment was a large glass jar filled with water. The bottle was corked, but a metal rod went through the cork into the water. The experimenter would rub pieces of amber, then touch the amber to the metal rod. After repeatedly charging the metal rod the experimenter could then obtain a distinct shock by touching the metal rod.

This particular experiment never amounted to much in itself. But it did lead to another experiment which resulted in a discovery of considerable importance. Some five years after the experiments with the bottle of water another experimenter living in Leyden, Germany devised a much more

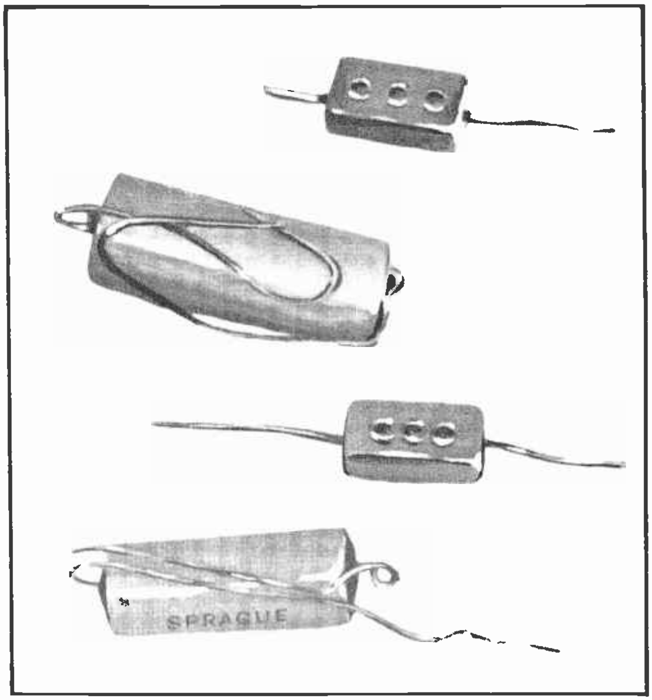

Fig. 1. Types of capacitors commonly used in radio and television circuits.

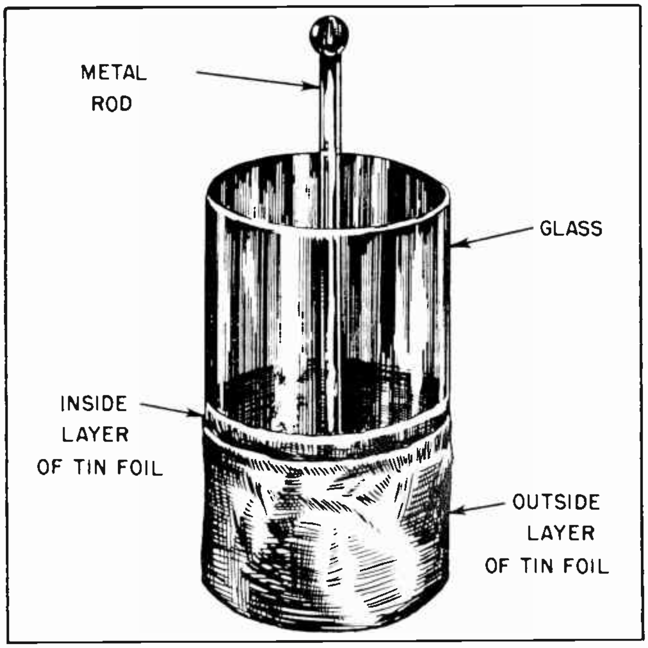

Fig.2. Leyden Jar.

efficient method of storing electricity. In the year 1745 he constructed a glass jar which was lined on both the inside and the outside with metal foil. It was found that a respectable electrical charge could be built up on the jar. By connecting several of these jars together a very strong shock could be given a person.

One of the experimenters, a man named Gralath, joined several of these jars together and was able to produce a shock great enough to kill birds.

A striking example of the power which could be stored in these jars was demonstrated before the King of France. A monkish scientist, the Abbe Nollet, charged up several of the jars. At the King's order 180 guardsmen joined their hands together. The Abbe then sent the charge through the guardsmen's bodies, causing them all to jump simultaneously. The King was greatly astonished, and impressed, by the demonstration.

It was only about five years after the demonstration of the Leyden jars before the King of France that our own Benjamin Franklin conducted his experiment with the kite. He tipped his kite with a bit of metal, then sent it up into the clouds during a storm. Electricity from the clouds traveled along the wet kite string and jumped from a key on the end of the kite string to his finger. A direct result of Franklin's experiment led to the erection of lightning rods on many buildings in this country and in Europe.

The Leyden jar is a simple form of a device which we now call a "capacitor" or "condenser". Franklin was able to obtain the transfer of electricity between the clouds and the earth because the earth and the clouds act like an enormous Leyden jar. The earth acts like one of the metal coatings on the Leyden jar and the layers of electrified gases in the clouds act like the other coating. The air of the atmosphere acts like the glass of the Leyden jar. This vast capacitor of the earth and clouds is always charged. Leakage between the two layers takes the form of lightning discharges.

Section 2. CONSTRUCTION OF A CAPACITOR

The Leyden jar, as constructed more than two hundred years ago, was remarkably similar to the commercial capacitors which are in such common use today. The Leyden jar consisted of two metallic conductors separated by a non-conductor (dielectric). The glass of the jar was the non-conductor, which in the case of modern capacitors is usually referred to as the "dielectric material", and the metal foil was the conducting material. A modern capacitor is very similarly constructed. It consists of two conducting surfaces separated by a non-conducting material.

Fig. 5 illustrates the essential features of every capacitor. The two metallic plates are connected to "pigtails" by means of which the capacitor can be tied into the electrical circuit. These pigtails are very similar to those used for the same purpose on resistors, and consist of short pieces of wire just long enough to make the necessary connections with other elements of an electrical circuit.

The metal plates may be made of almost any conducting material. The exact material which may be selected for any specific capacitor will depend upon the use to which the capacitor is to be put. Aluminum, aluminum foil, tin foil and copper are the most commonly used materials.

The shape of the capacitor may take almost any form which will satisfy the needs of the manufacturer or the user. The metal may remain in flat sheets or may be rolled up into cylinders, or made into almost any other shape which may be necessary or convenient.

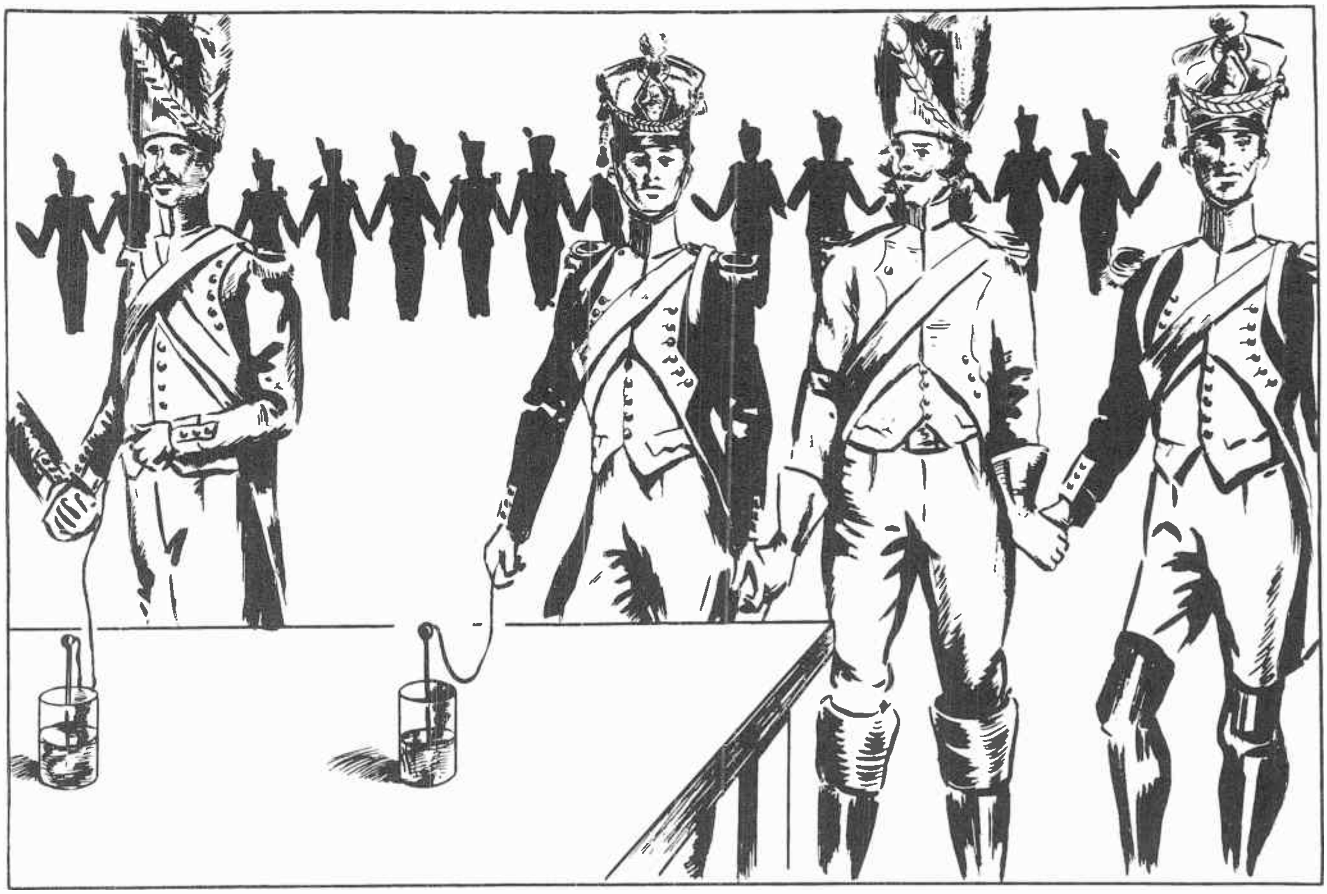

Fig.3. Shocking ability of Leyden jar being demonstrated before the King of France.

The dielectric material, likewise, may vary widely. The exact kind which is selected will depend upon the purpose for which the capacitor will be used, the cost, the voltage, and the requirements of size.

Air, waxed paper, mica, glass, porcelain, and sometimes rubber and a few of the newer plastics are the materials most generally used as dielectrics in commercial capacitors.

A special type of capacitor which is widely used in radio and television work, called the "electrolytic capacitor", uses a dielectric formed by chemical action. At least one, and usually more, electrolytic capacitors will be found in nearly every electronic device. It is such an important type we will discuss it separately from the other general types.

Inside the capacitor proper the non-conducting dielectric material is placed so it will completely insulate the two metal surfaces from each other. This usually means the surface of the dielectric is slightly larger than the surface of the metal plates.

Very frequently both the metal and the dielectric will be flexible materials. Examples of this would be a paper dielectric and a conducting surface of tin foil or aluminum foil. When materials such as these are used they can both be cut into long strips, then rolled into a small, compact cylinder. Fig. 6 shows how the paper and the foil are cut into strips. There is first laid down a strip of the paper, then a strip of the foil (cut slightly smaller) is placed upon the paper. Next a second strip of paper is laid upon the foil. Finally the second strip of metal foil is placed upon the second strip of paper.

Pigtails are attached to each of the strips of metal foil. One pigtail extends from one side of the foil and the other pigtail extends from the other side of the other foil. The arrangement of the strips of paper, the strips of metal foil and the pigtails are shown in Fig. 7. The entire mass is then rolled into a tight roll. The paper is fastened securely to prevent it from unrolling. Sometimes a cylindrical cover of tougher paper is placed around the mass and glued into place. Finally the

Fig.4. The earth and clouds form a huge capacitor.

completed capacitor is dipped into a special electrical wax. This seals out the air and moisture and is a big factor in extending the life of the completed capacitor. This type capacitor is usually referred to by radiomen and the radio trade as a "paper capacitor." They are very widely used in all types of radio and television receivers.

Section 3. **WHERE CAPACITORS ARE USED**

The first introduction to the construction of a capacitor often causes one to wonder just what part such an insignificant appearing piece of apparatus could play in the operation of a radio or television receiver. Before going into the explanation of what a capacitor does in a radio or television circuit we will make the flat statement that capacitors are so important that without them we could have no such thing as radio or television. They are vital to both the transmission and the reception of radio and television. Do not allow their insignificant appearance to fool you. The better you understand the operation and functioning of capacitors the better you will be able to understand the operation of all radio and television circuits. The more skilled you will be in this field.

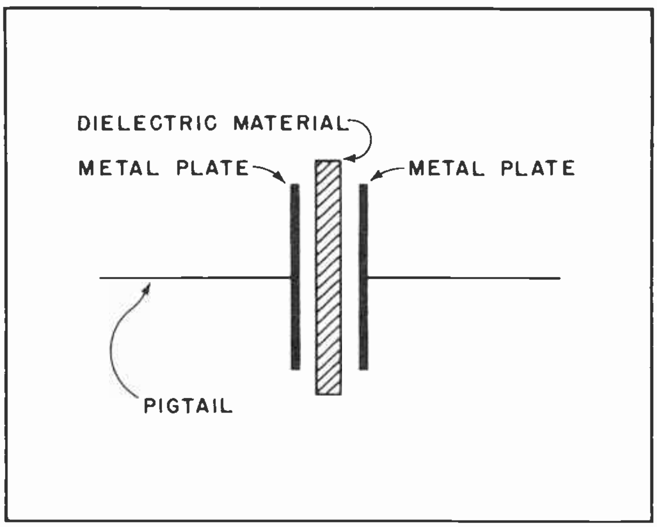

Fig.5. Essential details of a capacitor.

Section 4. **WHAT CAPACITORS DO**

We have previously mentioned that in some radio and television circuits we would find both direct current and alternating current flowing. We went even further and said that in some of those circuits there would be alternating currents of more than one frequency -- one or more operating at high frequencies and possibly one or more others operating at lower frequencies.

By the very nature of radio and television these situations cannot be avoided. In fact, the very existence of radio and television depends upon the fact that these

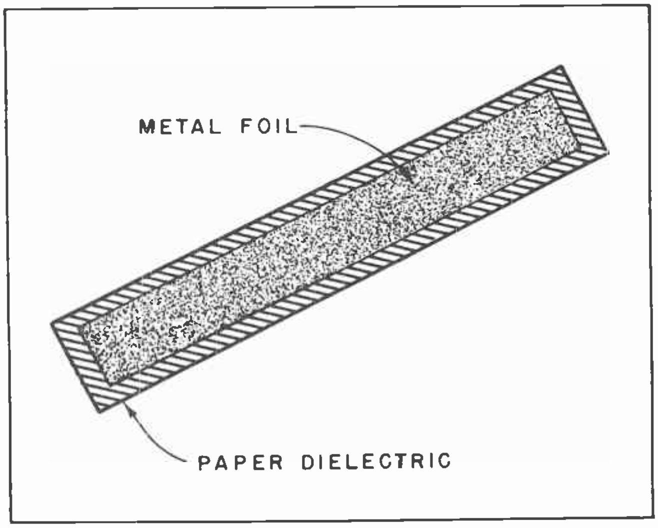

Fig.6. Foil and paper for a paper capacitor.

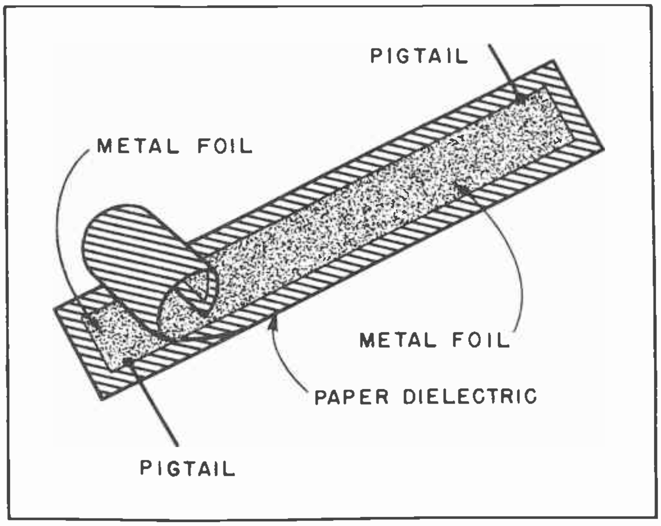

Fig.7. How a paper capacitor is assembled.

things can happen. As an example of this we will repeat something which was mentioned before -- the radio frequencies which are capable of being radiated out into space are far too high to be perceptible to the human senses, and the low frequencies which we can hear are far too low to be radiated. In order to broadcast speech, music and other sounds which are audible to the human ears these sound frequencies must be skillfully mixed with the higher radio frequencies which can be radiated.

In the receiver then, whether it be radio or television, these two frequencies must be separated from each other. The capacitor plays a vital role in performing this function. But, this is only one of the many things capacitors do.

Since the two metal plates of the capacitor are separated from each other the natural reaction of a person being introduced to it for the first time is that such a device can be of little value of an electrical nature. It is because of the fact that the two metal plates do *not* touch that enables a capacitor to perform one of its important functions; prevents the passage of direct current.

But in the case of alternating currents we have another situation. A capacitor *apparently* passes alternating current. Note that we say "apparently" passes. For all practical purposes a capacitor does "pass" alternating current, and all experienced radio and television men speak of capacitors as passing alternating currents. Perhaps from a strictly technical viewpoint no current actually passes completely through a capacitor but the fact that it *apparently* does makes the capacitor an extremely useful device. We will discuss this in detail and completely clear up what may seem a confusing situation.

Section 5. HOW CAPACITORS OPERATE

When the experimenters back in Leyden, Germany were fooling around with their jar they did not know just what they were doing. It was only by the sheerest chance they stumbled upon something which has proven to be of immense value all down through electrical history.

Fig.8. Paper capacitor.

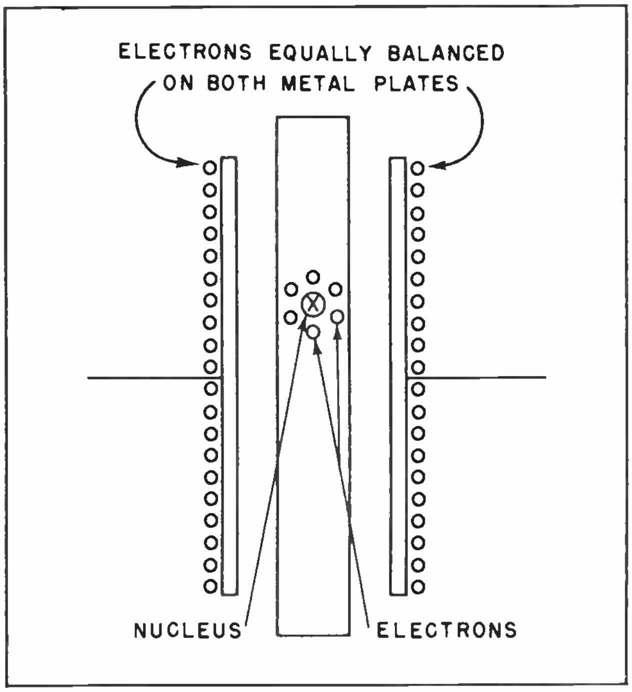

Fig.9.

When the metal foil was first placed on the inside and the outside of the glass jar it is reasonable to assume the number of electrons per unit of metal material was the same on the inside as the outside. In other words the two sheets of metal foil were at the same electrical potential -- no voltage existed between them. In any event no attempt was made to change the electrical potential between the metal foils during the course of the construction of the device.

It was only after the jar was completed that any attempt was made to "charge" it. This was done by rubbing a piece of amber and touching it to the metal rod leading to the foil on the inside, or by touching the amber directly to the metal foil on the outside of the jar. Touching the amber to one of the plates changed the number of electrons in the metal foil. This resulted in one of the sheets of metal foil having more electrons than the other sheet -- or you could say that it resulted in one of the sheets having less electrons than the other. The end result amounts to the same thing.

Now let's take a look at the dielectric, the non-conducting material which forms the insulation between the plates. It is interesting to note just what is taking place in the dielectric material as a result of the unbalanced condition of the electrons on the metal plates of the capacitor.

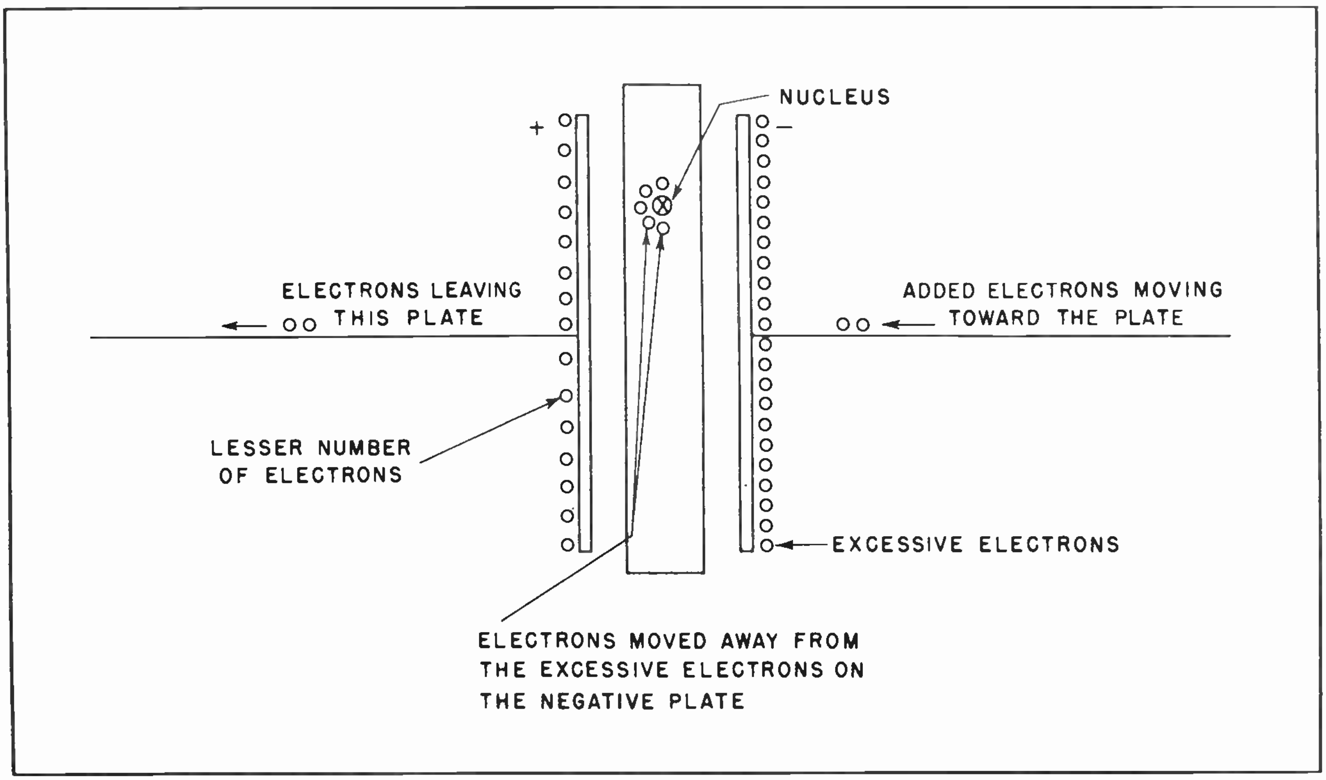

Fig.10.

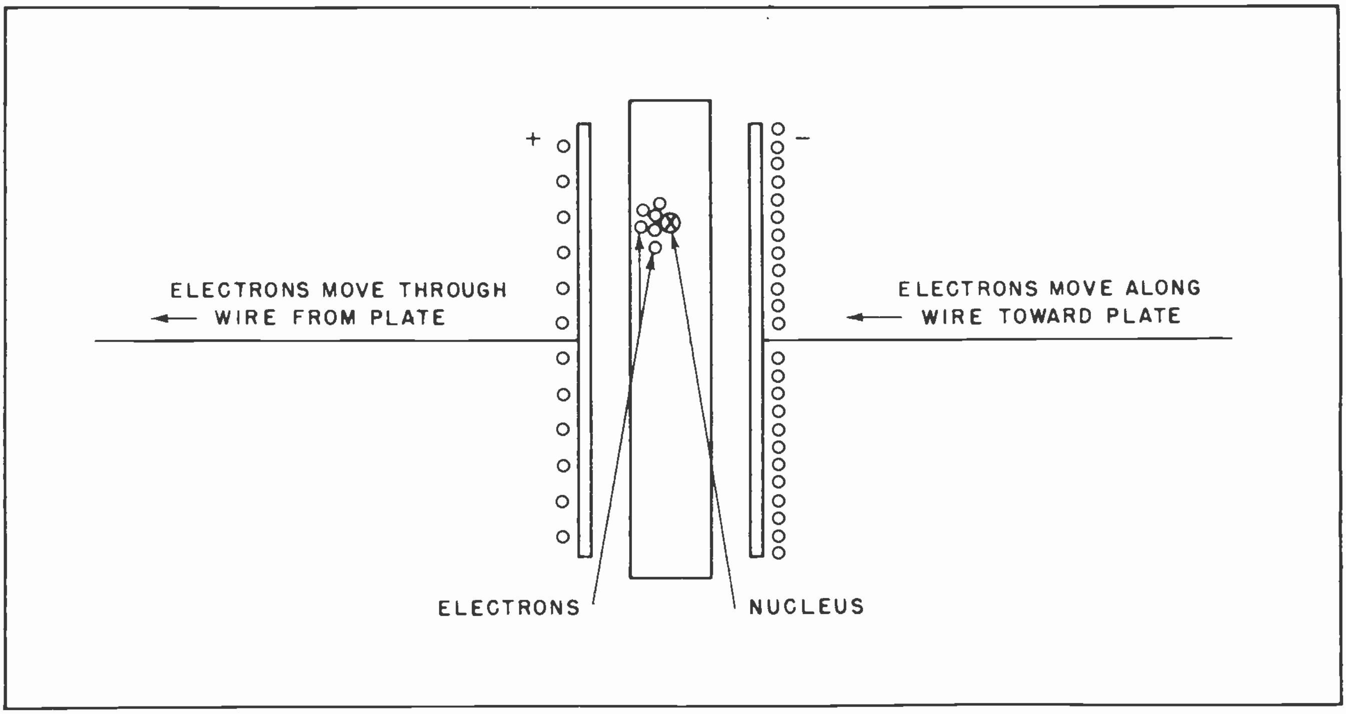

Fig 11.

It should be recalled that an insulator is some substance whose electrons are bound so tightly to the nucleus they are not free to move from one atom to another as in the case of conducting materials. But that does not mean the electrons in an insulator are completely unaffected by electrical potentials.

It is impossible to show what happens to all the electrons, and each nucleus, which go to make up an atom of the material in a dielectric when placed between two metal plates at the time an electrical potential exists between them. But we can examine the case of *one* nucleus.

In Fig. 9 is shown the cross-section of a hypothetical capacitor. Each metal plate has the same number of electrons. At the instant shown there is no potential difference between the two plates. In the dielectric is shown the nucleus of one atom with its electrons arranged symmetrically around the nucleus. This is the way the electrons will be distributed on the plates and within the dielectric material when the capacitor is not charged.

In Fig. 10 we see what happens when a few extra electrons are forced onto the metal plate at the right as the result of the pressure of an external voltage. We speak of any voltage or circuit outside the capacitor itself as being external. The electrons move along the wire leading to the metal plate. The excess electrons on the right hand plate affect the electrons surrounding the nucleus of the atom in the dielectric.

The electrons are bound so tightly to the nucleus they cannot actually move away from the nucleus, but they can be distorted in their orbit to the extent that they move away from the excess number of electrons on the right hand plate. The electrons are reluctant to move. They only do so because they are repelled by the excess of electrons on the metal plate. They will remain in this distorted position only so long as they are repelled by the excessive number of electrons on the plate. They keep straining to return to their normal position. This strain takes the form of a voltage which tends to oppose the external voltage.

If the external voltage is increased and more electrons are forced onto the right hand metal plate the electrons around the nucleus will be moved even farther around in their orbit. The more electrons there are in the metal of the plate the farther the electrons in the atoms of the dielectric will be distorted in their orbits. But the farther they are distorted the more they will strain to get back into their proper positions. This is shown quite clearly in Fig. 11.

It should be noted that as the electrons in the dielectric material are distorted by moving toward the left, they, in turn, tend to repel the electrons in the metal of the left hand plate. The electrons in the metal are reasonably free to move, and this they do by moving along the wire which is connected to the left hand metal plate.

In other words, as electrons from the external circuit move toward the right hand plate along the wire which is connected to that plate they cause the electrons in the dielectric to become distorted in their orbits. The movement of these electrons in the dielectric then cause some of the electrons in the left hand plate to move away from that plate, along the wire to which it is attached, toward the external circuit.

If a meter were placed in the wire leading to the right hand plate and another meter were placed in the wire leading to the left hand plate, it would be found that as a current of electrons flowed in the wire to one plate an equal current would flow away from the other plate. Fig. 12 shows a meter in each wire leading to the plates of a capacitor. At *A* no current is flowing in either direction. At *B* a current is flowing from the right toward the left. At *C* a current is shown flowing in the opposite direction. The main point to be remembered is that the same amount of current will be flowing in each wire at the same time, and it will be flowing in the same direction.

It is rather obvious that this condition could not continue indefinitely. The question is just how long can electrons continue to flow onto one plate of a capacitor and away from the other plate of the capacitor?

To answer this question we must turn our attention again for a moment to the electrical strain, or stress, which has been set up in the dielectric. It takes an external voltage to distort the electrons in their atomic orbits within the dielectric. This distortion is itself a form of voltage which is striving to get the electrons back into their normal position. If 50 volts are applied to the external circuit the electrons within the dielectric will be distorted just

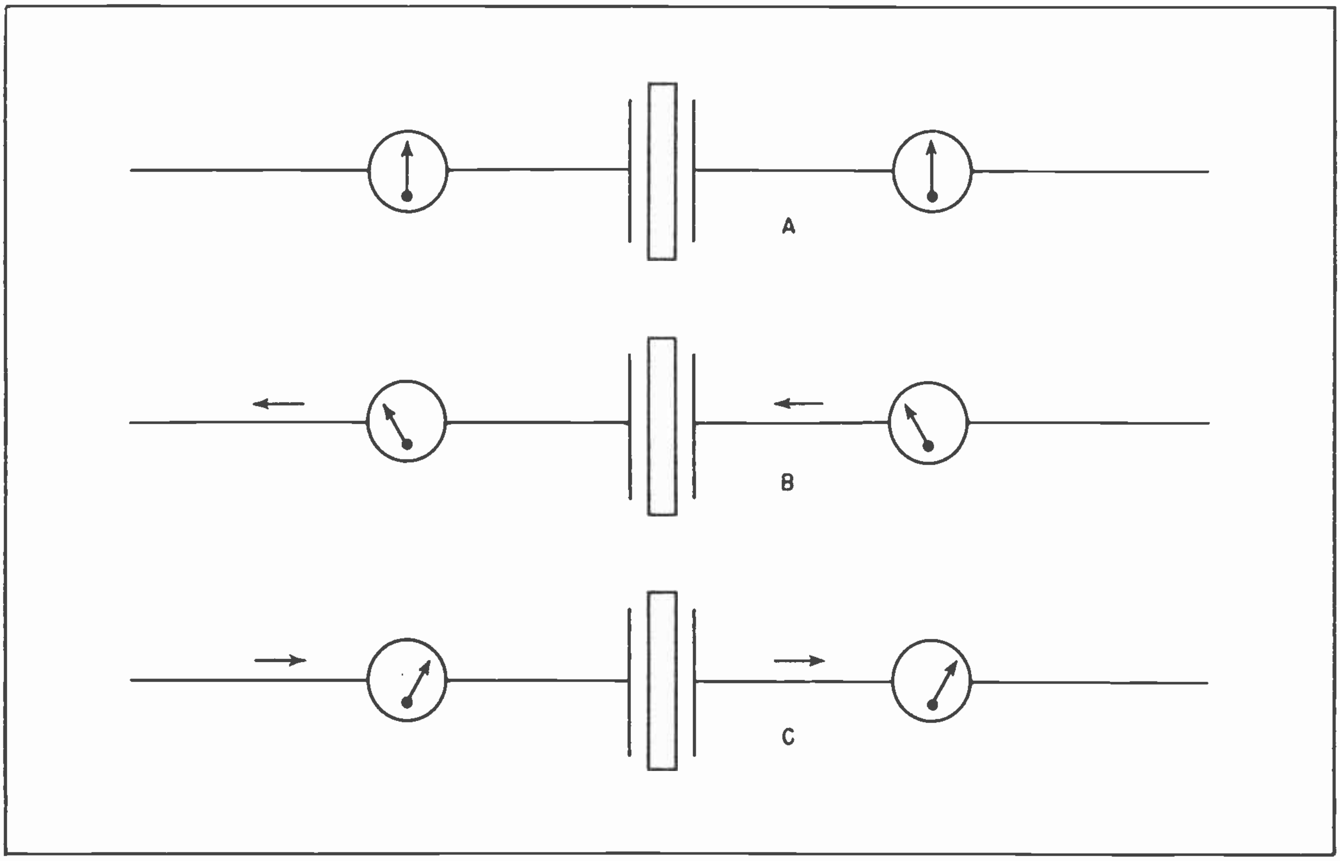

Fig. 12.

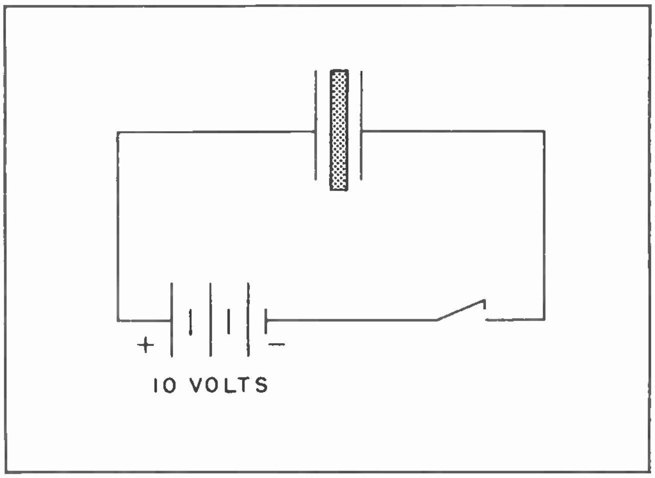

Fig. 13.

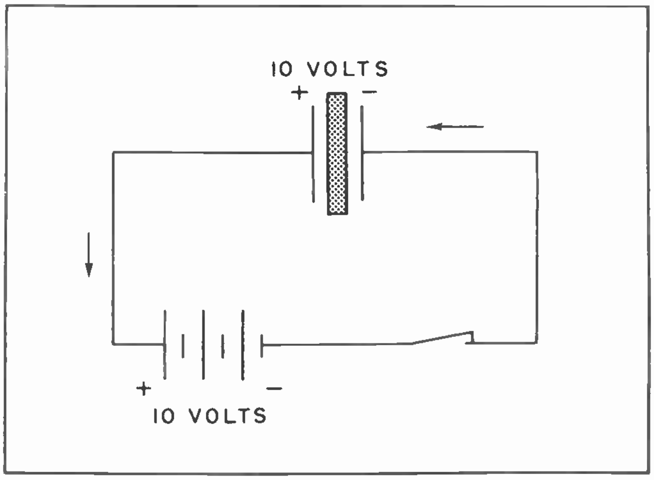

Fig. 14.

enough that their straining to regain their normal position will amount to exactly 50 volts. If more voltage is applied to the external circuit, say it is raised to 75 volts, then the electrons in the dielectric will be distorted a little farther until their straining to get back will amount to 75 volts. If the external voltage is raised to 100 volts then the strain within the dielectric will rise to 100 volts.

When a voltage is first applied to the external circuit leading to a capacitor, electrons will flow onto one plate until the strain in the dielectric increases to a value, which balances out the externally applied voltage. When the voltage strain within the dielectric balances out the externally applied voltage, electrons will cease to flow onto the metallic plate. So long as the external voltage remains at the same value no electrons will flow in or out of the connecting wires leading to the metal plates. But, should the external voltage be decreased then voltage strain within the dielectric will operate to force some of the excess electrons from the plate, and an electron current will flow in the opposite direction to that which took place when the external voltage was first applied.

As an example of how this would work in actual practice let us look for a moment at Fig. 13. Here we have an uncharged capacitor, a battery, an open switch and enough wire to connect these things into a series circuit. The capacitor is not charged at this time but we have an external voltage available in the form of the battery which we can use to charge the capacitor any time we close the switch.

In Fig. 14 the switch has been closed. The battery causes electrons to flow through the switch and the wire leading to the right hand plate of the capacitor. The electrons moving onto the right hand plate of the capacitor sets up a dielectric strain within the dielectric between the two plates of the capacitor. As the strain is set up it forces electrons from the left hand plate into the connecting wire which leads to the positive terminal of the battery. Electrons flow onto the right hand plate of the capacitor until the strain in the dielectric of the capacitor reaches a value of 10 volts. Then electrons cease to move in any part of the circuit.

Now if the switch should be opened, as in Fig.15, the battery would no longer be applying any external voltage to the

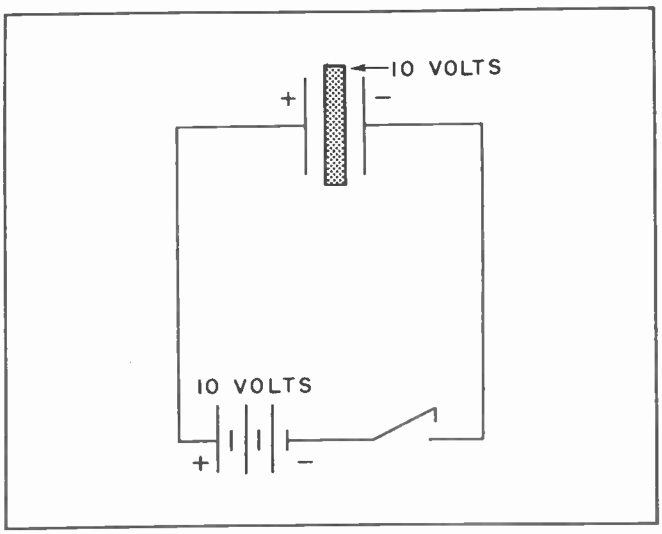

Fig. 15.

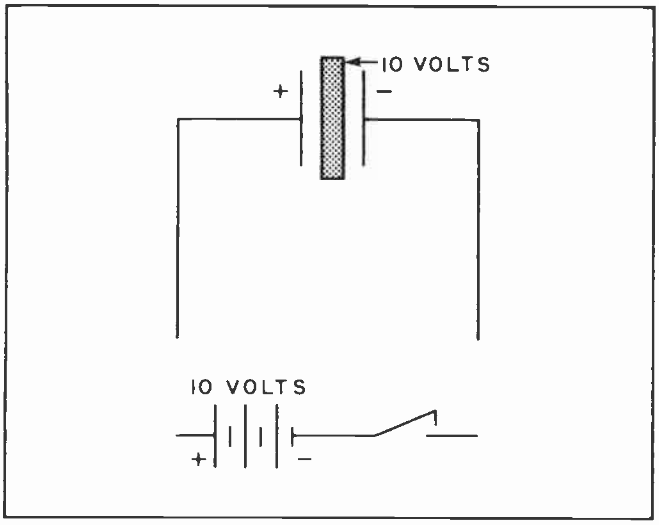

Fig. 16.

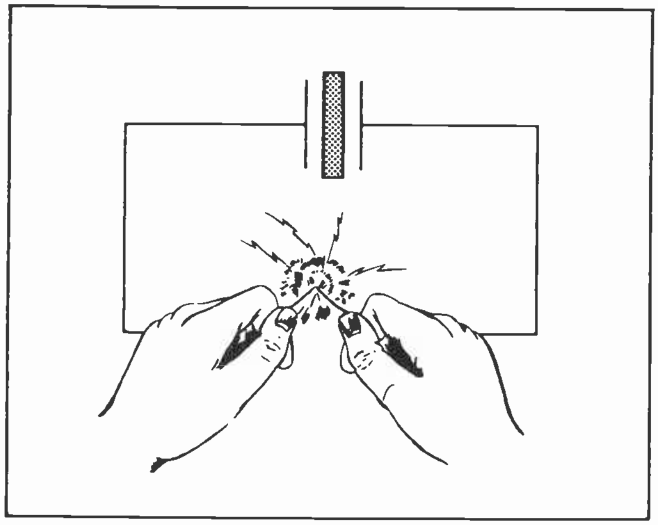

Fig. 17.

capacitor and it might be thought the strain within the dielectric of the capacitor would be relieved. But, remember, the strain is caused by an excess number of electrons on the right hand plate of the capacitor. These electrons are still there even though the external voltage has been removed. There is no way for them to get off. The circuit is open.

The battery and the switch can be completely removed from the capacitor as in Fig. 16, but the capacitor will continue to hold its charge of 10 volts. The excess of electrons will still be on the right hand plate. The internal dielectric strain will still remain. This charge will remain for an indefinite period of time, depending upon the construction of the capacitor and the type of dielectric. Some capacitors will retain their charge for only a few seconds or a few minutes; others will retain their charge for days.

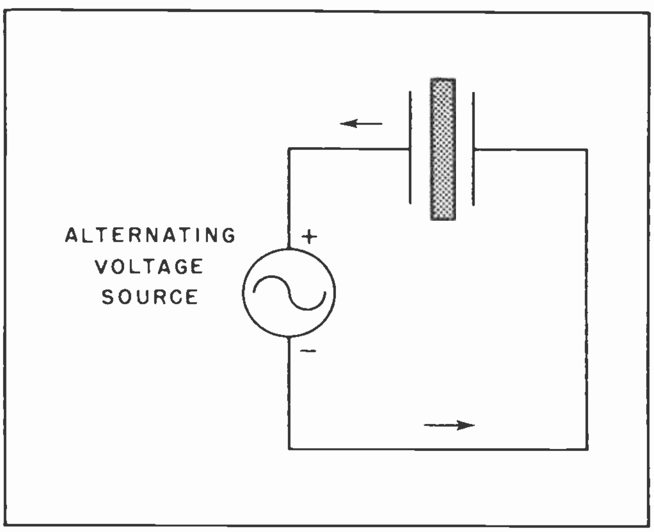

Fig. 18. Current flow as alternating voltage is applied to the plates of a capacitor.

If the two wires leading to the plates of the charged capacitor are brought together as in Fig. 17 a complete circuit will be created by means of which the excessive electrons on the right hand plate can make their way around to supply the deficiency of electrons on the left hand plate. When this happens the strain will be removed from the dielectric and the capacitor can be said to be discharged. When the two wires are brought together a spark will usually result at the point where they are brought into contact.

Section 6. ACTION OF CAPACITORS IN ALTERNATING CURRENT CIRCUITS

It might be argued that the action of a capacitor when used with a battery is all very interesting, but of what practical value is it? True, a current will flow in the circuit to the capacitor while the capacitor is charging up, but it only takes a fraction of a second to charge up the average capacitor. When the capacitor is fully charged all current ceases to flow in the external circuit; the capacitor is then almost like an open circuit.

All this is true enough when the source of voltage is a battery. But suppose the voltage source is an alternating voltage as in Fig. 18. At the instant shown in Fig. 18

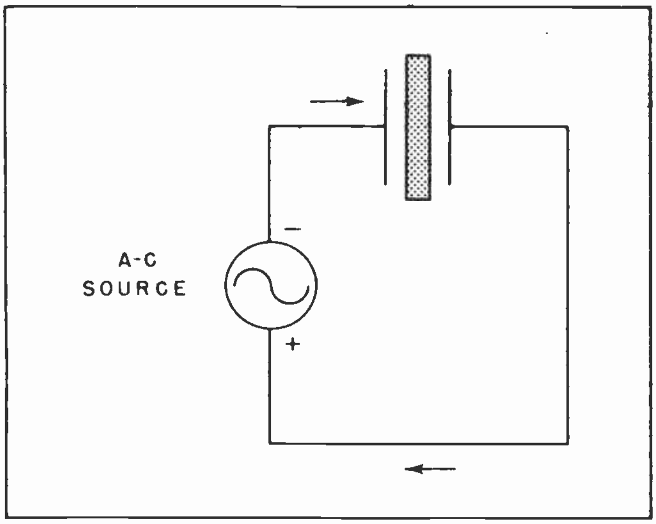

Fig. 19. Current flow after the voltage is reversed.

the voltage is in the direction shown by the arrows. Electrons will be moving onto the right hand plate of the capacitor in much the same manner as when the capacitor was being charged by the battery in Fig. 14. As in the case of the battery, it will probably take only about 1/50 or 1/60 of a second, possibly less, for the capacitor to become fairly well charged. But suppose that by the time the capacitor has become charged, or even slightly sooner, the polarity of the alternating voltage has reversed itself. Such a situation is shown in Fig. 19. When this happens the capacitor will discharge itself, the electrons on the right hand plate will flow back into the external circuit, and an instant later an excessive number of electrons will gather on the left hand plate charging up the capacitor just opposite to what it was the instant before.

Since alternating current is constantly flowing first in one direction then the other, the electrons will flow onto first one plate of the capacitor, charging it up in one direction; then the next instant reversing themselves and flowing onto the other plate, charging the capacitor up in the reverse direction. This action takes place over and over, many times a second. Since the electrons flow onto one plate for an instant and out from the other, then reverse themselves and flow in the other direction, alternating current appears to flow right through the capacitor, almost as though it were not there.

Sometimes this action can be understood a little more clearly when its operation is compared with that of water in a pipe. In Fig. 20 we have a water pump connected with a closed pipe circuit. In the pipe circuit is a sphere within which is a flexible diaphragm. The sphere is very similar to an electrical capacitor, with the diaphragm duplicating the action of the dielectric of the capacitor. The diaphragm will not allow any water to actually pass all the way through the sphere, but since the water is flowing back and forth in response to the pressure of the pump the water appears to flow right through the sphere. This action can be followed a little more clearly by studying Figs. 21 and 22 along with Fig. 20.

Section 7. **CAPACITY**

The amount of electricity a capacitor can hold, or store, is determined by its *capacity*. In determining capacity we must learn two new electrical terms, or units of measure.

Earlier in our studies we mentioned that electrical current flow in a conductor was generally measured as the *rate of flow* of electrons. This was compared with gallons of water per minute which might flow in a pipe, or more nearly similar, the speed in *knots* of an ocean vessel. All this is true.

Normally we are far more interested in the *rate* at which electrons flow in a circuit than we are in exactly *how many* flow during a particular period. But there is a unit for measuring the quantity of electrons just

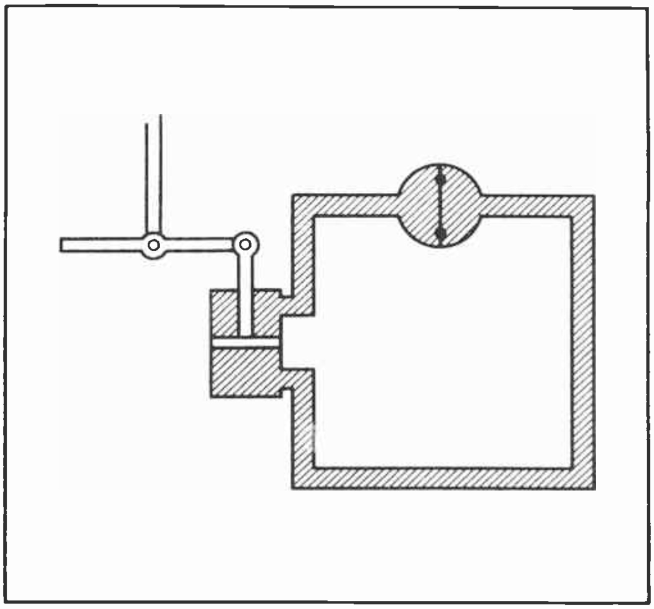

Fig. 20.

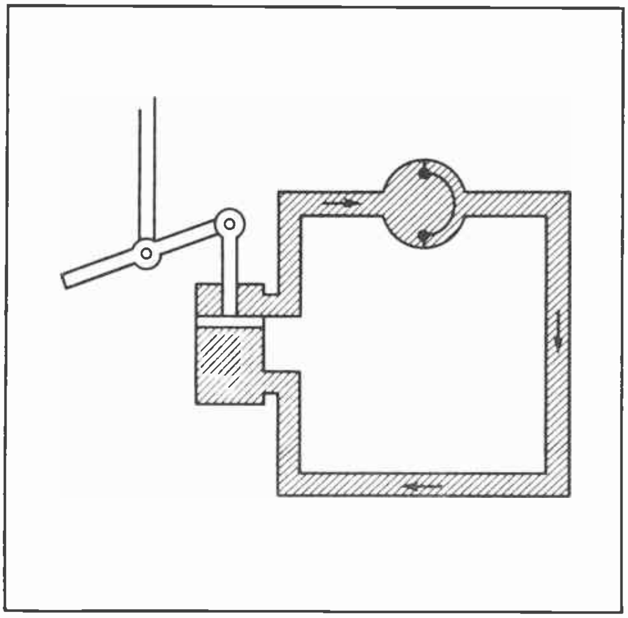

Fig.21.

as a gallon is a unit for measuring the quantity of water. When an electrical current is flowing in a circuit at the rate of one *ampere*, one *coulomb* of electrons will pass any given point in the circuit during one second of time.

Except for strictly scientific measurements the coulomb is seldom used by electrical or radio men. Neither is it commonly used by technicians working with television. Nevertheless it is a definite unit of measurement, and it is well to know exactly what it is. The number of electrons which are needed to make one coulomb, staggers the imagination. The number is so large few of us can actually visualize it. One coulomb is equal to 6,280,000,000,000,000,000 electrons. Radio men would write this number as 6.28×10^{18}. This is a form of arithmetical shorthand.

The coulomb is also used as a standard for measuring the capacity of capacitors. Any capacitor which is capable of storing one coulomb of electricity is said to have a capacity of one *farad*. Thus the *farad* is the unit of capacity. This unit was named in honor of Michael Faraday, the great scientist who contributed so much to the advancement of electrical knowledge.

Since a capacity of one farad must be large enough to store one coulomb of electricity it is understandable that a farad is a very large unit. It is so large in fact that it is seldom, if ever, used in actual practice. The *microfarad*, which is one-millionth of a farad is the most common unit for measuring capacity. Nearly all capacitors are rated in microfarads unless they are very small. In that case they will be rated in *micromicrofarads*, which is one-millionth of one-millionth of a farad. At first acquaintance microfarads and micromicrofarads may seem just a little confusing, and unnecessarily complicated. But you will soon find yourself working with them so frequently you will forget there was a time they seemed strange.

The amount of electricity a capacitor can store -- its capacity -- depends upon several things. One important factor is the area of the metal plates. The larger in area the flat surfaces of the plates the greater will be the capacity. The dielectric has a very important bearing upon the capacity of a capacitor. If two plates with a certain given area has a capacity of 1 microfarad when air is the dielectric, they will have a capacity of 3½ microfarads if dry Kraft paper is the dielectric. If porcelain were the dielectric the capacity would be increased to 7 microfarads, and if Mica, the capacity would be increased to about 8.7 microfarads. All of this assuming the plates remained the same distance apart in each case.

The distance the plates are spaced apart also plays an important part in determining the capacity of a capacitor. The farther the plates are apart the less will be the

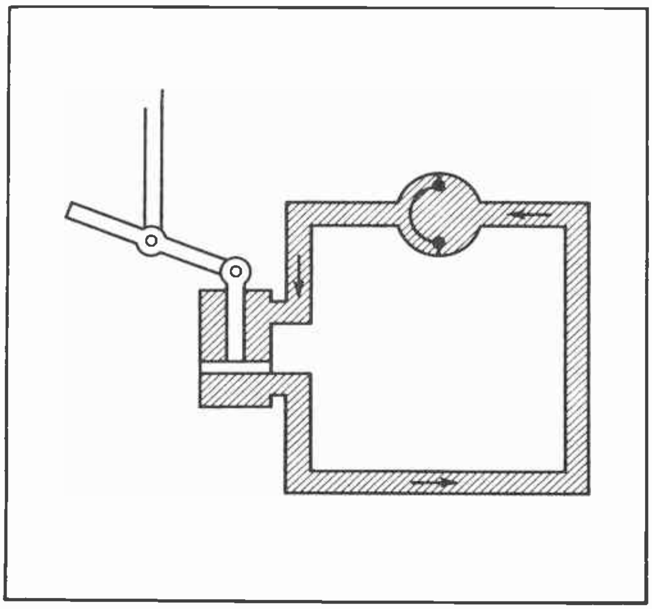

Fig.22.

Fig.23.

capacity. Thus it can be seen that three things play leading roles in determining the capacity of a capacitor; the size of the plates -- the distance between them -- and the type of dielectric.

In addition to the amount of electricity which can be stored in a capacitor there is the factor of voltage breakdown. If the plates are too close together -- that is, if the dielectric is too thin -- there is danger the dielectric will be punctured and the electricity will arc over between the plates if the voltage is too high. Thus it can be seen that reducing the thickness of the dielectric increases the capacity, but it also lowers the maximum voltage which can be impressed across the capacitor. In selecting a capacitor for any job, therefore, it is necessary to know the voltage it must withstand as well as the capacity it must have. Capacitors are built in many values of capacity and many different working voltages. If the working voltage is low, a large capacity can be packed into a very small size. But if the working voltage is high the physical size of a capacitor having the same capacity might need to be quite large. Usually the best capacitors are those which use mica as a dielectric. Mica can provide large capacity in a small space and will withstand a very high voltage before breaking down. Mica capacitors have the disadvantage, however, of being considerably more expensive than paper capacitors having the same value.

Section 8. **CAPACITIVE REACTANCE**

Although alternating current appears to flow through capacitors without much trouble, there is, nevertheless, some opposition to such current flow. This opposition is called *capacitive reactance* to distinguish it from resistance and inductive reactance. The exact amount of opposition, or capacitive reactance, any given capacitor will present to an alternating current will depend upon several things. The capacity of the capacitor has a definite bearing on the reactance. The higher the capacity the less the opposition, or reactance.

This is understandable when a little thought is given to the way a capacitor charges up and then discharges, as an

Fig. 24.

alternating voltage is applied to it. When an external voltage is applied to the plates of a capacitor, electrons will start flowing onto one of the plates. When these electrons first start gathering on the plate they meet little opposition. But as more and more of them congregate on the plate a strain is built up within the dielectric. The more electrons on the plate the greater the strain on the dielectric, and the greater the strain the higher the opposition voltage becomes. This continues until a point is reached where the voltage strain within the dielectric equals the external voltage. Where the electrons could flow onto the plate at the beginning with little opposition they will meet more and more opposition as the strain on the dielectric becomes higher and higher.

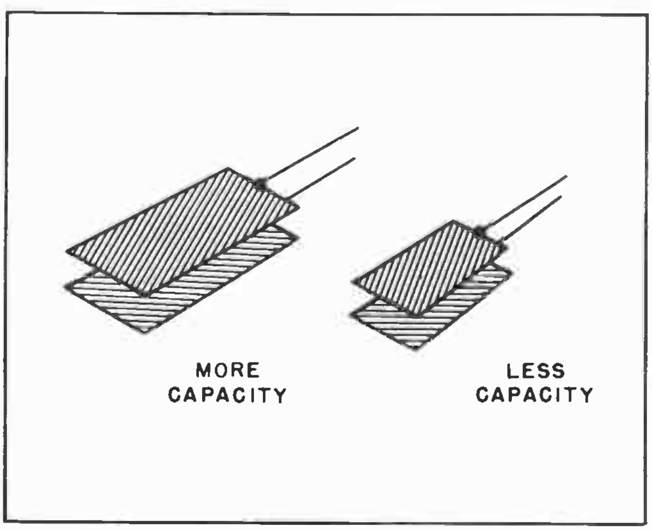

Fig. 25.

This can be said another way. At the instant the alternating current begins to charge the capacitor there will be no internal voltage within the capacitor. As the result of this a very small voltage will be sufficient to send a tremendous current of electrons toward the plate of the capacitor.

But this situation can last for only the very tiniest fraction of a second. The very instant any excess electrons reach the plate of the capacitor the dielectric will begin setting up an internal voltage to oppose the entrance of the electrons. For this

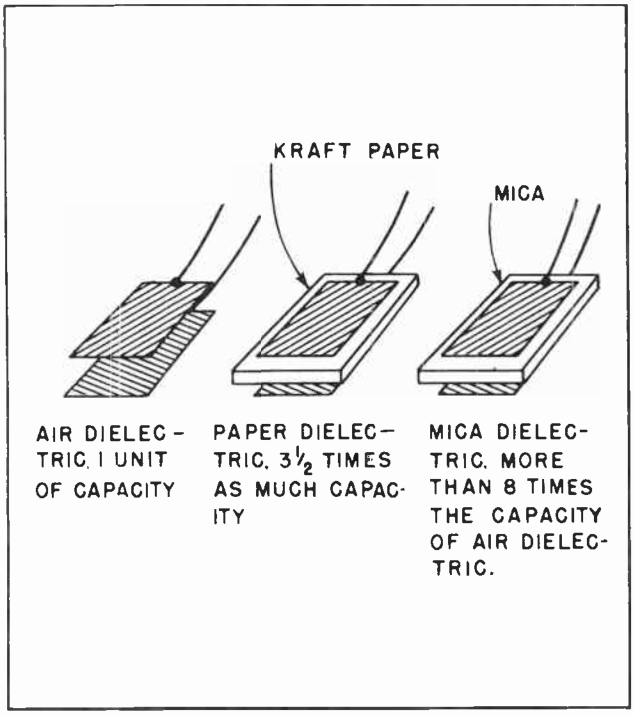

Fig.26. Dielectric material affects the capacity. Air is generally considered unity.

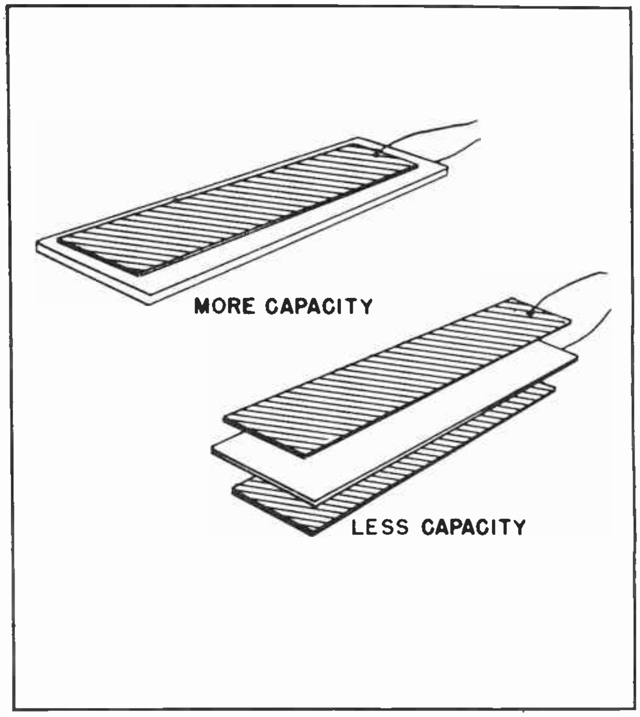

Fig.27. The closer the plates to each other, the greater the capacity.

reason the magnitude of the current will fall off very rapidly. See how this works out on a chart. Fig. 28 shows two graphs, both having the same time base. As the external voltage starts to rise on the top chart it will cause a very large current on the bottom chart. This is shown on the bottom chart as "maximum current".

Before the voltage has been increasing for more than 1/480 of a second it has risen to about half of its peak value. But the rush of electrons to the plate of the capacitor has set up so much opposing voltage strain within the capacitor the electron current has been reduced more than half. All this happens during the first 1/480 of a second of the voltage cycle.

By the time the voltage has risen to 100 volts -- its maximum amount -- the internal voltage within the capacitor has become so great it prevents any more electrons from entering the plate. The chart, therefore, shows that as the voltage on the top chart reaches 100 volts the current entering the capacitor has been reduced to zero.

The chart shows the voltage going in the negative direction but no attempt has been made to show the current in the negative direction. You can draw it in by completing the sine wave.

When the voltage again starts in the positive direction 1/60 of a second after the beginning of the chart it will be seen that the current is again maximum in that

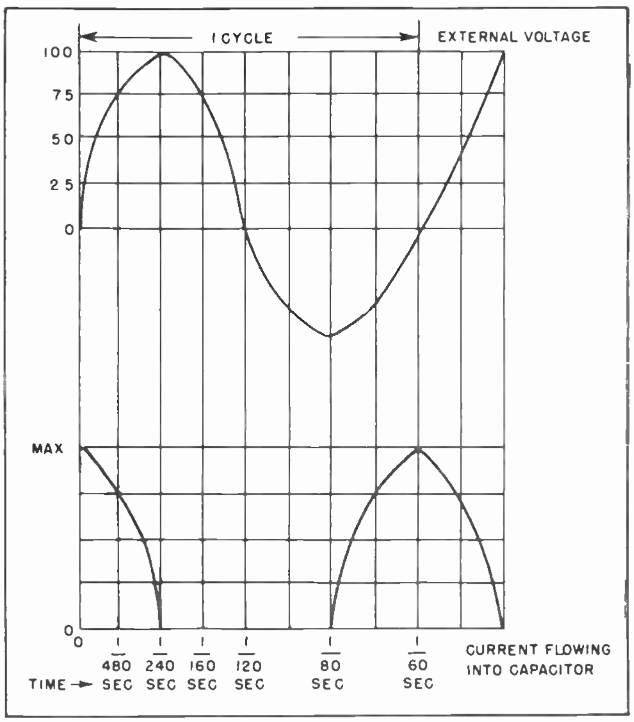

Fig.28. The relationship of the current flowing into a capacitor as the result of a changing voltage.

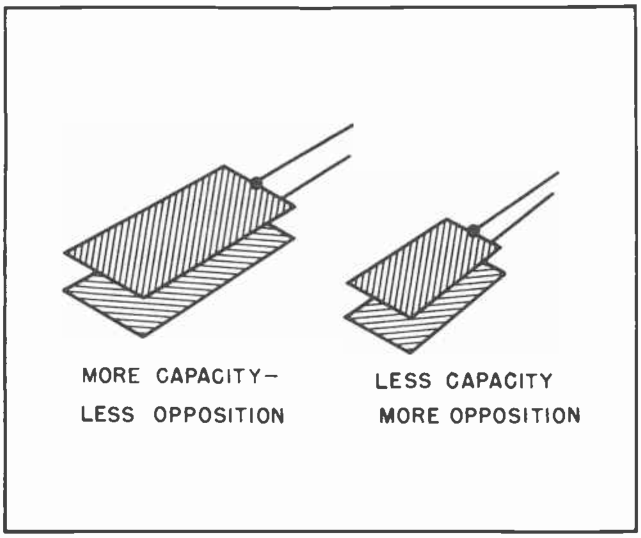

Fig.29. Capacity affects the opposition offered to alternating current -- the more capacity the less opposition.

direction. It again starts declining toward zero immediately after the beginning of the second voltage cycle.

If the capacitor is quite large and has a high capacity the electrons can flow onto the plate for a considerable period of time before the opposition becomes very great. But if the capacity is less, the opposition to the electron flow will become quite high very rapidly. For example, a capacitor of a given size might allow electrons to flow onto the plate for perhaps 1/30 of a second before the opposition became very great, but if the capacity of the capacitor was greatly reduced the opposition to the flow of electrons might become great enough to stop their flow within 1/100 of a second.

To allow the alternating current to flow freely through a capacitor the capacitor should have enough capacity to allow the current to flow in and then start reversing before the voltage within the capacitor becomes great enough to present any serious opposition. Thus it can be said that the larger the capacity of a capacitor the less will be its opposition to the flow of alternating current. As a matter of fact, in most actual circuits the capacitors generally do present a measurable amount of opposition, or *reactance*, to the flow of current. But the smaller the capacity the greater the opposition, or reactance.

The frequency of the alternating current also has a distinct bearing on the amount of opposition it will meet in any given capacitor. If an alternating current circuit has a frequency of 100 cycles per second it will flow into a capacitor for 1/200 of a second before it starts reversing. The longer it flows in, the greater will become the opposition. If the frequency is increased to 200 cycles per second the current will

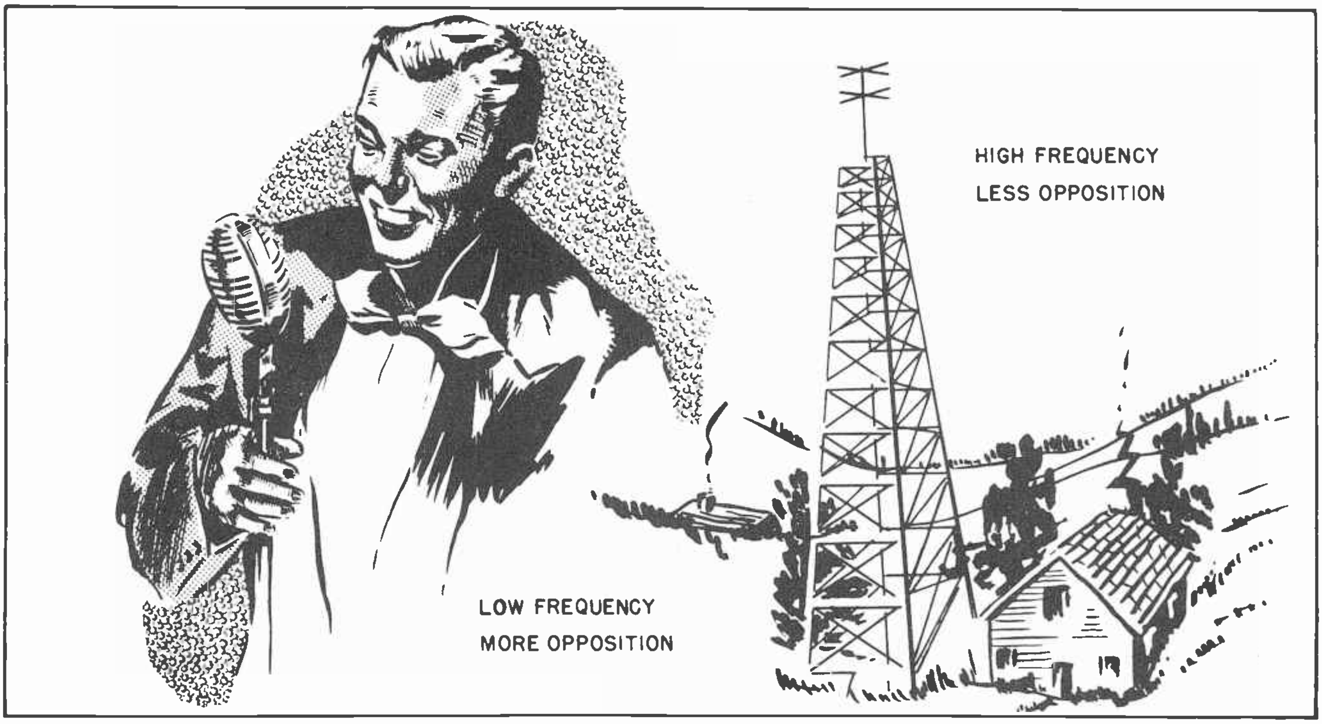

Fig.30. The higher the frequency the less opposition.

flow into the capacitor for only one-half as long, or 1/400 of a second. Thus it will flow in, and then reverse before the opposition builds up to any great value.

From this it can be seen that two things are important in determining the opposition any given capacitor will present to the passage of alternating current. One is the capacity of the capacitor, the other is the frequency of the alternating current.

Electrical engineers have worked out a special formula by means of which the capacitive reactance of a capacitor can be worked out very easily. It is something else you will find quite useful in your notebook.

The symbol for capacitive reactance is X_C. The *X* is for reactance and the subscript is to show the reactance is capacitive and not inductive. The capacity is represented by the letter *C*, and the frequency by the letter *f*, just as with inductive reactance. The unit for measuring capacitive reactance is the ohm. Thus the formula becomes:

$$X_C = \frac{1}{2\pi fC}$$

Section 9. THE FORMULA

To demonstrate just how this formula applies to a practical problem suppose we have occasion to find out the capacitive reactance (or opposition) of a 1 microfarad capacitor at 60 cycles. It is important to remember that the formula applies to capacity in farads, not microfarads or micro-microfarads. It also applies to frequency in cycles, not kilocycles or megacycles.

Whenever any capacitor is placed in an A-C circuit it will tend to oppose the passage of the current. But, it is important to remember that it will not oppose all such currents to the same extent. The degree of the opposition will depend upon the frequency and upon the capacity. We discussed the matter of frequency as it applies to alternating current a couple of lessons back and it is not believed you will have any trouble understanding what we mean when we mention the term: Frequency. But to refresh your memory we will repeat that the tendency of alternating current to flow in one direction for a certain length of time, then reverse itself and flow in the other direction, is directly related to frequency. The number of times the current goes through the complete cycle of reversing itself each second is referred to as its frequency.

Now to get back to our problem of learning how to figure the capacitive reactance (opposition) of a given capacitor when the size of the capacitor is known and the frequency at which it is used is known. If we study the basic formula for capacitive reactance for a few moments, we soon become aware of the fact that two of the values in the formula are fixed and two are variable. The figure *1* above the line is always the same (unless for some reason we decide to multiply both the top and the bottom values by the same number for some purpose), and the 2π is always the same. The 2π is roughly equivalent to 6.28.

The only values in the formula, then, which ever change are those of the frequency and of the capacity.

Now let's see just how all this applies to the specific problem we mentioned above. The formula, as we have mentioned before, reads:

$$X_C = \frac{1}{2\pi fC}$$

The thing we usually want to find is the capacitive reactance, or the opposition, of some specific capacitor to the flow of alternating current. This capacitive reactance is the X_C in the formula.

The amount of opposition presented by the capacitor depends upon the frequency (*f*), the capacity of the capacitor (*C*), and the constants. *C* in this formula is in FARADS, remember. Not microfarads.

The symbol π (pronounced "Pi") originated over 1000 years ago with the Greeks who were trying to determine the relation between the circumference of a circle and its diameter. They cut a solid sphere in two and took a tape and measured from side to side to get the diameter. Once they knew the diameter they wanted to learn (by practical means) what relation there was between the circumference of the sphere and its diameter. They accomplished this by taking the same tape and wound it around the sphere (or ball) and found the circumference was 3.14

times its diameter. Through a large number of experiments with various size balls they found the ratio between the diameter and the circumference - 3.14 - is always the same, whether the sphere (or circle) is 1 inch or 1 mile in diameter. In other words, the length of the circumference of a circle is always 3.14 *times* the length of its diameter.

Electrical men learned long ago that they could apply this same relationship of π (Pi) to their own calculations when they had to work with the constantly reversing currents encountered in alternating current work.

There are TWO reversals of the current for each cycle, so in our formula we must use the value of a π twice, thus the 2π. This gives us a constant value of 6.28 and it is a value we will use countless times in our electrical work.

f in the formula is the frequency, and in this particular problem is 60, since there are 60 cycles in the circuit under discussion.

C is the capacity, and is 1 microfarad. (When converting microfarads to farads, remember that ONE MICROFARAD is one-millionth of one farad (.000001 farad). In other words, there are one million (1,000,000) microfarads in ONE FARAD. "Micro" means "millionth".

We can sum up all of this in the following manner:

$$X_c = \frac{1}{2\pi fC}$$

2π = 2 x 3.14 which equals 6.28 (as explained above.)

f = frequency. In this case it is 60 cycles. (Frequency is always expressed in CYCLES, not kilocycles or megacycles.)

C = the capacitance of the capacitor. (In this case it is .000001 farad.)

Our first step is to substitute the numerical values for the letters in the formula.

Step #1. Substituting for 2π gives us:

$$X_c = \frac{1}{6.28}$$

Step #2. Substituting for *f* will give us:

$$X_c = \frac{1}{6.28 \times 60}$$

Step #3. Substituting for *C* will now give us:

$$X_c = \frac{1}{6.28 \times 60 \times .000001}$$

Step #4. Multiply 6.28 x 60. This will give us 376.8. (We can round this off to 377.)

Step #5. We now find that we have:

$$X_c = \frac{1}{377 \times .000001}$$

Step #6. We will now multiply 377 x .000001. This will give us .000377.

Step #7. We now find we have:

$$X_c = \frac{1}{.000377}$$

Step #8. There are several things we could do here. The best thing would be to get rid of the decimal fraction. You will recall from your grade school arithmetic that we can always multiply both sides of a fraction by the same number and it will not change the value of the fraction.

In this case we could multiply both sides of the fraction by 1,000,000. Then the value of X_c would look like this:

$$X_c = \frac{1,000,000}{377}$$

Step #9. Now all we have to do to find the value of the capacitive reactance is to divide the denominator (377) into the numerator (1,000,000) in accordance with the rules for simplifying fractions which you learned in grade school. This is a simple problem in long division as shown at the top of the following page:

```
        2,652
377 /1,000,000
      754
      2460
      2262
       1980
       1885
         950
         754
```

Therefore, $X_C = 2{,}652$ ohms.

We suggest that you study the information contained here very carefully, as we believe it will help you to obtain a better understanding of the formula, and how to solve the many problems you will be constantly running into in your daily work in radio and television.

Section 10. COLOR CODE FOR CAPACITORS

Because of the many frequencies which are used in radio and television work it follows that many different kinds of capacitors will find applications in such work. Most of the higher voltage capacitors and the higher capacity capacitors have sufficient physical size that it is readily possible to print directly on their surfaces such information as is needful for the user to know. (See Fig. 8.) The capacity is usually printed in microfarads or in decimal fractions of a microfarad. In the same manner, the voltage rating of the capacitor is also printed on the capacitor so it is easily readable.

Many of the capacitors used with the higher frequencies, however, have relatively little capacity. As a consequence the physical size of such capacitors is often quite small. Because of such small size it becomes increasingly difficult to print the necessary information on the surface of the capacitor so it can be deciphered.

To overcome the difficulty of trying to provide the necessary information regarding the capacity and the voltage breakdown rating of the capacitor the manufacturers of these components have resorted to the color code used by the manufacturers of resistors. In most respects the color code used to rate capacitors resembles very closely the code used to rate resistors. The individual colors represent the same individual digits.

Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9
Black	0

The actual use, or application, of the colors to convey the needed information differs slightly. This is partly due to the fact that more information is usually needed to properly rate capacitors than is needed to rate resistors. Another difference results from the fact that many capacitors have a different physical shape than resistors have. This makes it necessary to alter the use of the colors in a minor respect.

The manner in which the colors are placed on the face of the capacitors follows two general patterns. In one of the patterns the colors are imprinted on the face of the capacitor in the form of a series of colored dots. (See Fig. 1.) The other capacitor, which is tubular, has the colors imprinted on the capacitor in the form of several rings which encircle the body of the capacitor. The appearance of the latter type of capacitor resembles that of a large resistor so closely many technicians are occasionally fooled. A little experience is usually enough to avoid such mix-ups.

Since color-coding of capacitors was first applied to mica capacitors we will discuss them first. Even with mica capacitors the method followed in using color to describe the characteristics of the capacitors is not exactly uniform. In fact, two general systems or methods of color-coding are followed. One of the systems or methods uses three colored dots as shown in Fig. 1, while the other system uses six colored dots. Both systems will be described.

Mica capacitors are usually formed in the shape of a small, relatively thin piece of rectangular or square plastic. The color of the outer cover is usually dark brown or yellowish tan, but there is occasionally some variation from this. The size of the capacitor is usually slightly less than one inch square and less than a quarter inch thick. But here, again, we often find some variations.

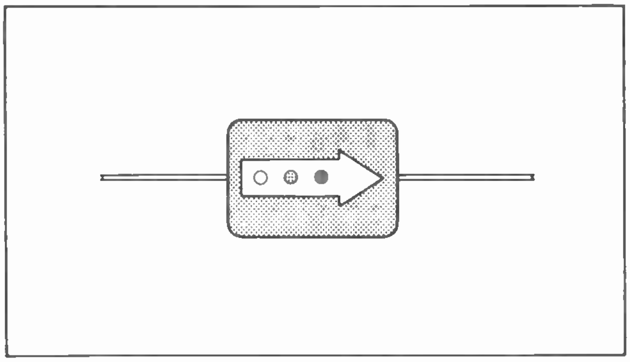

Fig. 31.

Those mica capacitors which use the three-dot system of marking usually have the three dots arranged in a straight row and enclosed within an arrow engraved into the face of the plastic covering of the capacitor. In appearance the markings look something like Fig. 31.

To read the value of the capacitor it is turned around until the arrow points toward the right. After this has been done the colored dots are read from left to right. That is, the colored dots are read starting at the tail of the arrow and reading toward the head.

In the three-dot system of marking the same method is followed as is used to mark the resistance of resistors. The first dot (nearest the tail) designates the first significant figure of the capacity value, the second dot (the middle one) indicates the second significant figure of the capacity value, while the third dot (nearest the head of the arrow) designates the number of zeros. This is just like reading the resistance color code.

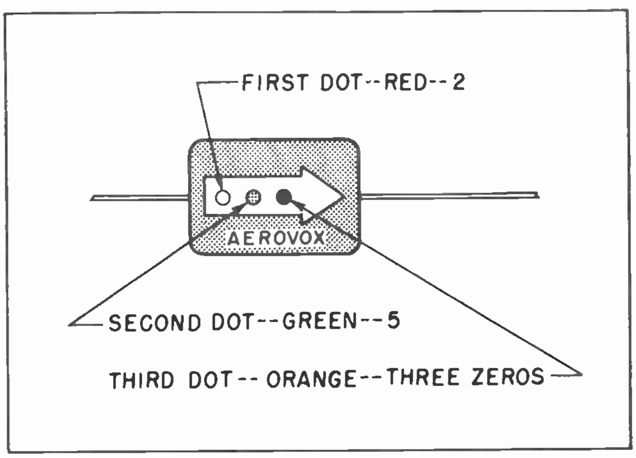

Fig. 32.

For example, suppose the dots on a mica capacitor were arranged as shown in Fig. 32.

The significant figures indicated by the colored dots then would be 2 - 5 - 000, or 25000. The next question is: 25000 what?

Since the color code is used with capacitors to mark only those which have small capacity it follows rather naturally that some very small unit of measurement is probably employed. This is true. The unit used for measuring these small capacity capacitors is the micromicrofarad.

From this it follows that the figure "25000" arrived at above is now understood to represent 25000 micromicrofarads. This can be converted into microfarads by dividing by 1,000,000. By doing so we quickly find that 25000 micromicrofarads is equal to .025 microfarads.

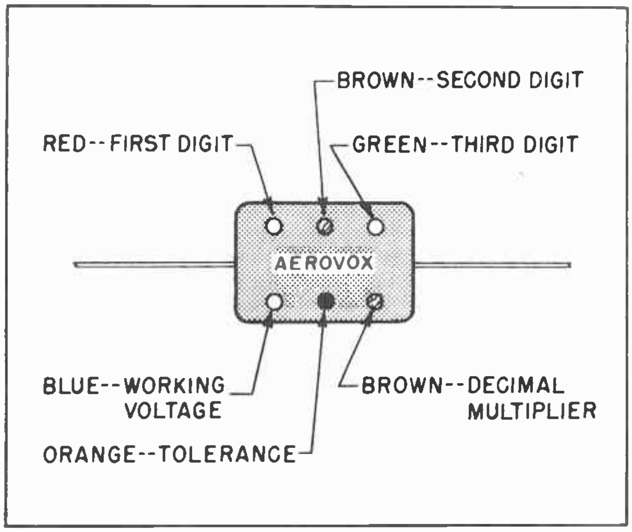

Fig. 33.

The other system used to color-code flat mica capacitors is the six-dot system. (See Fig. 33.) No arrow is generally used with this method. The positioning of the capacitor for the purpose of reading the capacity value is done by moving the capacitor around until some word on the face is in proper position to be read. Often the word is the name of the manufacturer, such as "Aerovox", or "Sprague" or "American", or something similar. The name is often located between the two rows of dots, with each row having three dots as shown in Fig. 33.

The use of six dots instead of three provides the user with much additional information. Furthermore, such a system makes it possible to show the exact capacity much more accurately than with the three-dot system.

Here is the way the six-dot system is used. The three upper dots indicate the three significant figures of the capacity value. (This contrasts with only two significant figures and a zero indicator in the three-dot system.) In the drawing we see a mica capacitor whose upper three dots are red, brown and green. From our color code chart we know these three colors represent 2 and 1 and 5. But in this case the green (or 5) does not represent zeros. Instead this is a third digit. This means the three upper colors mean the significant figure value of the capacitor is 215. But 215 what? This number must still be multiplied by some multiplier to obtain the actual capacity of the capacitor.

The actual capacity of the capacitor is learned by multiplying the three significant figures above by the decimal multiplier represented by the colored dot in the lower right side of the capacitor. This is shown to be brown in this particular case. Brown represents the figure one (1), so to obtain the correct value of the capacitor we must now add one zero to the figures 2 and 1 and 5. This means the value of the capacitor is 2150 *micromicrofarads*. By using four colored dots to represent the capacity value a much more accurate rating can be designated than was possible with only three dots.

But the six-dot system provides additional information. The voltage breakdown rating of the capacitor (working voltage) is also indicated. The colored dot in the lower left corner of the capacitor shows the voltage rating. In the illustration, the lower left colored dot is shown to be blue. Our color code tells us blue represents 6. But in this case, 6 what?

The voltage is rated to the closest 100 volts. In this case the color blue stands for 6, which in turn stands for 600 volts.

There is still another colored dot on the capacitor. This is the center one in the lower row. This colored dot stands for the tolerance. In the illustration we see the lower center dot is orange in color. Orange stands for the figure three (3). This means the tolerance is 3%, which is another way of saying the *exact* capacity of the capacitor is within 3%, plus or minus, of 2150 microfarads. This is pretty accurate rating. But when using the capacitors in some of the circuits we use at the higher frequencies, it is necessary to work with much greater accuracy than was necessary at the lower frequencies. Most of the mica capacitors used in television work will be rated with the six-dot system.

In recent years there has been a tendency toward making paper capacitors in smaller capacity ratings than was formerly attempted. This has resulted in reducing the physical size of the capacitors, making it more difficult to imprint the ratings on the surface of the capacitors. Color coding has been resorted to in this case as a substitute for the numerical figures themselves.

It is not generally practical to rate paper capacitors quite so closely and accurately as can be done with mica capacitors. So, when color coding has been used with tubular paper capacitors no attempt has been made to rate them beyond two significant figures.

The colors are placed on the capacitors in the form of bands, in much the same manner as the color is placed on axial type resistors. The appearance of the smaller capacitors resembles very closely that of many resistors. The principal distinguishing feature is that the resistors seldom have more than four colors while the capacitors have five colors.

The illustration in Fig. 34 indicates reasonably accurately the appearance of a color-coded paper capacitor.

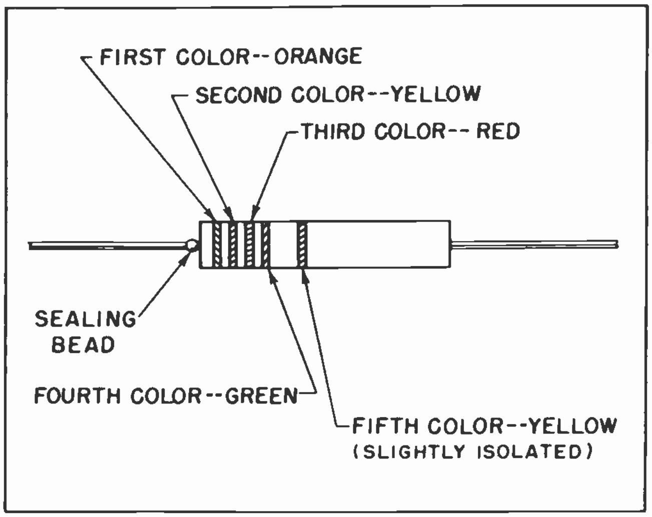

Fig.34.

The body color of such a capacitor is usually black. The rating colors are usually clear and vivid.

The first three colors indicate the capacity rating. In the illustration the first three colors are orange, yellow and red. From the color code we know these colors stand for the figures 3 and 4 and 2. The first two colors represent the significant figures of the capacity value while the third is the multiplier designating the number of zeros to be added to the first two numbers.

In this case the first two significant figures are 3 and 4, therefore the first two figures of the capacity rating is 34, with the red indicating two additional zeros to be added. This means the capacity rating of the capacitor is 3400.

The fourth color band, in this case the color green, indicates the tolerance. The color green, standing for 5, means the indicated rating is within plus or minus 5% of the actual rating. In other words, the capacity rating of the capacitor is 3400 *micromicrofarads*, plus or minus 5%.

The fifth and last color band indicates the voltage rating of the capacitor. In this case the voltage rating color is yellow, standing for the figure four (4), meaning the voltage rating is 400 volts. The voltage rating color is usually isolated slightly from the other four colors.

The isolation of the voltage rating color aids in determining how to read the colors on the capacitor. On the smaller capacitors the colored bands often come close to filling most of the space on the body of the capacitor. Often it is difficult to determine just which end of the capacitor should be considered the starting point for the purpose of reading the values. If the capacitor is positioned so the isolated band is to the right, the correct values can then be determined without difficulty.

There are other points of interest which aid in reading the values from the colors. The sealing bead is at one end of the capacitor. This is a small globule of metal which encloses the pigtail at the point where one end joins the body of the capacitor. Usually this end is the one from which to start reading the colors. This is not an infallible rule, but it is an aid.

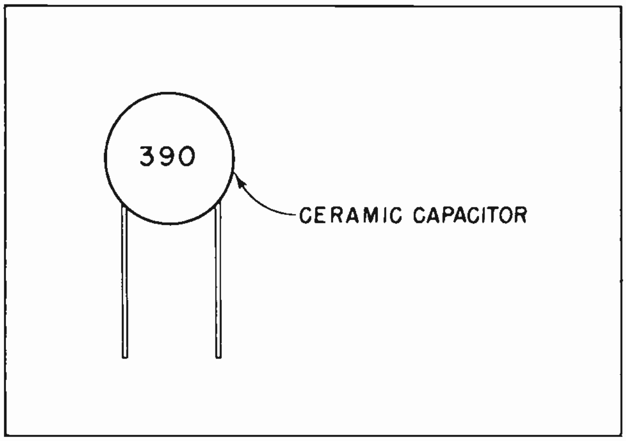

Fig. 35.

Still another frequently used capacitor that finds many applications in the high-frequency circuits of TV receivers is the ceramic capacitor. These little capacitors are built in the shape of a small disk from which a couple of pigtails project. In appearance they look like the illustration in Fig. 35.

They are usually brown or tan in color. Some use color to indicate the capacity, but many more have the actual capacity stamped on one side with figures. The exact capacity is indicated, without any tolerance percentages or voltages being given. Dozens of these ceramic capacitors are used in the R-F and I-F sections of TV receivers.

There is another type of ceramic capacitor which resembles very closely a very small resistor. These capacitors are usually coated with a cream-colored covering which closely resembles wax. The capacity is indicated by use of colored dots. Little difficulty is experienced in reading the values because the colors follow the standard accepted practice as used with other kinds of capacitors and with resistors. No attempt is made to rate such capacitors for voltage or tolerance. There isn't room on the body.

NOTES FOR REFERENCE

Electricity derived its name from the Greek word for amber.

The Leyden jar was invented in Germany in 1745.

Capacitors will not pass direct current.

Capacitors will apparently pass alternating current, but will present some opposition to its passage.

The opposition presented to the passage of alternating current by capacitors is called capacitive reactance.

The capacitive reactance of any capacitor can be determined by the formula: $X_C = \frac{1}{2\pi fC}$.

The names "Capacitor" and "Condenser" are generally used interchangeably.

A typical problem in finding the capacitive reactance is worked out in detail.

Trend in capacitors today, because of their small size, is to color coding the values.

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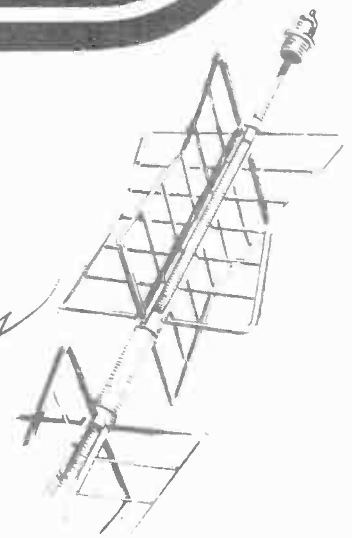

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VACUUM TUBES

Contents: Introduction - Electrons in the Vacuum Tube - Electron Emission - Thermionic Emission - Indirectly Heated Cathodes - The Electrostatic Field - The Space Charge - Electrostatic Fields - Arrangement of the Vacuum Tube Elements - Notes for Reverence.

Section 1. INTRODUCTION

Man has been striving to improve his mode of life since the dawn of recorded history. During the thousands of years of which we have a record, many new things have come into existence. Most of these new things have made our daily lives easier, or more enjoyable. Yet many of the things which we accept with such little thought did not come into existence until civilization had been developing for untold centuries.

Where today we can flick a switch and illuminate our homes, turn a faucet and obtain an almost limitless supply of water, step on the starter of an automobile and be whisked quickly and effortlessly to any place that strikes our fancy, it is hard to realize that none of these were known to our grandparents in their childhoods. It is even harder to realize that we need turn our history pages only a little further back to find a time where man was dependent almost entirely upon his own brute strength.

It was not many generations before the birth of Jesus Christ when all farm work was performedby the sheer strength of the farmer himself and the other members of his family. The hoe was the universal tool for cultivating crops. It was used to break the ground, chop the weeds, nurture the growing plants, and often to cut them down at the end of the growing season.

It remained for an inventive Egyptian to fasten the handle of a hoe to a beast of burden so the hoe could be pulled *through* the ground. He attached another handle to the hoe so it might be guided in its proper course. By just such an innovation was born the plow.

Down through countless centuries of time man could call upon only his own strength and that of domestic animals when there was need for work to be done. Even upon the sea the only means of locomotion was that furnished by the muscles of the oarsmen. Not for many centuries did anyone think of harnessing the winds by means of sails to aid in the progress of the water-borne craft.

Several centuries after the invention of the sailing vessel, another inventive genius

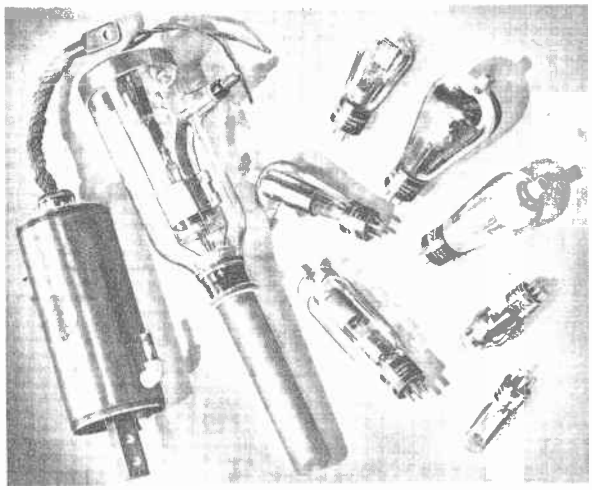

Fig.1. Various Types of Electron Tubes found in Radio, Television and Industry.

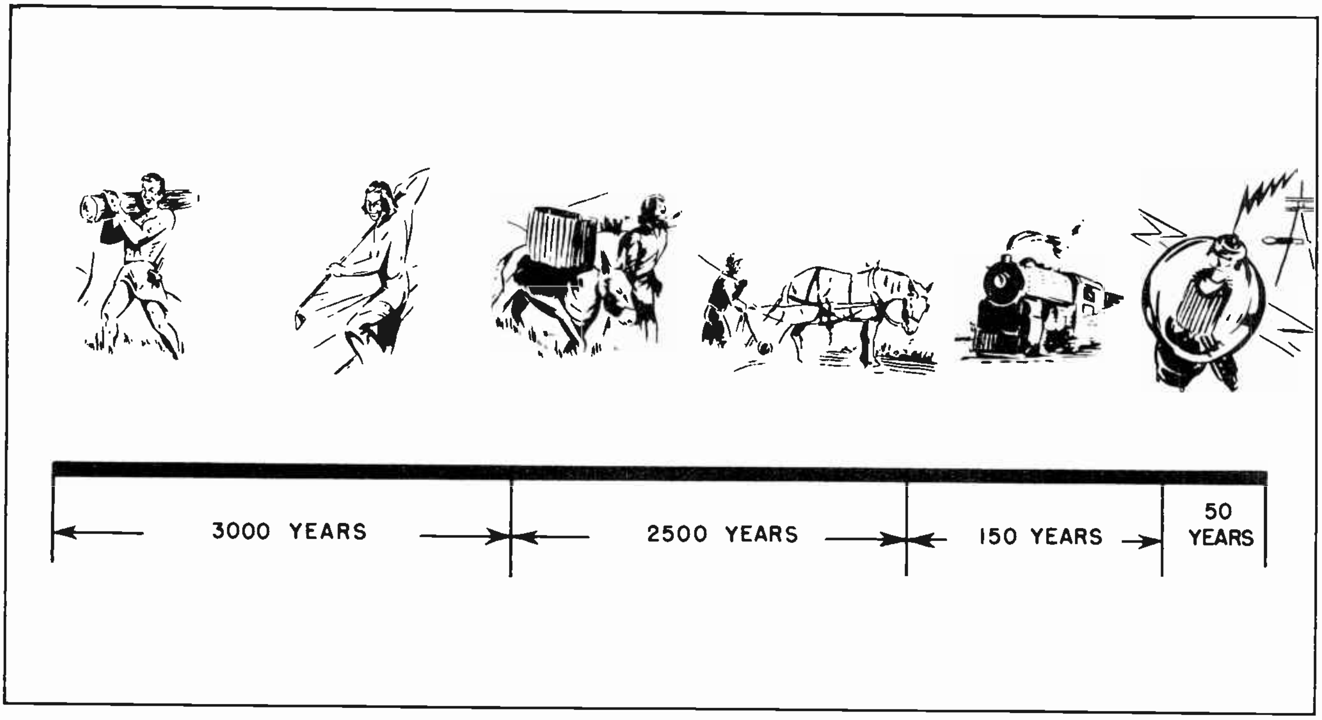

Fig.2. It was more than 3000 years after the dawn of history before man began using animal power. It was another 2500 years before he developed artificial power. It was only 150 years from there to the invention of the vacuum tube, but during the 50 years since then, man has learned almost as much as he did during all the other years of recorded history put together.

thought of harnessing the winds to lift water for irrigation, and to grind grain into meal and flour. The first windmills were crude affairs, and for the most part remain rather crude. Their use was limited to such times as the wind was blowing at a velocity sufficiently strong to turn the windmill vanes. Yet limited though this use was, it did provide man with his first source of power which did not depend upon him or his animals.

The white man discovered America, established settlements and colonies here, and continued to live here for nearly three hundred years before any other source of power was known. The pioneers in this wilderness of forest, swamp and towering mountains had no bulldozers nor tractors, nor even dynamite, to aid them in their herculean tasks of clearing land for crops, and erecting shelters for themselves and their families. The pioneering white man had been struggling for nearly three hundred years to obtain a lasting foothold on this continent before James Watt, in England, invented his steam engine.

In brief, despite all the knowledge he had gathered during several thousand years of developing civilization, man's acquisition of knowledge had moved forward at such a slow pace that he did not arrive at a sufficiently high degree of learning where he could devise an artificial source of power for himself until a little less than two hundred years ago. It is only against the background of such a long struggle for learning that we can fully appreciate the almost unbelievable developments which have taken place since the introduction of the vacuum tube.

The vacuum tube came into existence through the combined efforts of many men, rather than being the invention of a single man. No one person can claim credit for the invention of the vacuum tube as James Watt could claim credit for the invention of the steam engine. Many scientists and inventors such as Edison, Fleming, Thomson and DeForest all contributed their invaluable shares toward the creation of the amplifying vacuum tube. In addition to these men, whose names will long continue to shine as the originators of the vacuum tube, there are tens of hundreds of others who have each contributed their bit toward bringing the usefulness of the vacuum tube to the high peak we know today. There will be many others in the future who will add one refinement to another to the end that it will be able to do things -- probably many things -- as yet unthought of.

Edison first noted the peculiar behavior of something within the glass envelope of one of his incandescent lamps. He reported his discovery to the scientific world. Edison's discovery, coupled with many of his own experiments, enabled Thomson in England to announce the existence of the electron. Fleming went on from there to develop his "valve" which we now call the *diode* vacuum tube. Dr. Lee DeForest went another step further and inserted a third element into the diode vacuum tube. By means of the third element, which we now call a grid, he was able to obtain a measure of control over the flow of electrons through the vacuum tube.

DeForest's invention of the three-element vacuum tube led directly to many of the wonders we accept so matter-of-factly today. Long distance telephone conversations were the first results of the vacuum tubes. Then voice radio broadcasting. From radio broadcasting the experimenters spread out in every direction. Their individual experiments are serving to increase man's collective knowledge of the potentialities of this still comparatively new scientific wonder.

Television is a direct outgrowth of DeForest's invention of the grid-controlled vacuum tube. Also radar, sonar, loran and other navigation and direction-finding equipment. One field as great as any has been the recent introduction of vacuum tubes as the control agent in many industrial manufacturing processes. This use of the vacuum tube has created an entirely new branch of electronics. The use of vacuum tubes in industry is generally separated entirely from the use of the tube in communication work, such as radio and television. Industrial uses of electronic tubes are generally referred to as "Industrial Electronics". Industrial Electronics is a specialized field and, in general, has little in common with radio, television and other communication uses other than the fact that electron tubes are used in all these fields.

Section 2. ELECTRONS IN THE VACUUM TUBE

We have discussed the manner in which electrons move from atom to atom in a conductor. Such movement, when continuously in the same direction, causes what we have come to know as the flow of electrical current.

Electrons move through a vacuum tube in a somewhat different manner. Within the evacuated space inside the tube, the electrons are completely free from the atoms, and can move through space unhampered by many of the things which restrict their movement while confined to the atoms which form metallic conducting materials.

There are several elements within a vacuum tube. At least two of the elements are metal. From one of these, which we call the *cathode,* the electrons are released into the free space within the tube. It is the general practice to refer to this release as *emission* from the cathode. At any rate, an action takes place which makes it possible for the electrons to gather in the free space within the tube, no longer bound to the atoms of the metal of the cathode.

Most vacuum tubes have another element which is called the *anode.* This is a specially prepared piece of metal within the evacuated space of the tube which serves to attract the free electrons which are *emitted* from the cathode. Thus in all the essentials of a vacuum tube we have a piece of apparatus which allows electrons to emerge from the surface of a piece of metal at one place, travel through an evacuated space, and land on the surface of another piece of metal. (See Fig. 11.)

Very simply, that describes a vacuum tube. The cathode is usually specially treated to aid the *emission* of electrons. The space within the tube is highly evacuated so the passage of the electrons will not be hindered. Then we have the anode toward which the electrons flow through the space.

It could well be asked just what practical value such a device could have. If it was desired to move a group of electrons from one place to another, such an end could be accomplished just as readily by connecting a piece of metal wire between the cathode and the anode.

So we could. But merely moving the electrons from one piece of metal to another is not the only thing we are interested in. Far more important than this is the fact that we have here a stream of electrons which are not bound to the atoms of a conductor. For a change we have a stream of electrons out free in space. And being free in space, they are subject to control such as is not possible so long as they are bound to the atoms of metal.

We can cause the electrons to pass from the cathode to the anode at extremely high speeds. We can slow down their passage to a very slow rate. We can cause a lot of electrons to flow during a given period of time. We can check the flow to a mere trickle, or even stop it entirely if we so desire.

We can bend the stream of electrons so as to send it in virtually any direction which might strike our fancy. We can expand the stream of electrons, or contract it to pin-point dimensions. All of these we can do at speeds which at first seem fantastic. It is our ability to thus control the flow of electrons through it which makes the vacuum tube such a valuable instrument.

Fig. 3 illustrates some of the things we can cause electrons to do during the time they are free within the space of the vacuum tube. Referring to the individual sections of that illustration:

A. They may be made to travel between the cathode and the anode at speeds almost as great as that of light; or they may be slowed down to a tiny fraction of that speed.

B. Practically all the electrons may be stopped at any desired point.

C. Some electrons may be stopped at one place and others allowed to proceed.

D. A tube element may be "Screened" from parts of the total electron flow, some portions remain in what amounts to an electronic shadow.

E. The electrons forming the stream between the cathode and the anode may be forced to spread out thinly in some places, yet be bunched closely together at other places.

F. Electrons may start out for one element, then be made to change their course and reverse, then swing back and forth before finally reaching an intermediate element.

G. The electrons may be concentrated into a straight beam. This is done in a television picture tube.

H. Electrons may be deflected in any desired direction. This is also done in a television picture tube as well as in the cathode-ray tubes used in oscilloscopes which are used for observing the voltage patterns in electrical circuits.

I. The stream of electrons may be focused like a beam of light.

J. The focused beam may be continually deflected so the electron spot follows a pattern which may be repeated over and over. This is the way a picture is painted on the screen of a television picture tube. It also features the operation of an oscilloscope cathode ray tube.

K. Electrons do not necessarily follow straight lines. They can be forced to follow curved paths which turn either gradually or sharply.

L. The curved path followed by electrons may be made in such a manner as to bring them back to the conductor from which they started; or, they may do several loops and finally arrive at the outgoing element conductor.

M. A flying electron may be made to hit a neutral atom and knock an electron from the outer orbit of that atom. This, in effect multiplies the number of electrons in certain portions of the tube. This action is commonly found in certain electron tubes widely used in industrial electronic control work. In them a small amount of inert gas is deliberately inserted into the tube during its manufacture.

N. The atom which has lost an electron thus becomes a positive charge. In the tube space we will have negative electrons going in one direction and positive atoms (ions) going in the other direction.

O. Electrons may be driven at such terrific velocities from the cathode to the anode that they cause the anode to emit X-rays. It is in this manner that X-rays for use in medical examinations and for industrial inspection are generated.

None of the things we have described and illustrated can be duplicated outside a vacuum tube. Further than this, while some of those things may seem to be of little importance at this time, actually they all

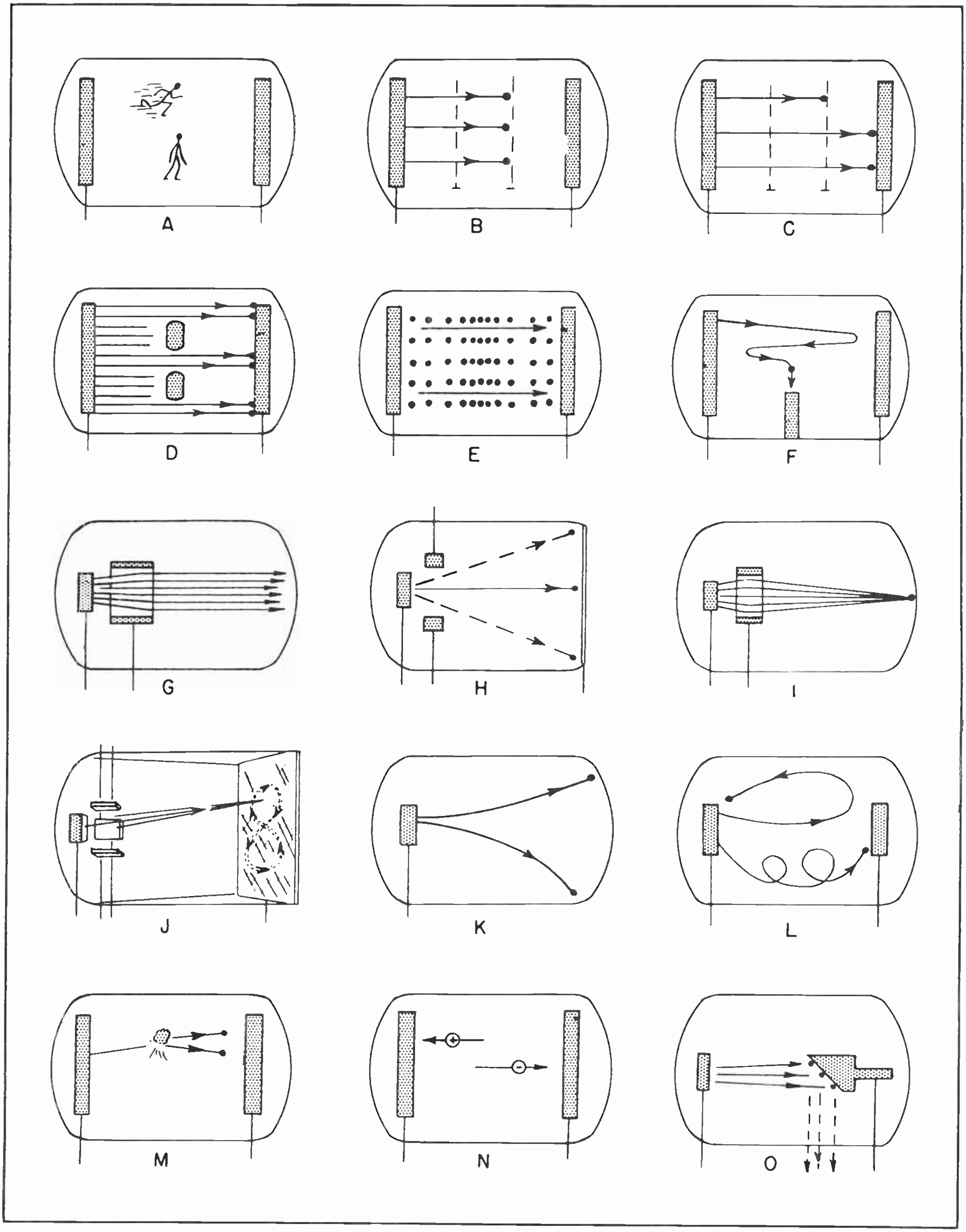

Fig.3. Some of the things electrons can be made to do in an electron tube.

play some part in putting the electron tube to work to perform some one or more of its marvelous functions. Several of them are absolutely essential to the proper operation of a television receiver. Others are the very key to the precision with which these tubes can control industrial production processes. Still others are useful in reproducing the sound of high-fidelity electrical phonographs and public address systems. In short, every movement described in Fig. 3 does some useful service for mankind.

Section 3. ELECTRON EMISSION

We have mentioned *emission* somewhat briefly several times in this lesson and in some previous lessons. Up to this time we have made no attempt to describe exactly what we meant by that term other than to intimate that it had something to do with the separation of the electron from the metallic mass.

In previous discussions of the movement of electrons in and through metals you will recall we have emphasized the multitude of free electrons which swarm somewhat haphazardly throughout the entire mass of the metal. Upon several occasions we have hinted at the agitation which is the normal state of atoms within the metal, and how at times they collide with each other. These collisions usually result in dislodging one or more electrons from the atom. The point is that materials such as metals contain an abundance of free electrons roving idly around from point to point within the metal.

Realizing these things, one is tempted to ask what prevents the electrons from moving right out of the metal under ordinary conditions, and flying right out into space. What are the restrictions which keep the electrons within certain boundaries? What, in other words, keeps the electrons tightly bound to the limits of the metal in a copper wire?

As a matter of fact, some electrons do just that very thing. But under ordinary conditions the number which escape are relatively few, and for most purposes can be considered to be a negligible number. In fact there are so few get away that we can say with reasonable accuracy that no emission of electrons from metal takes place until certain special conditions are deliberately introduced.

Although the actual conditions are somewhat different, the action of what takes place can be visualized by thinking of a group of children at play. One group has joined hands and formed a circle. Another group is inside the ring. Those on the

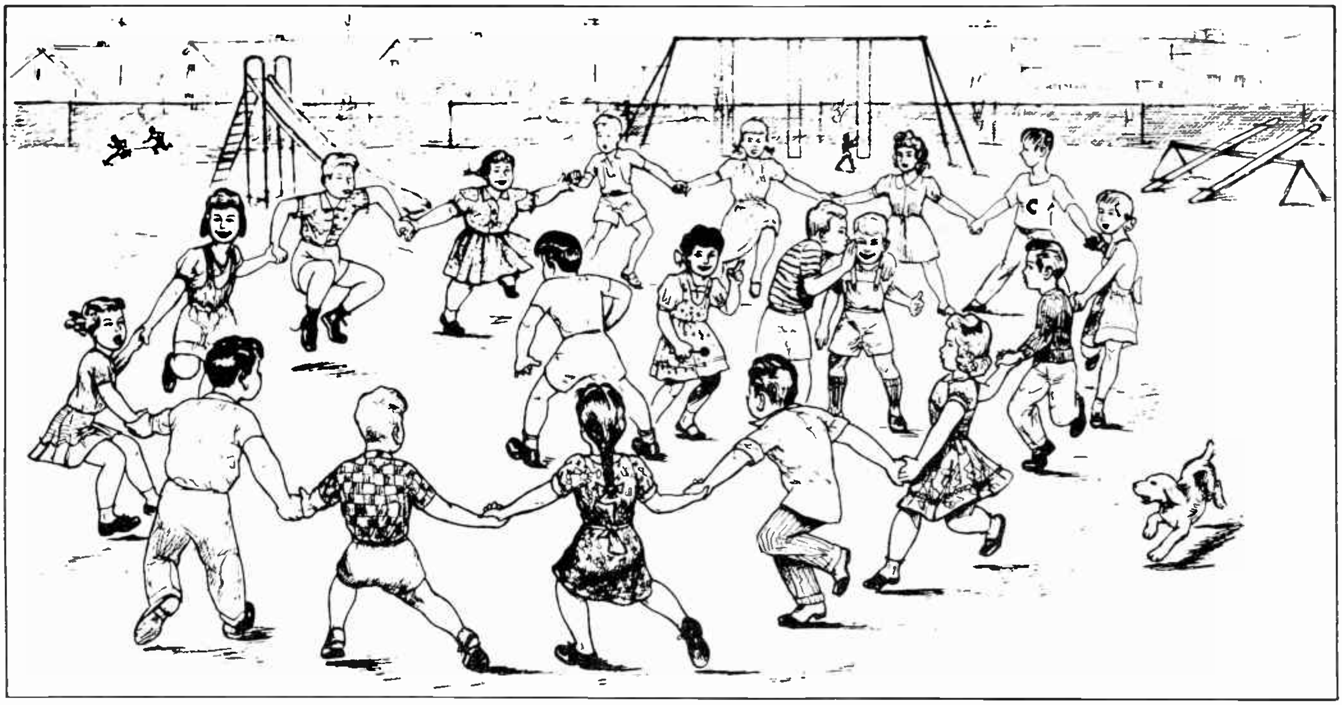

Fig. 4. The children on the inside cannot break through the encircling ring unless they attain considerable "kinetic energy".

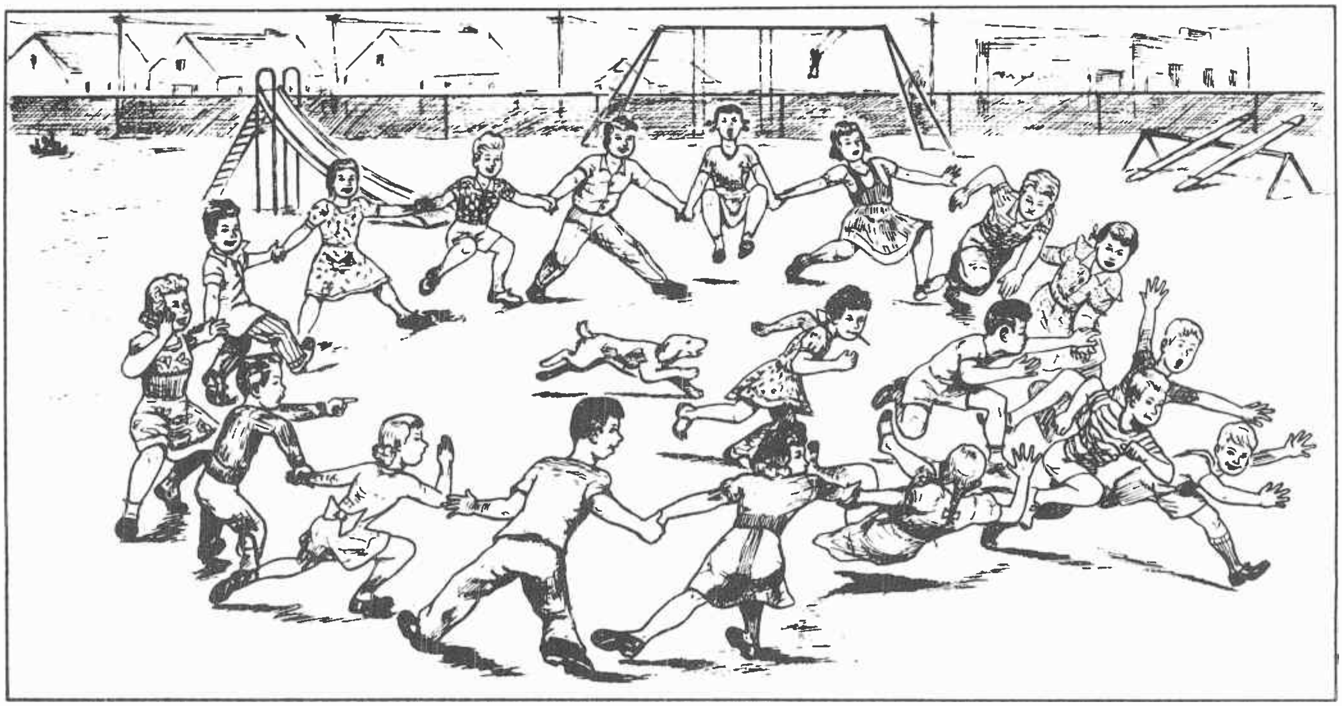

Fig.5. By developing considerable "kinetic energy" some children are able to break through the encircling ring.

inside are trying to get out, but are making no really determined effort. This situation is somewhat comparable to that of a piece of metal under normal conditions. Some of the electrons are seeking escape, but they are unable to do so. To state it scientifically, they do not have sufficient *kinetic energy* to break through the surface tension and overcome the work being done to keep them in. Likewise the children within the circle do not have sufficient kinetic energy to break through the encircling ring and overcome the work done by the encirclers to keep them in.

Should the children in the inside of the ring suddenly increase the speed of their movement so that they rush toward the encircling ring with such force as to break through, such action would be similar to that which takes place in a piece of metal when it is heated. When a piece of metal is heated, the agitation of the atoms and electrons is greatly increased. In their agitation some of the electrons attain sufficient kinetic energy so they break through the surface tension of the metal and fly right out into space. This is the phenomenon known as *electron emission*. Because in this case the emission resulted from the action of heat, this particular type of emission is known as *thermionic emission*. Thermionic emission is the kind of emission most frequently encountered in vacuum tube work. Heat is deliberately applied to the cathode of the tube in sufficient quantity to cause it to emit electrons in great numbers.

Still another example which is useful in attempting to understand this phenomenon of thermionic emission is the emission of steam from a boiling teakettle. Fig. 6 shows an ordinary teakettle partially filled with water. At this time no heat is being applied to the water and no noticeable amount of water is being evaporated into the air. As we all know, a certain small amount of water is being evaporated at all times but the amount is so small as to be negligible. This is much the situation which prevails in a piece of metal when it is not heated.

But in Fig. 7 heat has been applied to the teakettle. Now we can see bubbles rising through the water, the water itself boiling, and steam rising from the surface in great quantities. Just as heat can cause steam to be emitted by the boiling water, so can heat cause electrons to be emitted from the surface of metals.

Section 4. THERMIONIC EMISSION

The phenomenon of thermionic emission is made use of more frequently in vacuum tubes than anywhere else. It is so generally

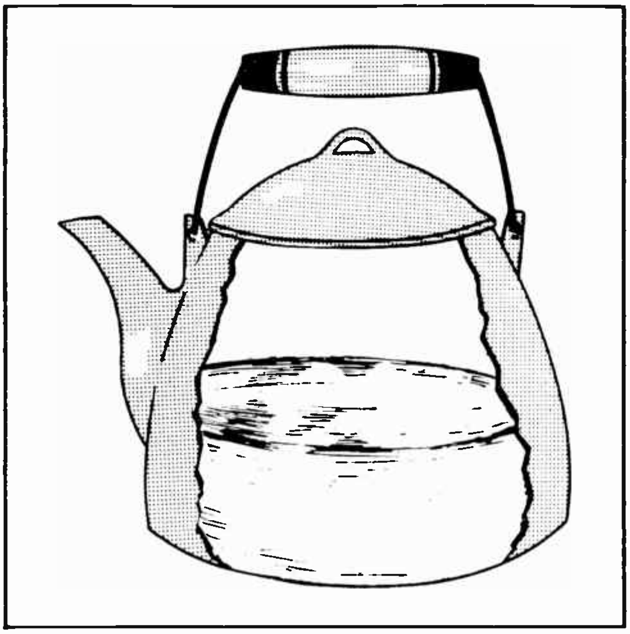

Fig. 6. Unless heated, water does not emit any noticeable steam.

thought of in connection with electron tubes that we often forget it had been observed long before electron tubes were thought of, and scientists had conducted many experiments in connection with it. In fact, scientific investigators had experimented with thermionic emission more than a hundred years before Thompson proved the existence of the electron.

In bringing about thermionic emission it is, of course, essential to apply sufficient heat to the source of electrons that they can be caused to be emitted. Almost any way that heat can be applied to the metal will cause the electrons to be emitted. A gasoline or acetylene torch, a gas flame, or even a coal or wood fire will bring about thermionic emission. But since, in a vacuum tube, the emitting surface (the cathode) is enclosed within a hermetically sealed glass or metal envelope, none of these methods would be at all practical.

Because electrical heat can be applied within an enclosed space just as readily as elsewhere, the universal practice is to heat the cathode of vacuum tubes with electricity. This is done by passing electric current through a heating element.

Some cathodes are heated directly. By this is meant that the heating element itself forms the cathode. Fig. 8 is a magnified view of a fanciful situation showing electrons emerging from a piece of wire heated by a current forced through it by a battery. In this particular case the wire is merely in open air. The same action would take place if the wire was a part of a filament within the glass enclosure of a vacuum tube. Fig. 9 shows an enlargement of a piece of filament within a vacuum tube. If the magnification were sufficiently great, we could imagine we could see the electrons emerging from the surface of the metal.

Where the filament itself forms the cathode we speak of it as being a *directly heated cathode*. It is also frequently referred to as a *filament cathode*. Other times merely as the filament. The wire of the filament is usually formed from the metal *tungsten*. In some vacuum tubes, especially those used for high-voltage, high-power radio transmitters, only the pure tungsten is used for the filament. Where the pure tungsten is used, the filament must be heated to a white-hot temperature. These temperatures range from about 2000 degrees Fahrenheit to a little over 2200 degrees Fahrenheit.

It is not generally satisfactory to heat the filament to such high temperatures. For that reason pure tungsten filaments are seldom employed except on those tubes where the voltage is so high that other types of cathodes would not be able to stand up under the strain.

Because so much work must be done on the metal of tungsten to start the emission of

Fig. 7. Heat applied to the teakettle causes the water to emit steam.

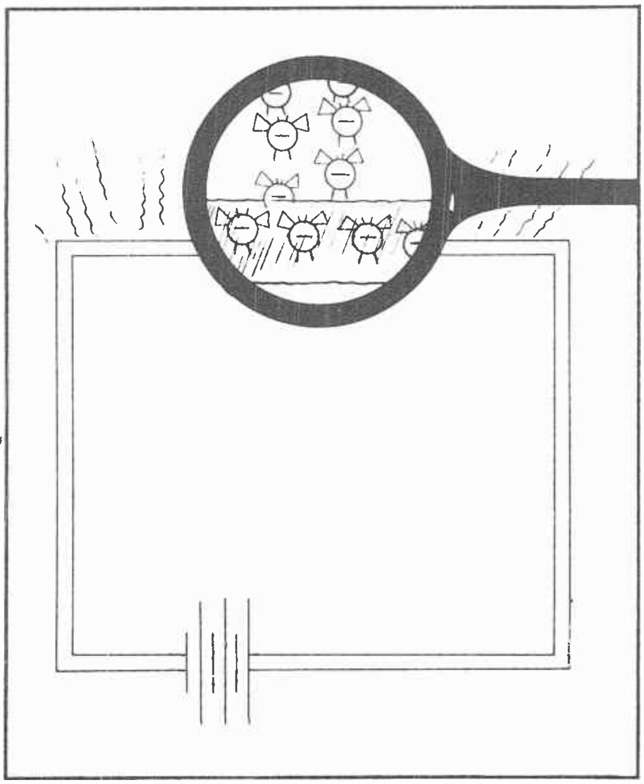

Fig.8. An artist's conception of electrons emerging from a heated wire.

electrons, tungsten is said to have a high *work function.* Work function refers to the amount of work which must be done on a metal to extract the electrons. In the case of tungsten the work is great, it being necessary to heat the metal to extremely high temperatures before it will give up its electrons.

To overcome the reluctance of tungsten to give up its electrons, a mixture of tungsten and the metal *thorium* is now widely used as the filament for many vacuum tubes. The thoriated-tungsten filaments have largely replaced pure tungsten filaments on all receiving tubes and on most transmitting tubes. The pure tungsten filament will be found only on those tubes where the operating voltage is very high.

The thoriated-tungsten filament will emit many times as many electrons as a pure tungsten filament at the same temperature. The basic purpose of the thorium which is added to the tungsten is to act as an emitter. The tungsten acts as the heating agent in the same manner as when it is used by itself. It likewise gives structural strength to the filament, keeping the filament rigid and in its proper place. It is claimed that though the thorium is mixed with the tungsten it never actually combines chemically. The molecules of the thorium are scattered throughout the filament, mingling with the molecules of the tungsten but never combining with them. The thorium molecules remain free to move around, and under most conditions a layer of thorium which is one molecule thick exists on the surface of the filament.

The thin layer of thorium has the property of emitting electrons in huge amounts. The layer of thorium reduces the surface tension making it much easier for the free electrons to escape from the filament and fly out into space within the tube.

Should the layer of thorium be burned away by any chance, such as by excessive filament temperature or for any other reason, the electron emission will be radically reduced. The absence of the thorium results in a marked change in the work function at the surface of the filament. The work function then becomes quite high.

When this happens, it is often possible to restore the tube to its original condition by *reactification.* Reactification consists

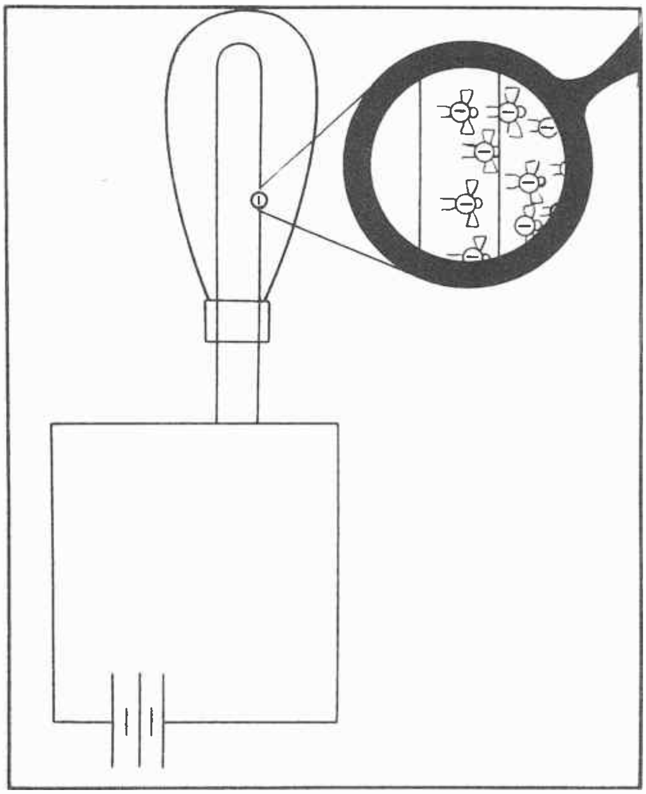

Fig.9 How electrons are emitted from a heated vacuum tube filament.

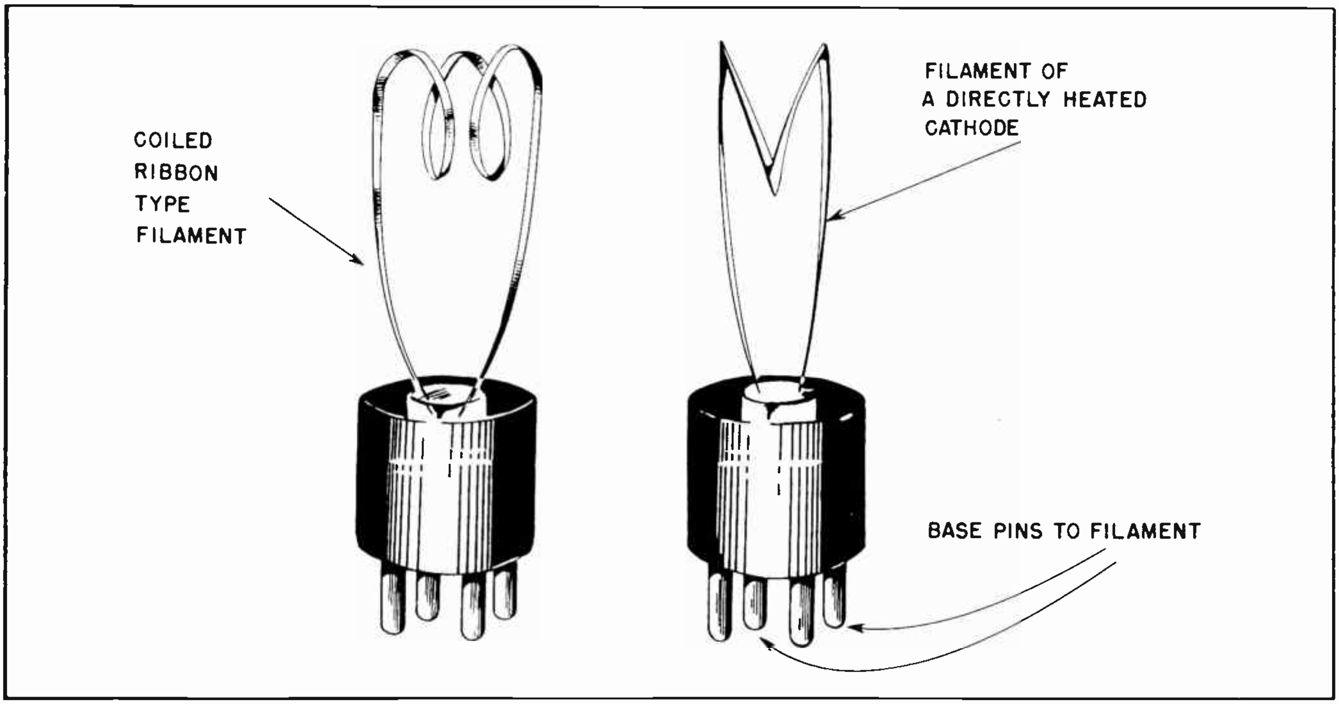

Fig. 10. Vacuum Tube Filament.

of an operation called *flashing*. In flashing a filament, it is operated at about three times its normal voltage for about 12 to 15 seconds. At the end of this period, the voltage is reduced to about one and a half times its normal operating voltage. It is then operated at one-and-a-half the normal voltage for about two hours. During the process of flashing, no other voltages are applied to the tube. As a result of the flashing, the molecules of thorium which are normally scattered throughout the filament are "boiled" to the surface. They again form a thin layer of thorium, one molecule thick, over the entire surface of the filament.

In some cases all the thorium in the filament will have been exhausted due to long use. In such case, flashing will result in little benefit. The emission will continue to be that of pure tungsten. Under most circumstances it will then be impossible to use the tube for the purpose for which it was originally designed and the only alternative will be to replace the tube.

Fig. 10 shows the general shape of a filament which is also used as a cathode (directly heated cathode). Usually the filament is in the form of a ribbon. When constructed in this shape, there is more surface area to the cathode than when in the shape of a circular wire.

The general shape, construction and operation of the simplest form of a vacuum tube is shown in Fig. 11. This illustration does not show how the cathode is heated, but it does show quite clearly how the electrons move through the connecting wire to the cathode, travel through the evacuated space within the glass envelope to the anode, then leave the tube through the wire connected to the anode. This is a tube with two elements; the anode and the cathode. Such a tube is called a *diode*. This word is coined from two Greek words meaning "two" and "path".

Section 5. INDIRECTLY HEATED CATHODES

There is another type of cathode in which the cathode is completely isolated from the filament heaters. These are called *indirectly heated cathodes*. The cathode in these tubes is formed in the shape of a small slender cylinder. The cylinder of the cathode is usually made of nickel. Nickel has a relatively high work function and is not normally considered a good emitter of electrons. To overcome this defect, the nickel is coated with certain metal oxides which are themselves good emitters. The oxides of Barium and Strontium are the ones most commonly used, but occasionally other kinds are used for special effects.

It is not essential to understand the actual manufacture of vacuum tubes in order to know how to use them. In fact, very few experienced electronic technicians have more than the vaguest idea of how tubes are manufactured. But an elementary explanation of the more essential features of manufacture is interesting, and certainly is not amiss if it leads to a better knowledge of the operation of tubes in their daily work.

After the Barium or Strontium oxides are applied to the nickel of the cathode, the entire unit is heated to approximately 1000 degrees Fahrenheit. In the process of heating, a certain amount of carbon dioxide is released. This carbon dioxide is then withdrawn by the evacuating pumps. The maintenance of the metal within the tube at temperatures higher than those at which it would normally be operated, tends to release other gases from the metal which would hinder proper functioning of the tube. These gases are also withdrawn by the pumps.

Despite their high efficiency, no evacuating pump can create a perfect vacuum within the tube. To overcome this deficiency, another operation is resorted to in the final steps in the manufacture of the tube. During manufacture, a small amount of chemical called a "getter" is placed within the envelope of the tube. This getter remains inert during evacuation. After the tube is sealed, the getter is flashed. The flashing

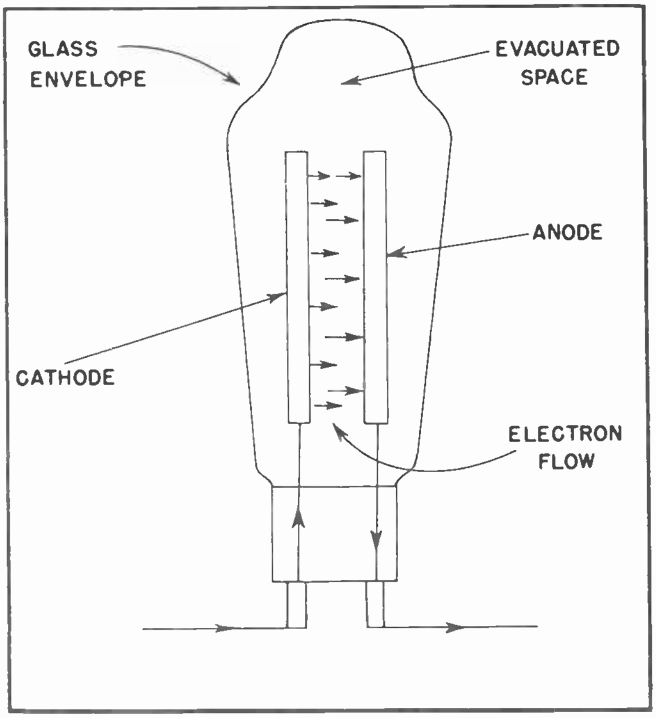

Fig. 11. How Electrons Move Through a Vacuum Tube.

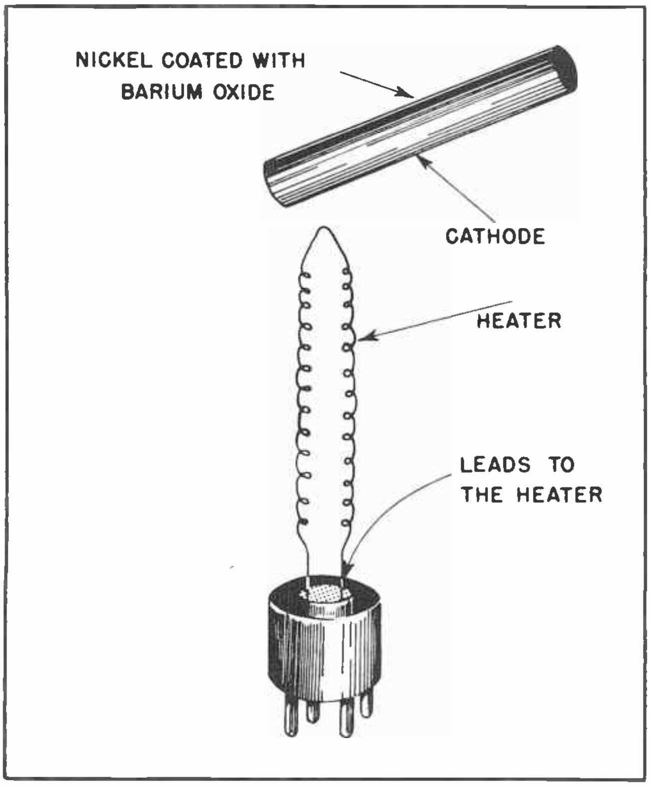

Fig. 12. A Vacuum Tube Cathode and It's Heater.

of the getter absorbs all remaining particles of gas within the tube, creating a vacuum which is as near perfect as man can attain. The flashing of the getter frequently is the cause of the discolored appearance of many glass tubes.

Indirectly heated cathode tubes are used wherever possible and practical. They can be operated at much lower temperatures than pure tungsten filament cathodes or even the thoriated-tungsten filament cathodes. Further than this, they are much better emitters at the temperatures at which they can be operated than are the other types of tubes.

One exception to this is the newer types of filament-cathode tubes used in portable radio and television receiving sets. The filaments in these tubes are exceedingly small, comparable in size to a human hair. They are used in circuits where the amount of emission is relatively unimportant but where the battery drain is important or where instant heating is a factor to be considered.

Fig. 12 illustrates rather clearly the construction of the indirectly heated cathode. The heater element is fastened securely to the base of the tube. It is

Fig.13. Wealth is a relative matter. The worker is relatively richer than the beggar, but he is relatively poorer than the wealthy man.

usually shaped somewhat like a kinked hairpin. By this means it can fit inside the cylinder of the cathode proper where it can apply its heat as directly as possible to the inner walls of the cathode cylinder. The inner surface of the cathode cylinder is coated with a ceramic material which prevents short circuits in case the filament should touch the cylinder wall.

Section 6. THE ELECTROSTATIC FIELD

When Thomas A. Edison was experimenting with his incandescent lamp he discovered that he could place an extra piece of metal within the glass envelope of the tube and obtain a current flow from it even though there was no metallic connection between it and any other part of the lamp's electrical circuit. He could not understand this but did report his observations to the scientific world. This mysterious effect he discovered came to be known as the "Edison effect", and is still known as such today.

The "Edison effect" accounts for the movement of electrons within the vacuum tube from the cathode to the anode. But in order to completely understand what takes place inside the tube it is necessary to make certain we understand those things we call "electric field", "electrostatic field", "electrostatic charges", and just plain "charges". In general these all refer to to about the same thing, and are merely different names for much the same thing.

It is well that we understand what is meant by the terms "charges" and "charged bodies". We will make frequent reference to charges in motion, and to charged bodies. We are already familiar with the fact there are two elementary charges, two basic particles of electricity. First we have the electron, which we consider to be a negative particle of electricity. Then there is the proton, which is a positive charge of electricity. The electron is mobile, able to move freely from place to place. This is because it has much less mass than the proton -- in other words, it is much lighter. The proton, on the other hand, we consider to be relatively fixed in position. It is not readily movable.

More than this, we have spoken of things in an electrical circuit being either *positive* or *negative*. For the purpose of our studies, any point in any electrical circuit which has a relative over-supply of electrons will be considered to have a *negative* charge. On the other hand, those locations in an electrical circuit which are deficient in electrons will be considered to have a *positive charge*. In this manner we can establish our electrical polarities as being directly linked to the presence or absence of electrons. It should always be remembered that these polarities, or over-supply and deficiencies of electrons, is strictly a *relative* matter. What might be a negative polarity with respect to one point may actually be a positive polarity with respect to another point.

This matter of the relative polarities in an electrical system is not greatly different from the monetary abundance of men in various walks of life. In Fig. 13 are shown three men. One is obviously a beggar, the second is an ordinary middle-class worker, even as you and I. The third, however, is obviously wealthy. Now if the amount of money each of these men possesses is likened to electrical charges we could say the middle class worker is negative with respect to the beggar because he has more money than the beggar. On the other hand, the middle class man is positive with respect to the wealthy man because he has much less money than the other.

Under normal conditions each atom in any material such as a metal is an electrically balanced particle. There are equal numbers of electrons and protons. But under certain conditions an atom may lose one of its electrons, and under certain other conditions may acquire an extra electron. This creates an unbalanced condition and the atom becomes what we call an *ion*.

We have never seen an electron, nor for that matter an atom. But that does not keep us from creating a picture of what we think

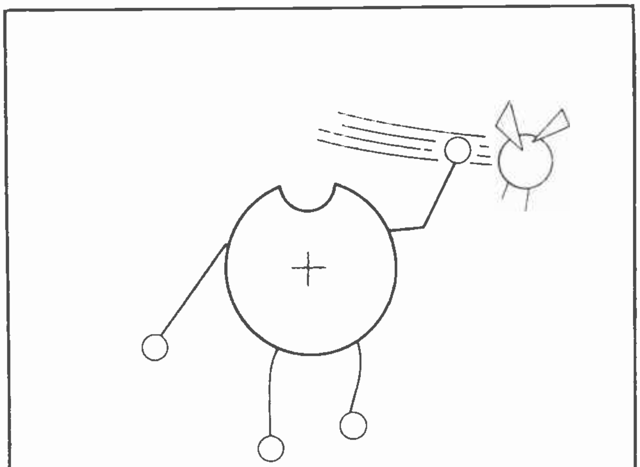

Fig. 14. The positive ion is an atom which has lost an electron.

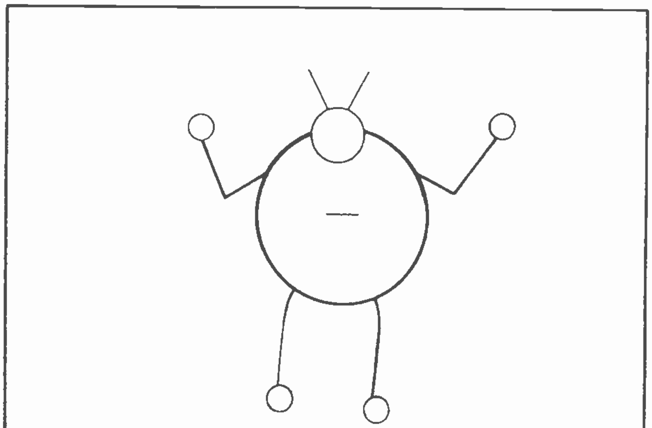

Fig. 15. The negative ion is an atom which has acquired an extra electron. Negative ions are relatively rare.

an electron or an atom might look like. In Fig. 14 we have what amounts to an artist's conception of what a positive ion looks like. A positive ion is an atom which has lost one of its electrons and, as a result of its unbalanced electrical condition, is now a positive charge. Due to its positive charge, the positive ion will now attract any stray electrons which might be in the vicinity. If a piece of metal has enough of these positive ions, it is said to be positively charged.

In Fig. 15 we give what amounts to the artist's conception of a negative ion. A negative ion is one which has obtained an extra negative from some place. If a piece of metal possesses enough negative ions it is said to be negatively charged.

But just as the wealth of each of the three men in Fig. 13 is a relative matter among them, so are the various charges on pieces of metal a relative matter among them. This is shown in Fig. 16. The piece of metal in the center is in an electrically balanced condition. Each of its atoms possesses its proper number of electrons. However it is negative with respect to the piece of metal at the left because the piece at the left has an insufficiency of electrons; that is, some of its atoms are deficient in electrons. In this case, the piece of metal in the center, having more balanced electrons than the piece at the left, is said to be negative with respect to the piece at the left.

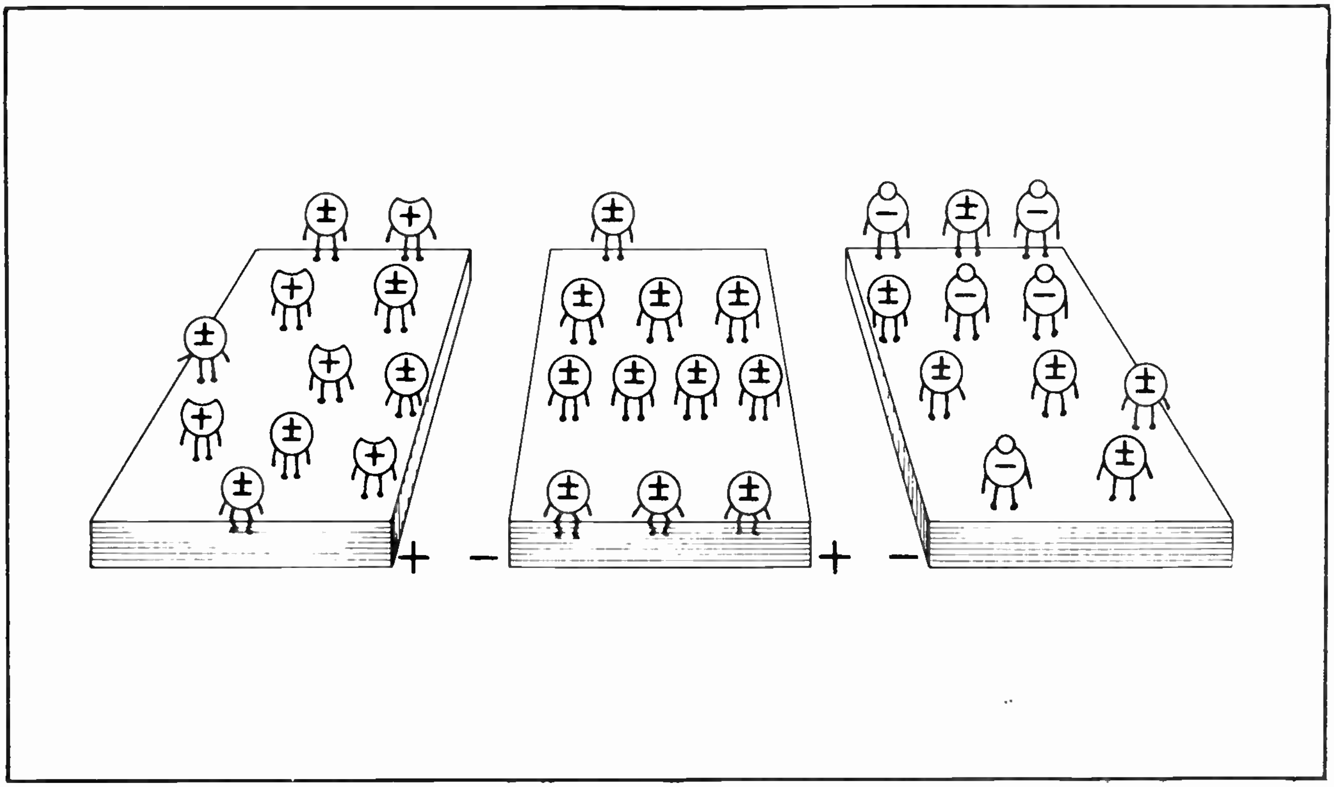

Fig. 16. The center piece of metal is more negative than the piece at the left because the one at the left has more positive ions. But it is more positive than the piece at the right because the one at the right has more negative ions.

But let's compare the same piece of metal in the center with the one at the right. Here we find the piece at the right has some negative ions, some atoms with an overabundant supply of electrons, Now we find there are more electrons in this piece of metal than in the one in the center. Thus we find that while the piece of metal in the center was negative with respect to the piece at the left, it is actually positive with respect to the one at the right.

In Fig. 16 we assumed some of the atoms in one piece of metal had lost electrons and in another piece of metal some of the atoms had actually acquired extra electrons. It is possible that this condition could exist. But it has been learned that such a thing as a negative ion seldom exists. What actually does happen is various degrees of insufficiency of electrons. This is shown rather clearly in Fig. 17. Here we see a piece of metal at the left which is composed of atoms, each of which is electrically balanced. In other words, the atoms in this piece of metal has all its normal supply of electrons. But the piece of metal in the center of Fig. 17 has some atoms which are deficient in electrons. As a result of this deficiency the center piece of metal is positive with respect to the piece of metal at the left. But let's take a glance at the piece of metal on the extreme right. Here we find a situation where even more of the atoms are deficient in electrons. This being so, we find that more of the atoms in the piece at the right are deficient in electrons than the piece of metal in the center. As the result of this, the piece at the right is positive with respect to the piece in the center.

Here we have a clear illustration of the *relative* polarities which might be found anywhere. While the center piece of metal in Fig. 17 is positive with respect to the piece at the left because it has fewer electrons, it is actually negative with respect to the piece of metal at the right because it has more electrons than the piece at the right.

In our illustration we have pictured relatively few atoms for each piece of metal. Actually it would take tens of billions of atoms to make any of the pieces of metal. But the situation which is pictured as prevailing where only a few atoms and electrons are involved is exactly the same as would occur with the uncountable billions of other atoms.

Section 7. THE SPACE CHARGE

As the result of the emission of electrons from the metal of the cathode two actions take place. Perhaps it would be better to say that as the result of the emission two special conditions are caused to exist. The electrons are negatively charged particles of electricity, and being such tend to repel each other. The cathode thus causes huge quantities of electrons to exist in the space around the cathode itself, each of the electrons strongly repelling all the other electrons. This being so, the natural conclusion is that the repulsion existing among the electrons would tend to cause them to spread throughout the space inside the glass envelope, getting further and further from the cathode.

Just such a thing probably would happen except for another condition which has been set up by the emission of the electrons from the cathode. Remember the cathode has *emitted,* or given up, electrons. This has the effect of making the cathode more positive than it was before it lost the electrons. In other words, the very action of emitting electrons causes the cathode to become more positive than it was before. This positive polarity of the cathode has an attraction for the electrons it has just emitted, and tends to keep the electrons in it's own vicinity. Such a situation is shown in Fig. 18. There we see a cathode which has been heated. This cathode has emitted some electrons which continue to remain close to the cathode.

The heating of the cathode will cause it to give up a certain number of electrons. The exact number will depend upon several things, including the temperature of the cathode. The electrons will continue to hang around in the vicinity of the cathode due to its increasingly positive polarity. The cathode will continue to emit electrons until such time as it becomes so positive that it will attract electrons back to it just as fast as others are emitted. If more heat is applied, the number of electrons emitted will rise, and the cathode will become slightly more positive until the situation reaches a state of balance. Under normal conditions the heated cathode will become only a few volts more positive than

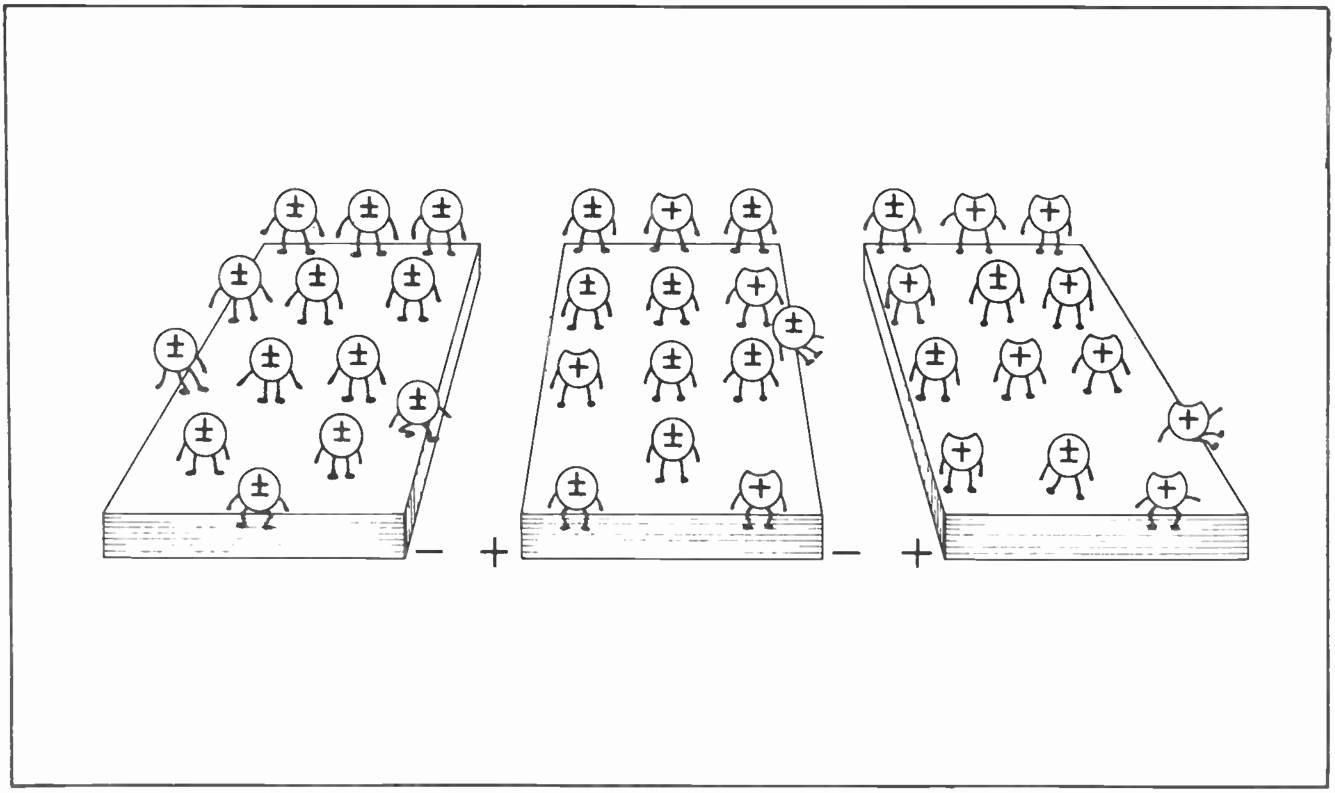

Fig.17. While the piece of metal in the center is more positive than the one at the left, it is more negative than the one at the right. Polarity is always a relative matter.

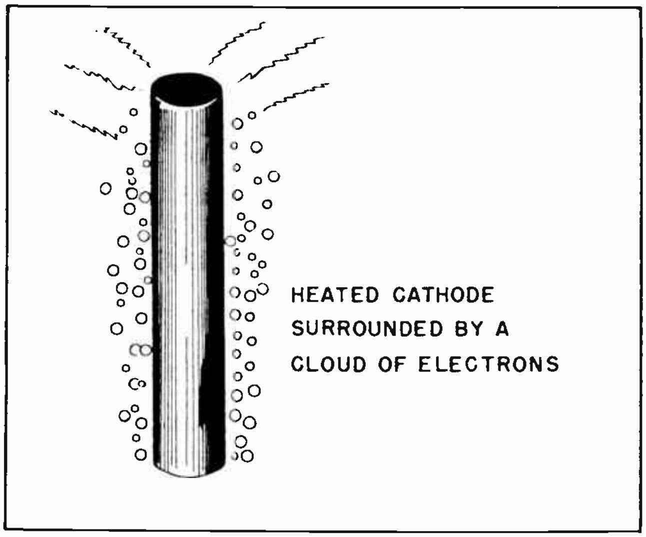

Fig.18. Cloud of electrons around a heated cathode.

the cold cathode, but this small voltage is sufficient to keep the emitted electrons clustering around it in a cloud. These free electrons in the space surrounding the cathode are called the "space charge", or about equally common, the "electron cloud". This condition will continue to exist so long as the cathode remains heated.

If the cathode is allowed to cool down it will discontinue emitting electrons. But the cathode will retain its positive polarity. Such being so, it will attract the electrons in the space charge. The electrons in the space charge will no longer be repelled by newly emitted electrons, so will come closer and closer to the cathode until they are actually reabsorbed back into the metal of the cathode. As the electrons are reabsorbed into the cathode, the cathode gradually loses its positive polarity and attains a balanced, or neutral, condition.

Section 8. ELECTROSTATIC FIELDS

If the cathode within a vacuum tube merely emitted electrons when it was hot, the electrons formed a cloud around the cathode during the period it remained heated, then returned to the cathode when it cooled, this whole business of thermionic emission would not mean very much to us. But this isn't all. In order to take advantage of the electrons which form the space charge we create an electrostatic field within the tube by the introduction of another element we have mentioned before, the *anode*. Under most normal conditions the anode is made much more positive than the cathode.

To understand exactly what takes place inside the vacuum tube it would be well to review a few things we have already discussed, and to explain a few other things. First, let us consider one of the fundamental laws of electricity and electrostatics, as well as things magnetic:

1. Like charges repel each other.
2. Unlike charges attract each other.

This states clearly and unqualifiedly that one electron has no use for another electron. They exert a strong force to repel each other. In a like manner, negative ions, that is, atoms which have an extra electron, have no attraction for each other; they repel each other. Neither will one positive ion attract another positive ion; they, too, repel each other.

An electron, however will be attracted to a positive ion. To put this explanation in a brief form, anything which is electrically positive has a strong attraction for any other thing which is electrically negative. But things which are electrically negative repel other things which are electrically negative, and things which are electrically positive will repel other things which are electrically positive.

It is not within the scope of these lessons to attempt to explain just why these things are as they are. Perhaps the learned scientists themselves are none too sure. But we can accept these things as being facts without understanding the reason for them. Even though none of us have ever seen the wind, nobody can deny there is such a thing. The evidence of the swaying trees, the swirling leaves, the disturbed dust, and

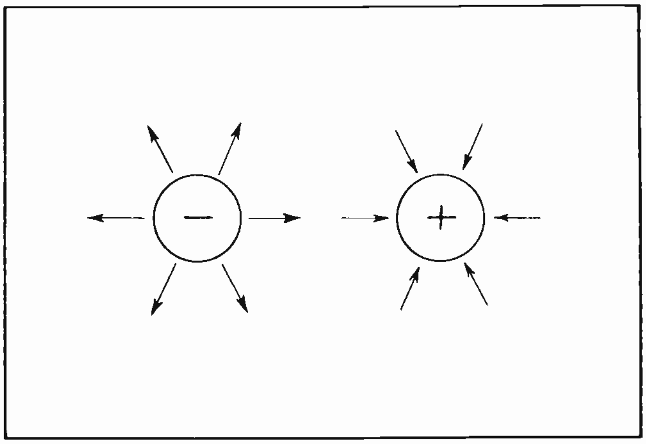

Fig.19. Lines representing the electrostatic field surrounding charged bodies.

its pressure upon our faces is more than enough to convince us there is such a thing as wind. In a like manner we can readily prove the truth of the laws governing attraction and repulsion of electrical charges even though we cannot explain why they should be.

Even though we cannot explain what it is we do know there is some invisible kind of force existing between electrical charges. There can be no question that it actually is some kind of force since it can be proven beyond any shadow of a doubt that it is capable of making things move. This force which exists between electrically charged bodies is called an *electrostatic field.* It is closely associated with electrical charges, electrons and ions. Because it is associated with these things, it is also associated with all other objects of much greater dimensions.

In a normal atom which is electrically balanced, the electrostatic fields exist. But because of the balanced condition, the presence of the electrostatic field is not noticeable. Each of the electrons and protons of the atom balance each other out with the result that no *external* electrostatic field can be noted.

However, should an electron be removed from an atom, the electrical balance of the atom is upset. The atom will become a positive ion; then the ion will be surrounded by an electrostatic field. Such field will be positive to the extent represented by the removal of the one electron.

The electrostatic field which surrounds a positively or negatively charged object can be represented by directional lines. By directional lines we mean something much like that shown in Fig. 19. There we see a negatively charged object with the lines extending away from it. In the same illustration we see another object which carries a positive charge. In this case we see the lines extending towards the object. Thus, if two negatively charged objects were brought near each other, the electrostatic lines of force would be in opposite direction and the two objects would repel each other. If two objects which were bearing opposite charges were brought near each other, the lines would be in the same direction and the two objects would be drawn to each other.

The electrostatic field would exist between the two oppositely charged objects

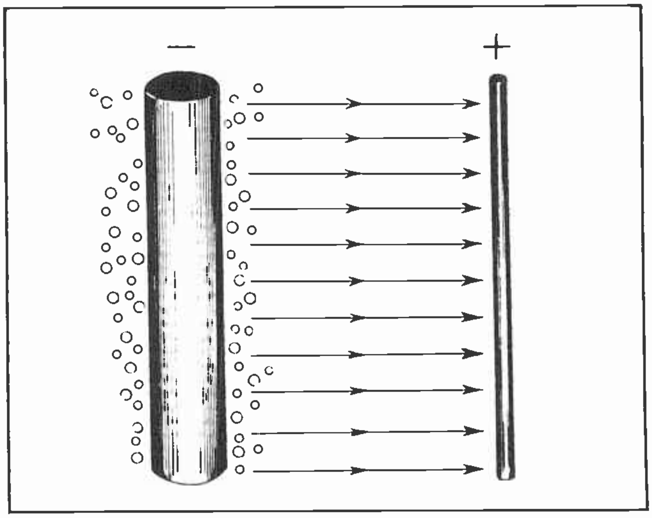

Fig.20. Electrostatic field between the cathode and the anode of a vacuum tube.

regardless of how far they were apart. But the farther they were separated, the less would be the attraction between them, and the weaker the electrostatic field between them. On the other hand, the closer they were brought together, the stronger would be the electrostatic field between them.

All this discussion may seem rather scholarly. But it does lead us up to the part the electrostatic field plays in the functioning of a vacuum tube.

In most vacuum tubes the *anode* has an electrical charge which is highly positive with respect to the *cathode.* Here we have two elements placed fairly close to each other inside the tube. One is much more positive than the other. The result is that an electrostatic field is created between the two elements. The basic principles on which the vacuum tube operates can be understood by studying Fig. 20. The anode is much more positive than the cathode. This is the same thing as saying the cathode is more negative than the anode. Between the two elements exists an electrostatic field.

Around the heated cathode is a cloud of electrons. The cathode is somewhat more positive than the electrons, but the anode is *much more* positive. The bulk of the electrons will continue to cloud around the cathode because, even though it is less positive than the anode, it is much closer than the anode. Thus its influence is relatively stronger. But on the outer fringe of the electron cloud a few of the electrons will come under the influence of the

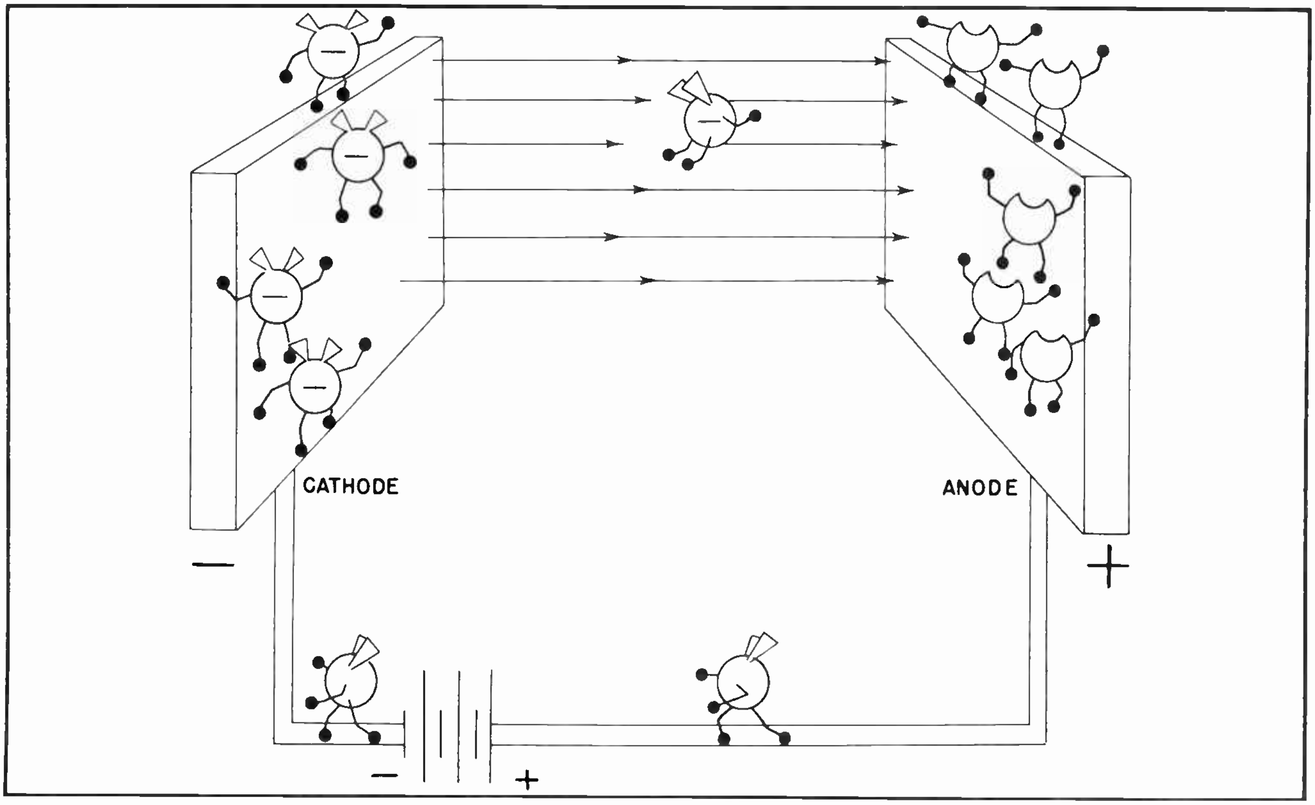

Fig.21 Electron movement through a complete circuit including anode, cathode and battery.

attraction of the anode and be drawn to it. The higher the voltage on the anode, the more electrons will come under the influence of its attraction and be drawn to it. But it should never be forgotten that the reason the electrons are drawn to the anode is because it is much more *positive* than the cathode. Should, by any chance, the anode become *negative* with respect to the cathode *no electrons* will be attracted to the anode.

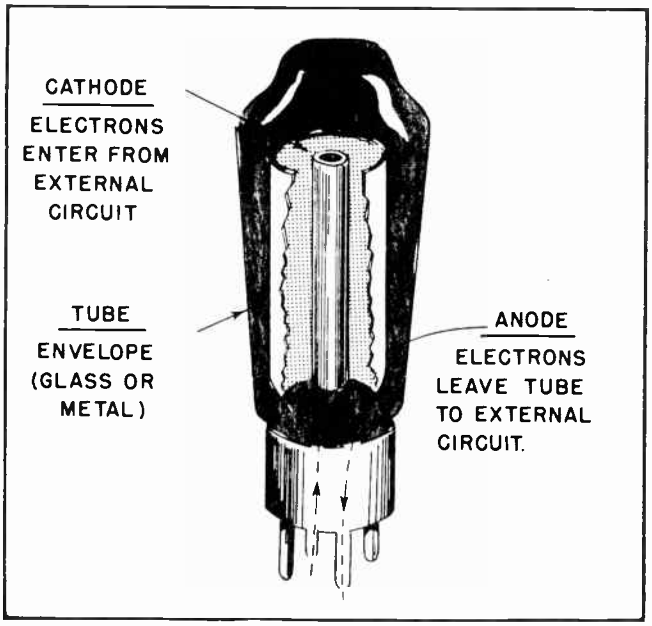

Fig. 22. Principle Elements of a Vacuum Tube.

Fig. 21 shows how the anode is maintained positive by means of a battery. The illustration is a bit fanciful in that it gives play to the artist's imagination, but it does show how the electrons are emitted from the hot cathode, how they are attracted to the positive plate, then return through the battery to the cathode. Essentially this represents the action which takes place in a circuit which contains a vacuum tube and its associated source of voltage.

Section 9. ARRANGEMENT OF THE VACUUM TUBE ELEMENTS

In our previous descriptions we have made no attempt to explain exactly how the elements were arranged within the tube. From Fig. 20 it might be surmised that the cathode was in one part of the glass envelope and the anode in another part. Actually such is not strictly true. Normally the cathode is firmly anchored in the center of the glass envelope. It is held rigidly in place by a glass stem which extends up inside the bottom of the tube and by insulated braces which extend from the upper end of the cathode to the glass envelope itself.

The anode is also a cylindrical piece of metal not greatly different from the cathode except that it is larger. The anode is then put into place inside the tube so it can surround the cathode, but will not touch it. The anode is also firmly anchored in place. Fig. 22 shows the general arrangement of the cathode and anode with respect to the glass envelope of the tube. When the anode is placed in this position it is much more effective in attracting electrons from the cathode.

It would be well to mention here the customary practice of naming the anode. In Industrial Electronic work it is the general practice to refer to the anode by that name, the *anode*. But in radio and television, it is much more general to refer to the anode as the "plate". Nearly all radio men use the term "plate" when speaking of the anode, and many television men follow this practice. In our lessons we will use both terms. This will enable you to become thoroughly familiar with both terms, regardless of what kind of work you might be doing or with whom you might be working.

It would be well to go another step further and mention that the picture tube used in television work often has several anodes. Some of these often perform functions somewhat different from those in other types of tubes. For this reason, television men who refer to anodes in other tubes as "plates", will speak of those in the picture tube as "anodes".

This may seem a bit confusing at first glance. But you will find that actually it is not. Certainly our explanation is not intended to confuse you. If there is anything confusing it is the practice of the men who have brought the use of these tubes to the high level they occupy today. We are merely passing on to you hints of these practices as they exist.

To clarify this situation just a bit further, we can say that "anode" is the correct technical designation for that particular element in a vacuum tube. The name "plate" has come into existence through usage of service men in the field. It came about largely because of the shape of the early anodes, and is so firmly entrenched in the vocabularies of the old timers there is little possibility it will ever be eliminated.

NOTES FOR REFERENCE

The vacuum tube is the result of the efforts of many men -- not just one.

Thomas A. Edison's discovery of the "Edison effect" was the first step toward the vacuum tube, though he did not know it.

The existence of the electron was proven by J.J. Thomson in England in 1899.

Fleming produced the first functional vacuum tube, which he called the Fleming valve.

Vacuum tubes are still called "valves" in England and Australia.

Two essential elements in a vacuum tube are the cathode and anode.

The purpose of the cathode is to "emit" electrons.

There are two general types of cathodes, the directly heated type in which the filament is also the cathode, and the indirectly heated type in which the filament heats a specially prepared cylinder which composes the cathode.

Most cathodes are specially treated with materials which aid the emission of electrons.

Many tungsten filament cathodes have Thorium mixed with the tungsten to aid electrons emission.

Barium and Strontium are often added to the surface of indirectly heated cathodes to aid emission.

"Work function" relates to the difficulty encountered in the emission of electrons from a metal. The higher the work function, the fewer electrons are emitted.

Where the filament also serves as the cathode it is usually referred to as the "Filament". Where it serves only to heat the cylindrical cathode it is usually referred to as the "heater".

Thoriated-tungsten filaments can often be reactivated by "flashing".

"Electrostatic field" is the name given the strain which exists around a free electron or positive ion, and especially to that space between two oppositely charged bodies.

"Space charge" refers to the electron cloud around an emitting cathode.

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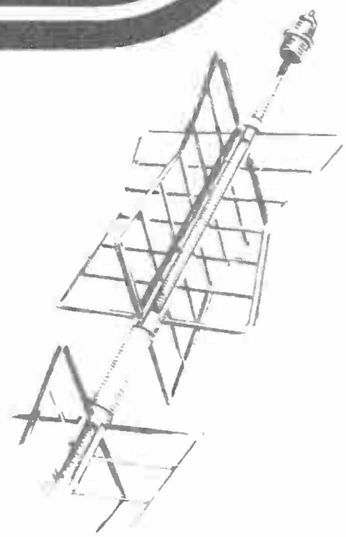

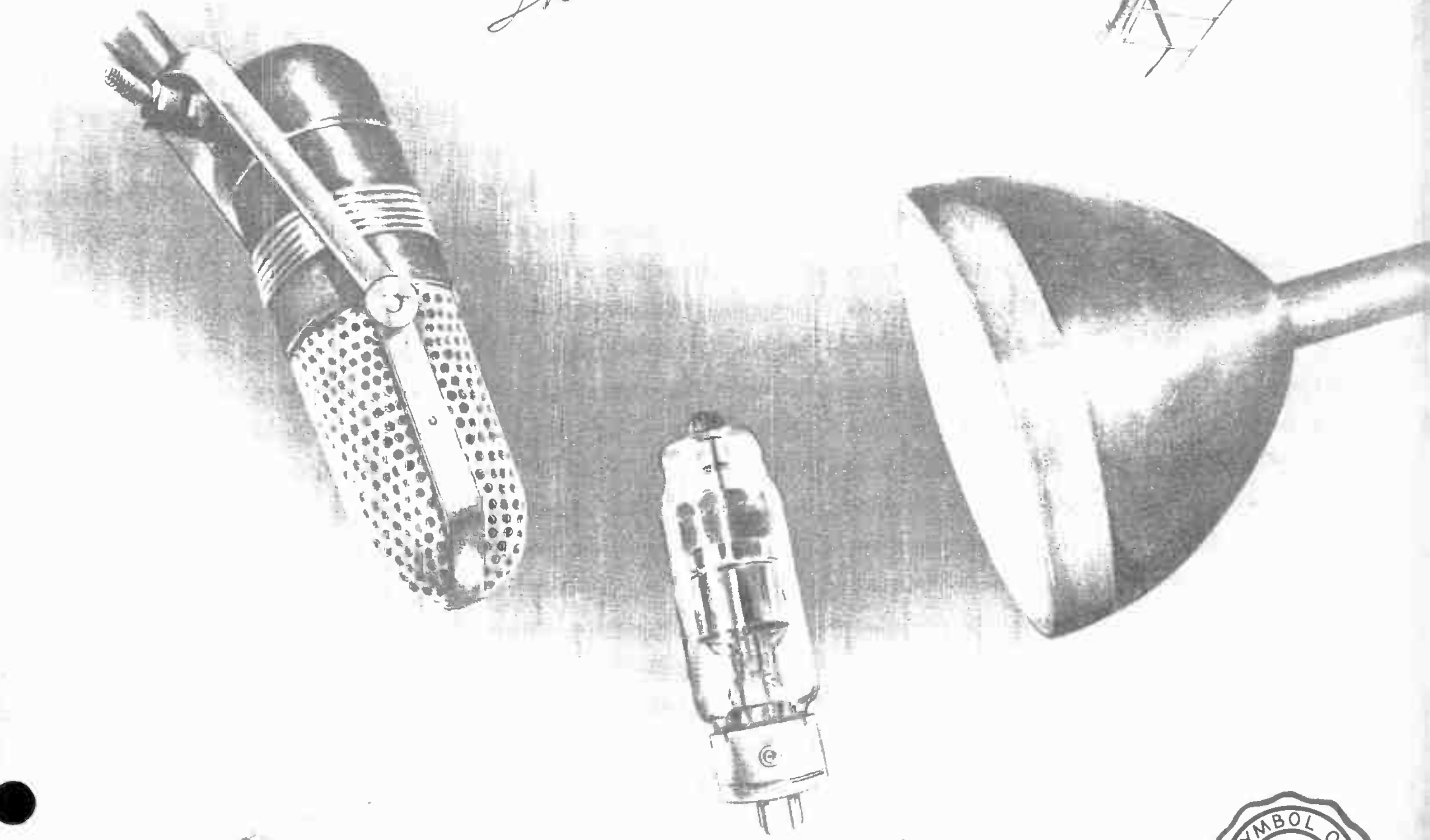

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Contents: Introduction - Cathode Emission - Charting Cathode Emission - Making a Graph - Using the Information From the Graph - Temperature Saturation - Effect of Anode Voltage - Voltage Saturation - Effect of Negative Anode Voltage - Vacuum Tube Rectifiers - Filters - The Filter "Choke" - The "Pi" Filter - Full-Wave Rectifiers - The Duodiode - Filter Capacitors - Notes for Reference.

Section 1. INTRODUCTION

The *diode* is the most simple type of vacuum tube we have. It consists of only two elements, the cathode and the anode. It is a direct descendant of the original Fleming valve, and from the standpoint of fundamentals is little changed from Fleming's original valve. True, the external appearance, and the construction of the elements which go into modern diode tubes, have changed considerably, but the principles of operation have not.

The diode tube continues to play a very important part in modern electronic devices such as radio, television and industrial controls. Most electronic devices depend upon one or more diode tubes as the source of high voltage D-C power for the operation of the other electronic tubes. In some respects the diode remains the "kingpin" of tubes; that is, if any one tube can be said to be more important than any other.

Because the diode occupies such an important place in the electron tube family, and because most other electron tubes are little more than modifications of the diode, it is well for us to study its operating characteristics in considerable detail before going any further.

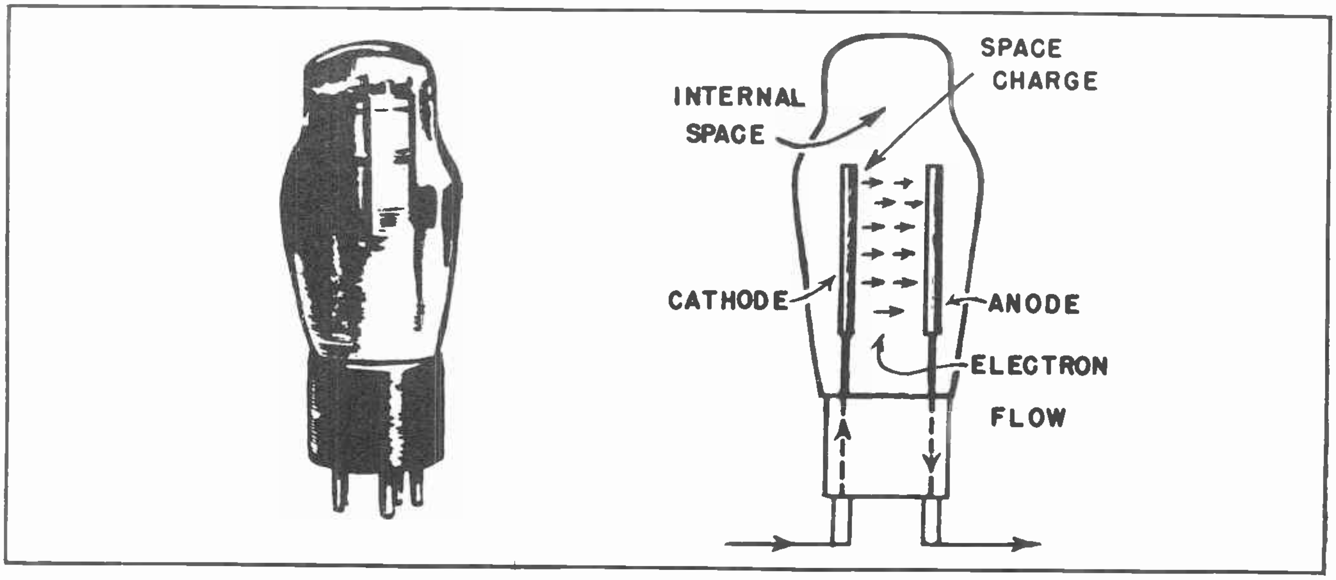

Fig. 1. The Diode Tube.

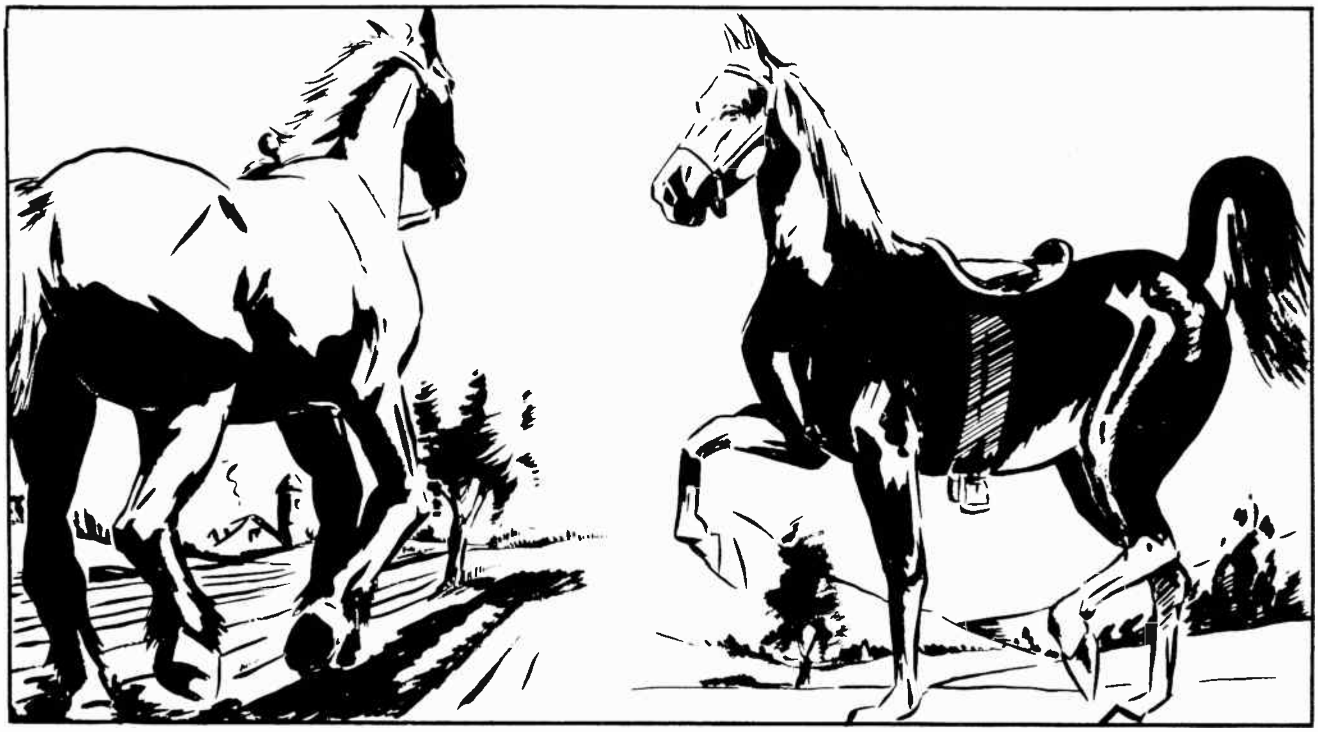

Fig.2. Each Horse has its Own Peculiar Characteristics.

Speaking of "Characteristics", that is one word you might just as well get used to right now. It will be used over and over many times in our discussions of vacuum tubes. It is the general name given by radiomen and electronic technicians to the individual peculiarities of each particular tube. Whole books have been written around the "Characteristics" of vacuum tubes, and many old timers in the business use the word in regular conversation without giving any real thought as to exactly what the word means.

Actually the application of the word to the description of electron tubes is little different from the way it would be used to describe a person or an animal. One horse might be described as being "high-stepping", while another could be described as plodding. The high spirits of the one horse would be called a *characteristic* of that type of horse. It would be useful for riding, hunting, and show. But such a horse would not do so well in pulling a plow, or as a member of a team of draft horses to pull heavy loads. On the other hand, a heavy draft horse would have certain important "Characteristics" of its own. It could pull heavy loads with ease, and perform enormous amounts of work. But it would be useless as a race horse, would not likely be very good for riding, and would be completely out of place as a hunting horse.

Here the word "Characteristics" is used to describe the abilities of the two horses. The characteristics of the one would include speed, good riding, spirit. The characteristics of the other would include great strength, ponderous weight, sluggish movements. The word "characteristic" could be said to mean the "distinguishing peculiarities" of each horse.

The term is also frequently applied to people. It is characteristic of some people to be good workers, steady in their actions, punctual in their appearances, and reliable. It is also characteristic of other people to be good leaders, to be capable of supervising the work of others, to welcome responsibility, and to be able to plan ahead. It is characteristic of still other people to work best under the supervision of another, to need direction, to lack the ability to plan ahead. The point is that the term "Characteristic" is used to describe the peculiarities of one group of persons which set them apart from other people. Some characteristics are good; others are bad. Some are one thing; some are another. Seldom, or never, are all possible characteristics found in any one person, any more than every kind of characteristic will be found in any one horse.

The same thing is true of electron tubes. Some tubes have been designed to do one certain job, and do it well. Other tubes have been designed to do some other job, and to do that job well. But no electron tube has yet been developed which can do every job equally well. It is extremely unlikely that any such tube will ever be designed. Such being true, it is necessary to learn the various things which electron tubes are expected to do, then determine how one tube, or one particular type of tube, can best do some specific job.

For these reasons we will be continuously studying the characteristics of various tubes. There are so many different types of tubes, and so many new tubes being added to each of the various types, it is difficult or impossible to become fully acquainted with them all. For this reason the tube manufacturers have prepared little booklets which they call "tube manuals". These manuals describe the exact characteristic of each tube. The trained technician can determine from these characteristics exactly how any particular tube will fit in with his needs.

Section 2. CATHODE EMISSION

In much the same way we use symbols to designate various electrical elements and properties when diagramming circuits. We also use certain symbols to designate the various elements of a vacuum tube. The envelope of the tube itself is shown by merely drawing a circle. See *A* in Fig. 3. Occasionally the circle is slightly distorted into the form of an oval, but the common method is to draw a simple circle. Many engineers omit the circle for the envelope of the tube, but the better practice is to include it in the diagram.

At *B* in Fig. 3 is shown the common symbol for the cathode. This symbol can be used to designate either the directly heated cathode or the indirectly heated types. This symbol is also used when it is not known exactly what type of cathode the tube to be used will have.

The tube heater, or filament, is shown in symbolic form at *C* in Fig. 3. Where the tube is of the directly heated cathode type, this is the symbol most commonly used, although the one shown at *B* can be used. Where it is definitely known that a tube is of the directly heated cathode type, the better practice is to use the symbol at *C*. The symbol at *C* is also used to show the heaters which are used to heat the cathode of an indirectly heated type where it is necessary or desirable to show the heater on the diagram. When it is necessary to show the heater of an indirectly heated cathode, it is the common practice to combine the symbols at *B* and *C* and draw it as at *D*.

The most common method of showing the anode, or plate, in an electron tube is that shown at *E* in Fig. 3. An older practice was to draw a small rectangle to represent the anode, but this method of designating the anode has just about disappeared. The rectangle is considerably harder to draw than the symbol shown at *E* in Fig. 3, and had no real advantages over it. A few of the old timers in this business occasionally use the rectangle to show the anode, and many of the diagrams of older electronic equipment continue to use that method. But for the most part it has almost disappeared from modern diagrams.

The method of drawing a symbol for a diode tube is shown at *F* in Fig. 3. The symbol for the anode is shown at the top of the circle. Near the bottom is shown the heaters for the cathode, and immediately above the heater symbol is the cathode itself. This would be the symbol for an indirectly heated cathode type of diode. Had there only been a symbol for a filament and a symbol for the anode, we would have known it was a directly heated cathode type of diode.

In counting the number of elements in a tube the heaters are never counted as being

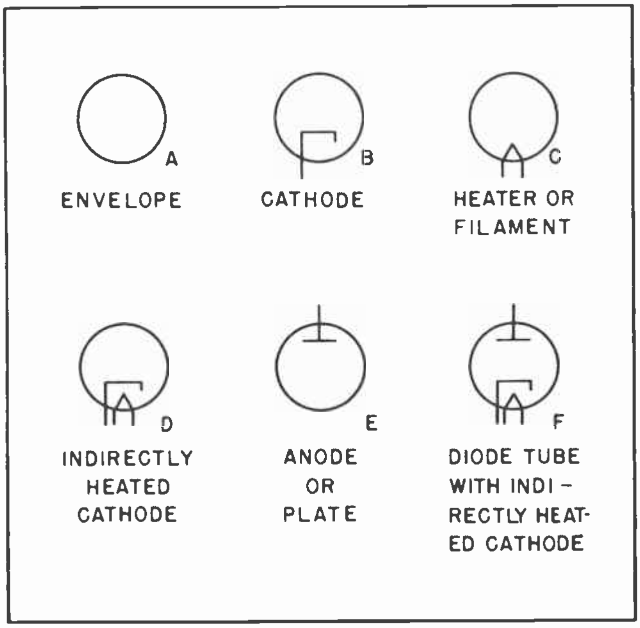

Fig.3. Tube Symbols.

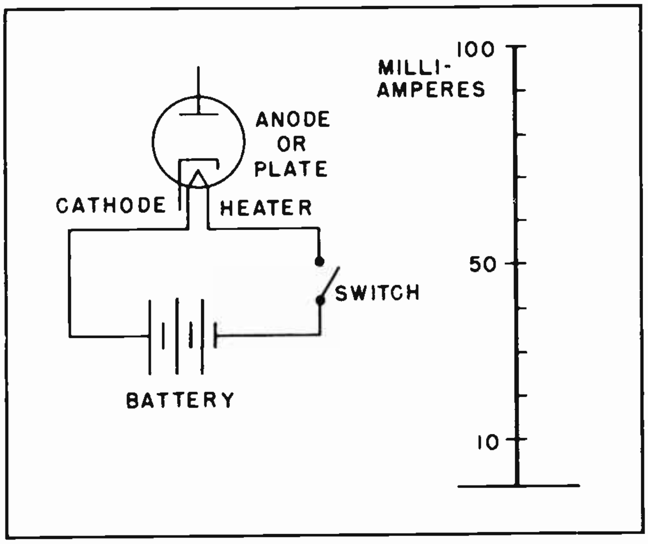

Fig.4.

one of the elements. However, if the heaters act as the cathode, as in a directly heated cathode type of tube, then they would be counted. However, they would not be counted as a tube element because they were the heaters, but because they were the cathode. Because there are so many circuits in most electronic devices, it is a common practice to omit the heaters from circuit diagrams when they do not act as the cathode.

Since we know the cathode must be heated, we can often leave the heater circuits out of circuit diagrams without misleading anyone. This makes it much easier to follow the more important circuits on the diagram.

These are merely comments on general practices, and much more will be said about them as we progress with our studies. When they are not mentioned, the newcomer into this field is sometimes just a little puzzled by what seems to be inconsistent practices. As you get a little deeper into this work you will see there actually is no inconsistency at all.

We already know the cathode of an electron tube will not emit electrons until it is heated. In Fig. 4 we have all the necessary elements for cathode emission with one exception. The cathode is not heated. But if the switch were to be closed, the voltage of the battery would force current through the heater of the cathode, causing it to heat the cathode.

But just how much current must be forced through the cathode to cause emission? Just how hot must the cathode be? Will the same number of electrons be emitted when the cathode temperature is low as when it is high? If more and more heat is applied to the cathode, will the emission of electrons continue to rise at a steadily increasing rate? All of these are natural questions, and you should know the answers to them in order to properly understand the use and operation of vacuum electron tubes.

Section 3. CHARTING CATHODE EMISSION

Suppose we set up a circuit as shown in Fig. 5 and study the action of the diode tube under various conditions. In order to provide a positive voltage on the anode of the tube we have connected a battery between the cathode and the anode with the negative terminal of the battery connected to the cathode and the positive terminal to the anode of the tube. In order to measure the amount of current which flows through the circuit we have placed a milliammeter in the anode circuit. A milliammeter is a current reading meter which is sensitive enough to read milliamperes -- a milliampere being 1/1000th of an ampere. Such meters are in common use in electronic work.

During the course of our experiments we will assume the voltage of the anode circuit does not change. This means that any change in the value of the current flowing in the anode circuit is brought about in some way other than by changes in the anode circuit voltage.

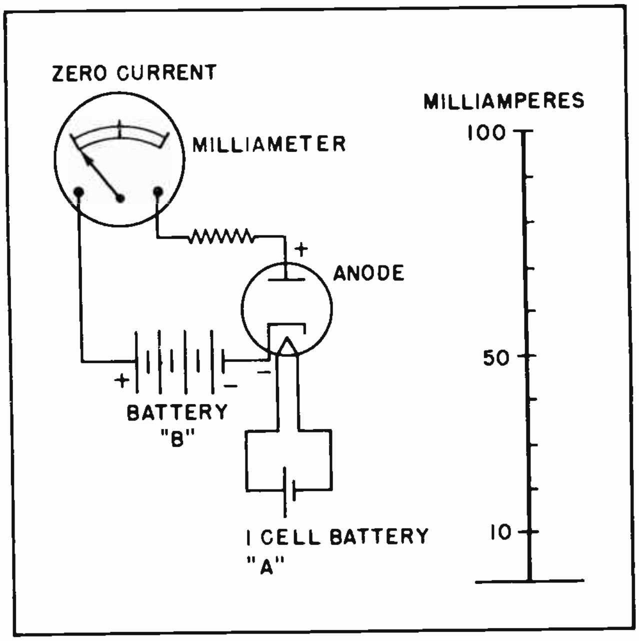

Fig.5.

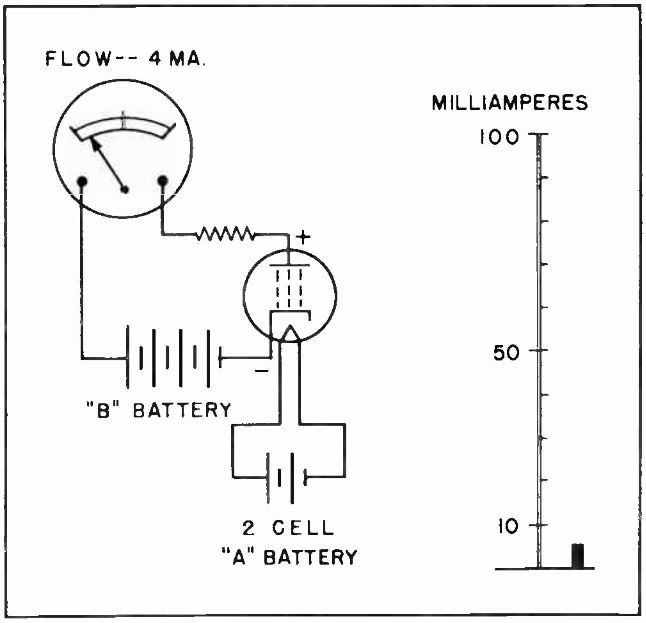

Fig.6.

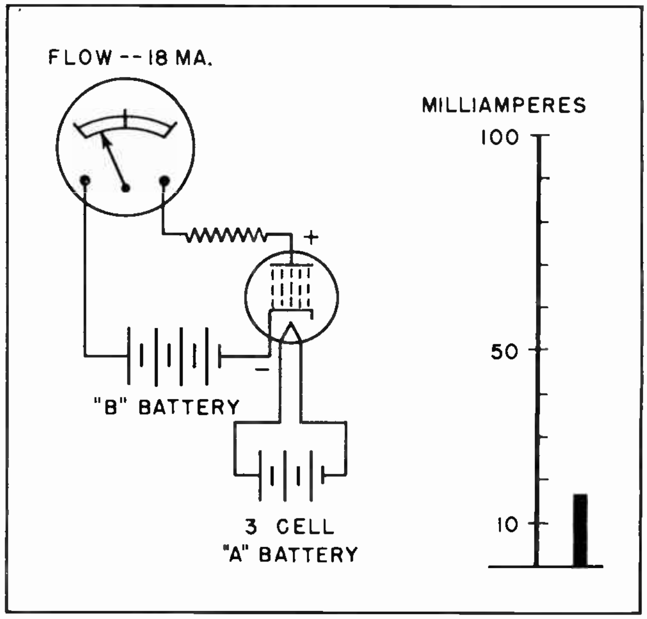

Fig.7.

In Fig. 5 we have 1 cell in the "A" battery. The "A" battery is the one used to supply heating current to the cathode heater. But the one volt does not force enough current through the heater to raise the temperature high enough to cause any measurable number of electrons to be emitted. The milliammeter does not register any current flow. For all practical purposes the use of one cell in the "A" battery does not set up any electron emission.

Now let's add another cell to the "A" battery as shown in Fig. 6. The two cells will force more current through the heater, thus raising its temperature high enough to start some emission from the cathode. The milliammeter shows that 4 milliamperes of current is flowing in the anode circuit. Some electrons are shown passing through the space of the tube from the cathode to the anode. At the right is a chart showing a small amount of current.

At Fig. 7 we have added another cell to the "A" battery. This extra cell forces still more current through the cathode heater, raising its temperature still higher. The milliammeter shows that 18 milliamperes of current will flow through the anode circuit when the heater circuit contains three cells. The 18 milliamperes of current in the *anode* circuit when three cells are used in the *heater* circuit contrasts sharply with the 4 milliamperes of anode current when there are only two cells in the heater circuit. The chart at the right shows the comparison of 18 milliamperes with the 4 milliamperes in Fig. 6.

Now let's see what will happen when we add still another cell to our heater circuit. This is shown in Fig. 8. When four cells are used in the heater circuit the temperature of the cathode is raised high enough so there are many electrons being emitted. The milliammeter in the anode circuits shows that now there are 50 milliamperes of current flowing in that circuit. This contrasts very sharply with 18 milliamperes for three

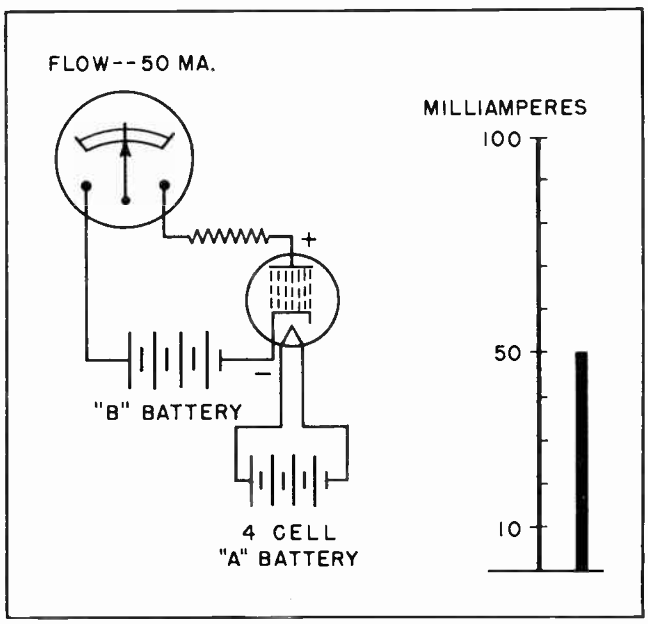

Fig.8.

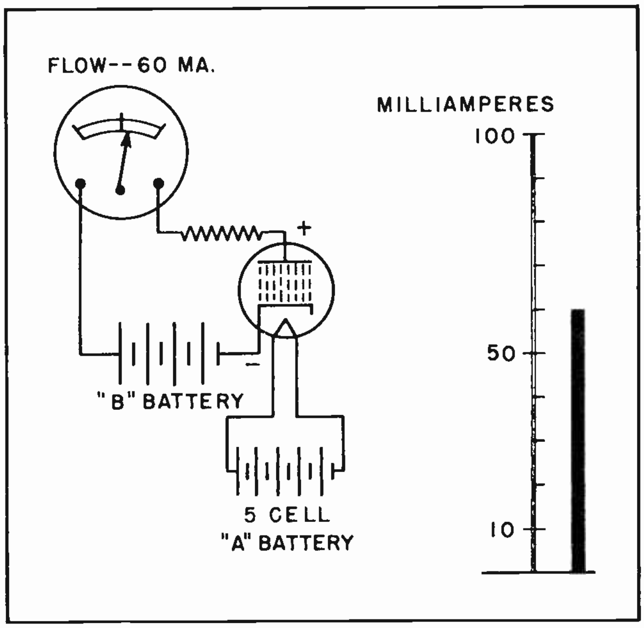

Fig.9.

cells in the heater circuit, and only 4 milliamperes when there are two cells in the heater circuit. Note the current flow on the chart at the right in Fig. 8. Compare this with the chart in Figs. 6 and 7.

In Fig. 9 we have added still another cell to the heater circuit. This raises the cathode temperature still higher, and causes it to emit still more electrons. But the milliammeter shows us that this time the anode current has risen only to 60 milliamperes from the 50 milliamperes when 4 cells were used. Although the cathode emission has risen enough for the anode milliammeter to show a gain of 10 milliamperes, nevertheless the increase is much less sharp than when the cells in the heater circuit was increased from three cells to four cells. This being so, one might suspect that a point had about been reached where additional electron emission cannot be obtained merely by increasing the cathode temperature. To test out this supposition we will add another cell to the heater circuit, making 6 cells in all.

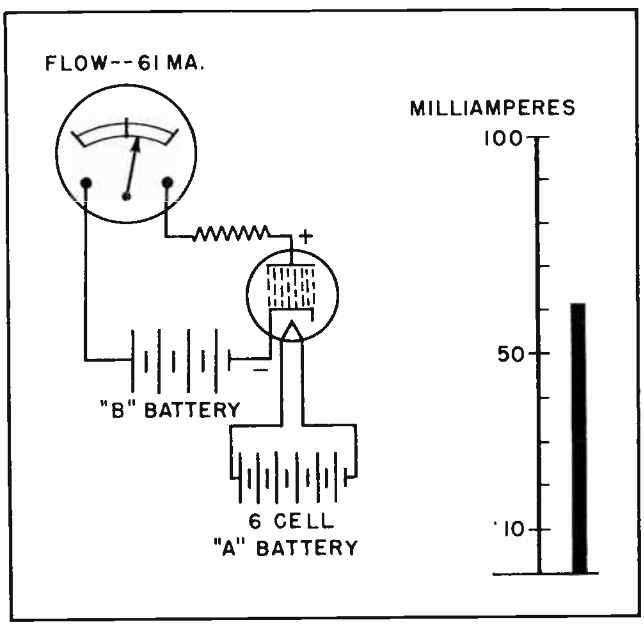

Fig.10.

The addition of the sixth cell to the heater circuit is shown in Fig. 10. But the addition of this extra cell does not apparently increase the electron emission from the cathode by any important amount. This is shown by the fact the milliammeter in the anode circuit shows an increase of only one milliampere when the sixth cell is added to the heater circuit. A comparison of the chart at the right of Fig. 10 to that in Fig. 9 shows only a very insignificant change in current flow.

To test this another step further, we will add *two* additional cells to our heater circuit, making a total of 8 cells all together. The addition of the two extra cells does increase the electron emission, but the amount is so insignificant as to be negligible. The milliammeter in the anode circuit shows the addition of the two extra cells in the heater circuit has increased the anode current by only one milliampere.

Increasing the number of cells in the heater circuit increases the voltage of that battery. The higher voltage causes more current to flow through the heater, thus raising the temperature of the heater and the cathode. With steadily increasing heater voltage the anode current first increased rather slowly, then quite rapidly. Finally, as the voltage was increased still further, the anode current increased at a much lower rate. These observations point out three very important facts to us:

1. Until the cathode gets quite hot there is no appreciable electron flow despite the fact the cathode-anode "B" battery is furnishing considerable potential difference between the cathode and the anode.

2. Increasing the cathode temperature, increases the number of electrons which are emitted from the cathode. This

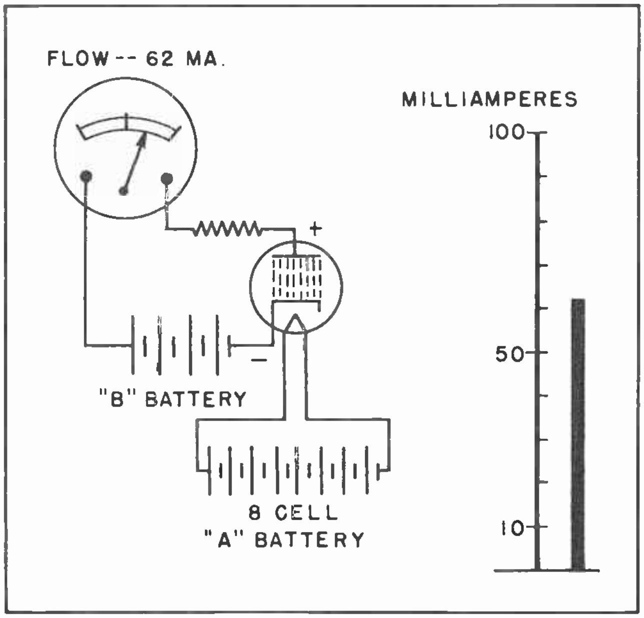

Fig.11.

permits a rapid increase in the flow of electrons through the space inside the tube from the cathode to the anode.

3. After the cathode reaches a specific temperature, there is very little additional increase in emission regardless of how much higher the temperature is raised.

Section 4. MAKING A GRAPH

The use of charts and "graphs" is a convenient and useful method of showing how a vacuum tube will perform under certain designated conditions. In Figs. 5 through 11, we have drawn a chart at the right of the illustration. These charts made possible a ready comparison of the actions which took place in each illustration. In Fig. 6 only 4 milliamperes of current is flowing in the anode circuit. The bare figures "4 M.A." do not mean very much themselves, but when they are set down as a certain length on a piece of paper they begin to acquire some significance. When they are set alongside other lengths on paper which represent 18 M.A. and 50 M.A., a comparison of their respective values can be observed in a glance.

In Fig. 12 we have taken all the charts from Figs. 5 through 11 and placed them side by side. The height of the marks indicate the number of milliamperes, the exact number can be ascertained by referring to the milliampere scale at the left of the chart. The marks are separated according to the number of cells in the heater circuit which each mark represents. Thus the first (which actually is zero) is shown for one cell, the second mark is for 2 cells, the third for three cells, etc. When the marks are located

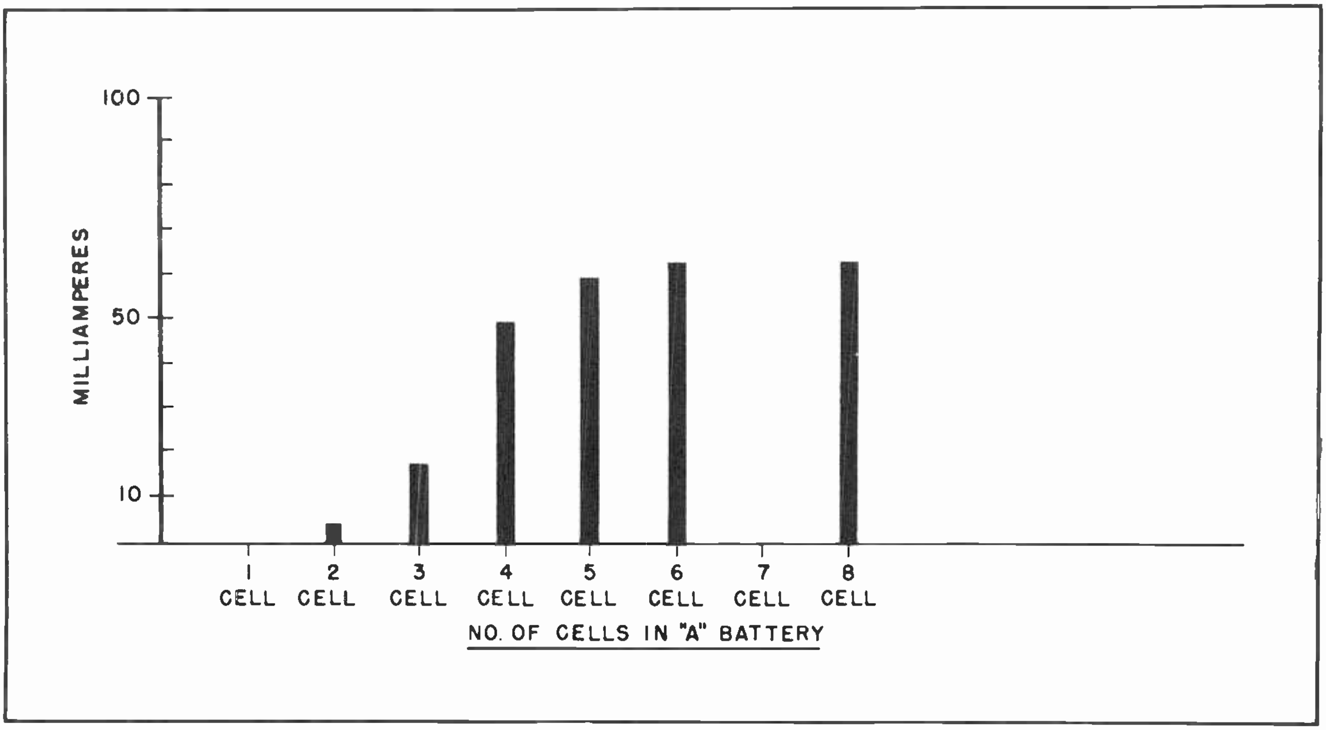

Fig.12.

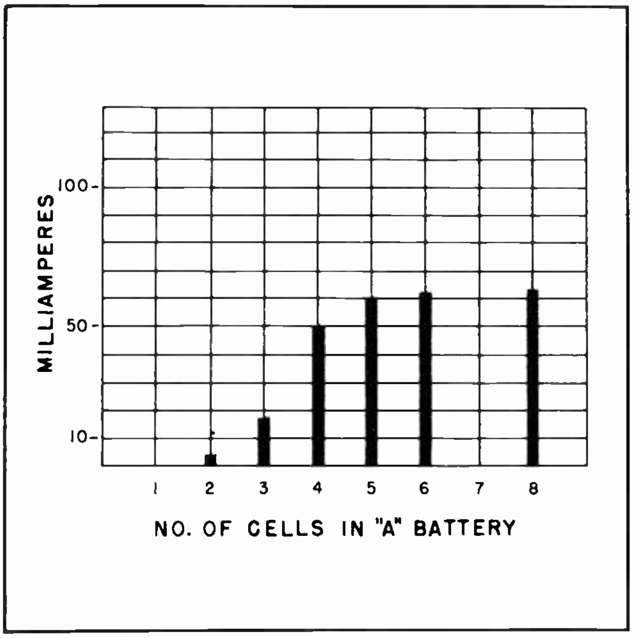

Fig. 13.

in this manner we can tell at a glance exactly what the situation is when any combination of circumstances exists. In Fig. 13 we have redrawn the marks on a regular graph. The horizontal lines indicate the various current values, the various vertical lines are evenly spaced so the locations of the various cell combinations can be readily designated. The use of regular *graph paper* makes it much easier to draw one of these charts. Graph paper can be readily obtained in almost any stationary store, or one of the dime stores.

When the graph paper is used, it is not even necessary to draw the entire mark we used in previous charts to show the relationship of anode current to heater circuit voltage. Fig. 14 shows how this can be done. When only one cell is used in the heater circuit it does not heat the cathode sufficiently to cause any electron emission, thus no anode current. So on the graph in Fig. 14 we locate a vertical line representing one cell in the heater circuit, then move our pencil along it until we come to "zero" current. This is right at the bottom of the vertical line. Next we move over to the vertical line representing two cells in the heater circuit. We move the pencil up this line to a point which corresponds to 4 milliamperes on the scale at the left of the graph. There we will place a dot. This is shown in Fig. 14.

Then we find a spot on the vertical line for three cells which corresponds to 18 milliamperes and place another dot. This is also shown in Fig. 14. We continue in the same manner on the vertical lines for 4 cells, 5 cells, 6 cells and 8 cells. A dot is placed on the graph paper at each point where the anode current corresponds with the number of cells used to obtain the meter reading. No dot is placed on the vertical line representing 7 cells. This is because no reading was taken with 7 cells.

Once the dots have been placed on the graph it is the common practice to draw a smooth curve from dot to dot. Such a curve is called the "Characteristic curve" of the cathode-temperature anode-current relationship of this particular tube. Similar curves are drawn to show many other relationships between various elements of vacuum tubes. The curve of the particular tube we have been discussing is shown in Fig. 15. Other diode tubes might pass larger or smaller amounts of anode current as the heater voltage was changed. It would depend on the size of the cathode emitting surface, the type of emitter, the resistance of the heater element and other things. But the relationship between the heater temperature and the anode current of *any* tube can be worked out by following the method we have described.

Section 5. USING THE INFORMATION FROM THE GRAPH

In the particular tube we have been discussing, we would learn from our experiments

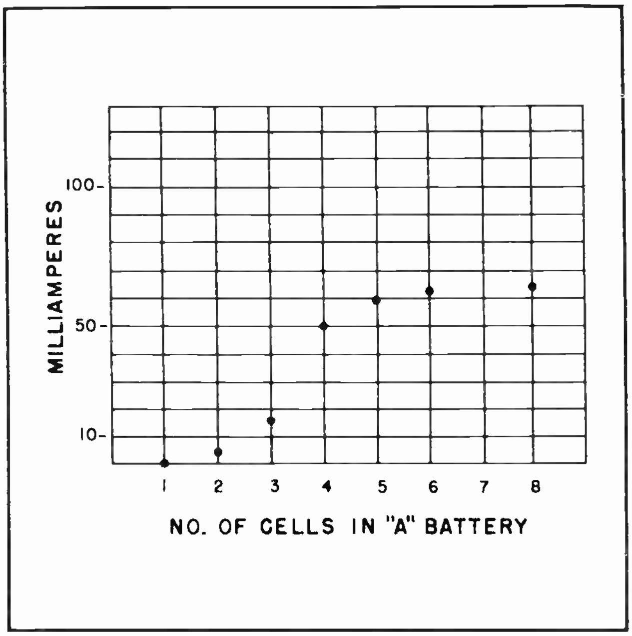

Fig. 14. Preparing the Graph of a Characteristic Curve.

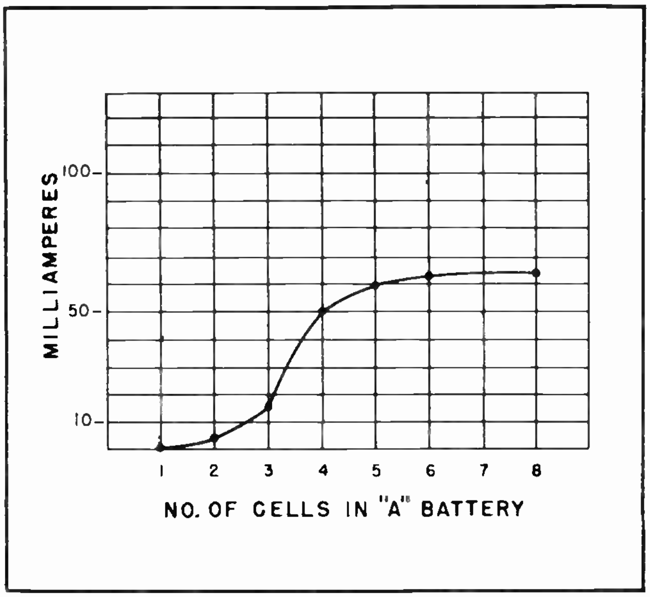

Fig.15. A Characteristic Curve Drawn on a Graph.

that it would operate most efficiently at a temperature created by placing about four cells in the heater circuit. Using less than this number of cells radically reduces the electron emission. Increasing the number of cells adds to the cost, the weight and the bulkiness, but does not give enough additional emission to justify the extra cells.

Running tests on some other tube might show that it would operate most efficiently at a much higher voltage. Still other tubes might operate more efficiently at much lower voltage. But the point is that creation of such a graph, whether you have to do it yourself or it is done by the manufacturer, gives you very important information at a glance.

Section 6. TEMPERATURE SATURATION

When the cathode has been heated to such temperature that further increase results in no increased electron emission we have reached a state known as *temperature saturation*. Before leaving this subject it would be well to make certain one thing is understood. That is to understand exactly what causes temperature saturation.

You will recall we said that during the course of our discussion we would assume the anode voltage would remain constant -- it would not change. Thus the electrostatic field between the cathode and the anode would remain virtually steady.

Furthermore, you will recall that as the cathode emits electrons the very act of emission causes the cathode to become somewhat more positive, thus exerting a measure of attraction for the electrons in the surrounding space charge. As the temperature of the cathode rises, it emits more and more electrons until it reaches a condition where it attracts electrons as fast as it emits them; that due to the cathode's location with respect to the electron cloud and the anode, it has as much attraction for the nearby electrons as the more positive -- but more distant -- anode. When this condition is reached, it does no good to increase the temperature of the cathode. No more electrons can get away from it.

However, when the point of *temperature saturation* is reached in a tube, it is possible to obtain a greater anode current by increasing the voltage between the cathode and the anode. The higher positive voltage then tends to make the anode relatively more attractive to the electrons. Fig. 16 indicates how a higher anode voltage will raise the point of *temperature saturation*.

Section 7. EFFECT OF ANODE VOLTAGE

We have seen the effect on the current in the anode circuit of changing the temperature

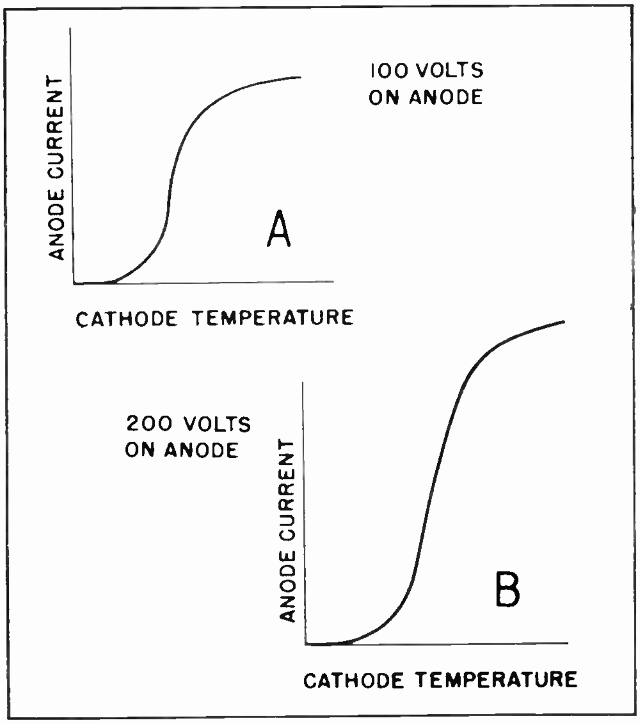

Fig.16. Upon Reaching Temperature Saturation, the Anode Current can be Increased by Increasing the Anode Voltage.

of the cathode. Now we shall investigate what changes will take place in the anode current when we change the anode voltage.

Perhaps it is well that we explain the terms "anode current" and anode voltage. A voltage normally exists between the cathode and the anode. This voltage is developed in a source of power outside the tube, such as the battery in figure 17. Inside the tube the current flows from the cathode to the anode. Outside the tube the current flows from the anode (under the influence of the battery voltage) to the cathode as shown by the arrows. This outside circuit is referred to as the anode circuit.

Probably the most accurate description would be "anode-cathode circuit. But this designation would be just a little too long and unwieldly for everyday use. It could not be called the "cathode circuit", because as you will soon learn, there are many circuits connected to the cathode and it would be confusing to call this circuit by that name. But this particular circuit does involve the anode, and no other circuit does go to the anode, so it is natural to call the one circuit which connects the anode to the cathode the "anode circuit".

Moving along another step from here, it is the most natural thing in the world to call any current which flows in the anode circuit by the name "anode current". It is equally natural to call any voltage which exists between the anode and the cathode by the name "anode voltage". You will encounter these terms constantly in your work with electron tubes, so it is just as well to get them straight in your mind at this time. In many electron tubes the cathode forms a part of many circuits, and as you will find out later, the cathode is the basic point from which all voltages in the tube are measured.

Beginning with Fig. 17 we will study the effect on the anode current of changing the value of the anode voltage. During these series of tests we will not change the voltage across the heaters. In other words the temperature of the cathode will remain constant during these experiments. In Fig. 17 we have a diode tube with 20 positive volts applied to the anode. A milliammeter is connected in the anode circuit in such manner that we can determine the value of the current flow. The meter shows us that when the temperature of the cathode is some particular value, an anode voltage of 20 volts will cause 17 milliamperes to flow through the tube and the external circuit.

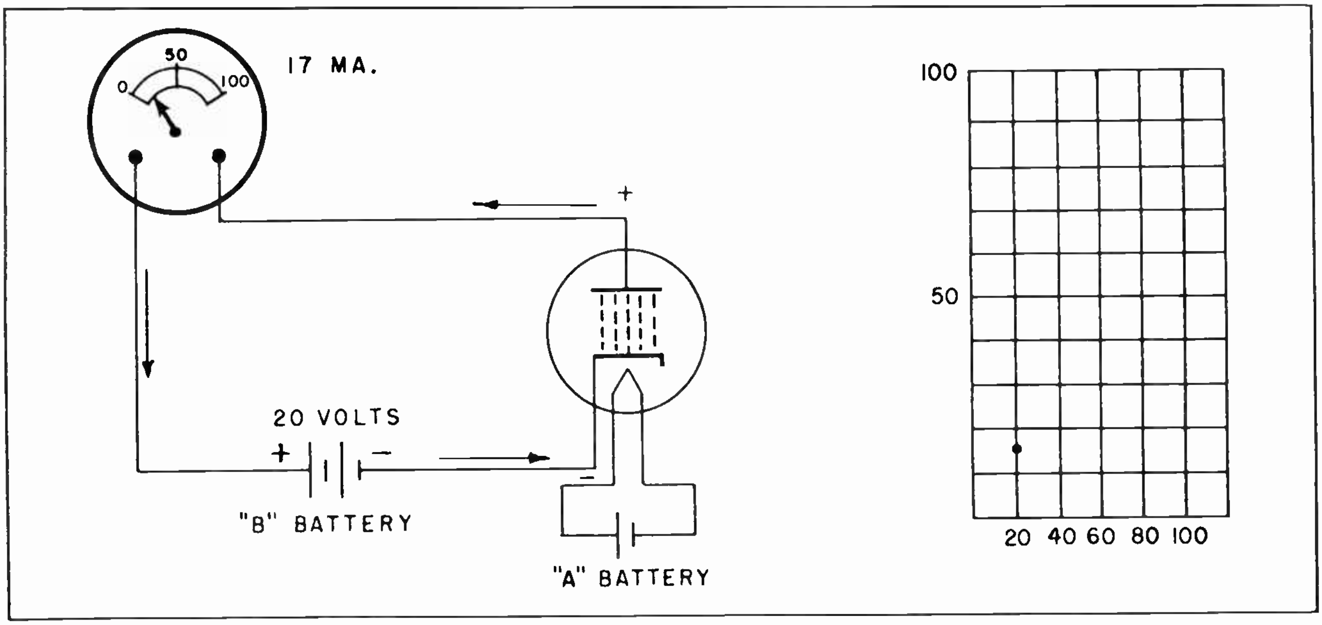

Fig.17.

We have constructed a graph at the right of the illustration. On this graph we have placed a dot to mark the value of the current when the anode voltage is 20 volts.

In Fig. 18 we have the same circuit with all the same components. The only difference is that in this circuit we have placed 40

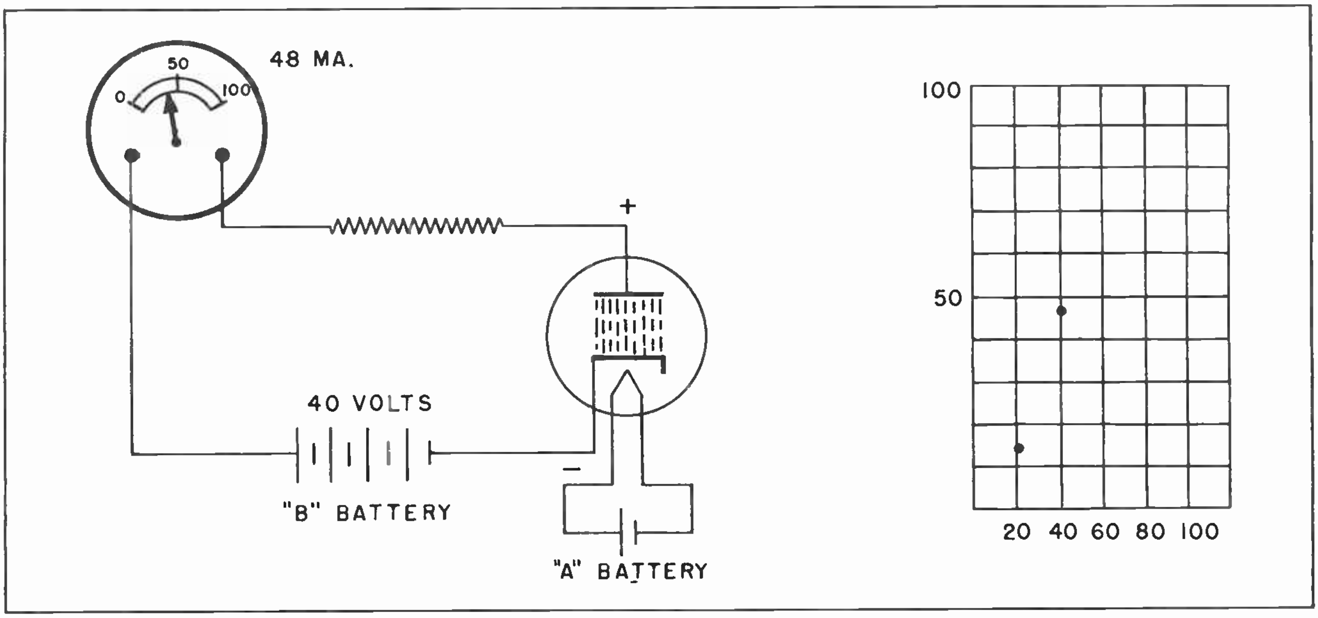

Fig. 18.

positive volts on the anode of the tube. The reading of the milliammeter shows us the anode current has increased to 48 M.A. We have placed a dot on the graph at the right to show the anode current when the voltage is 20 and 40.

We have increased the anode voltage still more in Fig. 19. Here the voltage has been raised to 60 volts. Nothing else about the circuit has been changed. The milliammeter now tells us the anode current has risen to 85 ma. The indication at this time is that the anode current values will rise clear off the chart if we continue to increase the anode voltage. This indication is shown by the three dots which mark the value of the anode current at the three anode voltages we have used, 20 volts, 40 volts and 60 volts.

To carry our investigation a little further, suppose we increase the anode voltage another 20-volt step to 80 volts. This condition is shown in Fig. 20. The increase in the anode voltage has again

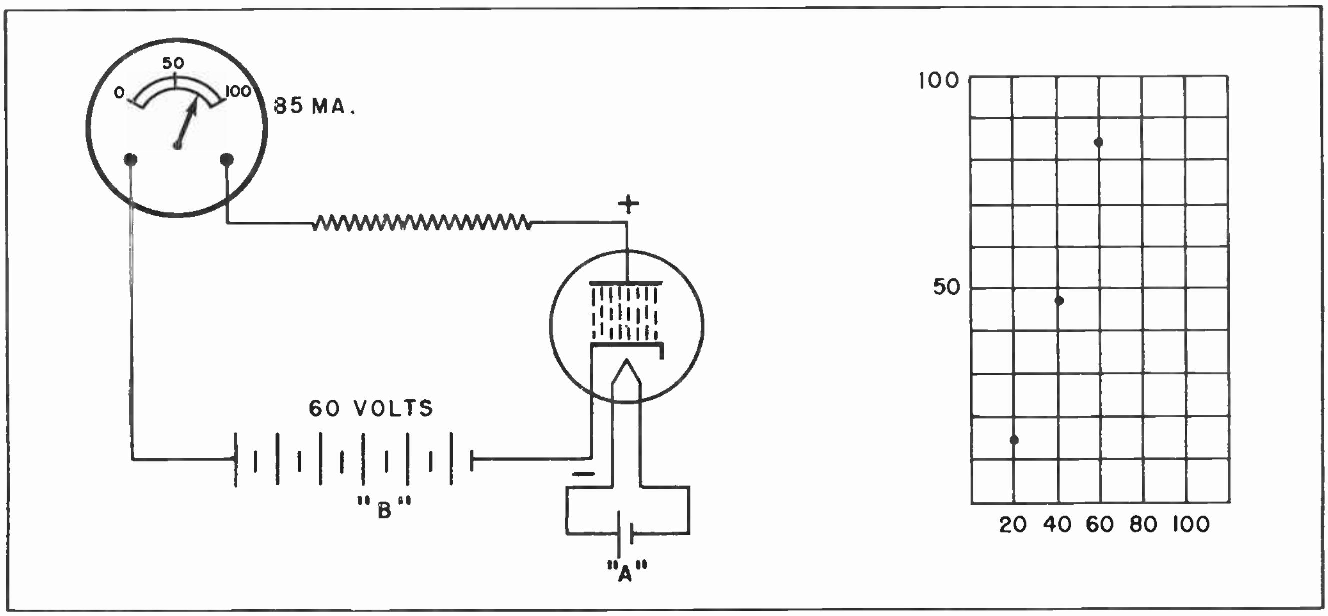

Fig. 19.

resulted in an increase in the anode current. But the increase is not now nearly so great as when we previously increased the anode voltage. Raising the anode voltage to 80 volts increases the anode current to only 92 milliamperes. This is shown by the reading of the milliammeter. The rising curve of dots on the graph at the right is no longer rising as steeply as before.

In Fig. 21 the voltage on the anode has been increased another 20 volts to 100 volts. But this increased voltage has resulted in increasing the anode current only one milliampere to 93 milliamperes. It is becoming evident that merely increasing the anode voltage is not going to keep the anode current rising. The location of the dots

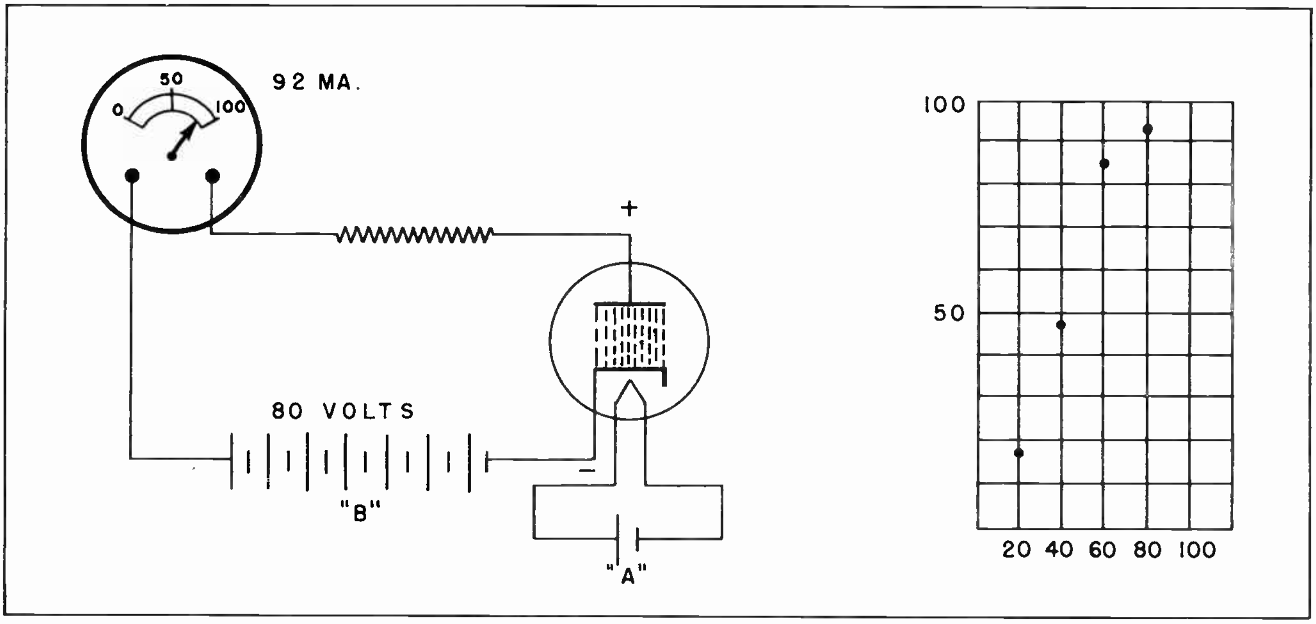

Fig.20.

representing the various voltage and current readings on the graph have been joined together with a curving line. The curve which had been rising steeply has now flattened out so that it is now moving almost horizontally. This flattening of the characteristic curve is a graphical visual indication that further increase in anode voltage has little effect on anode current.

Section 8. VOLTAGE SATURATION

When the curve of the line on the graph flattens out so that additional anode voltage does not result in any appreciable anode current, we say the tube has reached *voltage saturation*. This means the tube has reached a condition where additional voltage has little or no affect; it is *saturated* with voltage. Although we call this condition *voltage saturation*, the condition is brought about because the anode is already attracting all the electrons the cathode is emitting. If there are no additional electrons available in the space charge of the tube, an increase in voltage would naturally have no further effect. When measuring the voltage and current, the appearance is that the tube has become so saturated with voltage that additional voltage has little effect -- thus the term, *voltage saturation*.

To a certain extent, the term *voltage saturation* seems almost a misnomer. But it has the sanction of long usage and there is little likelihood the designation will be changed. The term is brought to your attention, and explained, so you will understand what is meant when you encounter it in your everyday work.

Which brings us to the point that we have now learned something about another characteristic of a diode vacuum tube. We have learned that:

1. Anode current, or electron flow in the anode circuit, can be increased by increasing the anode voltage.

2. After the anode voltage reaches a certain high value, no additional current flow can be obtained by increasing the anode voltage to still higher values.

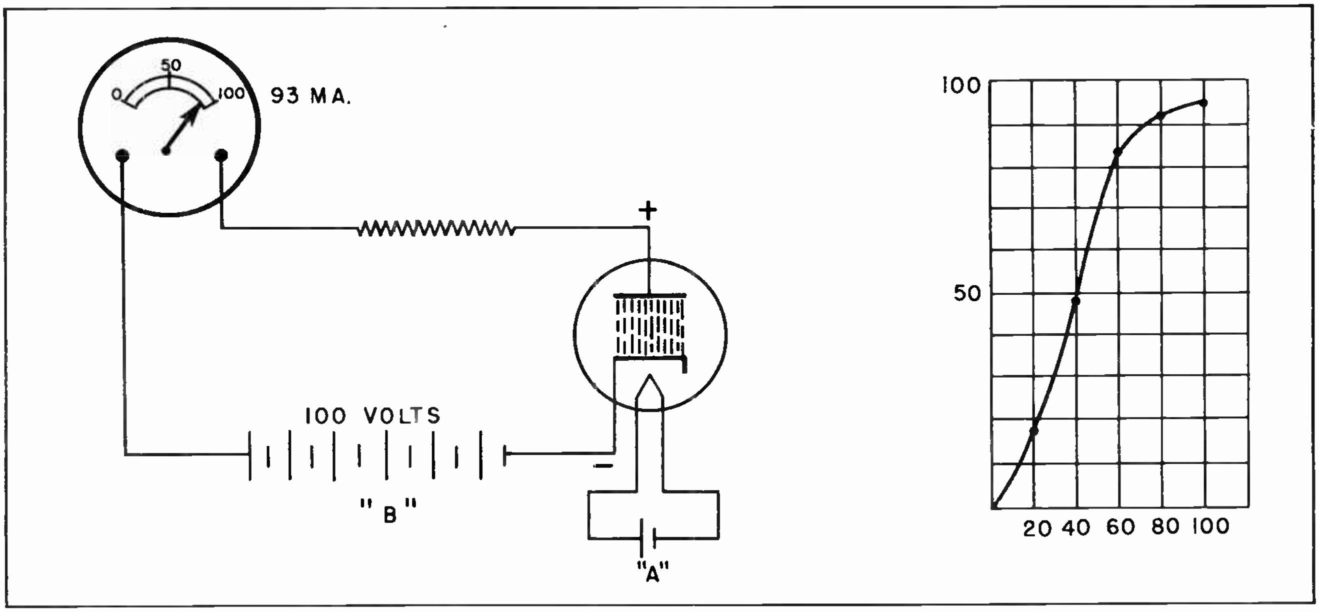

Fig.21.

Section 9. EFFECT OF NEGATIVE ANODE VOLTAGE

In all our discussions of anode current flow we have assumed the voltage on the anode was positive in polarity. Such is usually the case. But suppose the anode were to become negative, such as would happen if the tube were placed in an A-C circuit. What action would take place?

It isn't hard to figure out the answer to that. You have probably figured it all out for yourself already. We can almost answer that question by asking another. Just what causes the electrons to be attracted to the plate in the first place? Because it is positive, of course.

Then if the plate should be negative rather than positive it would not attract electrons. In that case, if the plate should become negative it would not attract electrons -- in fact it would repel them -- with the result that no anode current at all would flow. This situation is shown in Fig. 22.

Section 10. VACUUM TUBE RECTIFIERS

This very ability of the vacuum tube to pass electrons only when the anode is positive makes possible its first use, and one which is still very valuable; the use of the tube as a *rectifier.* A rectifier is a device which changes alternating current into a current which flows only in one direction. As a matter of fact, the diode vacuum tube is used more frequently as a rectifier than for any other purpose. Even its use as a diode detector involves its ability to act as a rectifier.

Nearly all commercial electrical power is generated and distributed in the form of alternating current. Ordinary alternating current power is not desirable on the anodes of many amplifying tubes. This means that before the regular A-C house current can be used to power a radio or television receiver, or be placed on the anodes of amplifier tubes in an Industrial Electronic

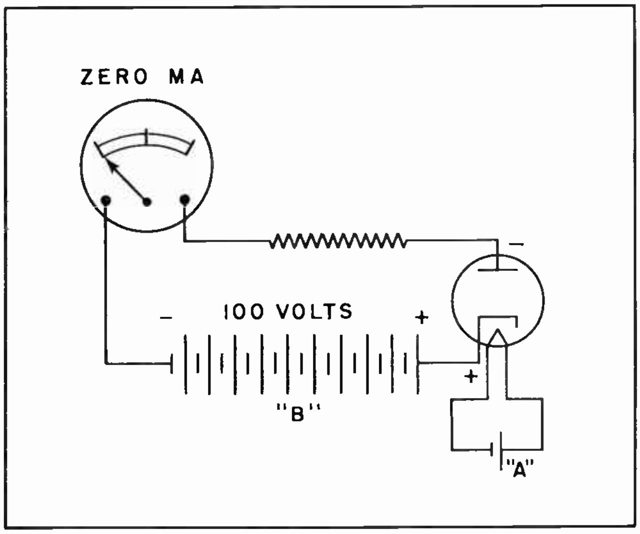

Fig.22. No Anode Current will Flow when the Anode is Negative.

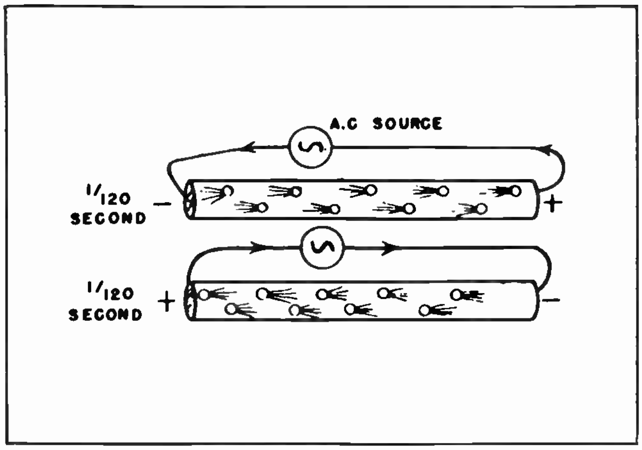

Fig.23.

device, the A-C power must be converted into direct current. This is where the vacuum diode tube is brought into use.

Fig. 23 gives an exaggerated view of the manner in which the electrons are continually moving back and forth under the influence of alternating voltages. The electrons in a circuit connected to ordinary 60-cycle house current will move in one direction for 1/120th of a second. Then they will reverse and move in the other direction for 1/120th of a second. They will immediately reverse again, keeping this up continually, a reversal every 1/120th second.

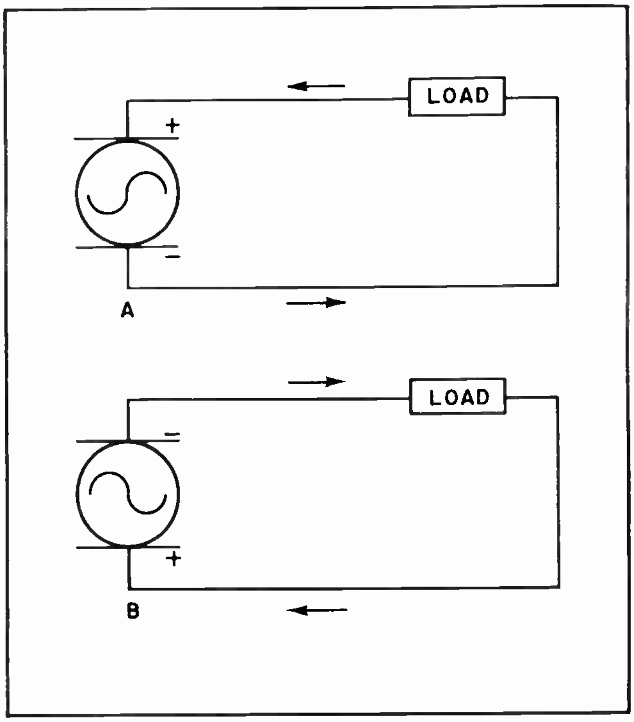

Fig.24. Direction of Current is Determined by the Polarity.

If an alternator is connected to a load, the current will flow for one instant as in Fig. 24, then an instant later will reverse and flow in the opposite direction as shown in the same illustration. For many purposes it makes no difference in which direction the current moves, and this continual reversal is no hindrance. In fact, alternating current is highly desirable for many applications.

But there are other places where the current cannot be used if it is constantly changing its direction. Electronic devices of many kinds cannot use A-C power on their amplifier tubes. Radio and television receivers, in particular, must have D-C for use on their amplifier tube anodes.

Suppose the load shown in Figs. 23 and 24 was such that D-C power must be supplied, but only A-C power was available. When that situation arises we make use of the vacuum tube *rectifier.* An electron tube would be inserted in the circuit as shown in Fig. 25. The action of the diode rectifier is such that it will allow the current to flow in one direction but will block its flow in the opposite direction. The direction of the voltages and current at the output of a diode rectifier is shown in Fig. 26. The current pulses shown at the lower part of Fig. 26 are all flowing in the same di-

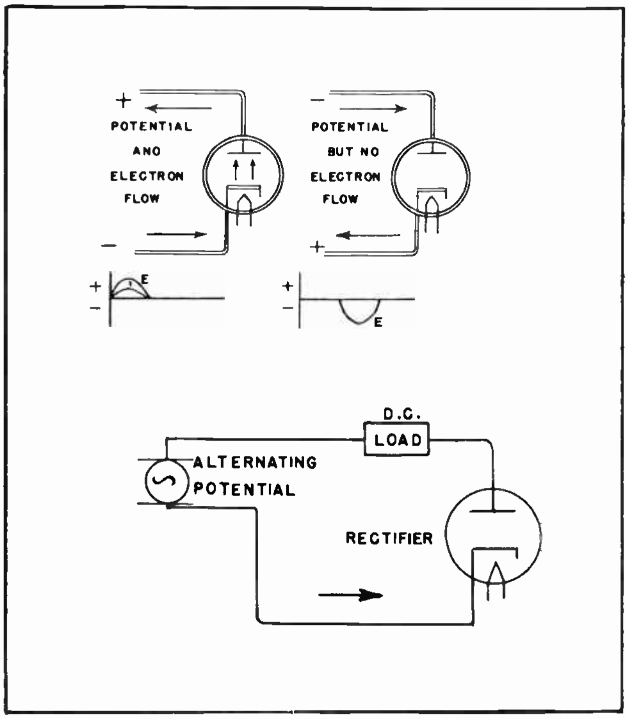

Fig. 25. A Diode Tube Allows Current to Flow in only One Direction.

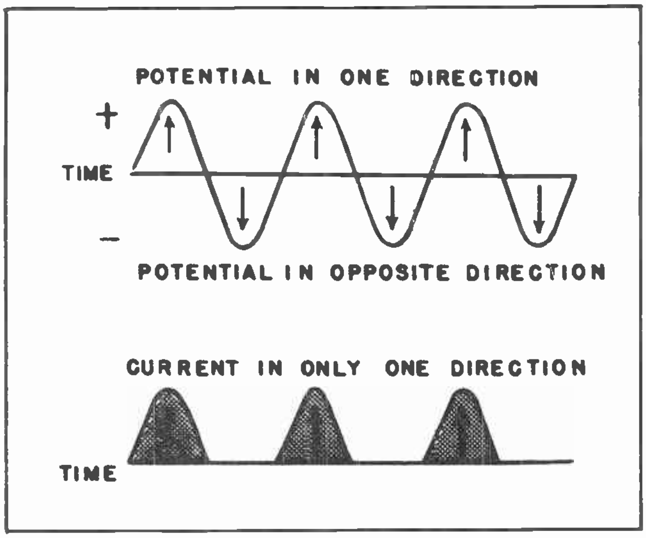

Fig.26. Potential is alternately in one direction, then in the other. But current flows only on the positive half-cycles.

rection. But the flow is not smooth and even, such as would be the flow from a battery or from a D-C generator. For this reason the current from a vacuum diode rectifier as shown in Figs. 25 and 26 is not usually called direct current. It is called *unidirectional* current, which means current flowing in only one direction.

Section 11. FILTERS

Such uneven current pulses are frequently undesirable. In order to use the unidirectional current provided by vacuum diode rectifiers it is usually necessary to smooth out the unevenness by means of circuits called *filters*. These filter circuits usually consist of high-capacity capacitors, or large inductance coils called *choke coils* and are used to filter out the uneven ripples in the unidirectional current.

In Fig. 27 is shown the method of connecting a large value capacitor into the circuit so as to smooth out the worst of the ripples. A-C voltage is applied to the anode and cathode of the vacuum tube, but since the tube will pass electrons only when the anode is positive, the electrons will move through the load in the direction of the arrows. Fig. 27 shows the circuit at an instant when the anode is positive. During this instant the capacitor will charge up with the polarities as indicated.

During the next instant the anode of the tube will be negative. (See Fig. 28.) This will effectively block the passage of any electrons in either direction. The tube will act just like a switch which is open. Note the equivalent circuit of Fig. 28. If the tube were completely removed from the circuit for this instant, the situation would be the same. This means that so far as the external A-C circuit is concerned, it might just as well be disconnected during this instant.

But the capacitor which had charged up on the positive cycle is now free to discharge. It cannot discharge through the tube -- the action of the tube is such that it is like an open circuit or an open switch. But the capacitor can discharge through the load, and this it does. If the switch in the equivalent circuit of Fig. 28 was *closed* during each positive cycle and *opened* during each negative cycle, it would act exactly like the tube.

It will be noted that the movement of the electrons through the load from the discharging capacitor is in the same direction as the movement of electrons when they were flowing through the circuit and the tube. What this means is that during the positive half-cycles the electrons will move through the load from one side of the power line to the other. At this time the electrons flow through the load and through the tube. But during the half-cycles when the anode of the tube is negative, the tube effectively opens the external circuit, but the capacitor can discharge through the load in the same direction that electrons from the power line were flowing an instant before. This means that electrons are flowing through the load

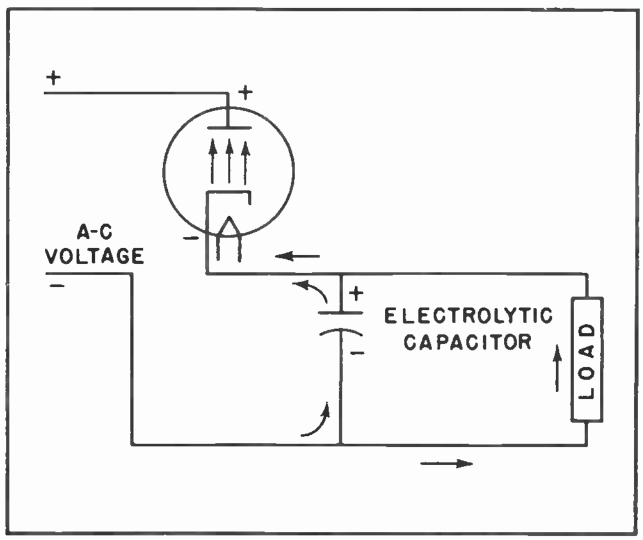

Fig.27.

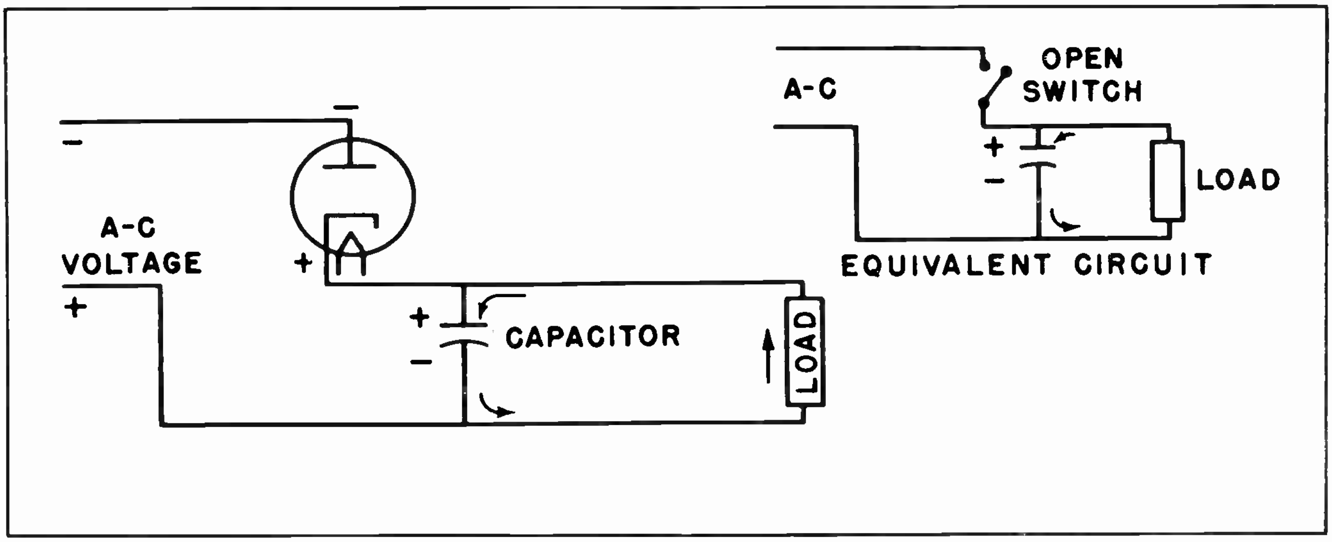

Fig. 28.

in the same direction during both half-cycles of the A-C power cycle. The load doesn't know nor care whether the electrons which are flowing through it at any particular instant are directly from the power line or are from the discharging capacitor, just so they are all flowing in the same direction.

Capacitors are especially useful in the filtering of unidirectional current pulses where the load is such that it needs relatively little current. Typical loads of this type would include high resistance relays, vacuum tubes, electrostatic air cleaners, television picture tubes, and similar things.

Section 12. THE FILTER "CHOKE".

Where the load is such that a fairly high current passes through it, the capacitor alone is not usually sufficient. In cases of this kind an inductance coil -- the "choke" coil -- is added in series with the load. The inductance acts somewhat like a flywheel. When the current surges begin, the inductance tends to hold the current back. But as the peak of the surges pass and tend to decrease, the action of the inductance coil is such as to keep the current flowing. Thus the coil has a smoothing effect where the current flow is of some consequence.

A common method of connecting a choke coil into the filter circuit is shown in Fig. 29. Here the capacitor and the choke both work to keep the voltage and current reasonably stable through the load. The capacitor strives to smooth out the voltage peaks, while the choke tries to smooth out the current peaks. Both working together are more effective than either a capacitor or a choke alone.

Such a capacitor might have a capacity ranging anywhere from about 20 mfd. to over 100 mfd., the exact value depending upon the purpose for which the power was being filtered. In small A-C - D-C radio receivers, capacitors of 30 mfd., 40 mfd. and 50 mfd. are quite commonly used.

The choke would normally have an iron core and would have an inductance of from 2 henries to about 10 henries. A very common type filter choke has an inductance of 5 henries. This type filter choke is

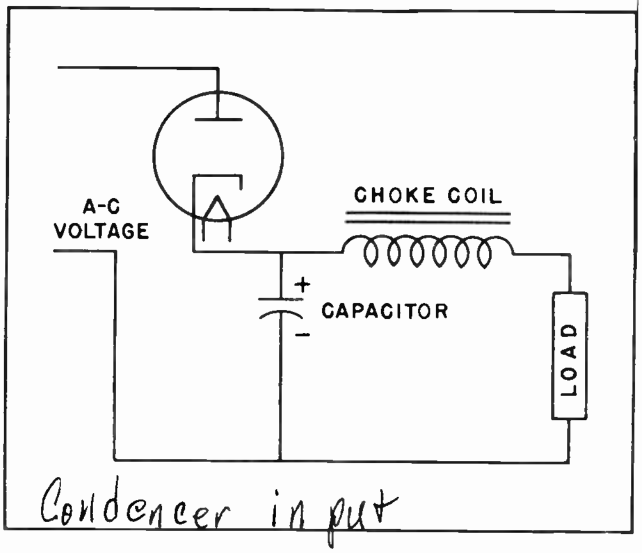

Fig. 29.

used in many radio and television receivers. The physical size of the choke would depend upon the amount of current it would be expected to carry. A small choke for use in circuits where the current drain did not exceed 50 milliamperes would be small enough to fit almost anywhere on a small chassis. None of its external dimensions would likely exceed 1-1/2 inches. Larger chokes for use in transmitters where the current drain reached, or exceeded, 500 milliamperes might be quite large, and very heavy. Such chokes might exceed six or seven inches in each of its dimensions and weigh anywhere from twenty to one hundred pounds, possible more.

Section 13. THE "PI" FILTER

Where even better filtering is desired than can be given by a single choke and a single capacitor it is customary to add another capacitor to the filter network. The second filter is connected in the manner shown in Fig. 30. The name "Pi" filter is given to this network because the normal schematic arrangement of the components is such as to resemble the Greek letter "Pi". This is shown in the small diagram of Fig. 30.

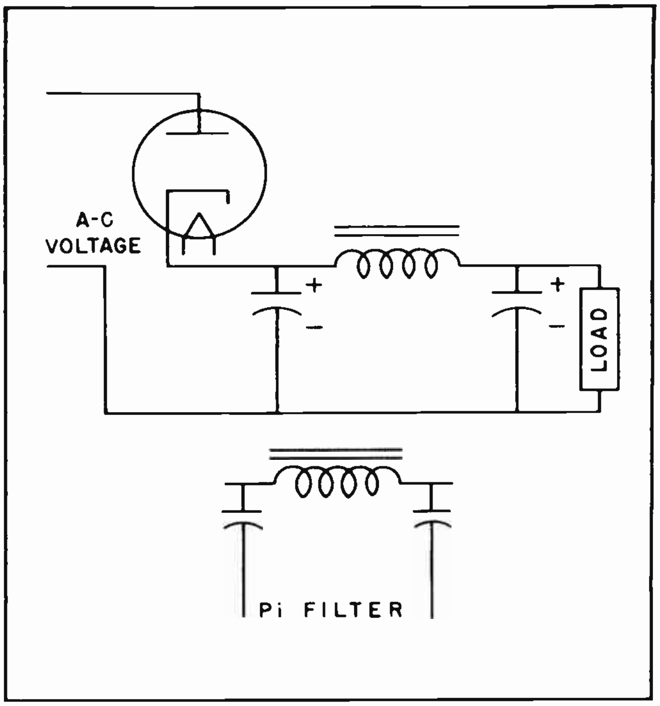

Fig.30. The "Pi" Filter Circuit.

Filter circuits which have the capacitor connected between the choke and the cathode of the tube are called "condenser input" filters. This name is given because the early common name for capacitors was "condenser", and because the first element of the circuit looking from the tube is the capacitor. Thus the name "condenser input". A condenser-input filter has the characteristic of maintaining the voltage of the main load circuit at a high level. The voltage through the load is frequently higher than the effective voltage of the A-C line. Where the current drain is relatively light, such as is common in radio and television receivers, the condenser-input type of filter circuit is most commonly used.

When the filter choke is connected between the capacitor and the cathode of the rectifier tube, as shown in Fig. 31, the circuit is referred to as a "choke-input" filter. This type of filter circuit is used where the current drain of the circuit is relatively high. Such conditions will be found in radio transmitters, some Industrial Electronic circuits, and in high-power public address systems. The output voltage of the choke-input filter circuit is not nearly so high as that of the condenser-input filter, but the voltage will remain much more stable under changing loads. In transmitters where the current drain is relatively high, and the high-power tubes use the power in rapidly fluctuating amounts, the choke-input filter holds the voltage at a much more stable level than would be the case if condenser-input filters were used.

Where the current drain is quite high and it is highly desirable to maintain the voltage at a constant level, it is a common practice to add additional elements to the

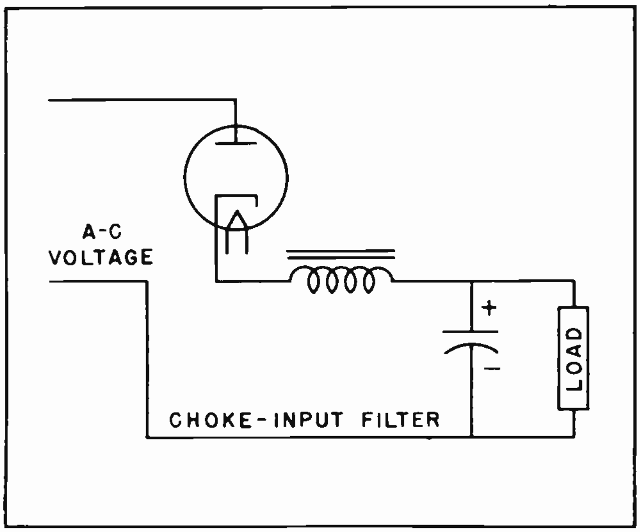

Fig.31.

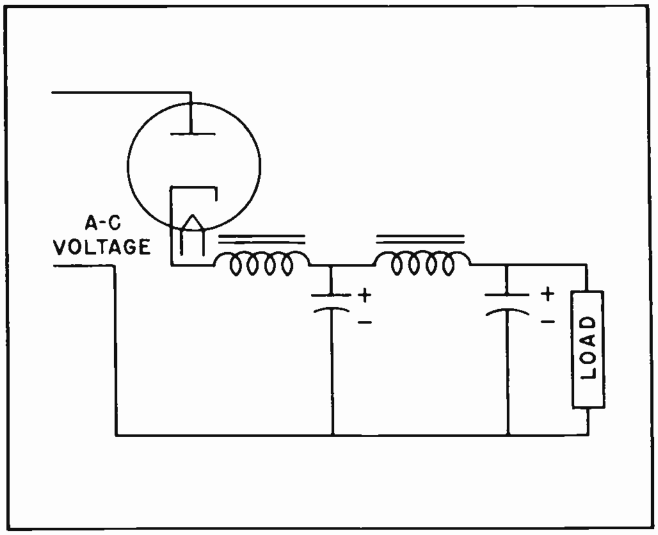

Fig.32.

filter circuit. Fig. 32 shows such a circuit. In this circuit there are two chokes and two capacitors. Such a circuit will handle very heavy demands in the way of fluctuating loads, eliminate all trace of the A-C ripple, and keep the output voltage very steady.

The rectifier circuits we have discussed so far, and their associated filter circuits, are all known as half-wave "rectifiers". A glance back at Fig. 26 will explain where this name comes from -- only one-half of the original A-C 60-cycle power is used. Since the current flows through the tube in spurts -- and no current flows through the tube itself during one-half the time -- relatively large capacitors and chokes are needed to keep the voltage and current smooth. The capacitors and chokes must be large enough to supply power for the load during the half-cycles when the tube is not conducting.

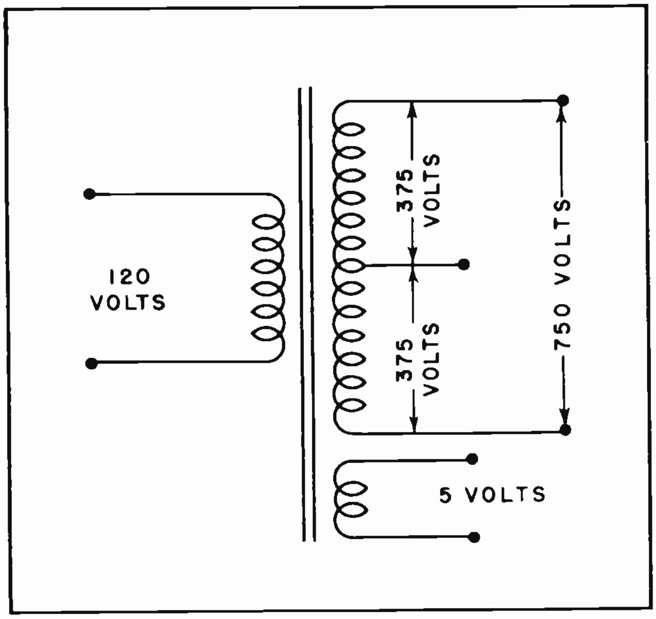

Fig.33.

Section 14. FULL-WAVE RECTIFIERS

The use of half-wave rectifiers is quite common. Nearly all the less expensive A-C - D-C radio and television receivers employ half-wave rectification. Many industrial electronic circuits also use half-wave rectification.

But there are some cases where half-wave rectification is not adequate. Too much power is being wasted. It costs too much to build the filter circuits to smooth out the A-C ripples. In these cases it is better to use "full-wave" rectification, thus using both sides of the A-C wave.

Full-wave rectifiers employ power transformers, the secondary of which is center-tapped. Fig. 33 shows the schematic of such a transformer. The primary is designed to be connected directly to the regular 120-volt, 60-cycle A-C power commonly found in most homes. The main secondary winding is such that the voltage between the two ends of the winding will be from about 600 volts to about 900 volts, although in some cases the voltage may be higher or lower. The transformer diagrammed in Fig. 33 has 750 volts between the two ends of the main winding. This winding is tapped in the exact center so there are 375 volts between the center tap and each of the two ends. The other secondary winding supplies the filament voltage for heating the cathodes of the rectifier tubes.

In Fig. 34 we show how one tube is connected into the rectifier circuit. During the instant in which the polarities are as shown, the tube in the circuit will conduct. In this respect the circuit is not greatly different from a half-wave rectifier. Note the arrows which show the current movement during this particular half-cycle. Note how similar the current flow is to that in a half-wave rectifier. The positive side of the load and filter circuit is connected to the rectifier filament circuit. Since the filament circuit is also the cathode circuit, this is the same as making the connection directly to the cathode. With this exception the circuit is almost identical, so far, to that of a half-wave rectifier.

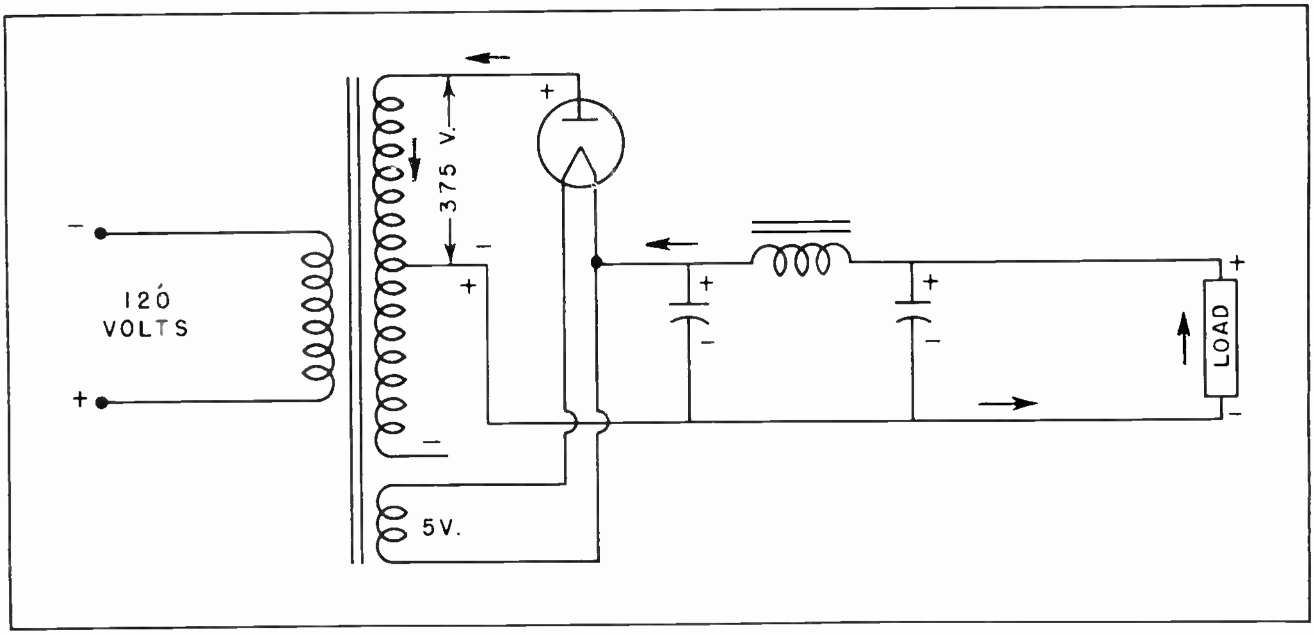

Fig.34. Full-Wave Rectifier During the Positive Half-Cycle.

Now let's see what happens during the next half-cycle. Fig. 35 shows the polarities reversed from the situation in Fig. 34. Now the bottom end of the high-voltage winding on the power transformer is positive. This means the top end is negative. Since this would put a negative voltage on the anode of the diode tube shown in Fig. 34, that tube could not now conduct.

But in Fig. 35 we have added another tube to the rectifier circuit. The anode of this second tube is connected to the bottom end of the high-voltage winding on the transformer. This means this second tube is now in position to conduct and will attract electrons from the cathode. Since the cathode of this tube is also the filament, and the filament of this tube is connected to the filament of the first tube, this all means that any electrons attracted from the cathode must also be brought in through the filter circuit. There is no place else for them to come from.

The fact that the low-voltage winding which supplies heating current to the filaments is also connected to the cathodes of

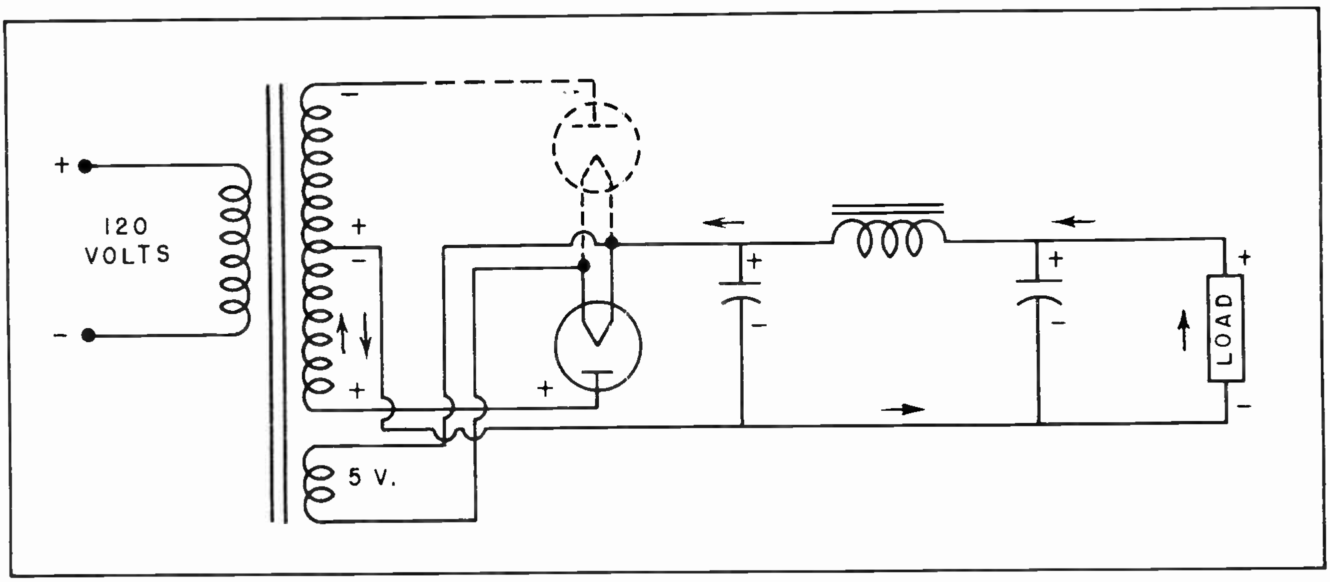

Fig.35. Full-Wave Rectifier During Opposite Half-Cycle.

the two tubes, is only incidental. No electrons can be attracted from that circuit -- it is a closed circuit and has only the *ONE* connection with the filter circuit, the load, and the high-voltage winding.

We now have a situation where electrons will be attracted through the filter circuit to the cathode of the top tube, and from there to the anode of the top tube when the respective polarities are as shown in Fig. 34. Then during the next half-cycle when the polarities are reversed, the electrons will be attracted through the same filter circuit to the cathode of the bottom tube, and from there to the anode of the bottom tube when the polarities are as shown in Fig. 35. Thus it makes no difference which end of the high-voltage winding is positive; it will attract electrons to the anode of one tube or the other. Furthermore, it makes no difference which tube is conducting; its cathode must obtain its electrons from the filter circuit, which in turn draws the electron current through the load. Now we have a circuit which makes use of both sides of the A-C sine wave.

It will be noted that the negative side of the filter circuit returns to the center tap on the high-voltage winding. A careful study will show that regardless of which tube is conducting, the center tap on the transformer will be negative with respect to the anode of that tube. For example, in Fig. 34 the anode of the top tube is positive. But the center tap is negative with respect to the anode of that tube. In Fig. 35 the bottom tube is conducting and its anode is positive. At this instant, the center tap is negative with respect to the anode of that tube.

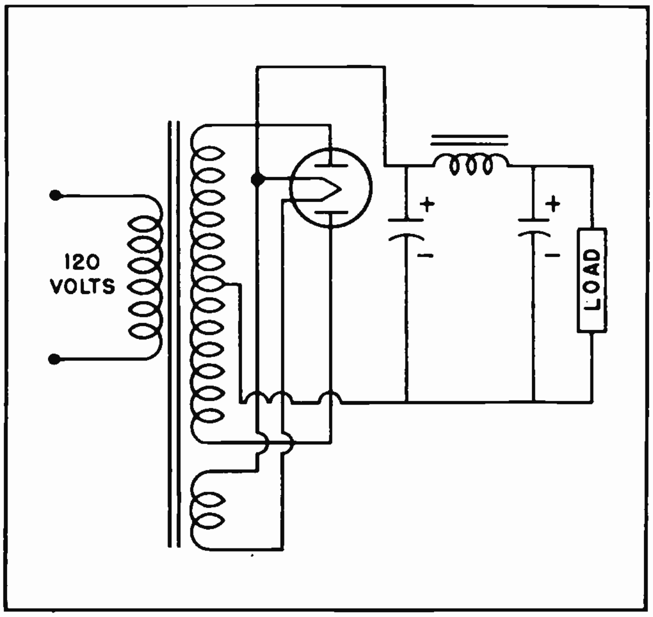

Fig.36. Full-Wave Rectifier Using a Duodiode Tube.

Section 15. THE DUODIODE

In our description of the operation of the full-wave rectifier we have shown the operation with two tubes. Two tubes are actually used in many cases such as transmitters, and heavy-duty public address systems. But vacuum tube manufacturers have designed special tubes which actually combine two tubes into one glass envelope, and thus perform the same function as two entirely separate tubes.

Fig. 36 shows such a tube, known as the *duodiode*, connected into a full-wave rectifier circuit. The filament acts as the cathode for both sides of the tube. There are two anodes. They are alternately positive; thus one is conducting while the other is at a negative potential. This situation reverses itself 120 times a second on 60-cycle A-C voltage. The tube is thus able to perform the same function as two separate diode tubes. It makes no difference which anode is positive, it will attract electrons from the same cathode. And since the cathode is connected directly to the filter circuit, it will maintain a constant voltage across the filter circuit and the load.

No attempt has been made while describing the rectifier circuits to explain the type of load which might be connected to a rectifier circuit. Actually we are not particularly concerned at this time what the load actually is. It might be a small motor, or an electric light or some other similar electrical device. More than likely, however, the load on such a rectifier circuit will be the anodes of vacuum amplifier tubes. The current through such tubes would be very small, on the order of about 2 to 10 milliamperes each. Since the ordinary rectifier tube is capable of passing from 50 milliamperes to more than 100 milliamperes, it can be seen that such a rectifier system can supply power to a large number of amplifier tubes.

Probably the oldest, and most common, example of a duodiode such as is diagrammed in Fig. 36 would be the type 80. Other tubes similar to the 80 are the 5Z3, 5Y3, 5U4 and several others. When you encounter any of the above named tubes in an electronic device, you will know it is a rectifier tube. Usually the rectifier tube is somewhat larger than the other tubes. However, this is not always the case. Reference to a standard tube manual will quickly tell you whether a certain tube is a rectifier tube or not.

Section 16. FILTER CAPACITORS

The capacity of the capacitors used with full-wave rectifiers can be much lower than those used with half-wave rectifiers. There are two reasons for this. The ripple frequency of full-wave rectifiers is 120 cycles per second whereas the ripple frequency of the half-wave rectifier is only 60 cycles per second. This is assuming the line frequency is the common 60-cycle power normally supplied to most homes. The other reason is that there are no wide gaps in the current and voltage surges as shown in the lower part of Fig. 26. The half-wave voltage and current surges are also shown at the top of Fig. 37. The lower part of that illustration shows how the gaps between the positive peaks are filled in by the other half of the sine wave.

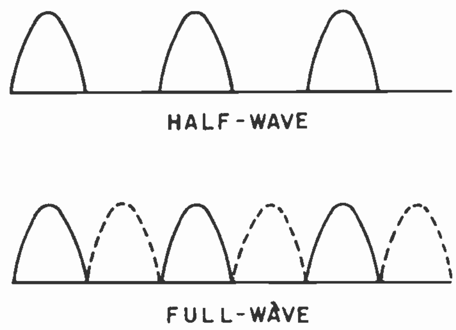

Fig.37. Ripple Frequency of Half-Wave and Full-Wave Rectifiers.

The capacitors used in the filter circuit of most full-wave rectifiers usually have a capacity of about 8 mfd. to 12 mfd., although some capacitors a little larger can be found in some electronic devices. Practically all capacitors used in filter circuits are of the electrolytic type. These capacitors are polarized and it is necessary to exercise care to see that the polarities are observed when installing them in a circuit.

NOTES FOR REFERENCE

The diode is the most simple type of tube, and is probably the most common.

An important use for diode tubes is found in the rectifier circuits of various electronic devices.

A duodiode is actually two diodes in one glass envelope. They are very common.

"Temperature saturation" refers to the condition in which increased temperature of the cathode does not result in any increased anode current.

"Voltage saturation" refers to a condition where increased anode voltage does not result in increased anode current.

The "A" battery is used to heat the filaments of a vacuum tube.

The "B" battery is used to supply anode voltage to a vacuum tube.

Rectifiers are used to change alternating current into direct current.

Unidirectional current is current which is flowing in only one direction, but is not necessarily a continuous current flow.

A half-wave rectifier is one which passes only one side of the voltage wave into the filter circuit.

A full-wave rectifier is one which utilizes both sides of the A-C voltage wave.

Electrolytic capacitors are used almost exclusively in the filter circuits of rectifiers.

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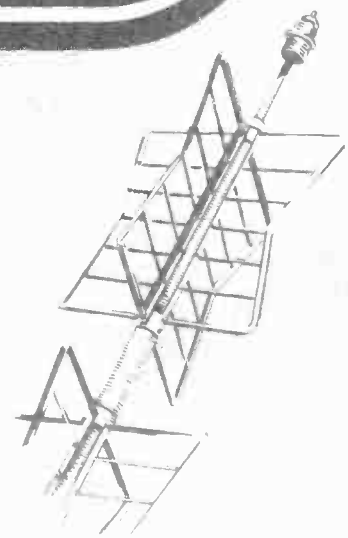

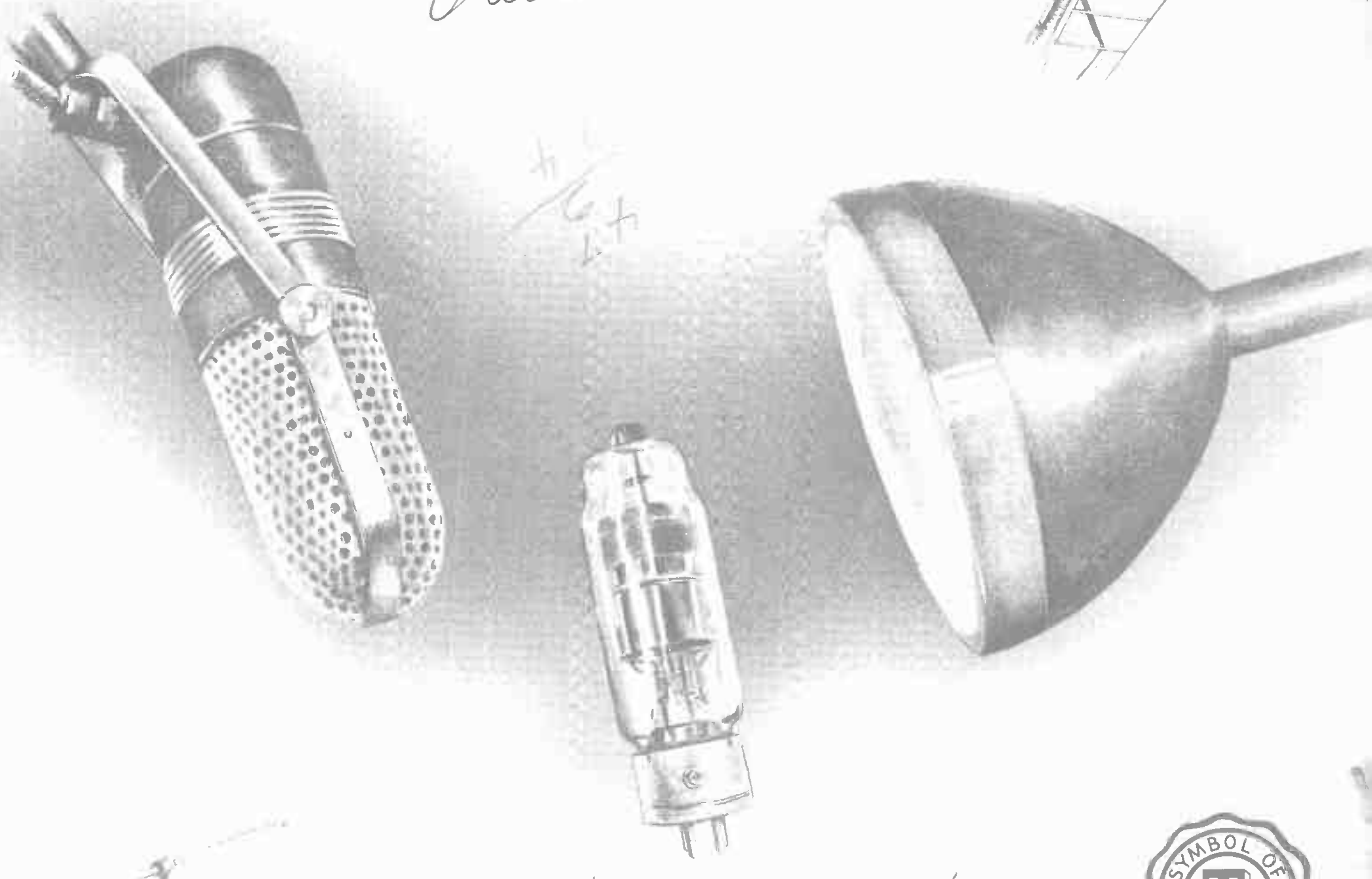

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VACUUM TRIODES

Contents: Introduction - The Grid - Triode Symbols - Action of the Grid - Effect of Anode Potential on Anode Current with "Zero" Grid - Effect of Anode Potential on Anode Current with Negative Grid - Putting the Graph to Use - Families of Curves - The Triode as an Amplifier - Tube Conditions Which Affect Amplification Factor - Names of Tube Voltages and Currents - Notes for Reference.

Section 1. INTRODUCTION

The perfection of the diode vacuum tube in the form of the original "Fleming Valve" opened up the electronic age. Although its first introduction to the scientific world created no great enthusiasm at the time, it is now hard for us to recall any other invention which has wrought so many changes in the lives of men.

But the diode tube had, and still has, many limitations. It is a perfect rectifier. And as such it has many uses, but the diode alone is relatively insignificant when its accomplishments are placed alongside those of the three-element tube, the *triode.*

The triode receives its name from two Greek words which mean "three" and "path". Literally, a triode tube is one which employs three elements in its operation. Two of them are identical with those we find in the diode -- the cathode and the anode. The triode tube has a cathode identical in most respects with the ones we find in the diode tubes. Some of the cathodes are directly heated, just as they are in the diodes, while others are indirectly heated.

In the same manner the anode is also quite similar. In some respects the anode in a triode may be somewhat different in its physical aspects from ones generally found in diode tubes, yet at the same time they are not significantly different. Because some diode tubes are called upon to pass larger amounts of current than triodes their anodes and cathodes may be somewhat larger. But in most essential respects the elements in a triode are patterned very closely after those to be found in diodes.

It remained for Dr. Lee DeForest to introduce a third element into vacuum tubes, and in so doing to open up entirely new possibilities for their use. Dr. DeForest is almost universally proclaimed the "Father of Radio". This title is well deserved. The third element he introduced into the vacuum tube literally opened up new worlds of opportunity

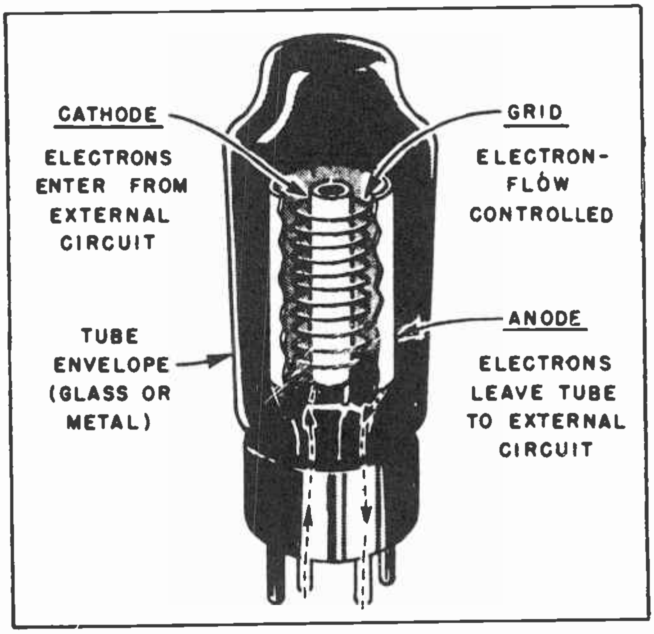

Fig. 1. The essential parts of a triode tube.

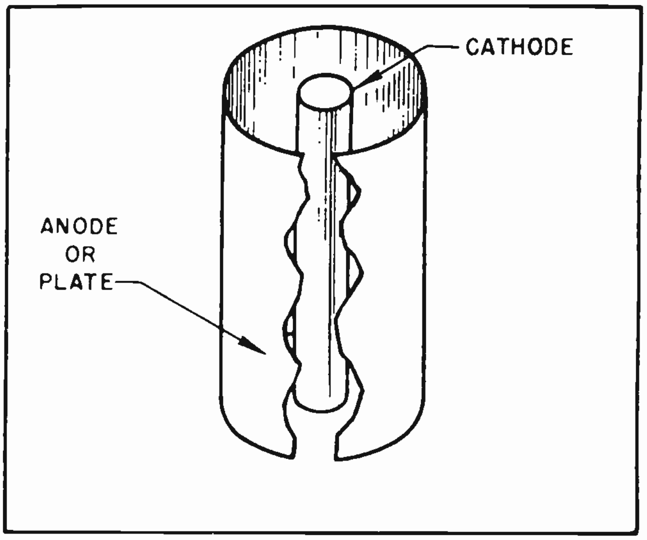

Fig.2. The anode and cathode of a triode tube.

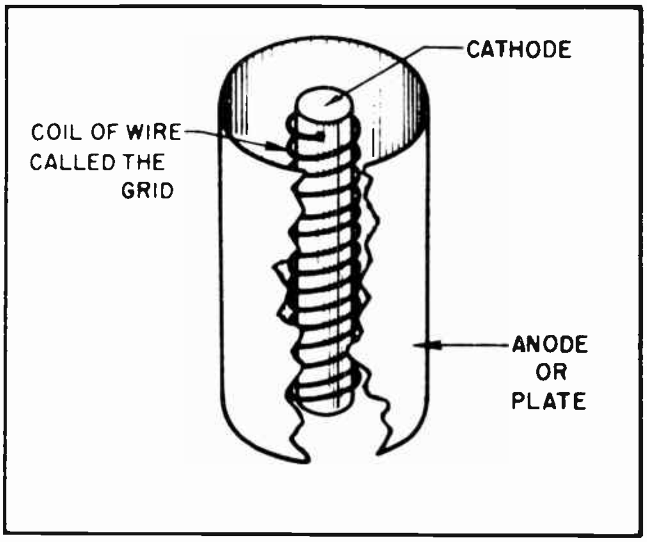

Fig.3. How the grid is located within a triode tube.

in the realm of electricity, electronics and science. Practically every advance in the field of electronics during the past half century has been made possible as a result of Dr. DeForest's pioneering work.

Section 2. THE GRID

The anode and the cathode are arranged in a triode very much the same way they are in a diode. The basic arrangement is shown in Fig. 2. There the cylindrical cathode is placed inside the larger cylinder of the anode. The illustration is that of an indirectly heated cathode. The heaters would be placed inside the cathode in the same manner as the heaters of an indirectly heated diode tube.

The third element in a triode tube, the one first introduced by Dr. DeForest, is the *grid*. In appearance the grid is a most insignificant looking piece of apparatus. It is nothing more than a piece of wire coiled around the cathode. (See Fig. 3.) It is so anchored, however, that it touches neither the cathode nor the anode. Should it touch either the cathode or the anode it would lose its effectiveness.

To make the grid appear less significant, it is not even connected to an electrical circuit at one end. In fact it is merely a piece of wire which comes up from the base of the tube, makes several turns around the cathode, then stops. From the conventional electrical standpoint it would appear to be of no use since it fails to make a complete circuit.

In order to understand just what the grid does inside the tube we will review very briefly the action of a diode. Fig. 4 shows an exaggerated view of a heated cathode from which electrons are being emitted. The electrons, being particles of negative electricity, are attracted to the positive anode. While only a few electrons are shown being emitted from the cathode, actually billions of them are emitted each second,

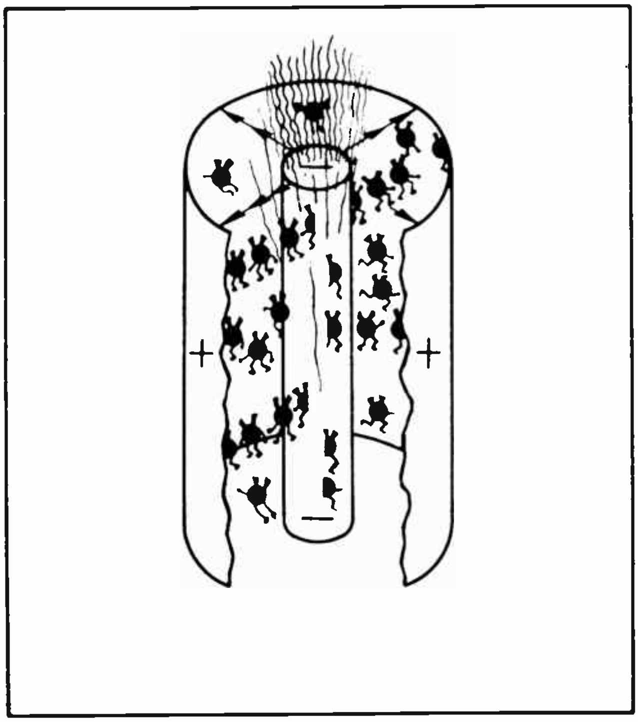

Fig.4.

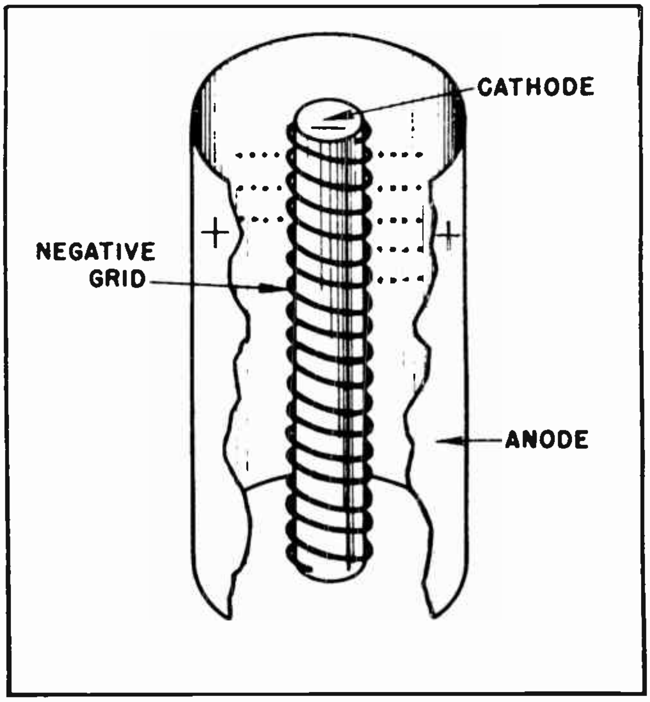

Fig. 5.

and then move through the space inside the tube to the anode.

In Fig. 5 we have the same cathode and the same anode. But in addition to these we have the coils of wire which compose the grid. The grid encircles the cathode in such a manner as to partially screen the cathode from the anode. It erects a sort of fence, so to speak.

So long as the grid remains electrically neutral, it will have no appreciable effect upon the passage of electrons from the cathode to the anode. The electrons will have no particular difficulty in passing through the gaps between the encircling coils of the wire.

But, if a negative voltage is placed upon the wire of the grid the newly acquired negativeness of the grid will tend to repel the electrons. The electrons will be repelled and prevented from coming close to the grid wire.

If the negative voltage is not too high, some of the electrons will still be able to pass through the spaces between the wires at points furthest from each coil of wire as shown in Fig. 5. This will mean that midway between each turn of the grid a few electrons will be able to break through and reach the anode. But the majority of the electrons will be unable to get through and will thus be forced to remain in the vicinity of the cathode. This means that when there is a negative voltage on the grid of a triode tube there will be far less electrons reach the anode than would be the case in a diode tube where there was no grid.

It should be noted that a current does not need to flow through the grid in order for it to repel the electrons. Merely the presence of a negative voltage is sufficient to hold up the passage of electrons through the spaces between its coils.

Section 3. TRIODE SYMBOLS

Just as is the case with other electrical and electronic components it has become the general practice to represent the elements of a triode vacuum tube by means of a symbol. Such symbol is commonly used on schematic diagrams and other places where it is necessary to designate the presence in a circuit of such a tube. The symbol shown in Fig. 6 is the one that has been used for many years to represent a vacuum triode tube. All the elements inside the tube are represented: the anode, the grid, the cathode and the heaters.

Very often it is convenient to omit the heaters from schematic diagrams. All persons who use such diagrams recognize the fact that heaters are necessary to keep the cathode hot. And since the presence of the wires leading to the heaters often tend to confuse an already complicated drawing it is a frequent practice to leave the heater symbols out of the tube symbols.

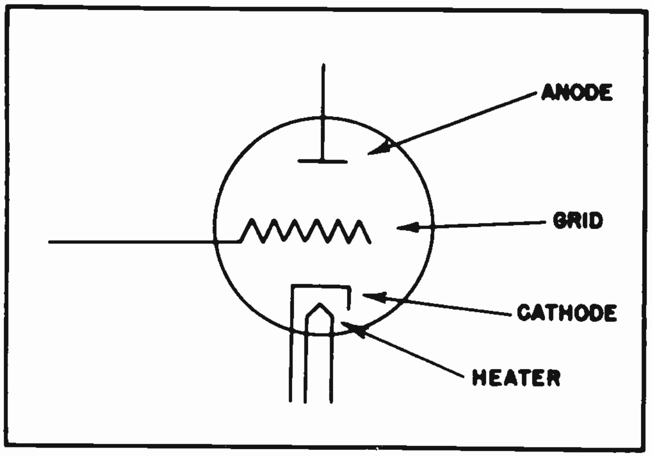

Fig. 6. Symbol of a vacuum triode showing the heaters.

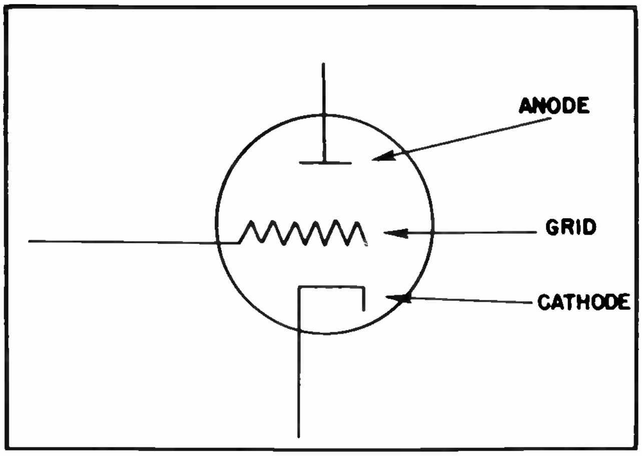

Fig.7. Symbol of a vacuum tube with the heater symbols omitted.

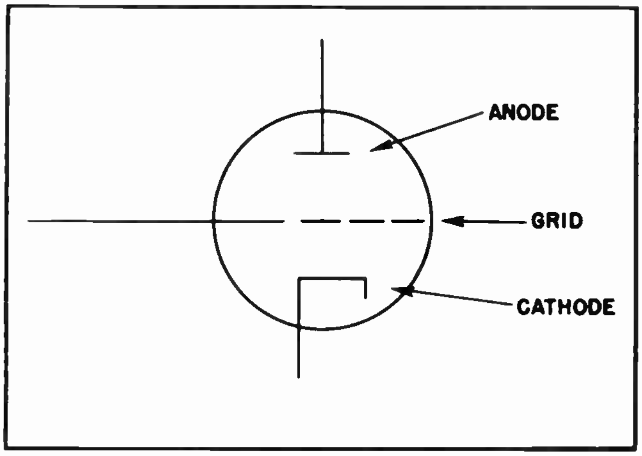

Fig.8. The newer symbol for a vacuum triode.

When that is done the triode tube symbols would be drawn as shown in Fig. 7.

The symbols shown in Figs. 6 and 7 are the ones which have been used for many years in radio and television work. However, that symbol has one drawback. It is somewhat hard to draw. It is hard to keep the zigzag lines of the grid even and symmetrical, and slows down the work of the draftsman in the engineering drafting rooms. To overcome that difficulty a slight modification of the symbol has been coming into use during recent years. This is particularly true with respect to Industrial electronic circuits, but the practice is also catching on in radio and television work. The newer symbol is drawn as shown in Fig. 8. It will be noted that there is no change so far as the cathode and the anode are concerned. But instead of the grid being drawn in a zigzag fashion as in Fig. 6 it consists of several dashes. Since this symbol has such an obvious advantage over the older one it will probably eventually replace the older one entirely. However, since both symbols are widely used at the present time we will use both of them in these lessons so you will become thoroughly familiar with them both.

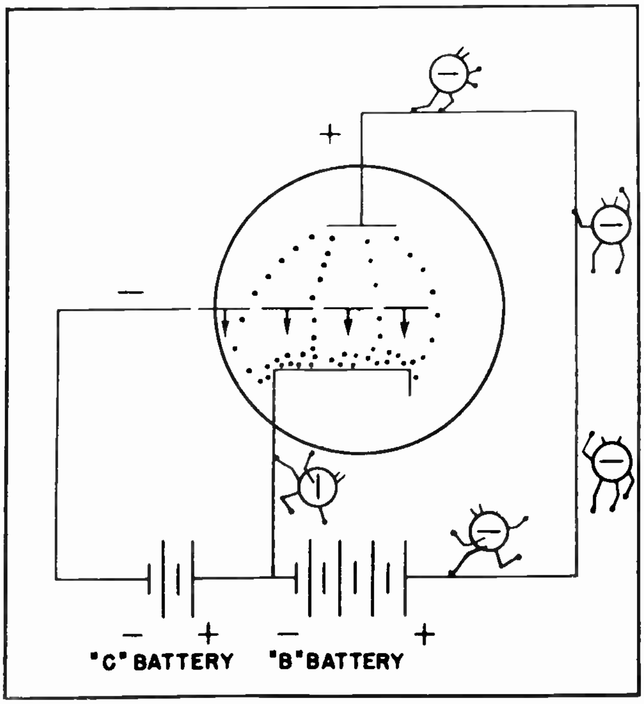

Fig.9. Effect of the grid on the movement of electrons.

Section 4. ACTION OF THE GRID

As we mentioned before, the mere presence of the grid wire in the tube has little or no effect on the passage of electrons so long as the voltage on the grid is the same as that of the cathode. But suppose, as in Fig. 9, a battery is connected between the grid and the cathode in such a manner as to place a negative voltage on the grid. When this occurs the wire of the grid itself will become negative, and when this happens an electrostatic field will be set up between the grid and the cathode. The electrostatic field will be such as to tend to repel the movement of electrons from the cathode toward the grid, and through the meshes of the grid to the anode.

If the voltage is not too high some of the electrons will be able to move through the spaces between the grid wires as shown in Fig. 9. After they pass through the grid they will come even more strongly under the influence of the anode and will be attracted to it. But it should be noted that a negative voltage on the grid reduces very materially the movement of electrons from the cathode to the anode.

On the other hand if the grid is made slightly more positive than the cathode it tends to boost the flow of electrons from the cathode to the anode. Fig. 10 shows the effect on electron flow of both a negative voltage on the grid and that of a positive voltage. The negative voltage at *A* radically reduces the flow of electrons, while the presence of the positive voltage at *B* materially aids the flow of electrons.

Section 5. EFFECT OF ANODE POTENTIAL ON ANODE CURRENT WITH "ZERO" GRID

Since it is possible to control the flow of electrons through a vacuum triode by adjusting the voltage on the grid of the tube we find many new possibilities opened up for us. In order to learn just what some of these possibilities are, suppose we conduct a few experiments. In these experiments we will study the effect upon the flow of anode current by placing a variety of voltages on the grid and on the anode of the tube.

In our first series of tests we will keep the grid voltage at what we call "zero potential". What this means is that the grid will be maintained at the same voltage as the cathode. You will recall that we have already mentioned that the voltages on all the elements of a vacuum tube are measured with respect to the voltage on the cathode. Since in this case the grid is going to be connected directly to the cathode it is rather obvious that the voltages on these two elements are going to be the same. When this condition exists it is the common practice to say the grid is at "zero potential", or is a "zero grid".

In much the same way we experimented with the diode, we will now place a milliammeter in the anode circuit of the tube. This will enable us to read the amount of current which flows in the anode circuit. Likewise, we will place a voltmeter so as to read the voltage which is caused to exist between the cathode and the anode. The various connections in the test circuit would be as shown in Fig. 11.

It will be noted that the battery is tapped so that only 10 volts are placed on the anode of the tube. These are positive volts -- 10 positive volts. As the result of these 10 volts on the anode electrons are attracted to it in sufficient quantity to cause 5 milliamperes of current to flow in the external anode circuit. The 10 volts are shown registered on the voltmeter and the 5 MA of current is shown on the milliammeter. Note particularly that the grid of the tube is connected directly to the cathode so that the voltage on the grid must be the same as that on the cathode.

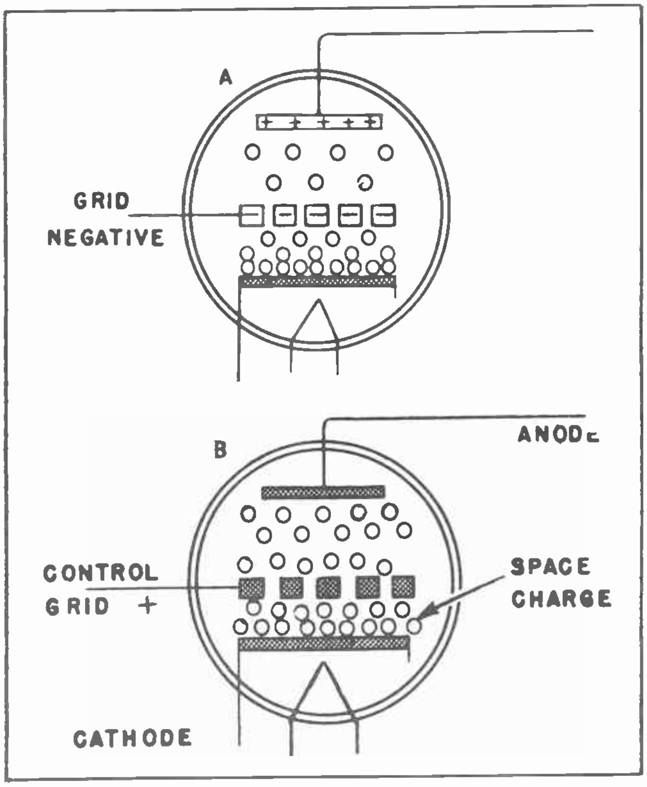

Fig. 10. The differing effects of a positive and a negative voltage on the grid.

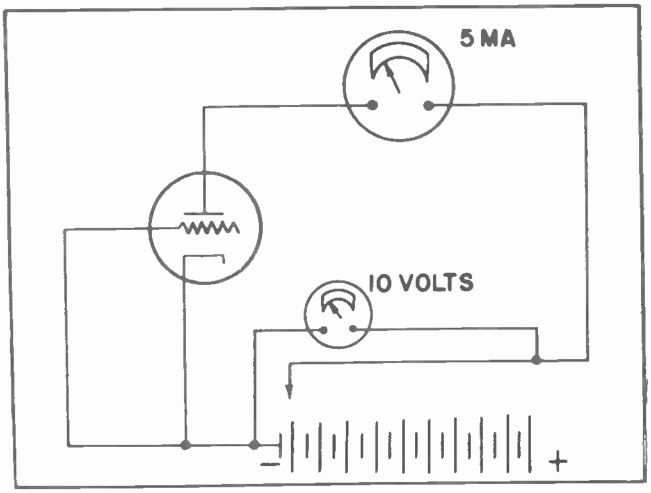

Fig. 11.

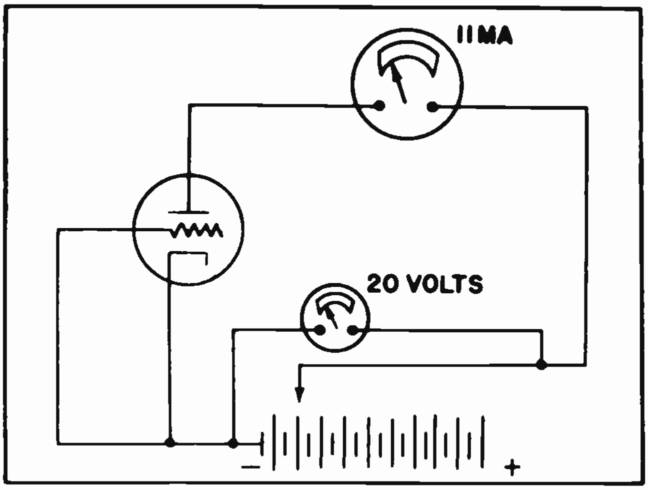

Fig. 12

In Fig. 12 the grid is also connected directly to the cathode. But in this illustration we find the voltage tap on the battery has been moved so that 20 volts are now placed on the anode. The milliammeter tells us that the 20 positive volts on the anode now cause 11 MA of current to flow in the anode circuit.

In order to keep track of the various currents which are caused to flow by the various voltages which are placed on the anode of the tube, suppose we set up a chart as shown in Fig. 13. Taking the reading we obtained in Fig. 11 we will move along the bottom of the chart until we find a vertical line which represents 10 anode volts. Then we will move up this vertical line until we find a horizontal line which corresponds to 5 milliamperes. There we will place a dot. This will represent the voltage and current in Fig. 11. For your convenience we have already placed a dot there for you. Now we record the readings we obtained from the meters in Fig. 12. Again we will move along the bottom line until we find a vertical line which represents 20 volts. Then we will go up the vertical line until we find a horizontal line which represents 11 milliamperes. There we will place another dot. Again we have placed the dot there for your convenience.

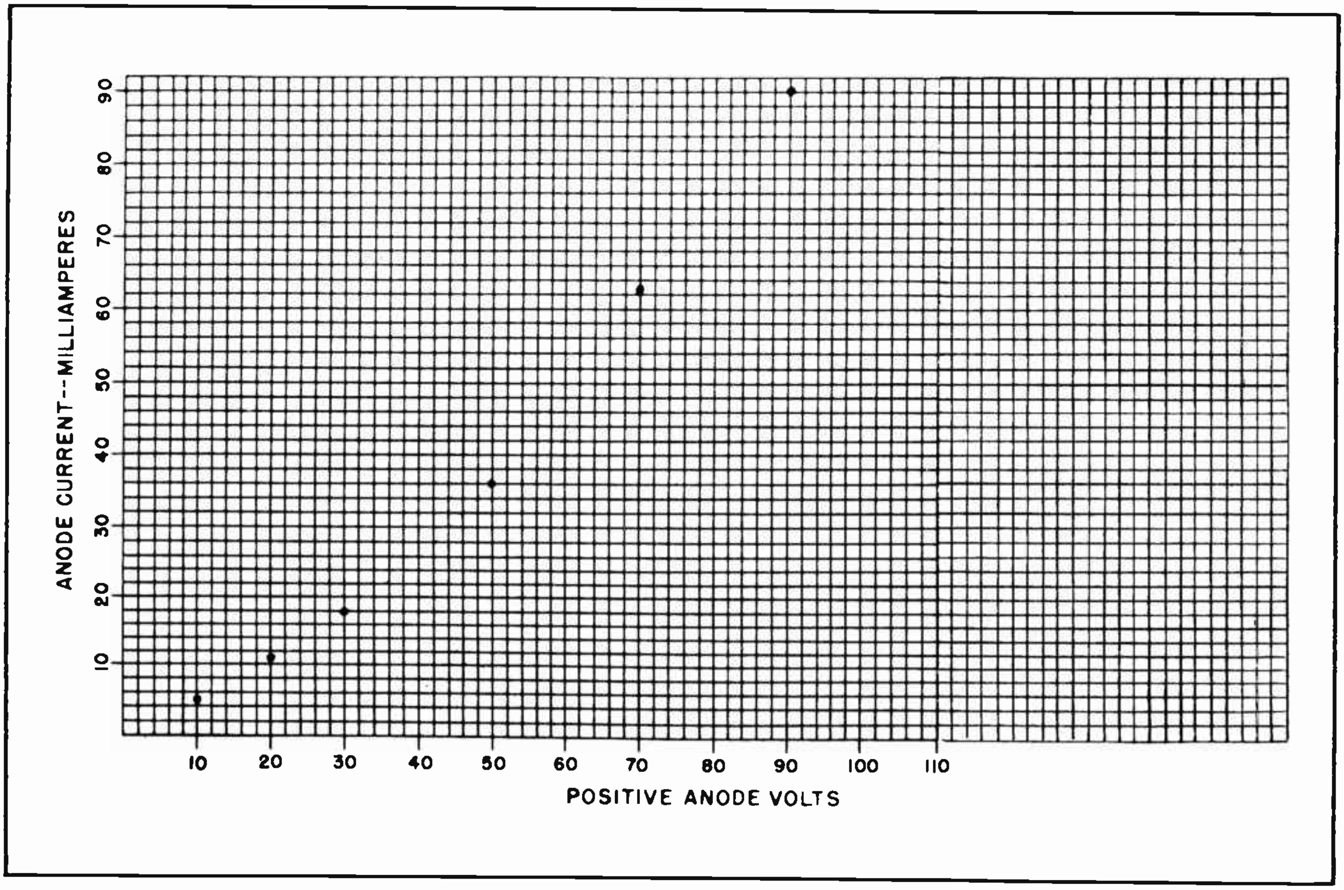

Fig. 13. Locating "coordinate points" on graph paper to represent current which flows as the result of variously applied anode voltages.

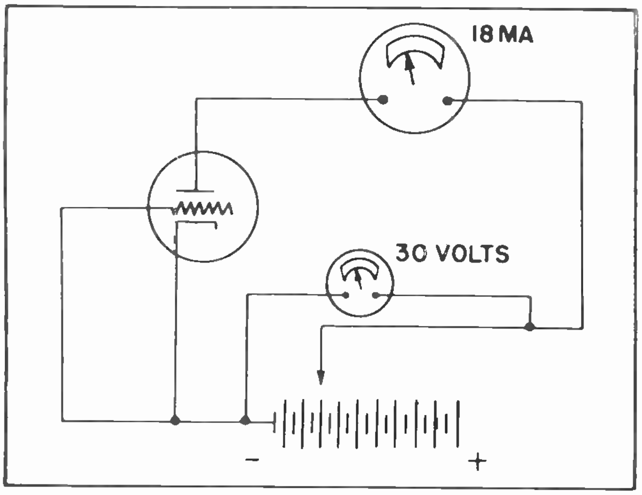

Fig. 14.

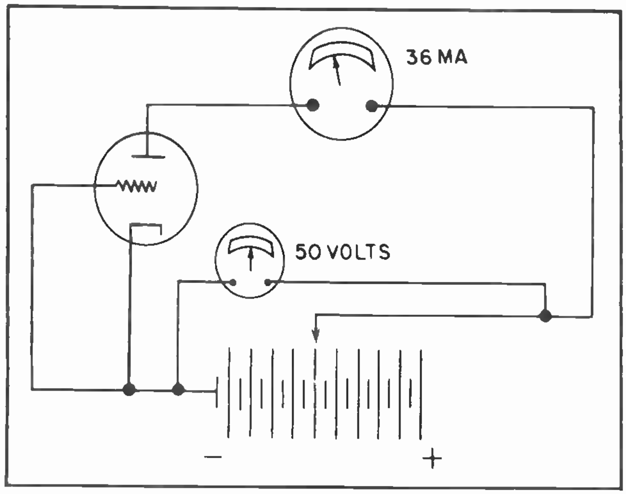

Fig. 15.

Now let's look at Fig. 14. Here we find the tap on the battery has been changed again, so voltage on the anode has been raised to 30 volts. The milliammeter tells us the 30 anode volts cause 18 milliamperes of current to flow in the anode circuit.

We will again record these results on our chart. We will find the "coordinate" point which is represented by the 30 anode volts and the 18 milliamperes of current. To find that "coordinate" point we locate the vertical line which represents the 30 volts, then move up that line until we come to the horizontal line for 18 milliamperes. There we will place another dot. And again we have marked the location so as to assist you in this first experiment. (See Fig. 13.)

Now we will go on to Fig. 15. In this illustration we have jumped the anode voltage from 30 volts to 50 volts. When this is done we find that the milliammeter reads 36 milliamperes. The next step is to find the "coordinate" point on our chart in Fig. 13, which represents both 50 volts and 36 milliamperes. If you find the point where the vertical line for 50 volts crosses the horizontal line for 36 milliamperes you will find that we have again placed a dot there so you can check the accuracy of your own attempt to locate that "coordinate" point.

In Fig. 16 we have jumped the anode voltage from 50 volts to 70 volts. When we do so we find the anode current rises to 63 milliamperes. You should now locate the coordinate point of 70 volts and 63 milliamperes. If you locate the correct spot you will find we have placed another dot there. (See Fig. 13.)

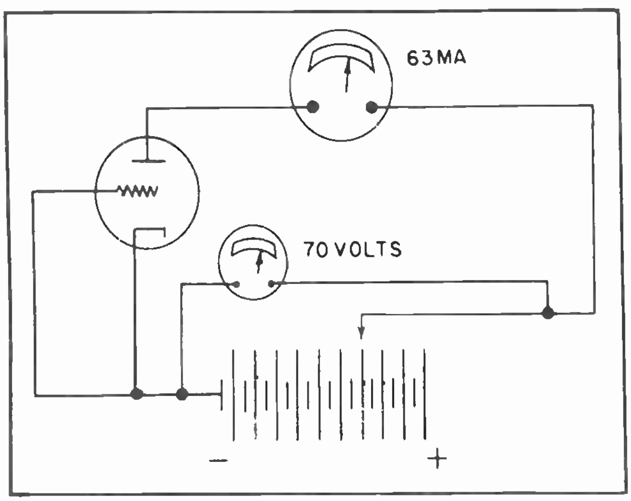

Fig. 16.

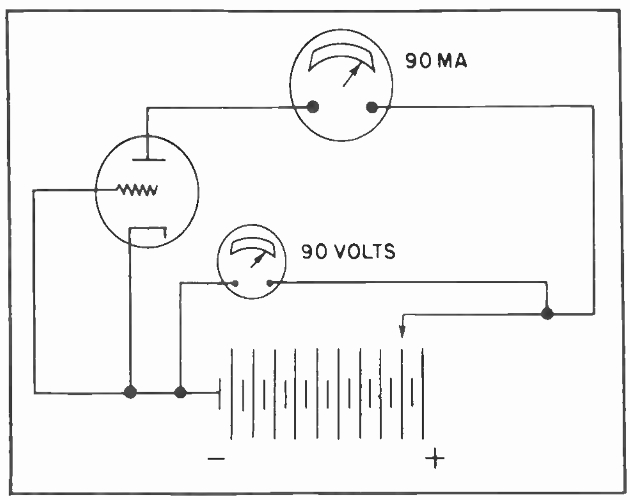

Fig. 17.

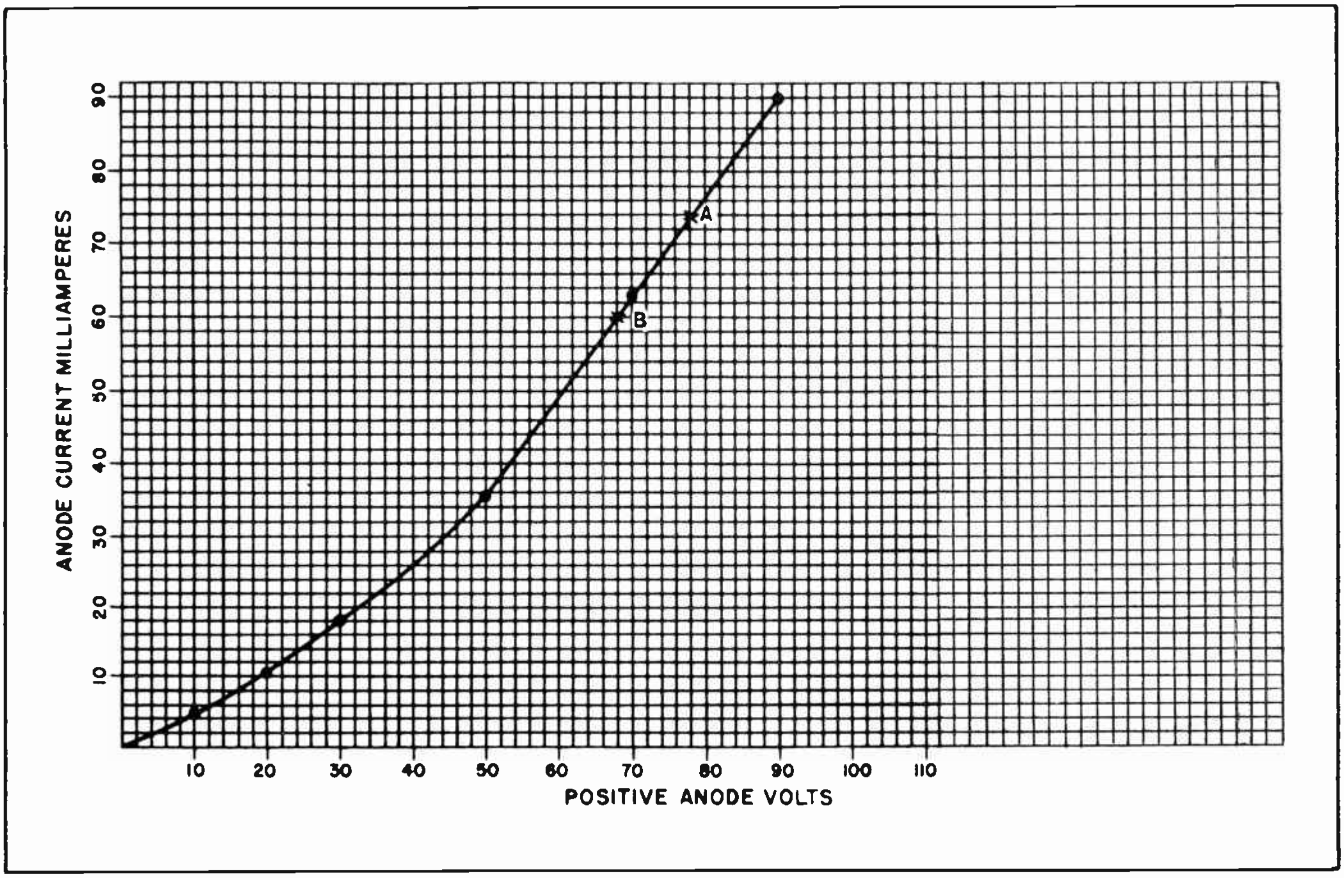

Fig. 18. A plotted graph showing anode current flow against anode voltage.

For our final experiment we will raise the anode voltage to 90 volts. When we do so the anode current will rise to 90 milliamperes. This is shown by the meter readings in Fig. 17. Again we have placed a dot on the chart of Fig. 13 which represents 90 anode volts and 90 milliamperes of anode current.

If this same series of experiments are carried out with the same tube each value of anode voltage should cause the same amount of anode current to flow as is shown by the chart. The chart can be made even more useful. If the dots on the chart in Fig. 13 are connected together with a smooth curving line as shown in Fig. 18 we can readily find the amount of current which would flow for any value of voltage we might wish to place on the anode. Thus we could determine ahead of time what the tube would do.

For example, suppose we wanted to know how much anode current would flow if we placed 78 volts on the anode. We could quickly learn this information without going to the trouble of actually connecting up the experiment. All we would have to do is locate the vertical line representing 78 volts. Then we would move up that line until we crossed the curving "characteristic curve". The point where the anode voltage line crosses the "characteristic curve" also represents the amount of current which would flow in the anode circuit as the result of placing 78 volts on the anode. The exact amount can be determined by following the line to the left to the milliampere scale. We then find the amount of current which would flow as the result of 78 volts on the anode, would be 74 milliamperes.

The point where the 78 volt vertical line crosses the characteristic curve is marked by a small "x" and the letter *A*. The point "A" in other words, marks the spot where the anode voltage line for 78 volts, the anode current line for 74 milliamperes, and the characteristic curve all come together.

The chart is equally useful to us in another way. Suppose we need 60 milliamperes of current in the anode circuit for some reason. It might be that we have a relay coil in the anode circuit which needs 60 milliamperes in order for it to "pull in".

Or, it might be that 60 milliamperes is the maximum amount of current it is permissible to allow to flow through the coil of a loud speaker. Or, it might be any number of other things. If we wanted to know how many volts were needed to cause 60 milliamperes of current to flow in the anode circuit we would locate 60 milliamperes on the horizontal milliampere scale. Then we would move to the right on the horizontal line which represents 60 MA until we come to the characteristic curve. This point is marked with another small "x" and the letter *B*. From this point we go downward in a vertical direction until we come to the voltage scale. When we do this we find that 60 milliamperes of anode current requires 68 volts on the anode.

Section 6. EFFECT OF ANODE POTENTIAL ON ANODE CURRENT WITH NEGATIVE GRID

In the series of experiments just concluded the grid of the triode was kept at zero voltage. The result was not greatly different than would have occurred had the tube been a diode rather than a triode. But suppose the grid had been somewhat negative. Then the results would have been materially different.

Suppose we take the same tube and by means of a battery place a negative voltage of 5 volts on the grid. The battery which is used to place negative voltages on the grid of a vacuum tube is called a "C" battery. This is to distinguish the grid battery from the "A" battery used to heat the filaments and the "B" battery which is used to supply voltage to the anode.

Suppose we start off our experiment in much the same way we did with the zero grid in Fig. 11. In Fig. 11 with a zero grid and 10 volts on the anode we obtained a current in the anode circuit of 5 milliamperes. But with 5 negative volts on the grid we find that by putting 10 positive volts on the anode in Fig. 19 we are unable to obtain any anode current at all.

Suppose we raise the anode voltage another 10 volts to 20 positive volts as in Fig. 20. We find here that even 20 positive volts are not enough to cause any anode current to flow.

We will raise the anode voltage another 10 volts and place 30 positive volts on the anode as in Fig. 21. We now have some anode current, but it is very small. Instead of the 18 milliamperes of current we had when we placed 30 volts on the anode with a negative grid in Fig. 14, we now have only 2 milliamperes at 30 anode volts and 5 negative volts on the grid.

Suppose we keep a record of the current which flows in the anode circuit when various anode voltages are applied. In this series of experiments we will keep the grid voltage at 5 negative volts in each of the experiments. We will prepare a chart in Fig. 22 in exactly the same manner as the one we had in Fig. 13. In Fig. 21 we find that we obtain 2 milliamperes of current with 30 positive volts on the anode. In order to mark this on the chart we will locate the vertical line which represents 30 volts, then move up that vertical line until we locate the horizontal line which represents 2 milliamperes.

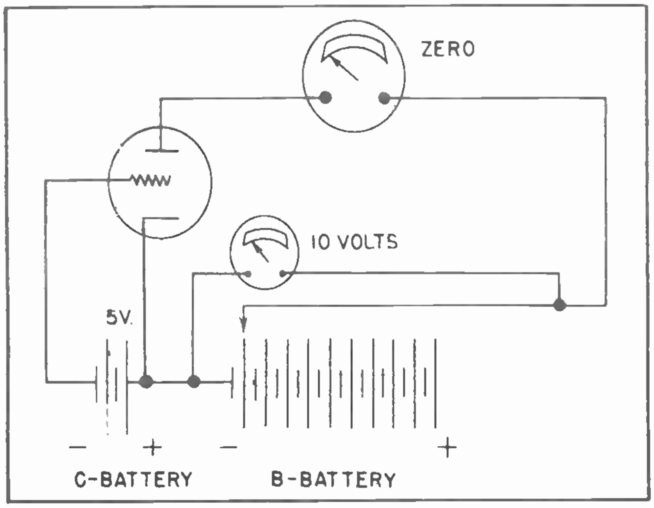

Fig.19.

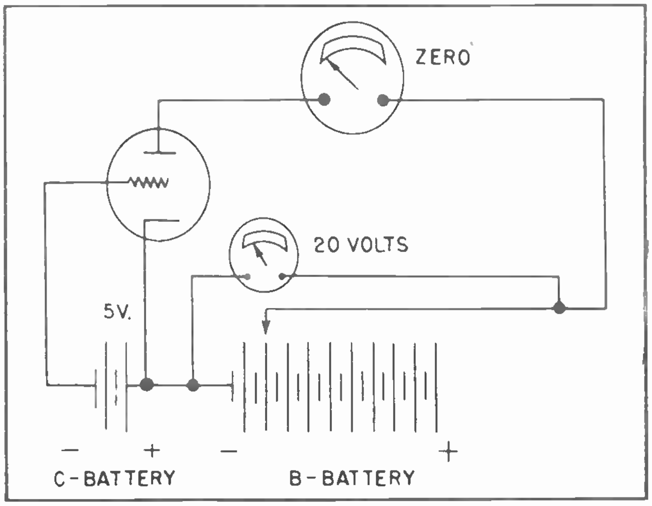

Fig.20.

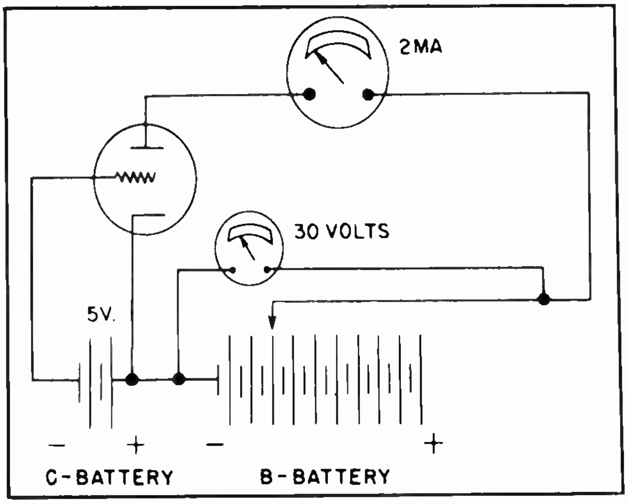

Fig.21.

In Fig. 23 we have placed 40 positive volts on the anode. The milliammeter tells us that 6 milliamperes will flow when this voltage is placed on the anode. In order to keep the record we will place a dot on our chart where the vertical line for 40 volts crosses the horizontal line which represents 6 milliamperes.

Next is the situation in Fig. 24. Here we have put 50 positive volts on the anode. The result is that we now have 12 milliamperes of current flowing in the anode circuit.

The next step is to mark these values on the chart at the proper coordinate point. We locate the point where the 50-volt vertical line crosses the 12 milliampere horizontal line. Here we have placed another dot.

Note that in all these experiments there are 5 negative volts on the grid. In Fig. 25 we find that 60 positive volts on the anode results in 18 milliamperes of current to flow, whereas when the grid is at zero voltage we need use only 30 positive volts on the anode to cause 18 milliamperes of current to flow. Another way to say this is that changing the grid voltage by only 5 volts has as much effect on the anode

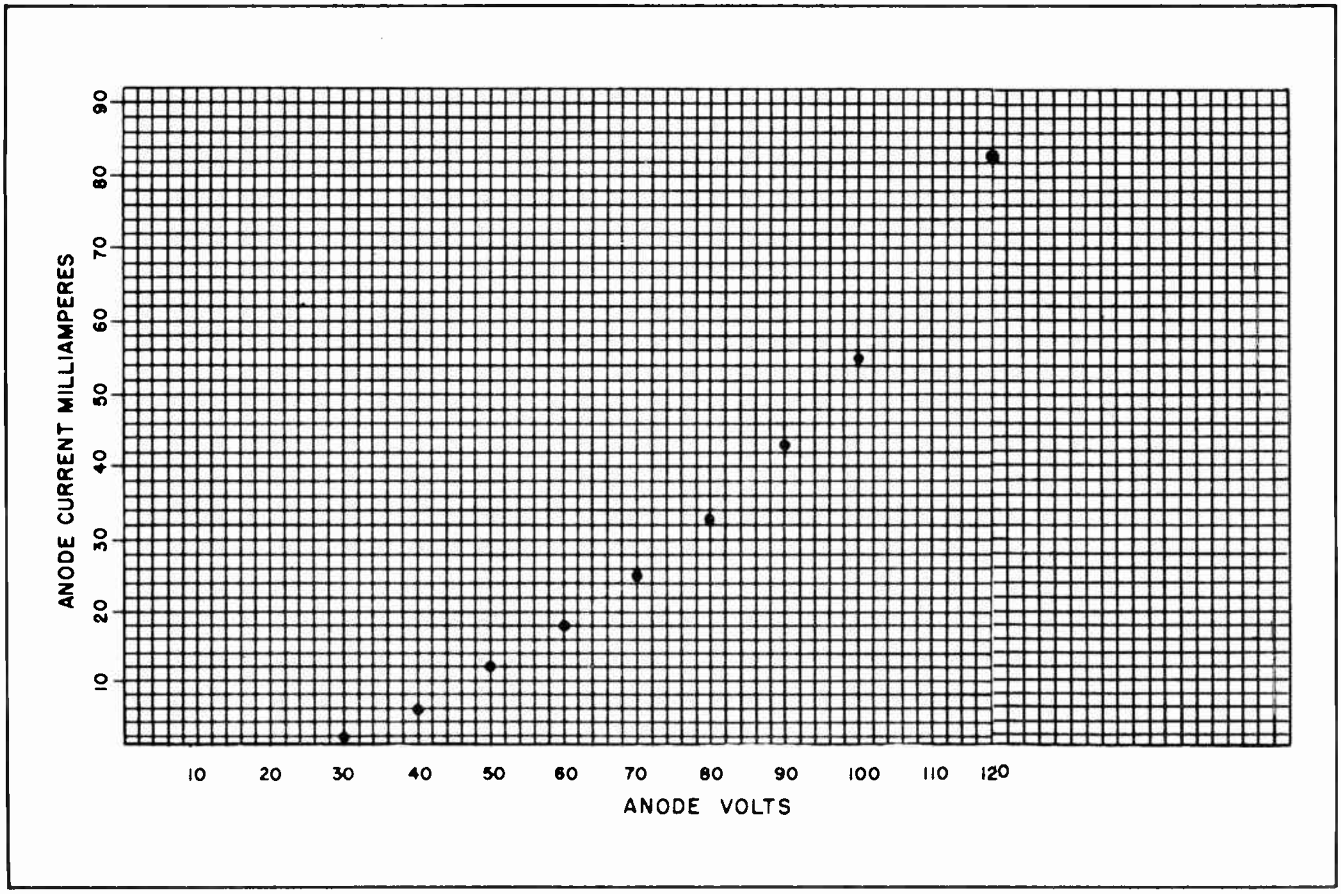

Fig.22. Plotting the "coordinate points" on a graph showing the anode current against the anode voltages when the grid is 5 volts negative.

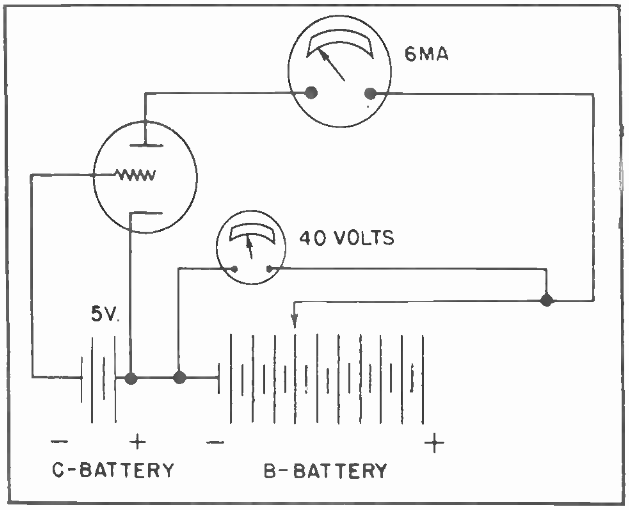

Fig.23.

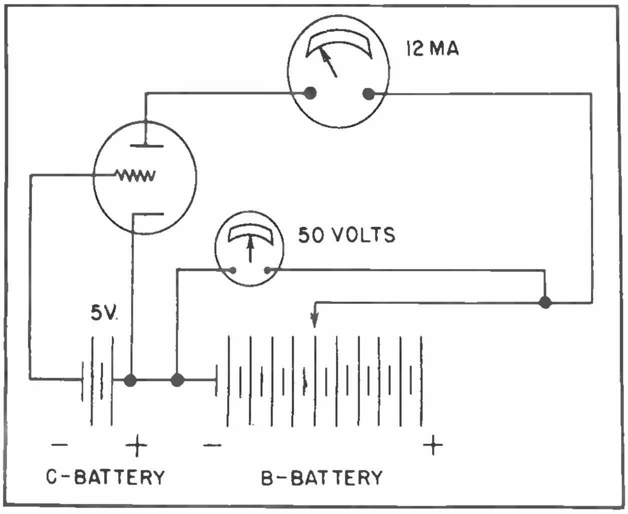

Fig.24.

current as changing the anode voltage 30 volts. A careful study of Figs. 14 and 25 will prove profitable in your future studies of electron tubes.

As an example of the importance of this point suppose we have a relay in the anode circuit which is closed, or "pulled in", at 45 milliamperes. By applying 60 volts to the anode of this tube without any negative voltage on the grid we can cause 45 milliamperes, or more, to flow in the anode circuit and through the coil of the relay. Now suppose the relay will open up, or "drop out" at approximately 18 or 20 milliamperes. There are two ways in which the current in the anode circuit, and through the relay coil, can be reduced. We could reduce the anode voltage from 60 volts to 30 volts while keeping the grid voltage at zero, or we could keep the anode voltage steady at 60 volts and place a grid voltage of 5 negative volts on the grid.

It can thus be readily seen that a small change in the voltage on the grid accomplishes the same results, so far as the anode current is concerned, as a large change in the anode voltage. Frequently it is much easier to bring about a small change in the voltage on the grid than it would be to bring about a large change in the voltage on the anode.

In Fig. 26 we still have a negative voltage of 5 volts on the grid, but have raised the anode voltage to 70 volts. This results in an anode current of 25 milliamperes. The next step is to locate the point on the chart in Fig. 22 where the 70 volt vertical line crosses the 25 milliampere horizontal line. We have placed another dot there.

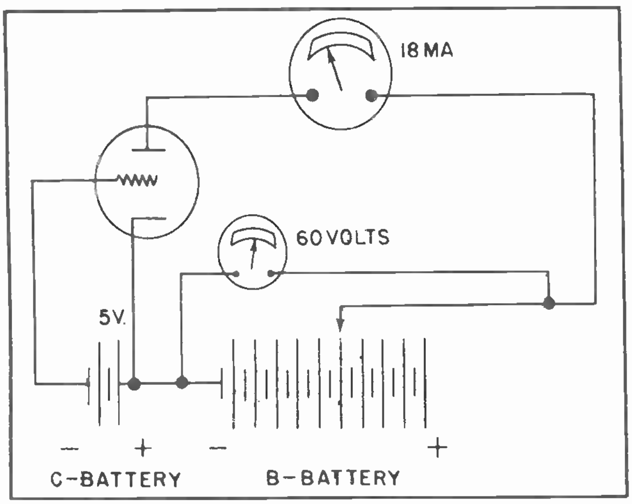

Fig.25.

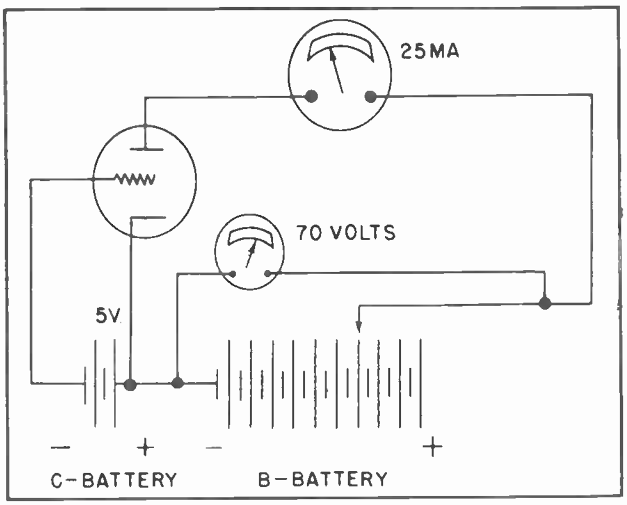

Fig.26.

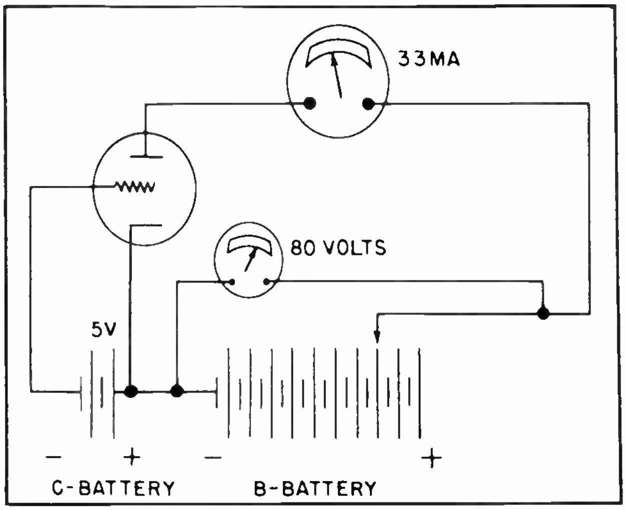

Fig.27.

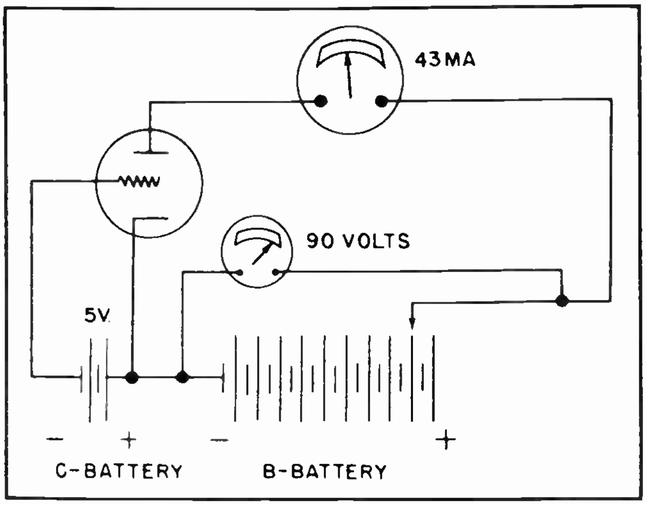

Fig.28.

In Fig. 27 we find that 80 positive volts on the anode causes a current of 33 milliamperes to flow in the anode circuit. In Fig. 28 the 90 anode volts cause 43 milliamperes to flow, and in Fig. 29 we have placed 100 volts on the anode which causes a current of 55 milliamperes to flow in the anode circuit. The coordinate points on the chart in Fig. 22 should be located where the respective voltages and currents meet for the various values involved in each of these illustrations.

Because 100 positive volts on the anode has not caused the current to rise to a value approaching that when the grid was at zero potential we have added 20 extra volts onto the anode circuit in Fig. 30. When we do this the anode current goes up to 83 milliamperes. This still is not as much anode current as we had when the grid was at

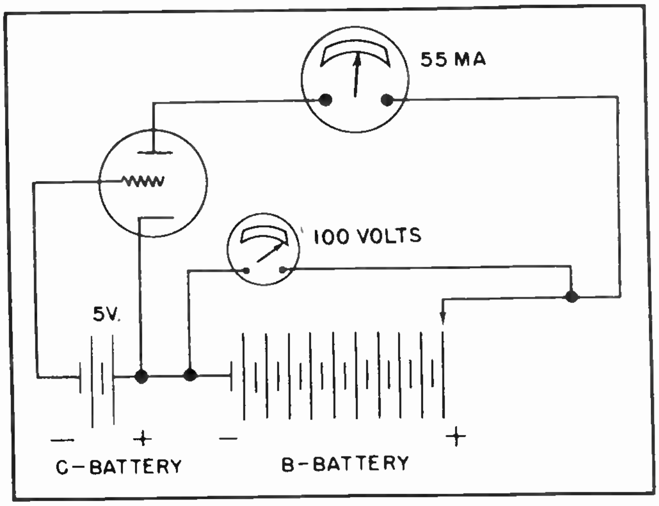

Fig.29.

zero, but it will be enough to show the effects on the anode current of the different voltages which we might place on the anode and on the grid.

If we connect all the dots on the chart in Fig. 22 we will come up with another "characteristic curve" for the triode tube we are discussing. (See Fig. 31.) This curve will show the various anode voltage and current relationships when the grid voltage is 5 volts negative. By means of this chart, or "Graph" as it is more commonly called, we can locate any value of current which would flow when any specific value of voltage was placed on the anode. Provided of course, that the grid voltage remains constant at 5 negative volts.

The graphs in Figs. 18 and 31 are both very valuable for many purposes when either of them are used alone. But suppose we place both graphs together on the same scale as shown in Fig. 32. Here we have something which is even more valuable. The broken line represents the characteristic curve of the tube when the grid is at zero potential. This is the identical curve we developed in Fig. 18. The solid line curve in Fig. 32 is the same as the one in Fig. 31.

Since they are both drawn on the same graph and on the same scale we are able to use the information provided by both curves at the same time. For example, suppose we had a tube which is operating with 90 positive volts on the anode. If the grid was at zero potential the anode current would amount to 90 milliamperes as shown by the intersecting lines at "A" Fig. 32. Should the grid of the tube then be made

5 volts negative, the anode current would drop to 43 milliamperes as shown by the intersecting lines at "B".

Section 7. **PUTTING THE GRAPH TO USE**

This information would be of great value to a person designing a piece of equipment in which that tube would be used. One would know by glancing at the graph that by a swing of 5 volts on the grid the current in the anode circuit could be changed from 90 milliamperes to 43 milliamperes, or could be swung the other way, that is from 43 milliamperes to 90 milliamperes.

By using the example of the relay again, we could set up a circuit with a relay whereby the relay could be opened or closed by changing the voltage on the grid of the tube. This might involve some kind of very delicate meter which could not carry any appreciable amount of current. Since no current is involved in changing the voltage on the grid of a vacuum tube it would be possible to use the unique abilities of a vacuum tube to solve such a problem.

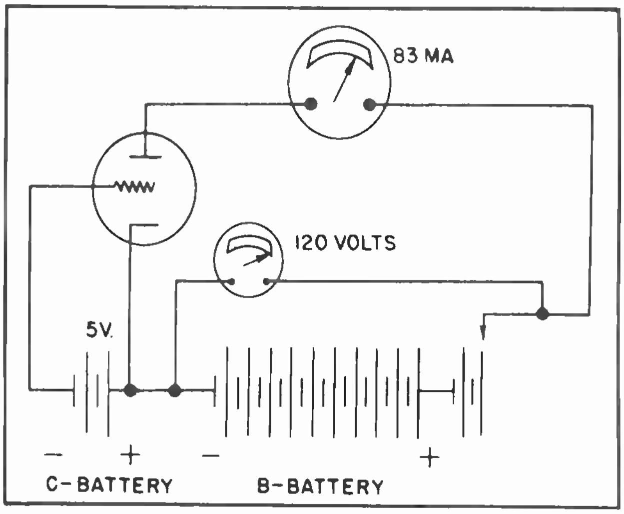

Fig. 30.

Fig. 33 shows a very delicate meter at the left of the illustration. Such a meter might be used to measure temperature, or voltage, or current, or power, or light intensity, or wind pressure, or any number of other things. The point is that its construction must be so light and delicate

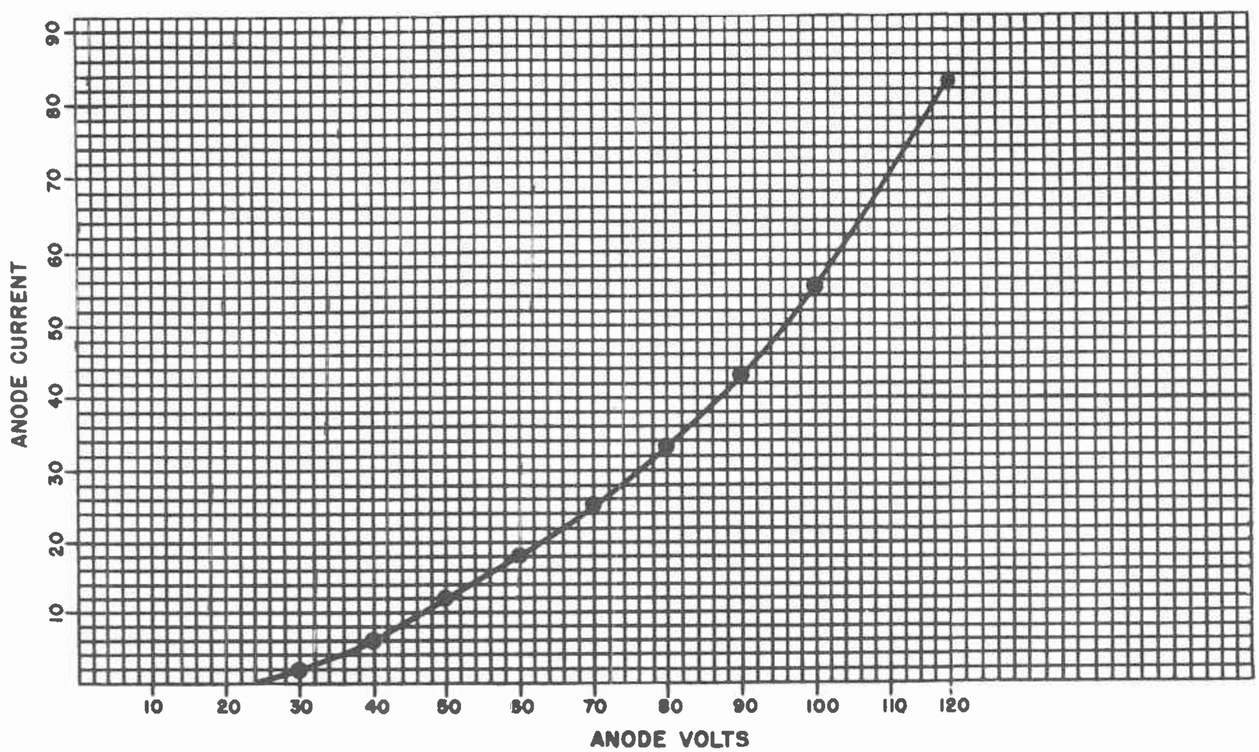

Fig. 31. Graph of a curve showing the anode current against the anode voltages when the grid is 5 volts negative.

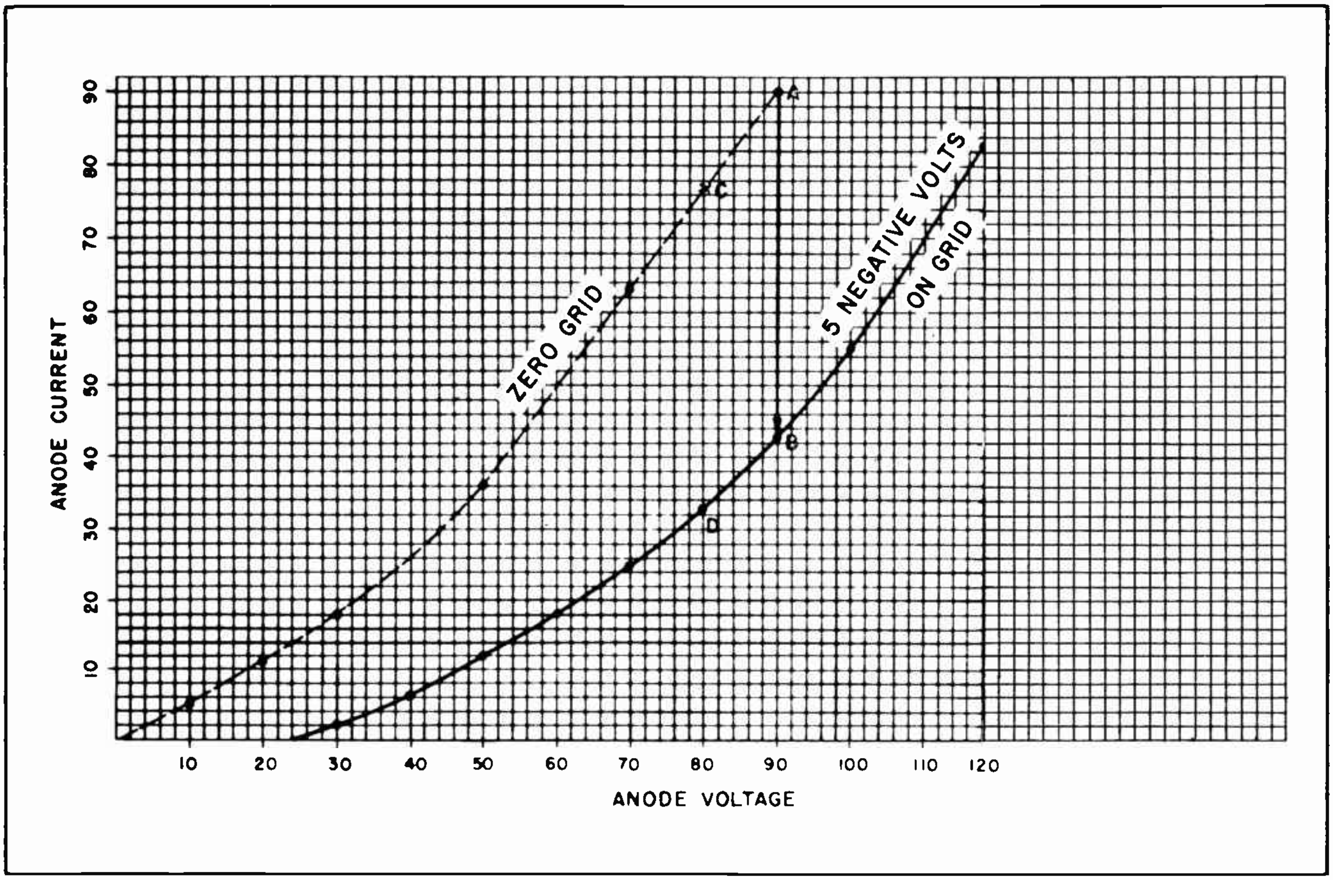

Fig.32. Plotting the anode currents against the anode voltages when the grid is at zero potential, and again when it is 5 volts negative.

in order to have the proper sensitivity that it cannot carry any electrical current without soon becoming pitted and useless. Fig. 33 shows that the movement of the hand on the meter will carry it back and forth across one or the other of two electrical contacts. When the meter needle swings to the left as in Fig. 33 it will contact a circuit which is connected directly to the cathode of a vacuum tube. The needle itself is connected to the grid of the same tube.

Thus, when the needle swings to the left it connects the grid of the tube directly to the cathode which places the potential on the grid at the same level as that of the cathode. If this is the same type of tube we have been previously discussing a current of 90 milliamperes would flow in the anode circuit. This current also flows through the magnet coil on a relay, magnetizing it sufficiently to make it pull in. When the relay pulls in, it closes another circuit through its two contacts. This second circuit can carry quite a heavy current — enough to control almost any apparatus.

Now let's take a look at the circuit in Fig. 34, Here the needle on the delicate meter has swung to the right. When it does so, it breaks the contact with the cathode and makes another contact with a circuit which goes to the 5 volt battery. Thus when the needle swings to the right it causes the 5 volts of the battery to be impressed upon the grid of the vacuum tube. Since this is the same type of tube we have been discussing we know that when 5 negative volts are on the grid and 90 positive volts on the anode, the anode current will drop to 43 milliamperes. (See Figs. 28, 31 and 32.) Since only 43 milliamperes are flowing through the anode circuit there will be only that amount of current through the coils of the relay. If the relay is properly designed or selected, it will become sufficiently deenergized that it will "drop out" when only that amount of current is flowing through its coils. When the relay contacts separate, the circuit to the control apparatus will be broken.

Thus with this type of circuit we are able to take the readings directly from a very

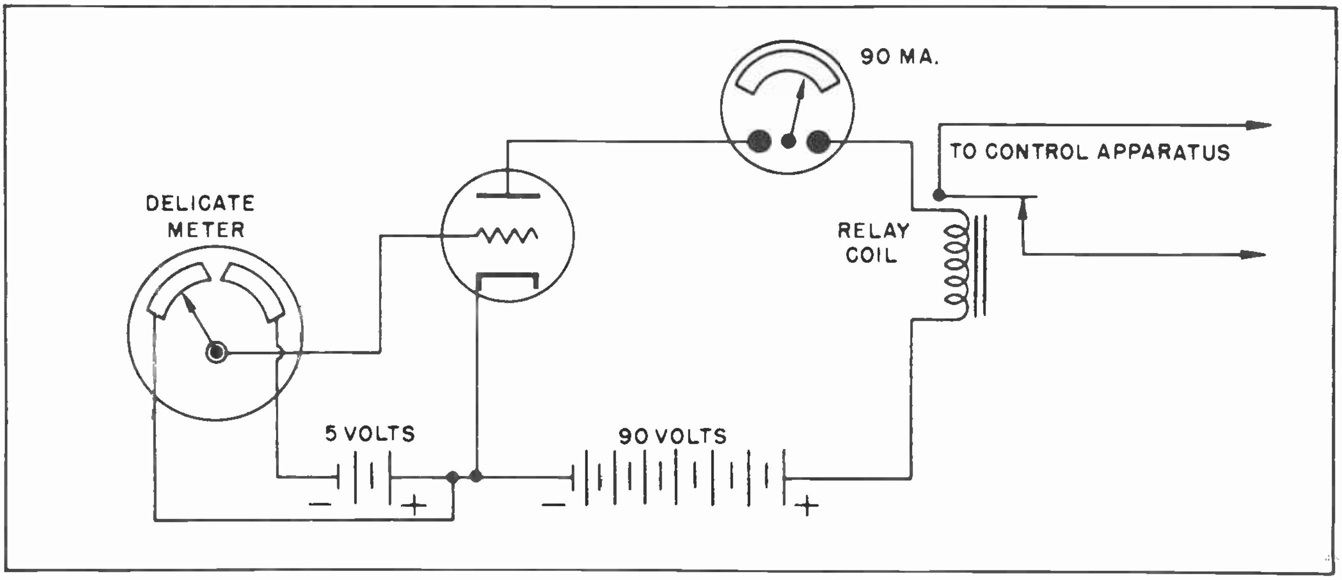

Fig.33. How a delicate meter needle can be used to place a zero voltage on the grid of a triode tube.

delicate meter and use them to control the grid of a vacuum tube. The vacuum tube can then change the current to any possible type of control apparatus. The vacuum tube is thus able to do something the delicate nature of the meter would not permit it to do directly.

It would not have been necessary to use exactly 90 volts on the anode of the vacuum tube. Perhaps we are placed in the situation where we must use a relay which would pull in when the current through its coils amounts to approximately 75 or 76 milliamperes and drops out when the current is reduced to about 33 to 35 milliamperes. We could use the same tube but we would not need to use so much anode voltage. By referring to the graphs of Fig. 32 we would find that 80 volts on the anode would provide 77 milliamperes of anode current when the grid was at zero potential. This is shown at point "C" in Fig. 32. 80 volts will also furnish only 33 milliamperes of current when 5 negative volts are placed on the grid. By use of the graphs we can select any combination of anode or grid voltages which are needed to work with any

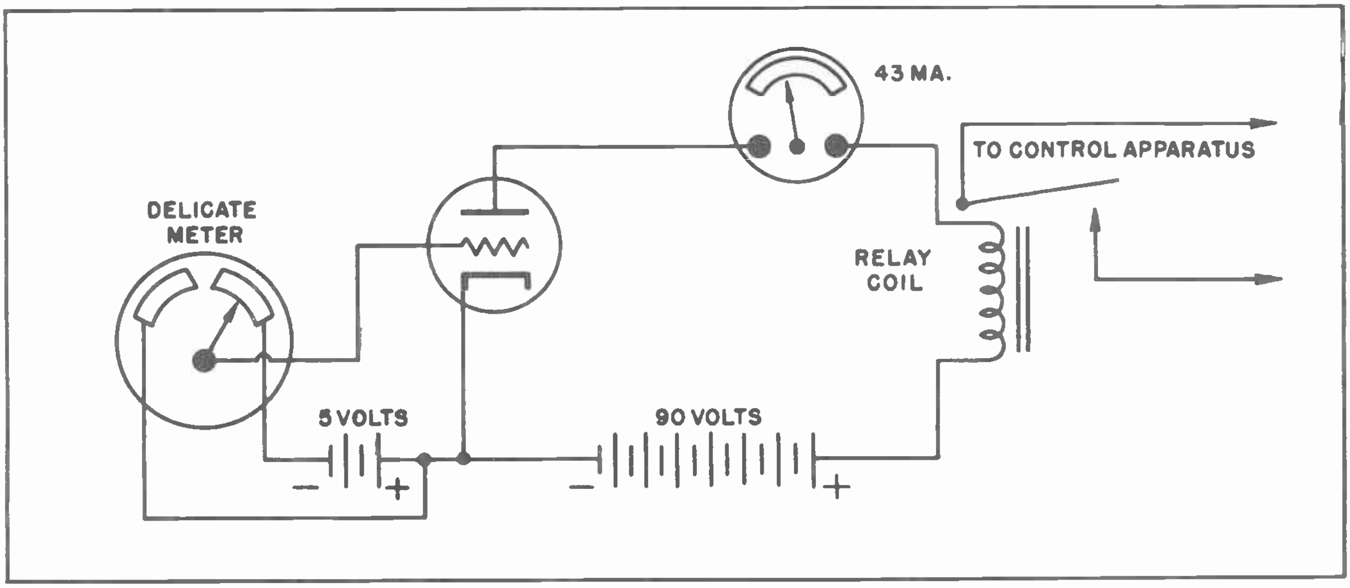

Fig.34. How a delicate needle can place a negative voltage on the grid of a triode.

particular type of relay. We have used the example of the relay to demonstrate one useful feature of these graphs. It should be emphasized that this is not the only place such graphs, or tubes, are useful. Far from it. We have selected them at this time merely because they enable us to explain one feature of vacuum tube work.

Section 8. FAMILIES OF CURVES

It is probably rather obvious to you by this time that it is possible to put still other negative voltages on the grid of the tube and obtain still other amounts of current in the anode circuit for varying anode voltages. In Fig. 35 we have drawn another chart on which there are six different curves. Each of these curves represent a different value of grid voltage, the exact value being marked at the end of the line, or curve. From these curves it can be seen that as the negative voltage on the grid is increased it becomes necessary to raise the anode voltage higher and higher in order to obtain any sizable amount of anode current.

As an example of this suppose there are 100 positive volts on the anode of the tube. If the grid is at zero potential, 116 milliamperes of current will flow in the anode circuit. But if the grid is made negative by 5 volts the anode current will drop to 54 milliamperes. If the negative voltage on the grid is increased to 10 volts the anode current will drop to 25 milliamperes. Increasing the negative grid voltage to 15 volts reduces the anode current to 8 milliamperes, and increasing it to 20 negative volts cuts off all anode current completely. This means that if 20 negative volts are on the grid of the tube the anode voltage must be considerably higher than 100 volts before any anode current will flow.

When a group of curves covering the various characteristics of a single tube are drawn on the same chart, or graph, as shown in Fig. 35 they are called a "family of curves". As we progress a little further in our studies we will find that such a family of curves become quite important to us in our use of vacuum tubes. The manufacturers of tubes furnish such families

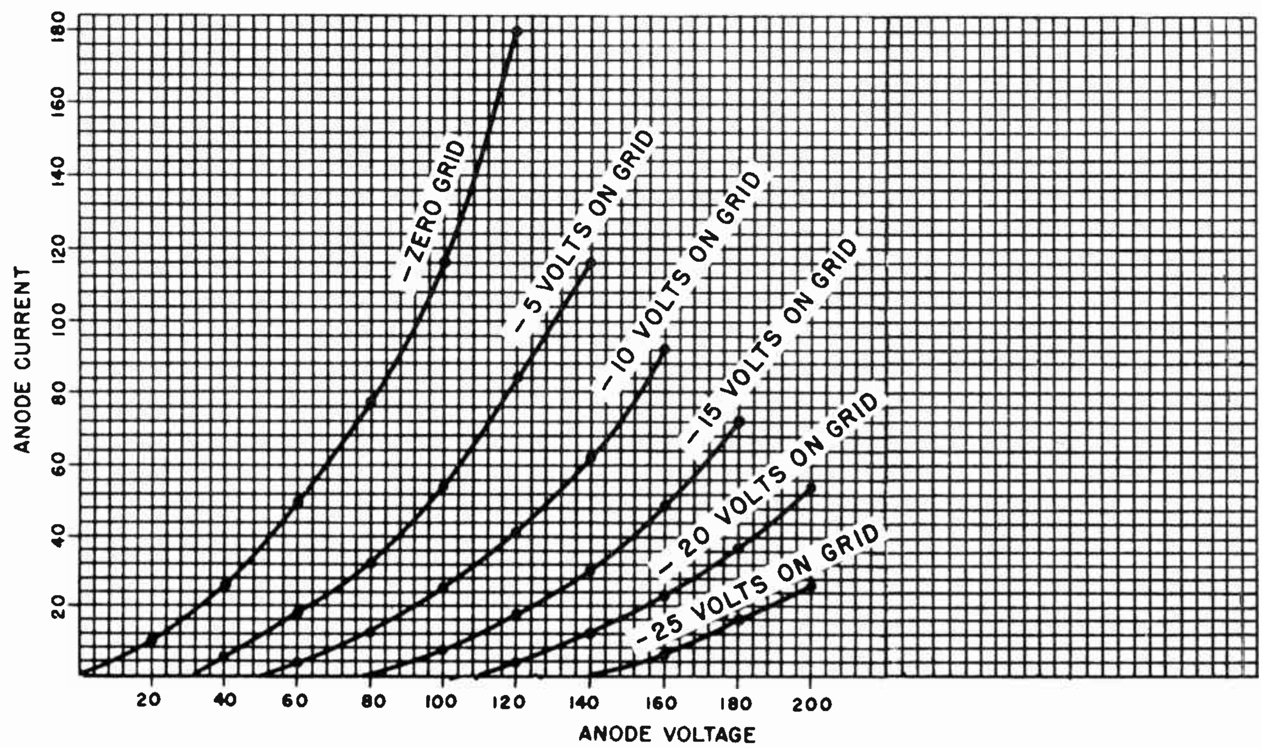

Fig.35. A "Family of Curves" representing various grid voltages. Each curve is plotted in the same manner as those in Figs. 18 and 31.

of curves for the information of the user. The trained radioman or electronic technician can then determine from these curves exactly how he can best use the tube, or can use the information to determine whether some particular tube will meet the requirements of whatever particular problem he is called upon to solve at that time.

Section 9. THE TRIODE AS AN AMPLIFIER

The triode tube is called upon to do many things, but probably the most important of all is its ability to "amplify". By amplify we mean to make larger, to increase.

When a vacuum tube is being used it is frequently desirable to change the value of the current flowing in the anode circuit. There are many reasons why we might find it desirable to change the anode current, it is not necessary to name any particular one.

Referring to Fig. 35 again, suppose we have a tube which has 120 positive volts on the anode and 10 negative volts on the grid. When this condition exists with that particular tube approximately 41 milliamperes of anode current will be flowing.

Now suppose we want to increase the anode current from 41 milliamperes to approximately 84 milliamperes. There are two ways in which we can do this. We can increase the anode voltage, or we can decrease the grid voltage. If we decide to increase the anode current by changing the anode voltage we must raise the anode voltage from 120 volts to approximately 156 volts, or a total of 36 volts. This is shown by following the curves on the chart.

But suppose we decide to change the anode current by changing the grid voltage. If we decide to do this we find that we can increase the anode current from approximately 41 milliamperes to approximately 84 milliamperes, by reducing the negative grid voltage from 10 negative volts to 5 negative volts. This is a difference of only 5 volts on the grid.

The effectiveness of a triode vacuum tube as an amplifier is measured by setting up a ratio of the number of negative grid volts change necessary to create an anode current change against the number of anode volts change needed to effect the same anode current change. To explain this just a little further, in the example just given we effected an anode current change of approximately 43 milliamperes by *changing* the anode voltage by 36 volts. We effected the same change in the anode current by *changing* the grid voltage by only 5 volts. Thus the effectiveness of the tube as an amplifier is measured by setting up a ratio of the 36 to the 5. This is equivalent to 7 1/5, which is found by dividing the 5 into the 36. This means the grid is 7 times as effective in controlling the anode current as is the anode.

Thus in this particular tube the *amplification factor* would be 7 1/5. Usually the amplification factor is given as an even number. In this case the amplification factor would most likely be 7. At this time it should be emphasized that the tube we have been describing is a hypothetical one. We have deliberately set up values for the purpose of explanation which would be fairly easy to understand. As a matter of fact many vacuum tubes have amplification factors much higher than this.

While we have not yet gotten into a discussion of the *linear portion of the characteristic curve* it is important that that portion of the curve be used when determining the *amplification factor* of any particular tube.

To carry this explanation of *amplification factor* just a step further we will mention that one triode tube might be able to effect a change of one milliampere in the anode current of the tube by changing the grid voltage by one volt. But it might take 20 volts difference in the anode voltage to change the anode current by one milliampere. In this case the grid would be 20 times as effective in changing the anode current as would the anode. We would say that this particular tube had an *amplification factor* of 20.

Some other tube might have an amplification factor of 40; a third tube might have an amplification factor of 50, and still another one an amplification factor of 70. One point should be made quite clear: the *total* current and the *total* voltages have no bearing on the amplification factor. It is only the *changes* in these values which are taken into consideration.

Section 10. TUBE CONDITIONS WHICH AFFECT AMPLIFICATION FACTOR

There are several things which affect the amplification factor of vacuum tubes. One

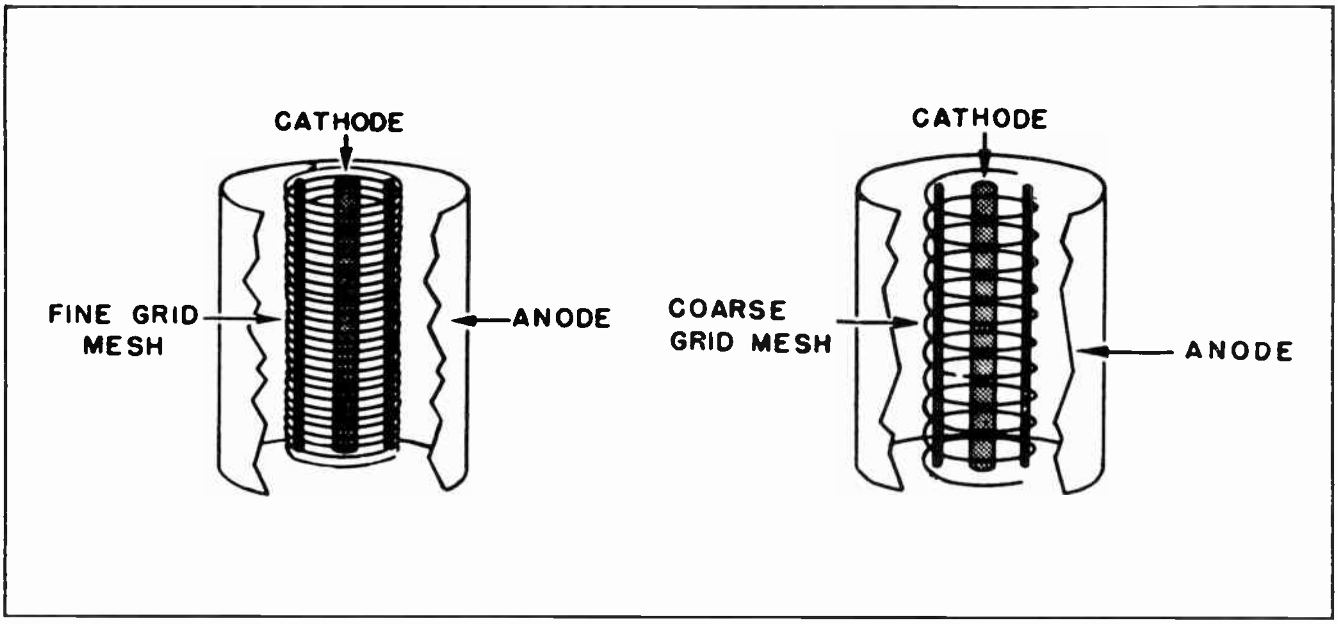

Fig. 36.

of the things which affect the amplification factor is the distance between the turns of wire which compose the grid -- the distance between them, or their closeness together. The closer the turns of wire are to each other the higher will be the amplification factor. Conversely, the farther the turns are apart the lower the amplification factor will be. (See Fig. 36.)

It might be well to mention that the amplification factor of a tube is commonly referred to as the "mu" of the tube. This comes about from the use of the Greek letter Mu (μ) as the symbol for amplification factor. Radio and electronic men are like most other Americans, they tend to shorten technical names into others which to them seem more convenient.

But to get back to our discussion of the wire which composes the grid of a triode tube. The closer the grid wires are together the greater is the effect of its electrostatic field in holding back the passage of electrons. It is understandable that a

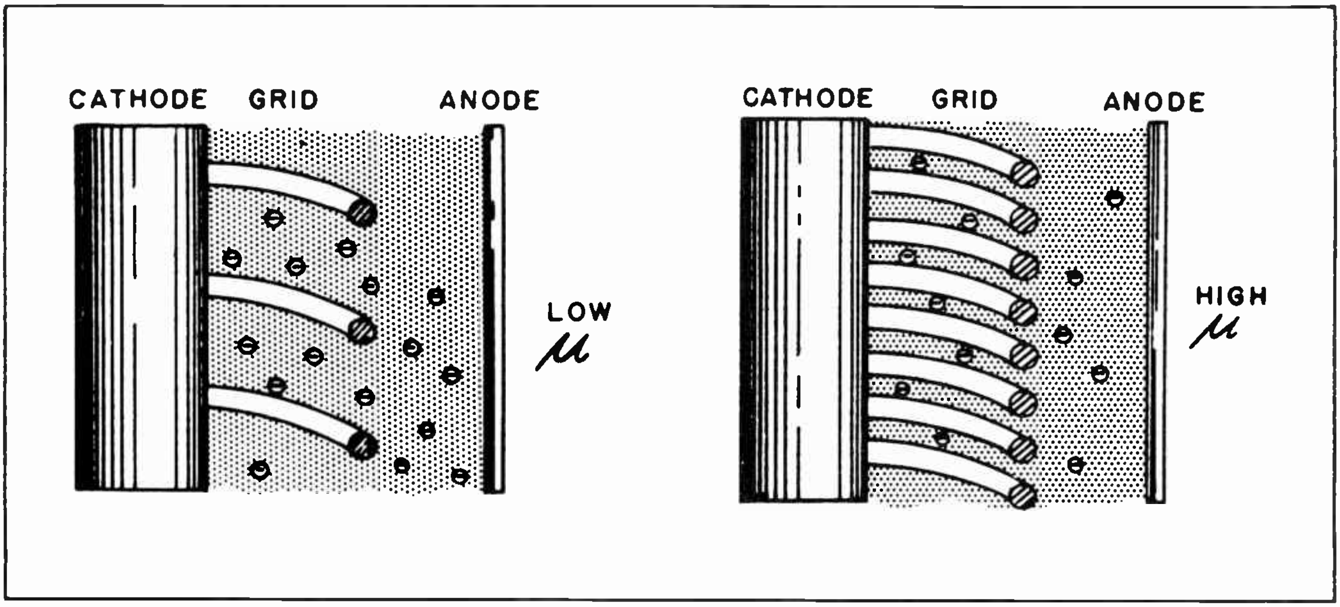

Fig. 37.

smaller negative voltage on a grid with the wires close together would be as effective in holding back electrons as would a higher negative voltage on a grid where the wires were farther apart. Since the smaller grid voltage of the one tube is more effective than the higher grid voltage of the other tube it follows that the tube with the closer grid wires would have the higher amplification factor, or to use the more common designation, would have the higher *mu*.

The effectiveness of the relative amount of space between the turns of wire which composes the grid of a triode can be better visualized by referring to Fig. 37. There it can be seen how the widely spaced grids allow the electrons to pass between the turns of wire much more readily than is the case where the turns are closer together.

the grid is located to the cathode the higher will be the overall amplification factor of the tube.

The ideal location for the grid would be a separation of only a few molecules of space between the cathode and the grid. But there are practical limitations. The grid must never actually touch the cathode, and since tubes are frequently subjected to rather rough usage, the grid must be far enough away that an accidental contact between it and the cathode can never occur.

This is a problem for the tube designer, and is one which has resulted in many innovations to increase the amplification factor of tubes higher and higher. Fortunately for us in our studies that is one problem we do not have to worry about.

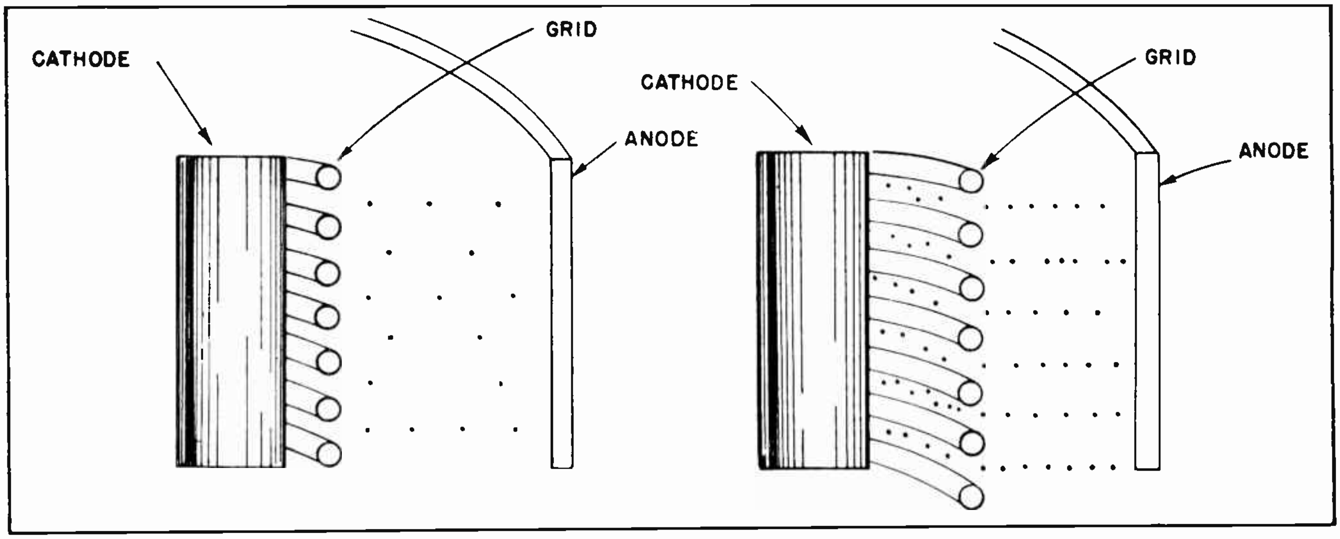

Fig.38. The grid is more effective when close to the cathode than when farther away.

Another item in determining the amplification factor of a tube depends upon the *position* of the grid between the cathode and the anode. It should always be remembered that the positive voltage on the anode is always much greater than the negative voltage on the grid. One of the reasons that the smaller voltage on the grid is more effective than the higher anode voltage is that the grid is located much closer to the cathode, and thus much closer to the newly emitted electrons.

Since the grid is closer to the newly emitted electrons than is the anode it is only natural that it would have considerably more influence on the electrons than would the anode. This brings us to the point which is illustrated in Fig. 38. The closer

Perhaps it would not have been necessary to describe the physical relationships of the various elements within a vacuum triode tube. Probably you will never have occasion to design such a tube. But there are still many things you must learn about tubes before you will be able to work with them with perfect confidence. Since many of the things you have to learn depend in some measure upon a knowledge of tube construction this information we have just given you will make your future studies somewhat easier.

Section 11. NAMES OF TUBE VOLTAGES AND CURRENTS

We have referred to the current which flows in the anode circuit as the *anode current*, and the voltage applied to the

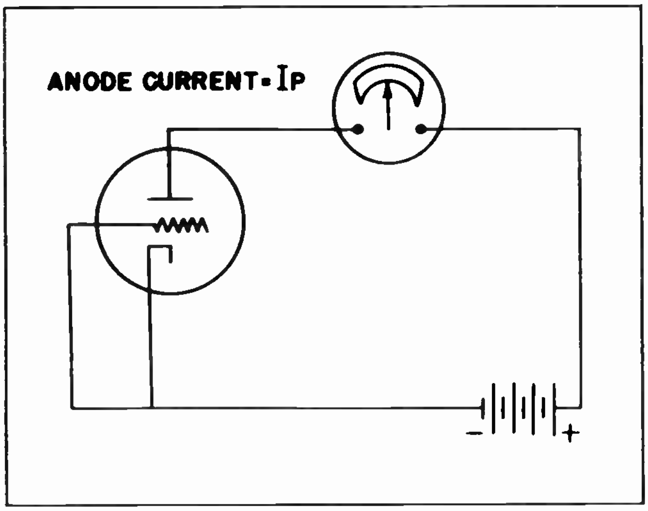

Fig. 39.

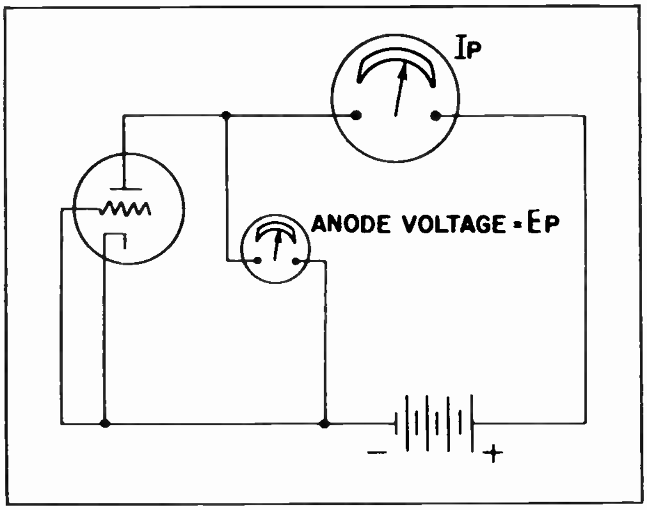

Fig. 40.

anode as the *anode voltage*. These terms are technically accurate, and are the names in common use. But like so many other things in electrical and electronic work, special designations have been adopted and have come into everyday use. Because there are so many circuits connected with vacuum tube work (many of which we have not yet touched upon), it has become necessary to adopt very short symbols, composed of letters, to describe these currents and voltages.

In the case of the anode current the letter I is used to designate the current just as that letter is used elsewhere to designate the flow of any current. But since in the case of anode current we want to distinguish that current from all other kinds of current we add a subscript to the letter I. Because the word "plate" is so frequently used as a designation for the anode the first letter of the word "plate" has been adopted as the one to distinguish anode current from all others. In this way the symbol I_p has come to be the commonly accepted symbol for anode current. It is pronounced *I-subscript-p*, which has been generally shortened to *I-sub-p*, or, in many cases, merely "I-p". (See Fig. 39.) Much the same thing is true of the anode voltage. The standard letter E is used to designate the voltage on the anode. But to distinguish that voltage from all other voltages it also is given the subscript p. This becomes E_p as shown in Fig. 40. It should be noted in Fig. 40 that the voltage is measured between the anode and the cathode. As mentioned before, all voltages involving a vacuum tube are measured between the cathode and the particular element under investigation. But in the

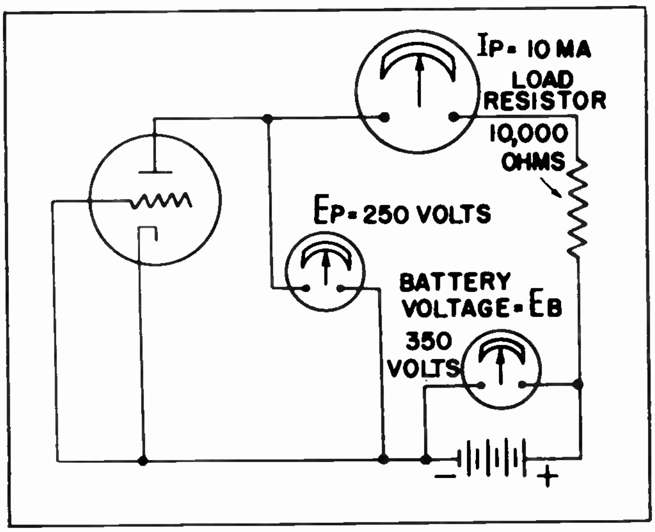

Fig. 41.

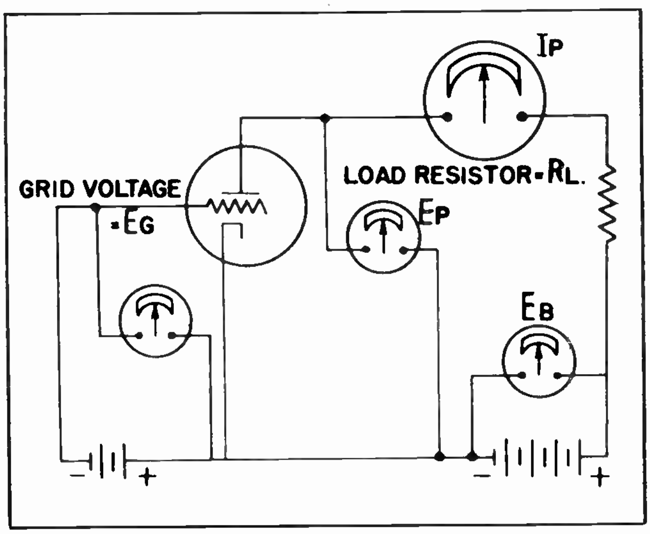

Fig. 42.

case of the anode one might ask why the voltage was not merely measured across the battery since that is the same as that between the cathode and the anode.

In the case of the circuit in Fig. 40, that could have been done. But such would not be true with many vacuum tube circuits. In fact, a separate designation is reserved for the voltage across the battery.

Suppose the circuit of Fig. 40 were changed so that a resistor was inserted in the anode circuit as shown in Fig. 41. Such a resistor would be known as a *load resistor* and is quite common to most vacuum tube circuits.

When the resistor is in the circuit there will be a *voltage drop* across that load resistor when anode current flows through it. When this happens the voltage on the anode of the tube will not be the same as the voltage at the terminals of the battery.

Fig. 41 shows a load resistor of 10,000 ohms inserted in the anode circuit. The milliammeter shows there is an anode current flowing through the anode circuit. When 10 milliamperes flow through a resistance of 10,000 ohms there will be a *voltage drop* of 100 volts. The value of the voltage drop is readily determined by applying Ohm's Law to the problem. In this case we merely multiply the resistance by the current. 10 x 10,000 equals 100,000. But since Ohm's Law applies to *amperes* whereas a milliampere is only 1/1000th of an ampere we must divide 100,000 by 1000. This gives us 100 volts.

If a voltmeter across the battery in Fig. 41 showed us the battery was creating a voltage difference of 350 volts we would have to subtract the *voltage drop* across the resistor in order to find the actual voltage which would be applied to the anode. In this case 100 volts subtracted from 350 volts would leave 250 volts for application to the anode. If voltmeters were placed as shown in Fig. 41 they should read the values as shown.

Note the manner of designating the voltage across the battery. It is not the same designation we used to describe the voltage applied to the anode. The anode voltage is called E_p. The battery voltage is called E_b. The *b* of the designation is not derived from the word "battery". Instead it comes from the fact that the battery under discussion delivers the "B" voltage for use with the vacuum tube.

There is still another voltage which has a special designating symbol with which we should become familiar. That is the voltage placed on the grid. In Fig. 42 we have placed a voltmeter in the grid circuit to measure that voltage. We have also added the generally accepted method of distinguishing that voltage from all others. We have named that voltage E_g.

You will also note that the load resistor in Fig. 42 has been designated by the symbol R_L. This is merely the letter *R*, which we already know is always used for resistors and resistances, to which has been added the subscript *L* to distinguish it as the *load* resistor from all other resistors which might be found in the vacuum tube circuit. It might be well to mention that as we continue our studies of vacuum tubes we are going to find several other resistors associated with the operation of the tubes. Thus it will become necessary to provide each of the various resistors with certain designating subscripts so as to distinguish each of them from the others. But we need not worry about that just at this time. The matter of the various resistors will be taken up at the proper time.

(Reference Notes on the page following)

NOTES FOR REFERENCE

The triode tube is a vacuum tube which contains three principal elements: the cathode, the anode and the grid. The grid of the triode can also be called the "control grid" to distinguish it from other grids which are found in other types of vacuum tubes.

The control grid of a triode is an effective device for controlling the current through the tube.

The grid is far more effective in controlling the flow of current than is the anode.

A small voltage on the grid is more effective in controlling the flow of anode current than is a much larger voltage on the anode.

The effectiveness of the grid results from the fact that a *negative* voltage can be impressed upon it. Since the electrons are themselves negative particles of electricity they are repelled by any other negative material.

Anode current is designated by the symbol I_p.

Anode voltage is designated by the symbol E_p.

"B" battery voltage is represented by the symbol E_b.

The negative voltage on the control grid is represented by the symbol E_g.

All voltages on the various elements of a vacuum tube are measured with respect to the cathode.

The varying characteristics of vacuum tube operation as the various voltages applied to its various elements are changed are often described by drawing "characteristic curves" on graph paper.

"Characteristic curves" are very useful in studying the usefulness of any particular vacuum tube.

A triode tube's principal usefulness stems from its ability to *amplify*.

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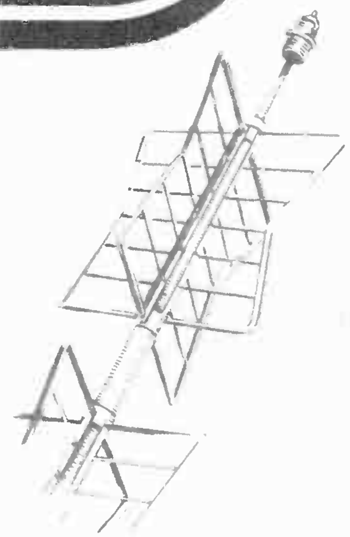
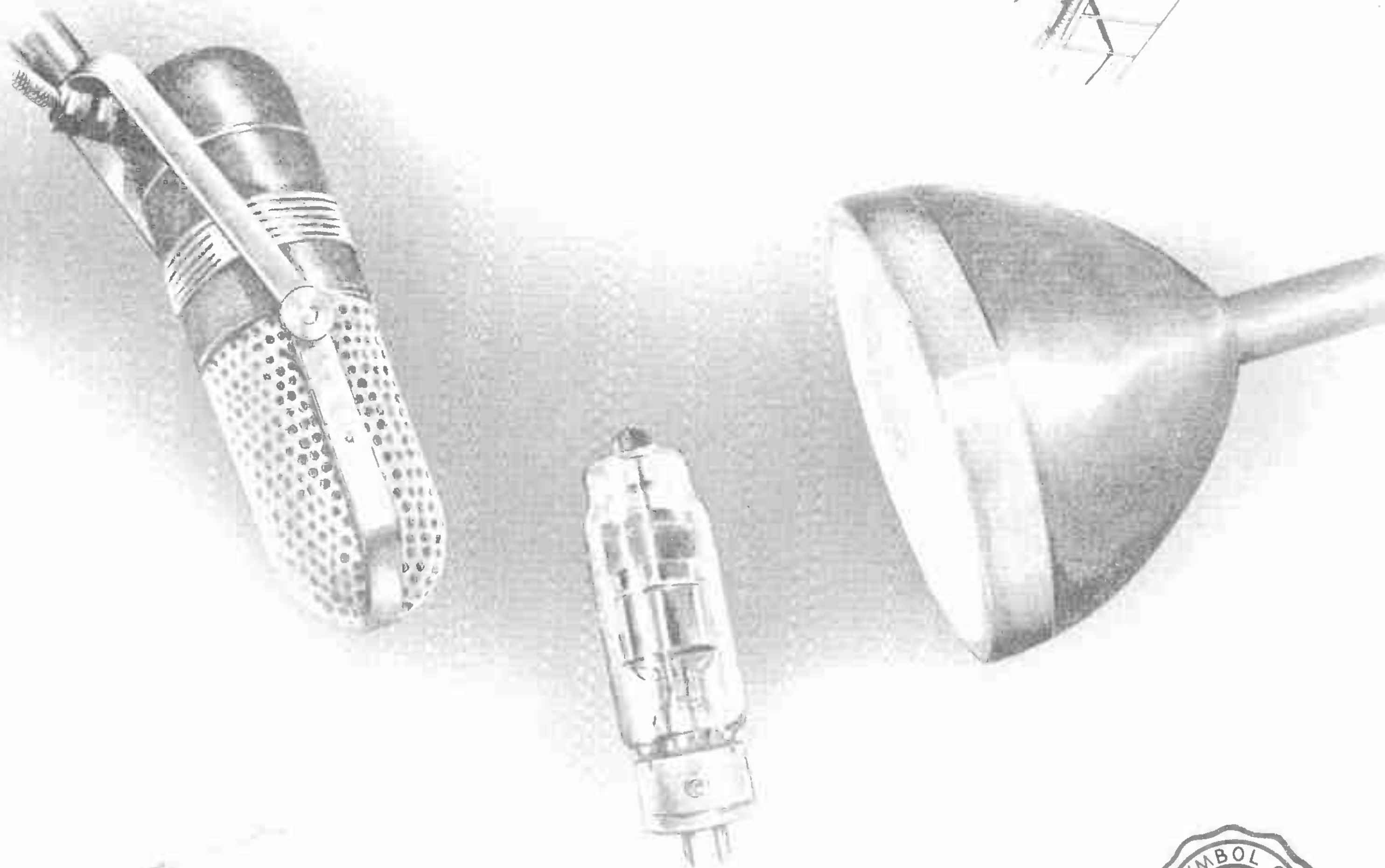
SYMBOL OF PROFICIENCY

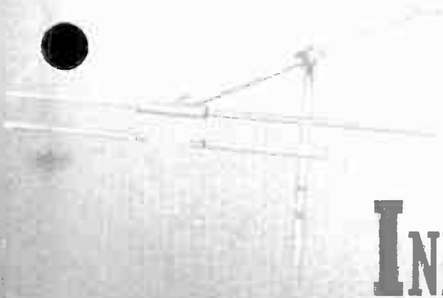
Technical Training
SERVICE

Radio and TELEVISION

Multi-Grid Vacuum Tubes







Multi-Grid Vacuum Tubes

INDUSTRIAL TRAINING INSTITUTE

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TECHNICAL TRAINING SERVICE

Revised 1952

RADIO TELEVISION

MULTI-GRID VACUUM TUBES

Contents: Introduction - Interelectrode Capacitance - The Tetrode - Secondary Emission - The Suppressor Grid - What the Suppressor Grid Does - Electrostatic Fields Within a Pentode - Amplification Factor of Pentodes - How the Suppressor Grid is Connected - Beam Power Tube - Tube Constants - Plate Resistance - Transconductance (Mutual Conductance) - Notes for Reference.

Section 1. INTRODUCTION

As has been pointed out in previous discussion of vacuum tubes, there are a variety of types of such tubes. Each is specifically designed to do one certain job better than any other tube, or to fit into a certain place in a circuit better than any other tube. Some vacuum tubes use filaments or heaters which operate on 1.5 volts. Others need 2.5 volts, or 5 volts, or 6.3 volts, or 12.6 volts. Still others operate on many other voltages.

Some vacuum tubes are relatively large insofar as their physical size is concerned. Other tubes do very nearly the same job but are much smaller. Some tubes operate at high voltages such as are supplied by A-C power supplies with their step-up transformers. Others do almost equally good jobs at lower anode voltages.

But all types of vacuum tubes have certain "characteristics" which are similar. When we learn and understand how to use the particular characteristics of one tube, we will encounter little trouble in utilizing the characteristics of all other tubes, and thus be able to put each of them to use to the best advantage.

Our studies so far have taken us through the basic fundamentals of thermionic emission, space charge, operation of the diode tube, and some of the characteristics of the triode. Almost everything you have learned about vacuum tubes will be useful in working with any vacuum tube you are likely to encounter. All vacuum amplifier tubes utilize the principle of thermionic emission. All have the problem of the space charge. Every tube has a cathode and an anode. In these respects all tubes are alike. Every vacuum tube except the diodes have a control grid such as was discussed in our studies of the triode.

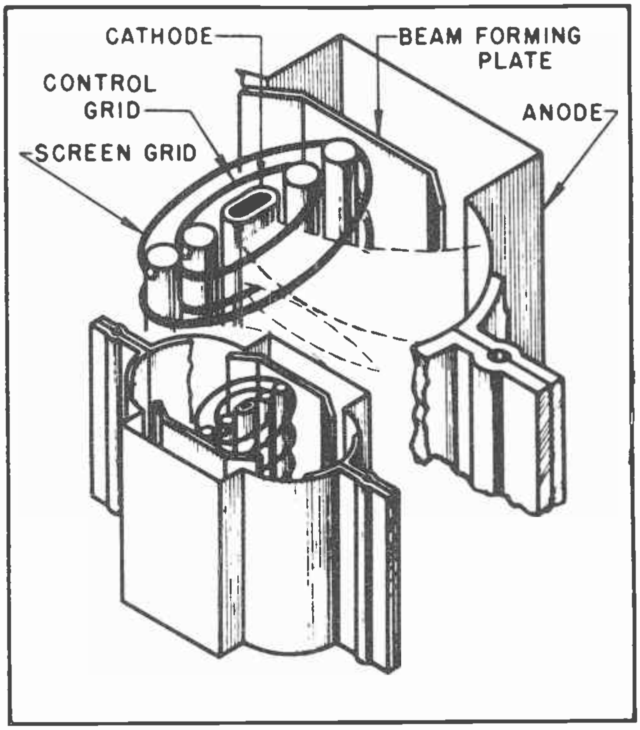

Fig.1. Construction of a Beam Power Tube.

The tubes we have previously discussed will be encountered in almost every electronic device you will ever be called upon to work with, regardless of whether it is a radio, a television receiver or some kind of industrial electronic control apparatus. Practically every kind of electronic device has need for one or more diode tubes for use as rectifiers, and most of them use triodes somewhere in their circuits.

Section 2. INTERELECTRODE CAPACITANCE

But even the triode, valuable though it is, has certain drawbacks which have been overcome in the design of other types of vacuum tubes. The triode has two principal drawbacks; first is the *feedback* from the anode to the grid at high frequencies due to *interelectrode capacitance* and the second is its relative low amplification factor.

The first of these drawbacks, the interelectrode capacitance, comes about due to the fact that both the grid and the anode are constructed of metal and are separated from each other, although being at the same time relatively close together. You will recall from our study of capacitors that the essentials of a capacitor is that two pieces of metal are separated from each other by means of a dielectric. Inside the vacuum tube we have the elements of this condition. It is not an *intentional* condition; it is one which has been brought about as the result of the very nature of the things with which we must work.

The capacity of the interelectrode capacitance which exists between the grid and the anode is relatively small. It is on the order of .000007 to .000015 mfds. At ordinary frequencies this amount of capacity

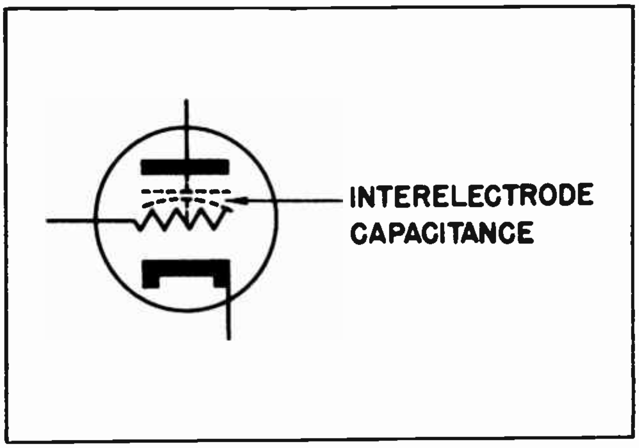

Fig.2. Interelectrode Capacitance Between the Grid and the Anode.

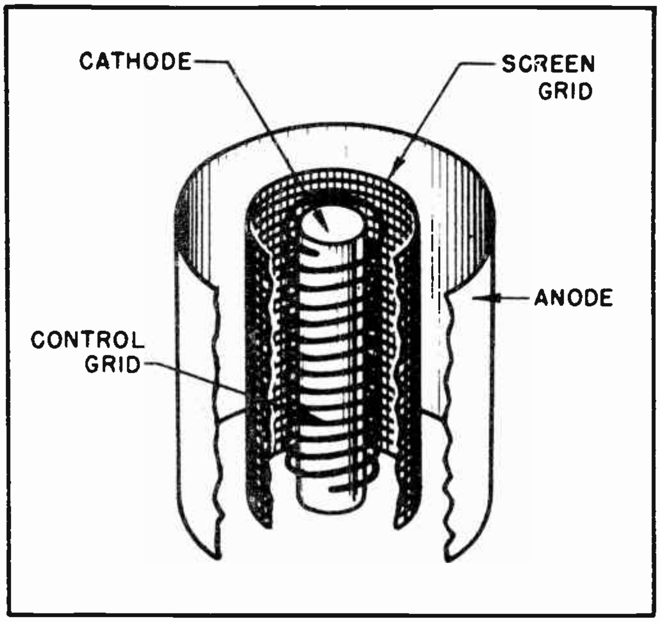

Fig.3. Physical Construction of a Tetrode.

is of little concern. In fact, the frequency can be increased to several hundred thousand cycles per second before the interelectrode capacitance becomes really bothersome. But at the higher frequencies, a portion of the amplified signal which has reached the anode circuit is *fed back* to the grid as the result of this interelectrode capacitance and creates very undesirable conditions.

It is not our purpose to go very deeply into the technicalities of feed-back at this time -- this will be taken up after you have been better prepared to understand it -- but the feed-back is mentioned as being an undesirable characteristic of the triode tube and hinders its use for many purposes. It should be mentioned, however, that that very characteristic is taken advantage of in some applications, and actually put to work.

The second drawback to the triode tube is its relatively low amplification factor. It is true that some triodes have amplification factors which go as high as 50 to 70, but the majority of triode tubes seldom have an amplification factor of more than 20.

It might be argued that a tube which can multiply a signal by as much as 20 is doing pretty good. And in the early days of radio that was mighty fine. But progress in radio and electronic work has not been satisfied with amplification factors of that value.

Section 3. THE TETRODE

Back around the year 1930, a new vacuum tube was introduced to the radio world which had what was then an amazing amplification factor. It overcame the two principal defects of the triode tube. It reduced the interelectrode capacitance to negligible values and attained an amplification of 400 or better. The very least that could be said about this new tube was that it was some tube. This new tube was called a *tetrode*.

The new tube accomplished these two things by placing another grid between the control grid and the anode as shown in Fig. 3. Placing the second grid between the anode and the control grid effectively reduced the interelectrode capacitance, thus making it possible to use this new tube on much higher frequencies than the triode could be used without special neutralizing circuits.

But the introduction of the second grid, which is generally referred to as the *screen grid*, also increased the amplifying ability of the tube many times. To fully understand how this was brought about, let us return to the triode for just a few minutes. Although it has not been stressed before, it should be recognized that the anode in a triode performs two functions. In performing one function it acts to collect the electrons which are emitted by the cathode and are able to pass through the coils of the control grid. It also performs this same function in the newer tube, and most other vacuum tubes.

But the anode in the triode also has the function of establishing an electrostatic field between it and the cathode. Thus the voltage on the anode would vary as the anode current varied. This changing voltage then causes the electrostatic field between the anode and cathode to vary in strength.

To see just how this condition affects the amplification factor of the triode, suppose that an electrostatic field of a given strength exists between the anode and the cathode when no anode current is flowing. In other words, the grid is so negative no anode current can flow. At this instant the full voltage of the "B" battery will be applied to the anode because at that instant there will be no voltage drop in the load resistor. (Since no current is flowing through the resistor, there will be no drop across it.)

With the full battery voltage applied to the anode, the electrostatic field between the anode and the cathode will be at its maximum strength.

Now suppose the grid is made a little less negative and some current is allowed to flow in the anode circuit. This current will flow through the load resistor creating a voltage drop. This voltage will be instantly reflected back on the anode, causing the voltage on the anode to be reduced. This reduces the strength of the electrostatic field, thus making the anode that much less attractive to the electrons near the cathode. As the grid is made less and less negative, more and more current will flow in the anode circuit. But as more and more current flows in the anode circuit, the anode voltage is reduced lower and lower.

The net effect of all this is that there is a definite limit to the amplifying ability of a triode.

In a tetrode, however, the screen grid is interposed between the anode and both the control grid and the cathode. The screen grid is then connected to a source of positive voltage. The positive voltage applied to the screen grid is usually somewhat lower than that applied to the anode. Normally it is about 90 volts. (See Fig. 4.) The screen grid acts to set up an electrostatic field between it and the cathode. This electrostatic field causes the electrons to leave the vicinity of the cathode in the same manner the field created by the *anode* in a triode causes them to leave the cathode.

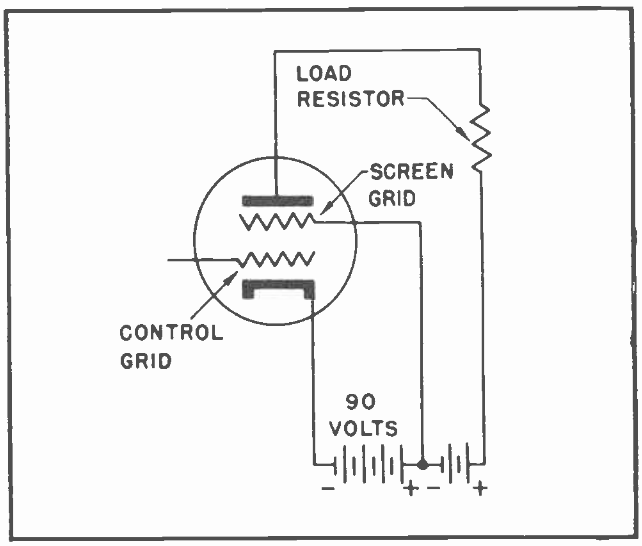

Fig. 4. Connections to a Screen Grid Tube.

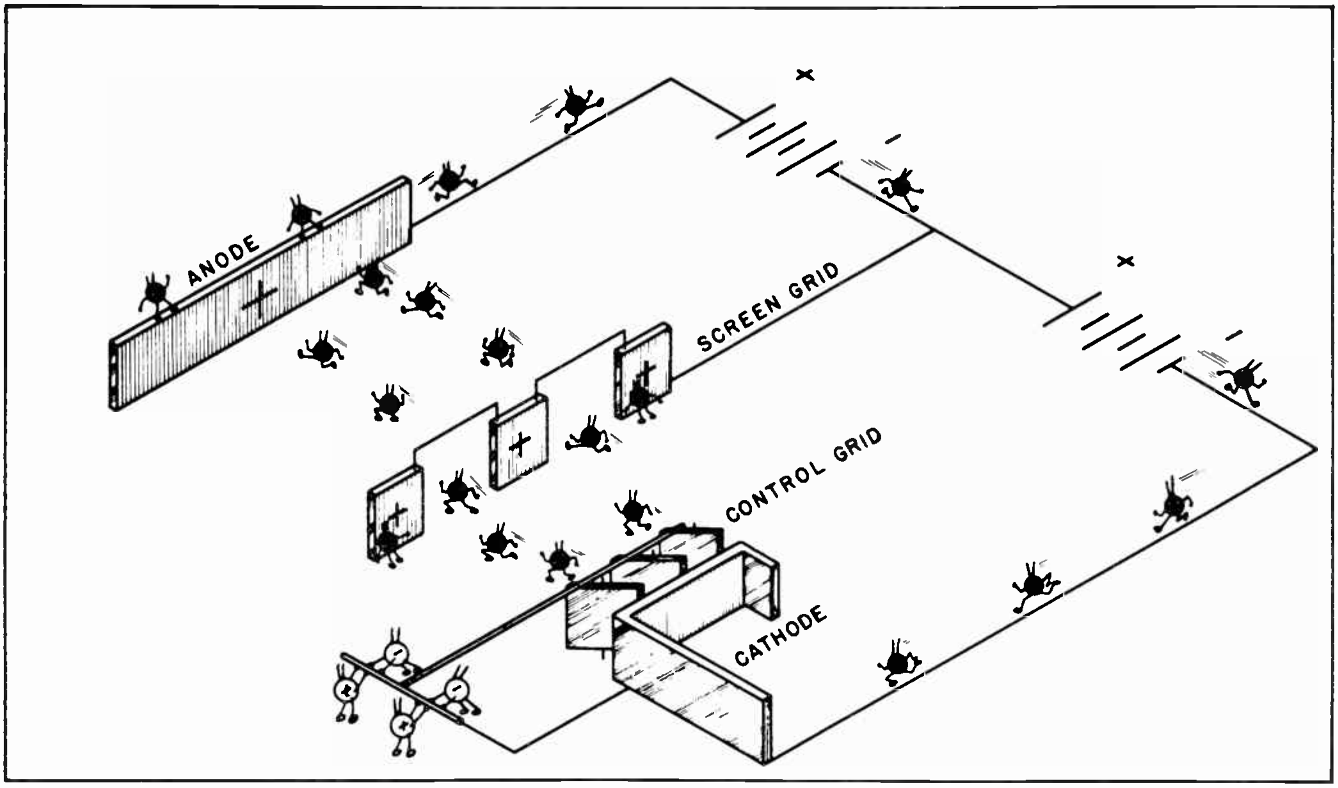

Fig. 5. Movement of Electrons Through a Screen Grid Tube

The electrons which pass through the coils of the control grid move toward the screen grid. Some of them strike the wire mesh of the screen grid and are passed on to the outside of the tube through the screen grid circuit. But these are comparatively few. The greater portion of the electrons pass through the meshes of the screen grid. This is due to the high velocity they attain while under the influence of the electrostatic field between the cathode and the screen grid. If it were not for the anode, these electrons which pass through the meshes of the screen grid would soon lose their momentum and would return to the screen grid.

But the instant the electrons pass through the meshes of the screen grid they come under the influence of the electrostatic field which exists between the screen grid and the anode. Remember that although the screen grid is much more positive than the cathode and the control grid, it is much more negative than the anode. Thus the instant the electron passes through the meshes of the screen grid it is caught in the electrostatic field between the screen grid and the anode, and since the anode is much more positive than the screen grid, the electron continues on to the anode. (See Fig. 5.)

The main point is that the electrostatic field which exists between the screen grid and the cathode remains virtually constant -- it does not fluctuate in strength as does the field between the anode and the cathode in the triode. This is because relatively few electrons go to the screen grid, and what few do reach it do not cause any appreciable voltage fluctuations between the grid and its external source of voltage. Further than this, the screen grid is also closer to the cathode in a tetrode than the anode normally is in a triode. Thus it is possible for a much lower positive voltage on the screen to set up a much stronger electrostatic field than a much higher voltage could set up in a triode between the anode and the cathode. The ultimate result is that the amplification factor of a tetrode can be made many times higher than that of a triode tube.

The screen grid itself is usually made of a wire mesh as indicated in Fig. 3. Very frequently this wire mesh is in two parts. One part is interposed between the anode and the control grid as shown in Fig. 3; the other part is actually placed outside the anode. Placing a portion of the screen grid between the anode and the outer glass envelope of the tube protects the anode from stray electromagnetic and electrostatic fields which might affect it from outside the tube.

In construction, the anode was connected to a pin at the base of the tube. So was the cathode and the heaters. The connection for the screen grid was also usually made to a pin in the base of the tube. But the control grid was brought out to a little metal cap on the top of the glass envelope. These tubes were so extremely sensitive that the control grid connection was moved just as far as possible from the other tube connections. By constructing the tubes in this manner, the grid connection could be made to the tube above the metal chassis on which the tube was mounted while all the other connections were made underneath the metal of the chassis. One of the best examples of the screen grid tube, the tetrode, is the type 24. The type 24 was at one time the finest radio tube on the market.

But like so many other tubes, the tetrode was not perfect. The tetrode required a voltage supply which was somewhat complicated. It needed a positive voltage for the screen grid of approximately 90 volts. It needed another voltage for the anode which was considerably higher. So long as these voltages were supplied, the tetrode operated beautifully. The public demanded good radios, yet lower and lower prices. This meant short-cuts had to be found through manufacturing practices. The heavy and expensive transformer for the power supply was dropped in many radio receivers. But when the transformer was removed, the tetrode did not always work properly. When the anode voltage on the tetrode dropped into the region below 90 volts, the anode current had a habit of dropping so low as to seriously distort the signal.

Section 4. SECONDARY EMISSION

This drop in the anode voltage was caused by what is called *secondary emission.* Up to this time we have discussed only one type of emission -- thermionic emission caused by heat. Actually there are several types of emission. It was one of these — secondary emission - which caused trouble in the tetrode when the anode voltage was reduced below certain critical values.

When an electron travels through the space of a tube under the influence of the electrostatic fields which exist there, it attains unbelievably high speeds. Although its travel through the tube covers only a relatively short distance, its speed sometimes approaches that of light if the conditions are just right. Under almost any condition which exists in a vacuum tube the electrons can attain velocities of many thousands of miles per second.

Any object which attains such speeds acquires considerable *kinetic* energy. When the electron strikes the metal of the anode it hits so hard that it frequently knocks two or three other electrons right out of the metal into the space which surrounds the anode. This knocking loose of other electrons is known as *secondary emission.* (See Fig. 6.) Such secondary emission is normally taking place all the time at the surface of the anode of any vacuum tube. But since the anode is the most positive element in a triode such electrons as are knocked loose from the anode are quickly attracted back to it. When the anode voltage of a tetrode is considerably higher than the screen grid voltage, the electrons which are knocked loose are also quickly attracted back into the anode.

But let's see what happens when the anode voltage drops to a value comparable to the voltage on the screen grid. The electrons will be attracted from the cathode as before. Many of them will pass through the screen grid, and due to the acquired kinetic energy will continue toward the anode until it strikes that element. In striking the anode, the electron may knock several electrons loose. These will be emitted out into the space of the tube. The force with which they are knocked loose will cause many of

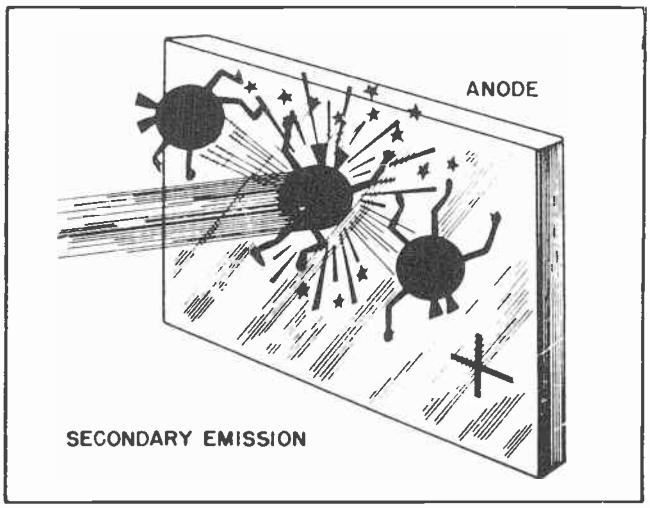

Fig.6. Fast Moving Electron Knocks Other Electrons from the Anode causing Secondary Emission.

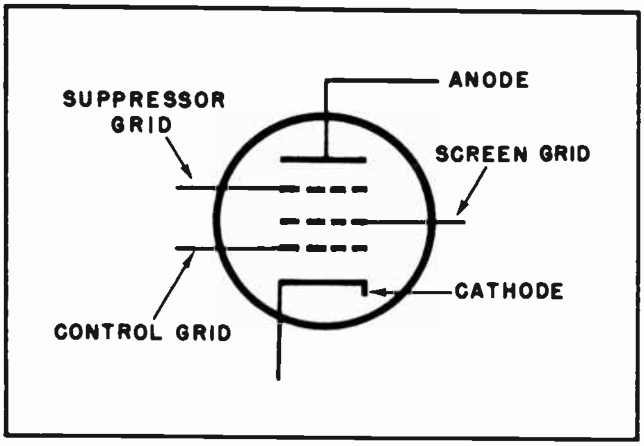

Fig.7. Symbol of Pentode Tube.

them to come under the influence of the attraction of the screen grid. If the anode voltage is low enough there will be enough electrons attracted to the screen grid to materially reduce the anode current. This reduction of the anode current in a tetrode is called the anode current "dip", and is a cause of considerable distortion in the output of the tube.

Since the tetrode tube is not suitable for operation at the low voltages found in radio receivers which do not use power transformers, the use of the tetrode gradually fell into disfavor. It is seldom used these days except for replacement purposes in the older model radios. However, these screen grid tubes will still be found in nearly

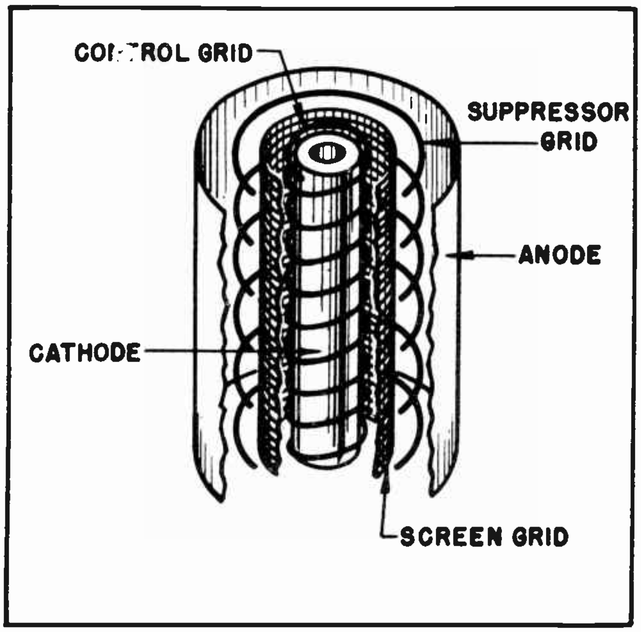

Fig.8. Construction of One Type of Pentode.

every radio receiver built between 1930 and about 1938.

Section 5. THE SUPPRESSOR GRID

Largely due to the fact that the general public kept demanding less expensive, and less bulky radios, the use of the tetrode gradually declined. Notwithstanding the fact that the tetrode, with its two grids, was a great improvement over the triode for use in receiving sets, the drawback of needing a high voltage power supply kept the price of the radio receivers which used these tubes too high.

Tube manufacturers, and their research scientists, kept on with their experimentations. Eventually, in the latter part of the 1930's, it was found that by adding still another grid to the vacuum tube the problem of secondary emission could be overcome. Not only was it possible to overcome that problem, but the amplification factor of the vacuum tube was increased far higher than that of the tetrode. This third grid was called the "suppressor grid" because its prime function was to suppress the secondary emission.

The suppressor grid was placed between the screen grid and the anode as indicated by Fig. 7, which shows the symbol for the "pentode" tube. The name "pentode" has been given to a tube with three grids. This is because the three grids, the cathode and the anode make five elements and the name "pentode" is a coined word which means "five" and "path". Some of the names which are used to designate the various type tubes seem to strain somewhat the original roots from which the words are derived, but these names have been applied to the tubes as we have described them, and will probably continue to be used far into the foreseeable future. Some of us may be inclined to question the aptness of some of the names applied to some of the vacuum tubes, or to some of their elements. But the fact remains that these are the names by which they are universally known and it is not for us to attempt to change them.

The actual physical arrangement of the various grids and the anode and cathode in some types of pentodes would be similar to that of Fig. 8. However, other types of pentode tubes have all the grids constructed of spiral turns of wire as shown in Fig. 9. Each of the grids will be securely anchored within the envelope of the tube so none of

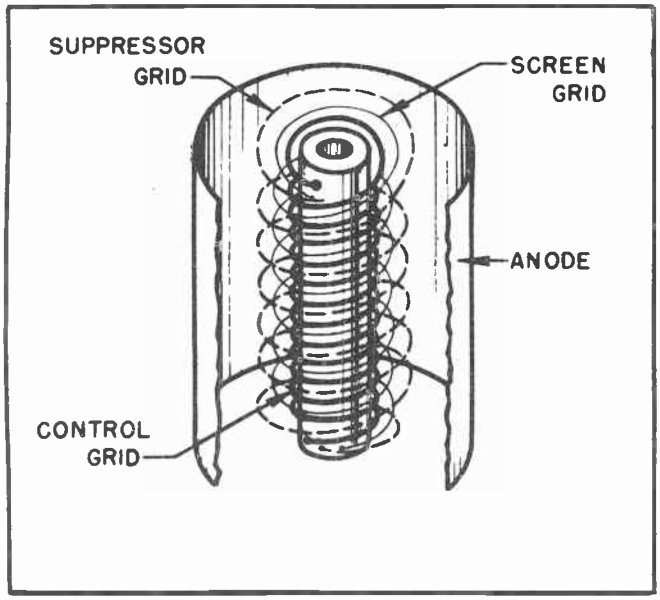

Fig.9. Physical Construction of Another Type Pentode.

the wires are free to move and thus accidentally make contact with any of the other elements.

If such a tube were sliced right down through the middle, cutting across the various grids and the anode, it would look something like that of Fig. 10. In a pentode of this type the spirals of the grids are usually arranged so the wire of each grid lies in the "shadow" of the grid ahead of it. This means the wire of the screen grid lies in the same plane as that of the control grid. When the screen grid is arranged in this manner, the electrons which have passed through the gaps between the spirals of the control grid will keep right on accelerating their speed as they approach the screen grid, and when they reach the screen grid, the greater majority of them will pass right on through the gaps between the spirals of the screen grid. Their speed will have become so great by the time they reach the screen grid that most of them will pass through the gaps which exist between the wires of that grid.

They will likewise pass through the spaces between the spirals of the suppressor grid which are also arranged so the turns of that grid also lie directly behind the turns of the screen grid. In this manner, those electrons which are able to sneak through the control grid find a wide open path straight through to the anode.

Section 6. WHAT THE SUPPRESSOR GRID DOES

You may say this is all well and good, but just what does the suppressor grid do? You remember that when the anode voltage on the tetrode tube dropped a little low we would encounter what is called secondary emission. This secondary emission is brought about because the electrons which strike the anode knock other electrons loose. These secondarily emitted electrons have no high degree of kinetic energy driving them toward the anode. On the contrary, when they are

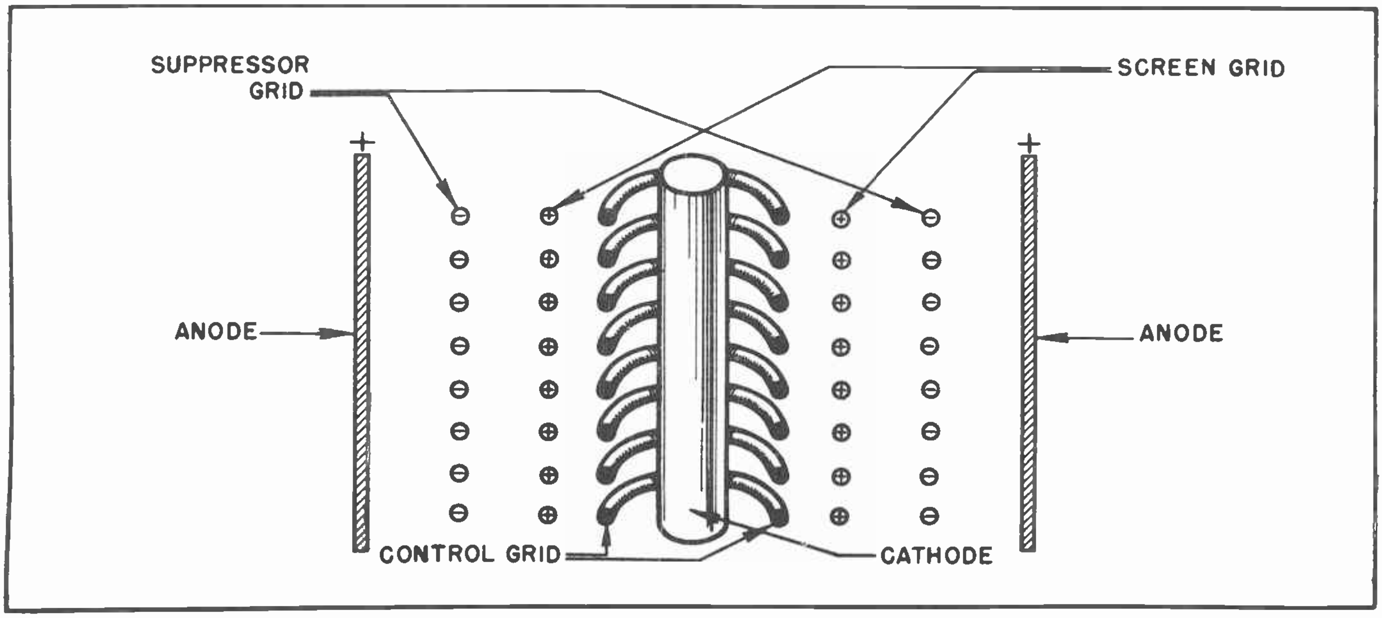

Fig.10. Arrangement of Grids in a Pentode.

knocked loose from the anode they are forced toward the screen grid. When the screen grid is almost as positive as the anode, many of these secondarily emitted electrons will reach the screen grid, and pass to the outside of the tube through the screen grid circuit. But let's see what happens when there is a suppressor grid between the anode and the screen grid.

A study of Fig. 10 indicates that the suppressor grid is negative with respect to both the anode and the screen grid. Maybe the illustration does not make this entirely clear, but such is actually the case. To review the voltages on the various elements within the tube, we can start at the cathode and count it as being at zero voltage. The first grid, the control grid, is usually negative with respect to the cathode. The screen grid will then be positive with respect to the cathode, a common voltage being about 90 volts. Then comes the suppressor grid; it is usually at the same potential as the cathode. In fact, the common practice is to connect the suppressor grid directly to the cathode. Finally we have the highly positive anode.

Now to study the action of the suppressor grid when the anode voltage drops somewhat low -- or at any other time for that matter. The electrons may be knocked loose from the anode under the bombardment of the fast moving free electrons which have been attracted from the cathode just as they were in the tetrode. But the instant the electrons are emitted from the surface of the anode, they emerge into an electrostatic field between the positive anode and the much more negative suppressor grid. The result is that they are immediately attracted right back into the anode again. Since the electrons have not gotten far from the anode they do not acquire any great amount of kinetic energy by the time they are attracted back to the anode. Thus they will not knock other electrons loose from the anode as do the fast moving electrons coming directly from the cathode.

Section 7. ELECTROSTATIC FIELDS WITHIN A PENTODE

To make certain you clearly understand the nature of the various voltage relationships which exist within a pentode tube, suppose we go back and review the complete action of such tube. First, it should be understood that the anode plays virtually no part in attracting the electrons from the vicinity of the cathode. This function is left to the screen grid. Actually, the anode is so completely screened from the cathode by the screen grid and the suppressor grid that it cannot have any material effect on the electrons near the cathode.

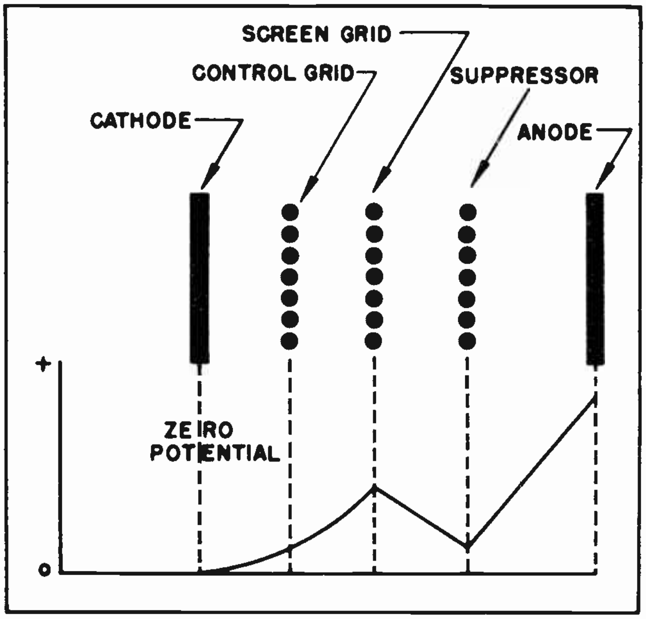

Fig. 11. Electrostatic Fields Which Exist Within a Pentode.

A study of Fig. 11 may help to clear up any possible uncertainty you may feel about this situation. The upper part of Fig. 11 shows the general physical arrangement of the various elements within a pentode tube insofar as they relate to each other. It can be seen that an electrostatic field exists between the cathode and the screen grid. This field is such that the screen grid is much more positive than the cathode, and thus attracts many electrons in that direction.

Electrons, under the influence of the electrostatic field which exists between the cathode and the screen grid, move toward the screen grid. The closer the electrons come to the screen grid, the stronger becomes the attraction. This results in the electrons moving faster and faster. By the time the electrons reach the locality of the screen grid they are traveling at terrific speeds, many thousands of miles per second. Those electrons which happen to be traveling directly toward one of the spiraling wires of the screen grid will strike the grid and pass to the outside of the tube through the screen grid circuit. But these electrons will be relatively few because the effect of the control grid is to create "shadows" in the direction of the screen grid wires, the electrons are "beamed" toward the spaces between the spirals of the screen grid wire. The electrons continue to rush ahead at great speed, but under the influence of the field which exists between the screen grid and the suppressor grid they are slowed down considerably. This is because the suppressor grid is much more negative than the screen grid. However, they still have enough kinetic energy for them to coast through the spirals of the wire which compose the suppressor grid.

After passing the suppressor grid the electrons are again caught up in another electrostatic field. This is the one which exists between the suppressor grid, which is at zero potential, and the anode, which is highly positive. The electrons are again speeded up, and continue to gather speed until they strike the anode. Since the distance between the suppressor grid and the anode is not so great as that between the screen grid and the anode in a tetrode tube, the electrons do not attain such great speed before striking the anode. Thus they do not cause as much secondary emission, and what they do cause is easily taken care of by the action of the suppressor grid.

The graph in Fig. 11 shows how the electrostatic field within the tube is built up in a positive direction from the cathode to the screen grid. From the screen grid to the suppressor grid, however, the electrostatic field is reversed. But it does not drop all the way to zero. This is what causes the electrons to slow down as they approach the suppressor grid. But between the suppressor grid and the anode, the electrons come under the influence of the electrostatic field between the suppressor grid and the anode. This is where they obtain their final burst of speed. The graph in Fig. 11 shows how the electrostatic field becomes quite strong between the suppressor grid and the anode.

Section 8. AMPLIFICATION FACTOR OF PENTODES

Because the anode in a pentode is so completely shielded from the cathode, and the electrons in the vicinity of the cathode, the anode voltage has very little effect on the anode current. This means that very great changes in the anode voltage must be made to effect any measurable change in the anode current. On the other hand, the anode current is greatly influenced by the control grid voltage.

Since it requires a very large change in the anode voltage to effect the same change in the anode current as is effected by a very small change in the control grid voltage, it follows that the amplification factor of the pentode tube is very high. Tubes such as the 6SJ7, a very common type, have an amplification factor of more than 1500. This is approximately 100 times the amplification factor of most triode tubes.

It can be readily seen how useful the pentode tube can be in building up the extremely small voltages which are frequently encountered in radio, television and industrial electronic work. The voltage which is built up on the antenna of a radio or television receiver is so small that it is measured in units called *microvolts*, a microvolt being one millionth of a volt. Antenna voltages of from 25 microvolts to 100 microvolts are very common. The pentode tube has no equal in building up these unbelievably small voltages to values where they can be used.

In the field of industrial electronics the pentode tube is also invaluable. The photoelectric tube, for example, passes currents which are measured in *microamperes*. The voltages found in photoelectric circuits are also so small they are measured in microvolts. The pentode is extremely useful in building up these voltages to values which are commercially useful.

But while the pentode is without par in building up voltages of very small magnitude it should not be thought that it is universally useful. So long as the voltage *changes* on the grid of the tube do not exceed approximately 0.1 volt, the tube does an excellent job. Thus it can take an extremely small voltage and build it up to more reasonable values. But when the grid voltage reaches a value where its changes exceed 0.1 volt, the pentode loses its usefulness. After the voltage has been built up to values on the order of 0.1 volt or greater, it is much better to use a triode tube. Pentodes introduce distortion when the grid voltage swings exceed about 0.1 volt. The triode will operate beautifully with voltage swings of many volts on its grid. Some power stages in transmitting stations use triodes on which the grid voltage swing amounts to 125 volts, and more.

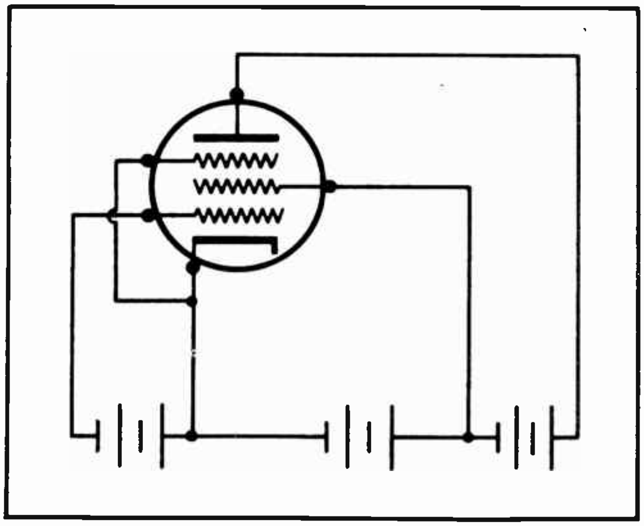

Fig. 12. Pentode with Externally Connected Suppressor.

This gives an indication of why no one vacuum tube can be universally used for all purposes. Where the signal is extremely small, as is the case of the one picked up by the radio or television antenna, the signal is commonly amplified by means of the pentode tube. Then when the voltage has been built up to a much greater strength the triode is often brought in and takes over the job to build up the voltage still higher in the final stages of amplification.

Section 9. HOW THE SUPPRESSOR GRID IS CONNECTED

There are several types of pentode tubes. Some have the connections to the suppressor grid brought out through a base pin connection so that it can be connected to an external circuit on the outside of the tube. This is shown in Fig. 12 which shows the suppressor grid connected to the cathode by means of connections outside of the tube. When the connection to the suppressor grid is brought out separately to the outside of the tube, it is possible to use the suppressor grid for other purposes besides that of suppressing secondary emission. There are not many other uses for the suppressor grid beside the one for which it was originally designed, but there a few. This is particularly true in the case of radio transmitters.

There are other types of pentode tubes where the suppressor grid is connected directly to the cathode inside the tube. (See Fig. 13.) When this is done it reduces the number of connections which must be made on the outside of the tube. It is also possible to use tube bases which have fewer base pins than when the suppressor grid connection is brought out separately. Since most uses of the pentode tube require the suppressor grid to be connected to the cathode, it can just as well be connected on the inside as on the outside.

It should be remembered, however, that there are several types of pentodes in existence which have the suppressor grid connected on the outside and there are other types which have it connected to the cathode on the inside.

Section 10. BEAM POWER TUBE

When a loudspeaker, such as those in radio or television receivers or in a public address system, is to be supplied with power from a vacuum tube we are more concerned with the tube's ability to deliver a lot of anode current than we are with its ability to amplify voltages. Tubes which are used to amplify voltages normally do not allow much anode current to flow. The 6K7 tube, a pentode, is usually used in circuits where the anode current will range from about 4 milliamperes to about 7 milliamperes. The 6J7, another pentode, normally delivers about 2 milliamperes to about 6 milliamperes. The 6C5, a triode used for voltage amplification and as an oscillator tube, delivers a maximum of 8 milliamperes of anode current.

Anode currents of these amounts are not enough to drive the cones of most loudspeakers. Neither are these currents enough to operate relays and other electrical loads commonly found in industrial electronic circuits.

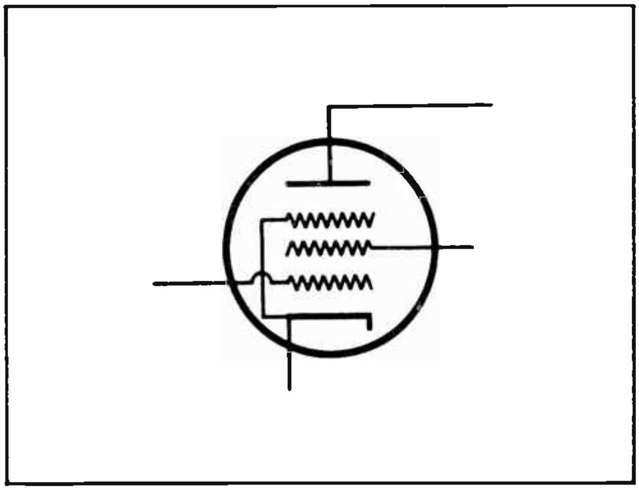

Fig. 13. Internally Connected Suppressor.

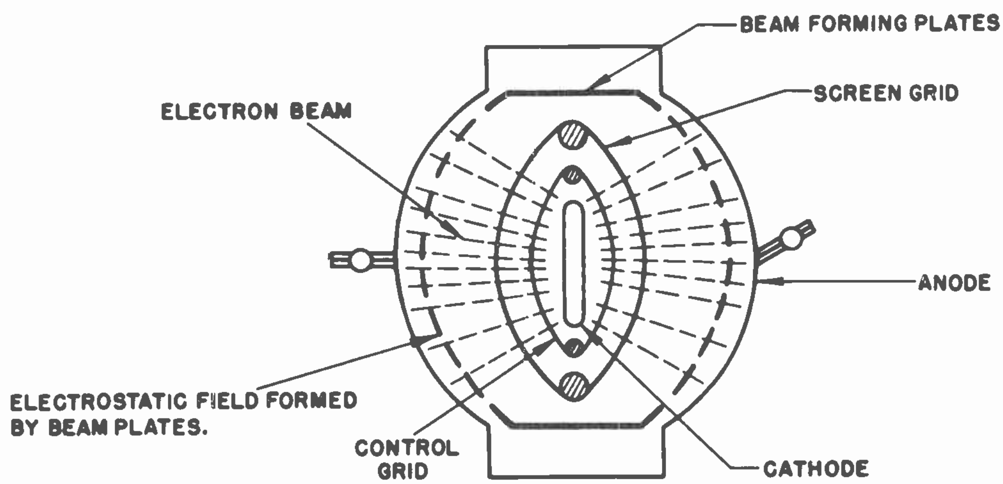

Fig. 14. Arrangement of Elements in a Beam Power Tube.

Some triodes are so designed that they are capable of delivering a lot of anode current. In fact, most of the high-power transmitting tubes are triodes. But a triode which will deliver a lot of anode current, and thus a lot of power, requires a wide swing of A.C. signal voltage on the grid. A large A.C. signal voltage is sometimes not available. To meet the need for a tube which can deliver a lot of anode current, yet not require a large signal voltage on the grid, a new type of tube was developed. This is the justly famed "Beam power" tube. The most important examples of the beam power tube are the 6L6 and the 6V6. A cutaway view of a beam power tube is shown in Fig. 1.

In a beam power tube the suppressor grid has been replaced by beam forming plates as shown in Fig. 1 and Fig. 14. Fig. 14 is a top view of the tube, such as would result if the top of the glass envelope of the tube were broken off. The spiral wires of the screen grid are located so as to be in the "shadow" of the control grid. This arrangement helps form the electron beam. The beam forming plates create an electrostatic field which extends from one plate to the other as shown by the dashed lines in Fig. 14. This field acts very much like the suppressor grid of the pentode tube.

But where the pentode tube is designed to pass only a very few milliamperes of current the beam power tube is capable of passing large amounts of electrons. In the case of the 6L6, anode current exceeding 100 milliamperes is quite commonplace. The advantage of the beam power tube is that it can control the flow of this large amount of current with approximately 30 volts on the control grid of the tube. A somewhat comparable triode power tube would deliver only about 40 milliamperes of anode current, but would require over 50 volts on the control grid.

The screen grid voltage can be somewhat higher on a beam power tube than it is on a tetrode. The beaming of the electrons into an almost solid stream between the screen grid and the anode causes a massing of the electrons at about the point where they pass through the influence of the beam forming plates. The electrons have a tendency to slow down their speed as they pass through that portion of the tube. When any fast moving body of individuals slow down, regardless of whether it is people or electrons, the tendency is for massing to occur. In the case of the electrons which form the beam in these tubes, the massing of a vast number of negative particles of electricity sets up what amounts to a flowing negative cloud. Any electrons which might be knocked loose from the anode due to secondary emission immediately come under the influence of this moving negative cloud and quickly return to the anode.

Section 11. **TUBE CONSTANTS**

Up to this time we have spoken in generalities about many things concerning vacuum

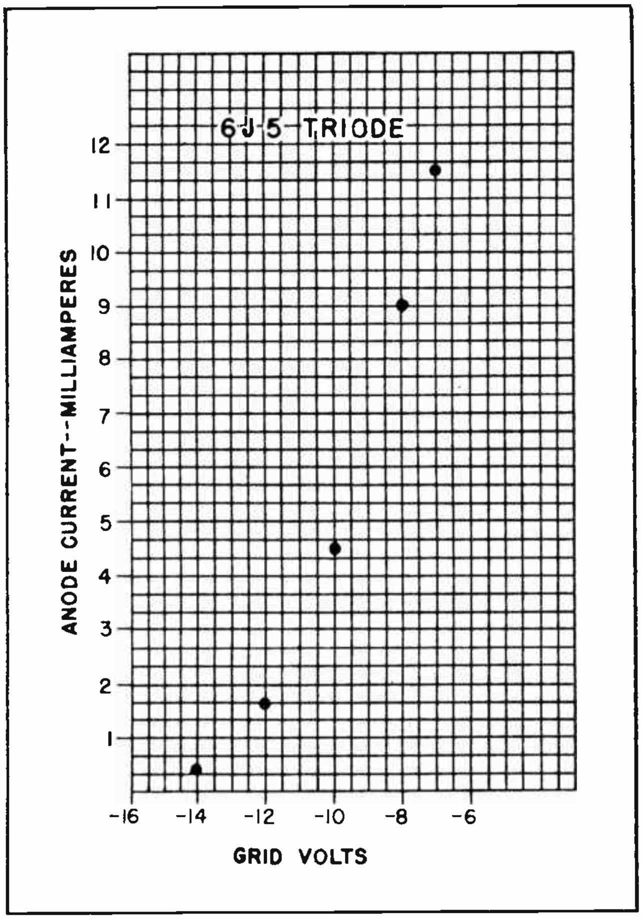

Fig.15. Graph of Grid Voltage Against Anode Current.

tubes. This applies to triodes, tetrodes, pentodes and beam power tubes. We are now ready to take up the discussion of what are generally called "tube constants". These are the interdependent relationships of the various operating characteristics of vacuum tube amplifiers which it is essential to understand if we are to put these tubes to work at specific tasks.

The tecnnical name for tube constants is the "parameters of tubes". This is the term used by many engineers and long haired writers. But the term "tube constants" seem more desirable, and has the sanction of long usage among most radio and electronic men.

One thing which is encountered in all vacuum tubes which are used as amplifiers is that they have three identifying ratings. Each rating has a different name but each is a *tube constant.*

Tube constants are ratings which depend upon the geometric structure of the tube. This means the physical size of the tube and the spacing of the various elements within the tube. These ratings -- tube constants -- have very practical values because they determine the performance of the tube when in operation.

One tube constant which we have mentioned before briefly is *amplification factor.* The tube constant of amplification factor expresses *numerically* how much greater is the effect of the grid voltage in controlling the anode current than is the anode voltage. To put this in other words, this is a numerical expression which has as its basis the action of the grid field and the anode field upon the electron cloud around the cathode with particular respect to the distance between the grid and the anode. In the final analysis, the amplification factor of a triode depends very largely upon the spacing of the anode and the grid with respect to the cathode.

The amplification factor is usually expressed as:

$$\mu = \frac{dE_p}{dE_g}$$

This does not mean that Mu, the amplification factor, is equal to the full *anode voltage* divided by the full *grid voltage.* Far from it. Note that little *d* in front of the *E.* Mathematically speaking, that little *d* stands for a "a little bit of". In this case Mu is equal to a "little bit of" the anode voltage divided by a "little bit of" the grid voltage. To make this clear, suppose we draw ourselves some graphs showing the relationships between the anode current, the anode voltage and the grid voltage.

In Fig. 15 we have prepared ourselves a chart for making a graph. Along the bottom of the graph we have marked off the vertical lines to represent various values of negative grid voltage. Along the left hand side of the graph we have marked off the graph to show the number of milliamperes of anode current which would flow under various grid voltage consitions.

For the sake of convenience, suppose we were to place 250 volts on the anode of the tube. We will keep this same anode voltage while we take several measurements of the anode current while we change the grid voltage. If we took the first anode current reading while the grid voltage was a nega-

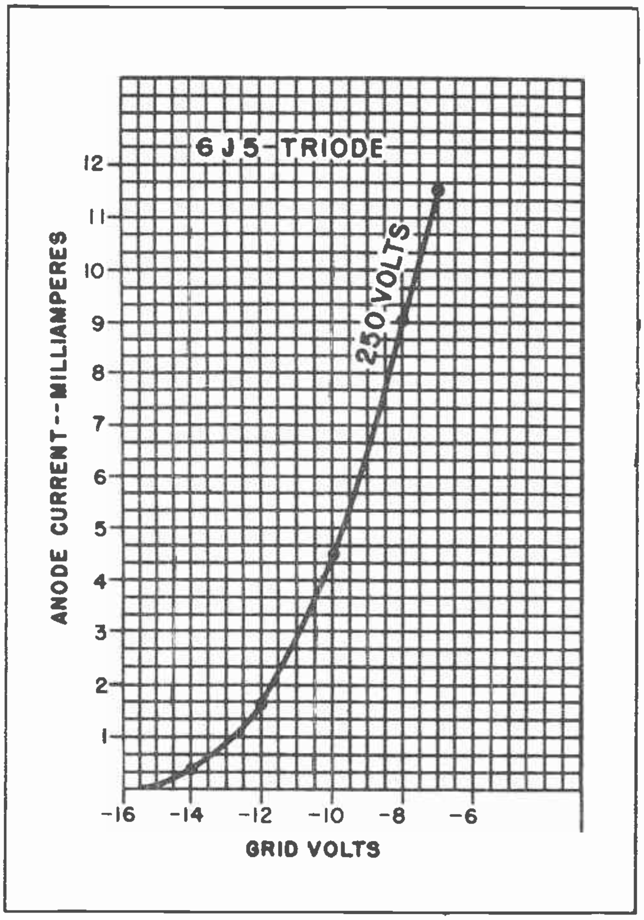

Fig.16. Grid Voltage - Anode Current Characteristic Curve.

tive 16 volts we would find there was no anode current at all. So let's take a current reading while the grid voltage is 14 volts. If we were making a real test we would find that this tube would have a little less than .5 milliampere of anode current at -14 volts. We have put a dot on the graph at that point.

Next we will take an anode current reading with the grid voltage at -12 volts. A real reading would show there was a little over 1.5 milliamperes flowing. We have placed another dot on the graph at that location.

We will next take a reading for -10 grid volts. This would show 4.5 milliamperes, and we have marked another dot at that location. At -8 grid volts we would have 9 milliamperes of current flowing, and at -7 grid volts we would have 11.5 milliamperes of anode current.

In Fig. 16 we have connected together all the dots we marked on the graph of Fig. 15. This gives us a smooth curve. This shows the anode current against the grid voltage for a constant anode voltage -- in this case 250 volts. This is quite commonly called the *I_p-E_g CHARACTERISTIC* curve. This characteristic curve is used constantly in working out problems revolving around the amplification characteristics of vacuum triodes.

In Fig. 17 we have drawn another curve on the graph in addition to the one drawn in Fig. 16. This gives us two curves in Fig. 17. One of these curves shows the changing anode current as the grid voltage is changed while the anode voltage is held steady at 250 volts. This is the same curve we drew in Figs. 15 and 16. The other curve in Fig. 17 shows the varying anode current as the grid voltage is changed but while the anode voltage is held constant at 200 volts.

These two curves resemble very closely those we would draw if we took actual measurements with a type 6J5 vacuum triode tube. Now suppose we wanted to find the amplification factor of that tube. Suppose we wanted to find the amplification factor when the grid was at -8 volts, and the anode was 250 volts.

The first step would be to locate a point which corresponded to those two values. In this case that would be at the point marked "P". Then we go up the 250-volt curve to some point, in this case we will use point "A". From point "A" we will drop a line vertically to intersect with the 200 volt line. This is the dotted line marked "dE_p". This line intersects with the 200-volt line at "B".

From "B" the line runs horizontally to intersect the 250-volt line again, this time at "C". This is the dotted line marked "dE_g".

At point "A" the anode current is approximately 11.5 milliamperes. At point "C" the anode current is approximately 5.4 milliamperes.

Note that point "A" also represents -7 grid volts and point "C" represents approximately 9.6 volts.

The *change* in plate current amounts to the difference between 11.5 milliamperes and 5.4 milliamperes, or 6.1 milliamperes. You should understand that this 6.1 milliamperes

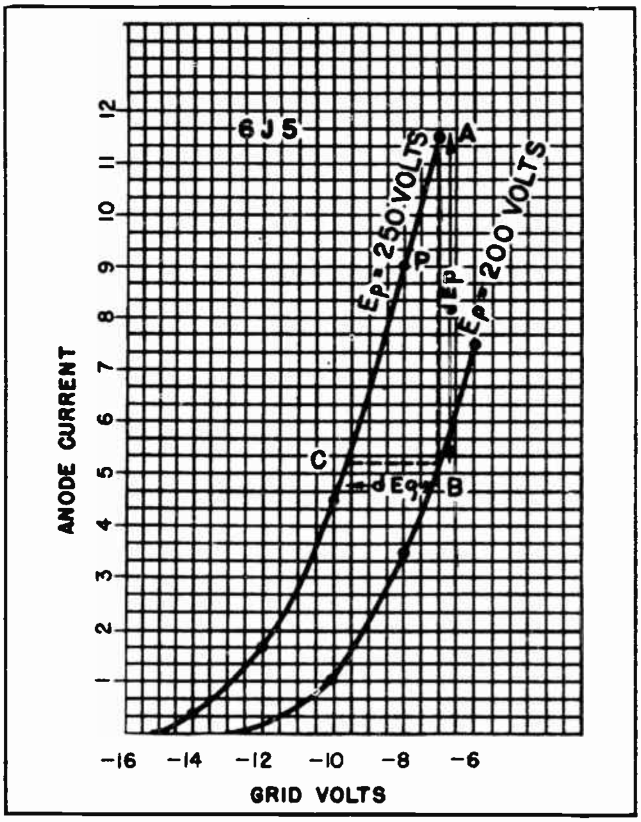

Fig.17. Characteristic Curves at Two Anode Voltages.

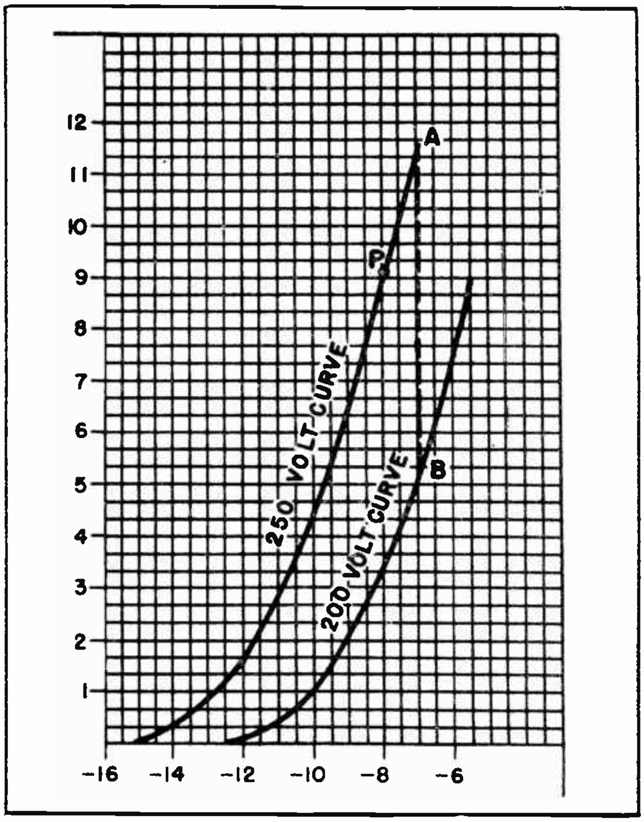

Fig.18. Graph Showing the Method of Calculating Plate Resistance.

represents a very significant value. It is *not* the *total* current which flows. It is *not* the *minimum* current which flows. *It is the change in anode current* we are bringing about.

Now note this. There are two ways in which we can bring about this 6.1 milliampere of current *change*. We can do it by changing the voltage on the anode, or we can do it by changing the voltage on the grid.

If the anode voltage is kept at 250 volts we can bring about the *change* by moving the grid voltage from "C" to "B", or from "B" to "C". This amounts to a grid voltage *change* of 2.6 volts. (2.6 volts is the difference between -7 volts and -9.6 volts.) If the grid voltage is kept at -7 volts, the anode current can be changed by 6.1 milliamperes by reducing the anode voltage from 250 volts to 200 volts as indicated by the "dE_p" line between "A" and "B". This is a difference of 50 anode volts.

$$dE_p = 50 \text{ volts.}$$

$$dE_g = 2.6 \text{ volts.}$$

Our formula says that amplification factor, or MU, is equal to:

$$\frac{dE_p}{dE_g}$$

In this case it is equal to 50 divided by 2.6 or roughly 19.2. This value compares very favorably with the rating of 20 which is given this type of tube by the manufacturer.

Section 12. PLATE RESISTANCE

Another *tube constant* which is important to us in our study of vacuum triodes is that of *plate resistance*. Actually there are two kinds of plate resistance: A-C and D-C. The D-C resistance is normally of little interest to us in vacuum tube work. The D-C plate resistance is quite easily determined for any given value of grid voltage.

Fig. 18 is similar to the graphs we worked with in Figs. 16 and 17. Suppose we wanted to determine the D-C plate resistance of the tube when operating with -8 volts on the grid, and 250 volts on the anode. First we find the operating point for such condition. To do so we move up the vertical grid voltage line for -8 volts until we come to the 250 volt anode curve. This is located at point "P". This point also represents 9.1 milliamperes of anode current. To find the D-C plate resistance we merely make use of Ohm's Law and divide the anode voltage by the anode current. In this case that is 250 volts by 9.1 milliamperes. This is roughly equivalent to 27,400 ohms.

For any other value of anode voltage the D-C plate resistance would be determined through the use of Ohm's Law in a like manner. But the determination of the A-C plate resistance is a slightly more difficult task. Yet not too difficult.

The A-C plate resistance of a vacuum triode is defined to be the ratio of the *change* in anode current resulting from a *change* in anode voltage. The formula for A-C plate resistance is:

$$r_p = \frac{dE_p}{dI_p}$$

We can again refer to Fig. 18. We want to find the A-C plate resistance of this tube with the grid held at a steady voltage. Suppose we maintain the grid at -7 volts. We will then reduce the anode voltage from 250 volts to 200 volts. This will result in the anode current dropping from approximately 11.5 milliamperes at point "A" to approximately 5.6 milliamperes at point "B". This is a difference, or *change*, of 5.9 milliamperes for a difference, or *change*, or 50 volts.

The A-C plate resistance is then found by dividing the 5.9 milliamperes into 50 volts which gives us approximately 8400 ohms. This is slightly higher than the rating given by the manufacturer but the difference can be accounted for by slight discrepancies in drawing the curves on the graph. The result is sufficiently accurate for most vacuum tube work.

Section 13. TRANSCONDUCTANCE (MUTUAL CONDUCTANCE)

The third *tube constant* which is always important to us in vacuum tube work is *transconductance.*

Let us ignore for a moment the fact we are dealing with vacuum tubes. We will think merely in the terms of simple electrical circuits. When we do this we know that any resistance in the circuit always tends to limit the current. By the same token it stands to reason that the plate resistance of a vacuum tube, regardless of what its value might be, would also tend to limit the value of the change in plate current which the change of grid value tries to produce.

Since the change in plate current which is caused by any change in grid voltage is always important, it would seem to be only natural that we should have some term to designate this important relationship. This is where *transconductance* comes in. It is the term used to define that relationship. Transconductance is also known as *mutual conductance.* In fact, the latter name was once the favored one for it, but in recent years it is being used less and less.

Transconductance is the ratio of change caused in the anode current by any change in the grid voltage.

The symbol for transconductance is g_m. It is expressed in *micromhos.*

The matter of transconductance will be discussed at considerably greater length in other lessons.

NOTES FOR REFERENCE

Tetrodes are vacuum tubes which have two grids. They are four element tubes.

Pentodes are five element vacuum tubes. They have three grids.

The screen grid is positively charged and is used to shield the anode from the grid, reducing interelectrode capacitance and raising the amplification factor.

The suppressor grid is used to suppress secondary emission.

Beam power tubes deliver relatively large power with relatively small grid voltage.

Tube constants refer to plate resistance, amplification factor and transconductance.

NOTES

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Contents: Introduction - Advantages of Parallel Connections - Series Connections - Where Series Connections Cannot be Used - Current in Series Circuits and Parallel Circuits - Effective Resistance - Unequal Resistances in Parallel - The Reciprocal Method of Finding Effective Resistance - Tapped Resistors in Parallel - Increasing the Range of a Meter - Another Method for Determining Effective Resistance - Finding the Value of One Parallel Resistor When the Other is Known - Series-Parallel Circuits - Reference Notes.

Section 1. INTRODUCTION

At the top of Fig. 1 we have two vacuum tubes whose filaments are connected in series to a source of potential. The source of potential might be a battery, or might be the power line from the power company. Each tube's filament is controlled by a switch, and both switches are open.

Now suppose we close the switch to the left-hand tube. Will the filaments of that tube light up? No, because the circuit to that filament also passes through the filament of the other tube, and through its switch which is also open. But if we now also close the switch to the right-hand tube, both filaments will light up. This is because there will be a complete circuit through the two closed switches and through both filaments.

But if either switch is opened, both filaments will go dark. We have no separate control over either tube individually.

Section 2. ADVANTAGES OF PARALLEL CONNECTIONS

In the lower part of Fig. 1 we have reconnected the filaments of the same tubes, using the same switches, and have connected them to the same source of power. But we have done away with the series connection and have now connected the two filaments in *parallel* to the source of power.

We will again close the switch to the filament of the left-hand tube. This time the filament will light up. There is a complete circuit to the filament entirely independent of the filament of the other tube. The circuit is from the source of

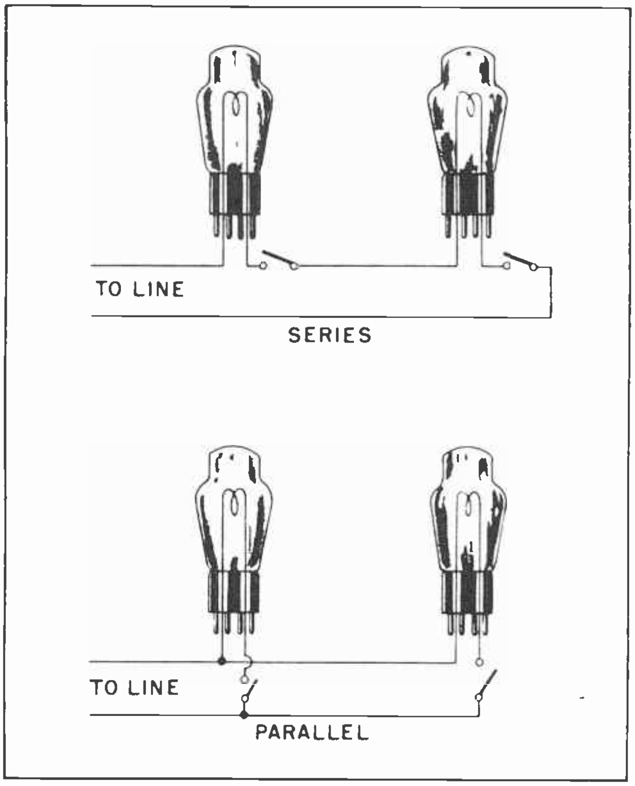


Fig. 1. Lamps Connected in Series and in Parallel.

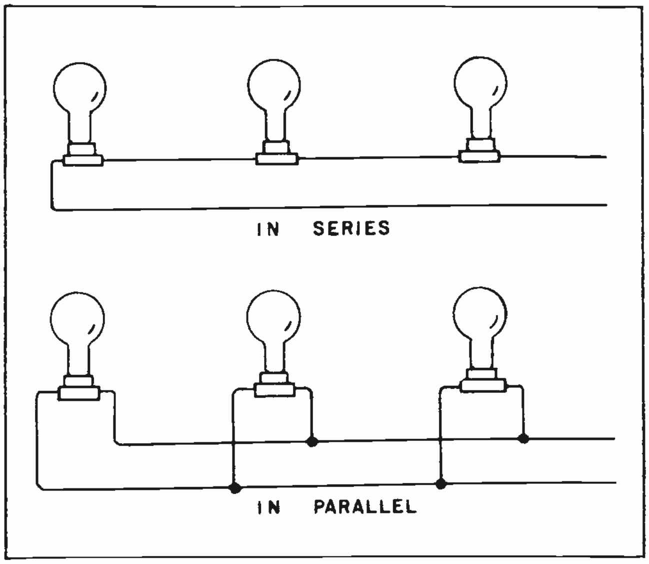


Fig.2. Lamps in Series and in Parallel.

power on the upper line, through the filament through the switch to the other line, then back to the source of power.

We will next close the switch to the filament of the right-hand tube. The filament of this other tube will light up. This is because there is a complete circuit to this filament -- a circuit that is in no way dependent on the circuit to the left-hand tube.

Each filament takes its own current from the line. The current through the filament of the left-hand tube does not flow through the filament of the right-hand tube. Neither does the current through the right-hand tube flow through the left-hand tube. Each is completely independent of the other. Each will work perfectly regardless of what is happening in the other tube. For this reason we can open or close the switch to either tube filament causing it to light up or go out as best suits our convenience. Thus with parallel connection we have individual control of each tube. As you have probably gathered, there are many places where the parallel connection is ideally suited.

Section 3. SERIES CONNECTION

Nearly all the electric lamps in our homes are connected in parallel. This makes it possible to turn on whatever lamp is needed at any particular time, and to turn off those which are not needed. If all the lamps in the house were connected in series it would be necessary to have them all burning at one time, or have all of them turned off. Furthermore, if all the lamps in the house were connected in series and one of them happened to burn out, then all the lamps in the house would go out. This would be most inconvenient to say the least.

This is shown a little more clearly in Fig. 2. At the top are three electric lamps connected in series. If one lamp burns out, or if one is removed from the socket, it breaks the electrical circuit and no current can flow through the other two lamps. As a result, the other two lamps also go out.

At the bottom of Fig. 2 the connections to the lamps have been rearranged. The three lamps are now connected in parallel. It is readily apparent that one or more of the lamps can burn out, or be removed from the socket, without affecting the other lamp, or lamps. This is because both sides of each lamp are connected directly to the source of power. There is a complete circuit from the source of power through each lamp entirely independent of the circuits through the other lamps. It should now be easy for you to determine from the actions of the other lamps when one lamp in a group burns out, or is removed, whether the lamps are connected in series or in parallel.

It has been mentioned that usually electric lamps are connected in parallel. But this is not always true. Frequently the lamps used to light up Christmas trees are connected in series. This is the reason that when one of them burns out they all go out. Some street lighting systems use lamps connected in series. In the past it was sometimes thought that series connections for street lighting circuits had certain advantages over the parallel system of lighting. But the disadvantages now seem to be somewhat greater than the advantages, and the modern trend is to get away from the series systems. Airport lighting on some landing fields use series connections for their landing lights where the lines to the lights lead for long distances across the fields. But these cases are all exceptions to the general rule that most electric lamps are connected in parallel.

Section 4. WHERE SERIES CONNECTIONS CANNOT BE USED

With series connection, all the separate parts of the circuit are connected end to end, one after another. Each of them must carry exactly the same current as all the others. And if any part does not carry any current, then no part has any current. In order to use a series circuit it is necessary to connect together only those types of electrical devices which use exactly the same amount of current. Two or three 100-watt lamps could be connected in series, for example, across the proper voltage and they would work perfectly. But if you tried to connect a 60-watt lamp and a 200-watt lamp in series you would run into trouble. These two lamps do not use the same amount of current. If you tried to force through enough current to light the 200-watt lamp you would likely burn out the 60-watt lamp. On the other hand, if the 60-watt lamp worked all right, the chances are there would scarcely be enough current through the 200-watt lamp to even redden its filament.

Neither could you connect an electric flatiron in series with a 100-watt lamp. They are not designed to use the same current and you would run into trouble with one or the other.

When using two or more devices which are designed to use the same voltage, it is usually more convenient to connect them in parallel than to connect them in series. Under most circumstances it is more convenient to maintain a power source whose voltage remains the same, than it is to have a source whose current remains constant.

Section 5. CURRENT IN SERIES CIRCUITS AND PARALLEL CIRCUITS

When using a series connection, all the various parts of the circuit use the same current, but may have widely varying potential drops. The difference of potential, or voltage drop, across each part of the circuit will depend upon the resistance of that particular part. This was gone into in considerably more detail earlier.

With a parallel connection, all parts operate at the same potential difference, but may use widely varying currents. The exact amount of current through each part of the circuit will be determined by the resistance of that part.

In Fig. 3 we show three lamps connected in series. One lamp has a resistance of 20 ohms, the second has 40 ohms and the third 60 ohms. According to our rule for combining resistance in a series circuit this would add up to a total of 120 ohms of resistance for the complete circuit. A voltage of 240 volts is impressed upon this circuit, and this voltage will cause a current of 2 amperes to flow in the circuit.

As a result of the current flowing through the various resistances there will be a voltage *drop* across each resistor. The exact amount of the drop will be determined by the amount of resistance and the value of the current. (See Fig. 4.) But the total voltage drops around the circuit will be equal to the original voltage of the source, 240 volts.

Now let us see just what the situation will be when we connect these same lamps in parallel across the 240 volt power source. Because they are connected in parallel, each lamp will have the full 240 volts of the source across it. This is shown in Fig. 5. The current through each lamp will be determined by the value of the resistance of each lamp and the voltage across it. Since

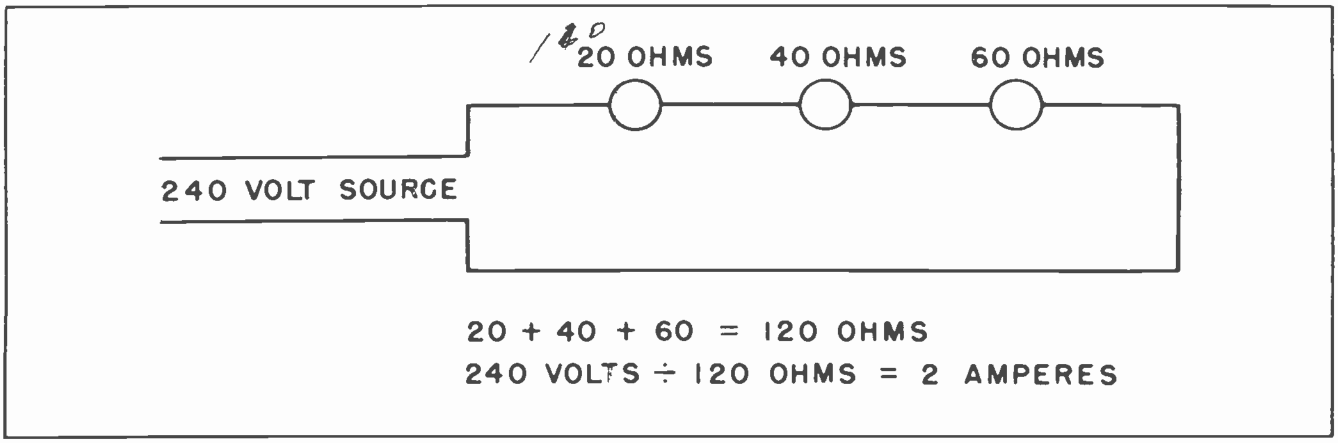


Fig.3. Resistance and Current in a Series Circuit.

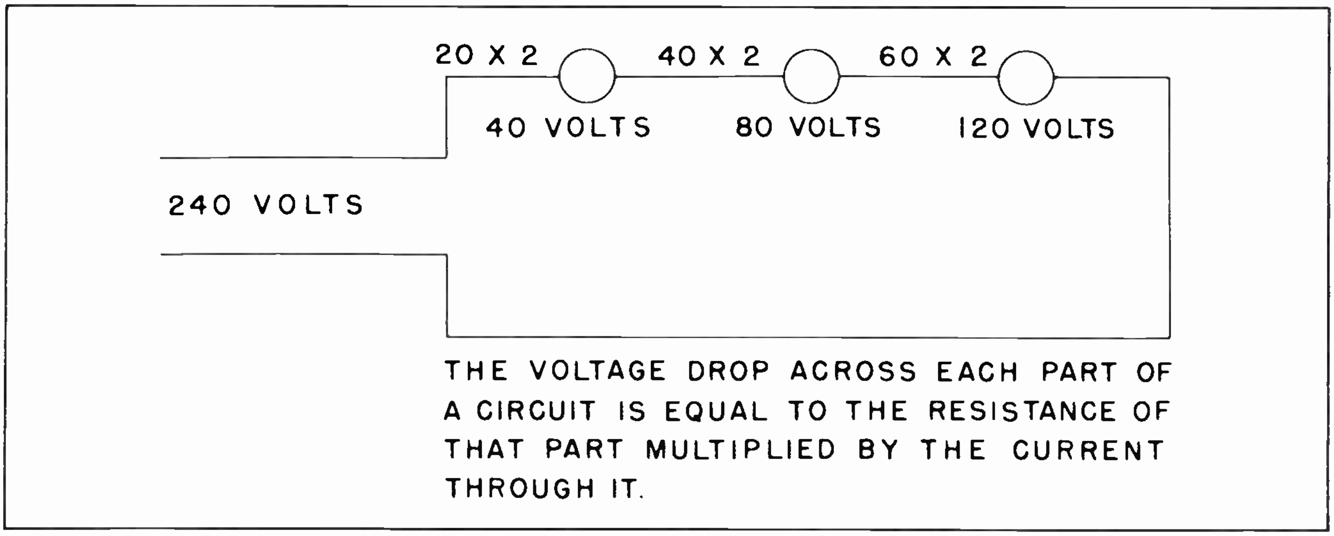


Fig.4.

the voltage is the same across all of them, 240 volts, the current will differ according to the resistance of each lamp.

When 240 volts are impressed across the lamp having 20 ohms of resistance, a current of 12 amperes will flow through it. 240 volts across the 40-ohm lamp will cause a current of 6 amperes to flow through it. And likewise, the 240 volts will cause a current of 4 amperes to flow through the 60 ohms of the third lamp. If we add these three currents together, we will find that a total of 22 amperes will flow through the parallel circuit consisting of the three lamps. This is shown in Fig. 6.

Now it is possible you might be inclined to ask: If only two amperes flowed in the series circuit from the 240 volt source, how could 22 amperes flow from the same source when the lamps were connected in parallel? Where did the extra current come from? How was it created?

If you ask a question like that, it is because you have forgotten what we mentioned back at the time we were studying Ohm's Law. There is always electricity present. Plenty of it. The amount that will move in any circuit is always determined by two things: The pressure behind it, and the resistance through which it moves. This is one truth you should always remember: *The current is always dependent upon the voltage and the resistance.* If the voltage is increased, more current will flow -- provided the resistance remains the same. If the resistance is increased, less current will flow -- provided the voltage remains the same.

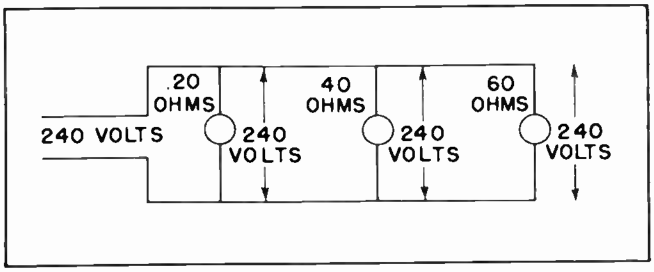


Fig.5.

Section 6 EFFECTIVE RESISTANCE

You have probably noticed by this time that if we connect two or more resistors in series, less current will flow through them than if only one is in the circuit by itself. In other words, the more resistors we connect in series, the less current will flow in any of them. The reason for this, of course, is that in a series circuit resistances add up, and the more resistance the less current can flow. On the other hand, if we connect two or more resistors in parallel, more current will flow through the circuit than if only one resistor is in the circuit by itself. Now let us examine this situation and see just why this should be.

In Fig. 7 we have three resistors. Each has a resistance of 15 ohms. These resistors might be electric lamps, flat irons, toasters, or anything else, but considering the value of their resistance it is most likely they are common wire-wound resistors such as are so commonly used in radio and television work. We will consider them as such.

If we want to use these three resistors in the same radio or television circuit we could connect them together in several ways. We could connect them in series, in which case their individual resistance would add together to give us a total resistance of 45 ohms. We could connect them in parallel, in which case their combined resistance would be another value. Or we could connect them in what is known as series-parallel, an arrangement which we will discuss later.

We have just said that if we connected these resistors in parallel, their combined resistance would be another value. Our problem now is to discover just what that value would be. Calculating the *effective* resistance of two or more resistors when connected in parallel is a never-ending part

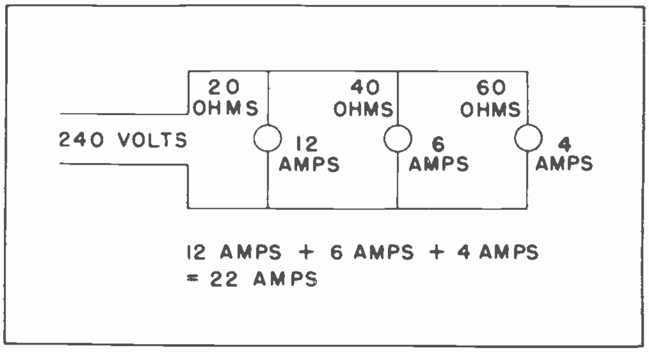


Fig.6. Current in a Parallel Circuit.

of the radio and television technician's job. He is confronted so often with the job of determining the *effective* resistance between two points when there are two or more resistors connected between them that after a few weeks experience he accepts the situation with scarcely a thought.

Our first step is to make certain we fully understand exactly what is meant by the expression *effective resistance*. Effective resistance is that resistance in any part of a circuit which determines exactly how much current will flow through the circuit. In Fig. 6 it could be seen that more current would flow through the circuit when three lamps are connected in parallel than if only one lamp was in the circuit. For example, if only the 20 ohm lamp had been in the circuit and the other two removed, 12 amperes of current would have flowed in the circuit. But adding the other two lamps to the circuit set up a situation where 22 amperes

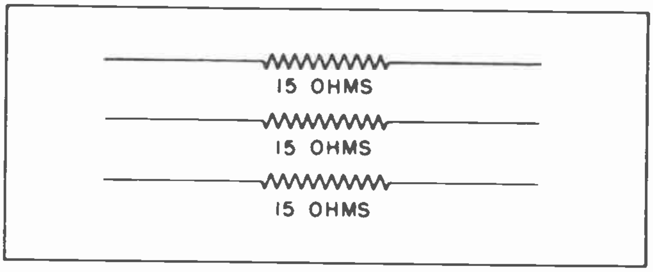


Fig.7 Three Individual Resistors of Equal Value.

of current flowed. It would be correct to say that adding the two extra lamps to the circuit *lowered* the effective resistance.

In Fig. 8 we have connected one of the 15-ohm resistors across a 60-volt power source. When we do this, 4 amperes of current will flow through the resistor. This, of course, is what we would normally expect.

But in Fig. 9 we have connected another of the 15-ohm resistors in parallel with the first resistor. Now 4 amperes of current flows through each of the two resistors, making a total of 8 amperes of current in the circuit. In other words, when we place two resistors of the same value across the same voltage in a parallel circuit, exactly twice as much current will flow in the circuit.

By Ohm's Law we could calculate the effective resistance of the circuit by dividing the 60 volts by the 8 amperes of current. This would give us an effective resistance of 7.5 ohms. Another way to say this is that two 15-ohm resistors connected in parallel will oppose the flow of current to exactly the same extent as one 7.5-ohm resistor. They have the same effectiveness as one 7.5-ohm resistor.

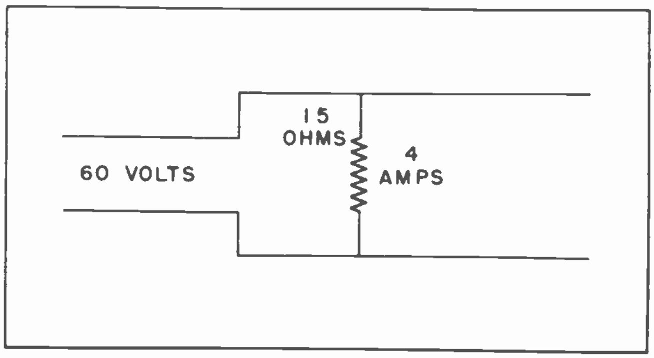


Fig.8. 15-ohm Resistor Across 60 Volts allows 4 amperes to flow.

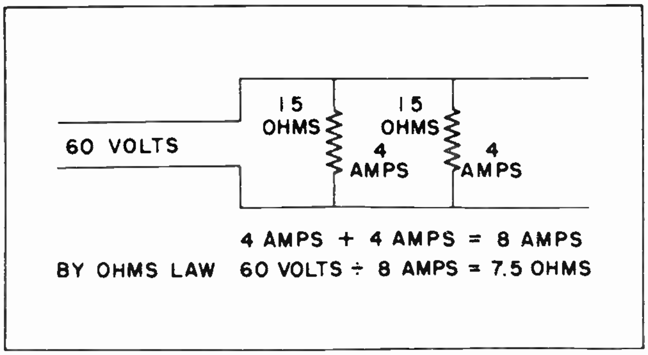


Fig.9. Two 15-ohm Resistors across 60 Volts allows 8 Amperes to flow.

In Fig. 10 we have added the third 15-ohm resistor in parallel with the other two, and placed all three across the 60-volt power source. 4 amperes of current will flow through each resistor, which means that 12 amperes of current will flow in the circuit. Again by Ohm's Law we can determine the effective resistance of the three resistors when they are placed in parallel. Dividing the 60 volts by the 12 amperes we obtain 5 ohms of resistance. This is the effective resistance of the parallel circuit when the three resistors are used.

It will be noticed that when two resistors of the same value are connected in parallel their effective resistance will be exactly one-half the resistance as when only one resistor is in the circuit. Likewise, when three resistors of the same value are connected in parallel, the effective resistance is cut to one-third of the resistance when any one of them is used by itself. This rule holds true regardless of how high the resistance. Two resistors of any single given value when connected in parallel will have their effective resistance reduced to one-half the resistance of either when used by itself. This is a very valuable point for any radioman to remember.

As mentioned before, there are an almost endless number of values of resistors manufactured by the various companies making them. It is almost impossible for any technician to maintain a constant supply of all kinds on hand. But suppose the technician has available to him an unlimited supply of 100,000-ohm resistors. This is a very common value and most radio men keep an abundant supply of them on hand. They cost only 1½¢ to 5¢ each, depending upon the type and the wattage.

Suppose the radio technician needs a 50,000-ohm resistor for some purpose, perhaps as a screen-grid resistor for a vacuum tube. He does not have a 50,000-ohm resistor on hand but he has plenty of 100,000-ohm resistors. Almost without second thought the technician takes two of the 100,000-ohm resistors, connects them in parallel in his screen-grid circuit, and has the 50,000 ohms of resistance which he needs. If it had been a 25,000-ohm resistor he needed he would have connected four of the 100,000-ohm resistors in parallel.

On the other hand, suppose he needed a 200,000-ohm resistor to replace the plate load resistor of a vacuum tube. Instead of connecting the resistors in parallel as before, he would connect them in series. Connecting the two 100,000-ohm resistors in series would give him the 200,000 ohms needed for the plate load.

All this can be summed up in a few words by saying that if a radioman needs a resistor with one-half the resistance of those he has at hand, he takes two of his resistors and connects them in parallel. If he needs one with one-third the resistance, he connects three of them in parallel. And if he needs one with one-fourth the resistance, he connects four of them in parallel. It is not likely he will need to connect more than two or three in parallel in most cases.

And if he needs a resistor with a resistance twice as great as any he has on hand, he will connect two of his resistors in series. If a resistor with three times the resistance is needed, he connects three in series.

Section 7. UNEQUAL RESISTANCES IN PARALLEL

If the technician needed a 150,000-ohm resistor and had a 100,000-ohm resistor and

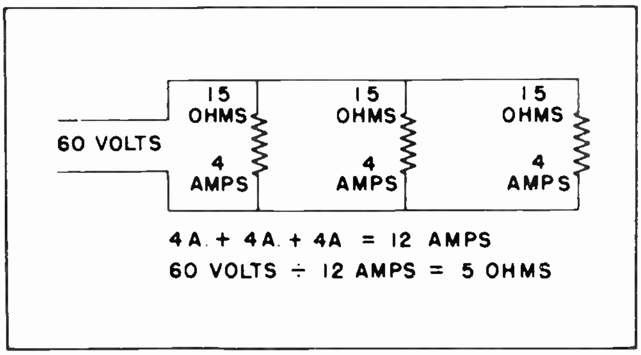


Fig.10. Three 15-ohm Resistors across 60 volts allows 12 Amperes to flow.

8
15 ⟌120

a 50,000-ohm resistor handy, he could connect them in series and have the value he needs. But suppose he needed a 75,000-ohm resistor. Could he connect the two resistors in parallel and get the value he wants? The answer is no.

Our problem now is to see just how resistors of unequal value can be combined so their effective resistance can be learned.

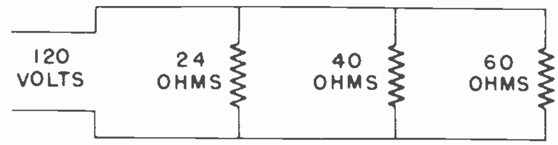
There are several methods by which the effective resistance of resistors in parallel can be determined. Some are more useful in one situation, and another method might be more useful in another situation. As a general rule when two or more resistors having different values of resistance are connected in parallel we are interested in knowing what their effective resistance is.

One way is to use Ohm's Law to determine the current through each of the resistances, then add the currents together to find the total current through the circuit. When we have learned the total current through the circuit we can readily find the effective resistance by again using Ohm's Law.

As an example of this, let us study the situation presented in Fig. 11. There we have three resistors connected in parallel across 120 volts. The resistors are all of unequal values, one having 24 ohms of resistance, the second having 40 ohms of resistance and the third having 60 ohms of resistance.

In using the Ohm's Law method of determining the effective resistance, the first step is to determine the value of the current through each of the resistors. We find there are 5 amperes of current in the first resistor, 3 amperes in the second and 2 amperes in the third. Adding these together, we find there are a total of 10 amperes of current flowing in the parallel circuit. Now to obtain the effective resistance we divide the voltage across the circuit by the current flowing through it. In this case we divide the 120 volts by the 10 amperes and find that the three resistors in parallel have the same effectiveness as would one resistor of 12 ohms. Thus, a 24-ohm resistor, a 40-ohm resistor and a 60-ohm resistor connected in parallel have an effective resistance of 12 ohms.

As an exercise for you it is suggested that you work the problem over again, but instead of using 120 volts as a power source



BY OHMS LAW: 120 VOLTS ÷ ~~24~~ 12 OHMS = ~~5~~ 10 AMPS
120 VOLTS ÷ 40 OHMS = 3 AMPS
120 VOLTS ÷ 60 OHMS = 2 AMPS
TOTAL CURRENT = 10 AMPS
120 VOLTS ÷ 10 AMPS = 12 OHMS EFFECTIVE RESISTANCE
15

Fig. 11. One method of finding effective resistance.

raise the voltage to 240 volts. See what your effective resistance would be in that case.

Section 8. THE RECIPROCAL METHOD OF FINDING EFFECTIVE RESISTANCE

There is another method for finding the effective value of two or more resistors connected in parallel which is used much more widely in radio and television work. It is more direct, and must faster, especially when it is necessary to learn the effective value of several resistors when they are so connected. This is called the reciprocal method.

But before getting into the reciprocal method of finding effective resistance for resistors connected in parallel, it is well that we mention something of the way resistors in a circuit are numbered.

In a radio or television circuit there might be many resistors, each doing an important job of its own. It would not be wise to designate a resistor merely by the work it was doing, such as a cathode resistor, or a plate load resistor, or a bias resistor, or a bleeder resistor. Since there might be twenty or more vacuum tubes in the circuit, and more than half of them with a resistor in the cathode circuit, if we were to designate any one resistor by the name "cathode resistor" or "cathode-bias resistor" it might be extremely hard for some other person to know exactly which cathode resistor we were referring to. To overcome this difficulty, it has become a standard practice to number the resistors in a circuit.

Fig. 12 shows one common way of numbering the resistors in a circuit. The resistors

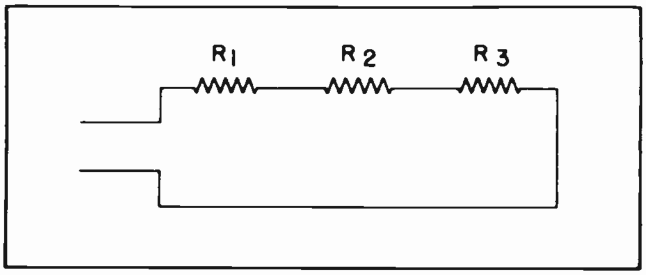


Fig.12. Common method of numbering resistors so each can be distinguished from the others.

are numbered "R_1", "R_2" and "R_3". Borrowing from the engineering practice of using subscripts, the radiomen started out by calling their first resistor in a circuit "Resistor R-subscript one", the second resistor would be called "Resistor R-subscript two", and the third "Resistor R-subscript three", and so forth. Well, radiomen being what they are, it didn't take them long to shorten that designation. Soon they were saying "R sub one", "R sub two" and "R sub three", and so forth. Even that practice has been shortened to the point where most radiomen now merely say "R-one", "R-two", and so forth.

To avoid confusion for you in the case you are well acquainted with algebraic methods it should be explained that in writing "R_1" and "R_2" and "R_3", the *R* is not a coefficient of *1* or *2* or *3*. The *R* is *not* multiplied by either the *2* or the *3* or the *4* as the case might be. The figures are merely used to distinguish one resistor from another.

In Fig. 12, R_1 is the first resistor in the circuit. The figure *1* serves no purpose except to distinguish the first resistor from all the others.

The resistors could have been distinguished from each other by naming the first one George, the second one Charlie and the third one Albert. Or they could have been named Alpha, Beta and Gamma. Or, they could have been named anything else which might have struck our fancy. In radio and television work it has become the practice to number the resistors R_1, R_2, R_3, R_4, and so forth because it is an easy thing to do. It is simple, and is easy to remember.

The reciprocal method of finding the effective resistance of several resistors connected in parallel consists merely of adding the reciprocals of the values of the resistors and then finding the reciprocal of the result. That sounds easy, but actually it takes a little explaining to become understandable.

The reciprocal of any number is the figure 1 divided by the number. The reciprocal of 2, for example, is 1/2. The reciprocal of 4 is 1/4. The reciprocal of 10 is 1/10.

In Fig. 13 we have three resistors. R_1 has a resistance of 40 ohms, R_2 has a resistance of 10 ohms and R_3 has a resistance of 8 ohms. To find the effective resistance of the three resistors in parallel by using the reciprocal method it is first necessary to find the reciprocals of the value of each resistances.

R_1. The reciprocal of 40 ohms is $\frac{1}{40}$

R_2. The reciprocal of 10 ohms is $\frac{1}{10}$

R_3. The reciprocal of 8 ohms is $\frac{1}{8}$

The rule says to add the reciprocals. In this case we will have to add 1/40, 1/10 and 1/8. In adding fractions it is necessary to find a common denominator. In this case the lowest common denominator would be 40. So now we change our reciprocals into fractions which all have the same denominator, 40.

$$1/40 = 1/40.$$
$$1/10 = 4/40.$$
$$1/8 = 5/40.$$

Adding the reciprocals together:

$$1/40 + 4/40 + 5/40 = 10/40$$

which is equal to 1/4.

Now the rule says that after we have added the reciprocals together we find the

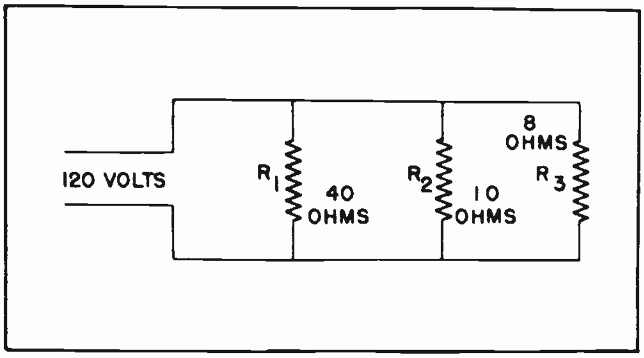
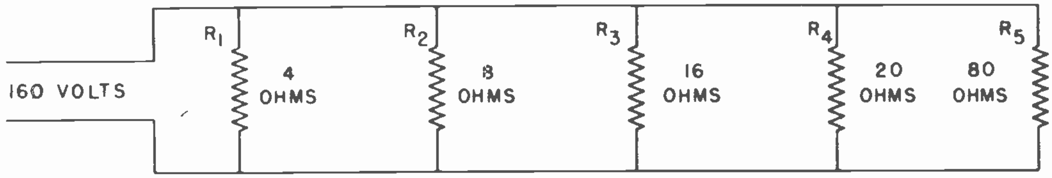


Fig.13. Three resistors in parallel.



THE RECIPROCAL OF 4 IS $\frac{1}{4}$

THE RECIPROCAL OF 8 IS $\frac{1}{8}$

THE RECIPROCAL OF 16 IS $\frac{1}{16}$

THE RECIPROCAL OF 20 IS $\frac{1}{20}$

THE RECIPROCAL OF 80 IS $\frac{1}{80}$

ADDING RECIPROCALS: $\frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \frac{1}{20} + \frac{1}{80}$

COMMON DENOMINATOR IS 80

ADDING RECIPROCALS: $\frac{20}{80} + \frac{10}{80} + \frac{5}{80} + \frac{4}{80} + \frac{1}{80} = \frac{40}{80} = \frac{1}{2}$

THE RECIPROCAL OF $1/2$ IS 2

THE EFFECTIVE RESISTANCE OF 4 OHMS, 8 OHMS, 16 OHMS, 20 OHMS AND 80 OHMS IS 2 OHMS.

Fig. 14.

reciprocal of the result. In this case, the reciprocal of 1/4 is 4. This means that the effective resistance of a 40-ohm resistor, a 10-ohm resistor and an 8-ohm resistor connected in parallel is 4 ohms.

The first time through the reciprocal method of finding effective resistance may look a little difficult. Actually it is not. It is by far the most widely used method among practical radiomen. It is fast, and after a little practice is easy.

It is suggested that you apply the principles of the reciprocal method of finding effective resistance to the circuit in Fig. 6. This will enable you to obtain a little practice in its use. As a hint, it is suggested that you make 120 the common denominator in that problem.

It is also suggested that you use the current method to solve the circuit of Fig. 13. This will give you a little more practice in that method also. It is always a good idea to know more than one way of doing things.

Fig. 14 shows how another parallel circuit, one containing five unequal resistances, is worked out using the reciprocal method of finding the effective resistance. For additional practice, it is suggested that you work this problem out for yourself using the current method of finding the effective resistance. Without looking at our figures, it is suggested that you then work out this problem again by yourself using the reciprocal method. The practice will make you more familiar with the actual operations, and give you a little more confidence in yourself.

Many radio and television technicians become so familiar with this method of finding effective resistance they can frequently figure the more simple problems in their heads without having to use pencil and paper. This is an ability they acquire by practice, of course, and it is not expected you will be able to do such a thing until after you have been in radio work for several years.

Section 9. TAPPED RESISTORS IN PARALLEL

Two vitreous enameled, wire-wound, resistors are shown in position at the left-hand side of Fig. 15. Each resistor has a tap connection brought out between its ends. The electrical diagram is shown at the right, and on this diagram we have marked the number of ohms in each section of the

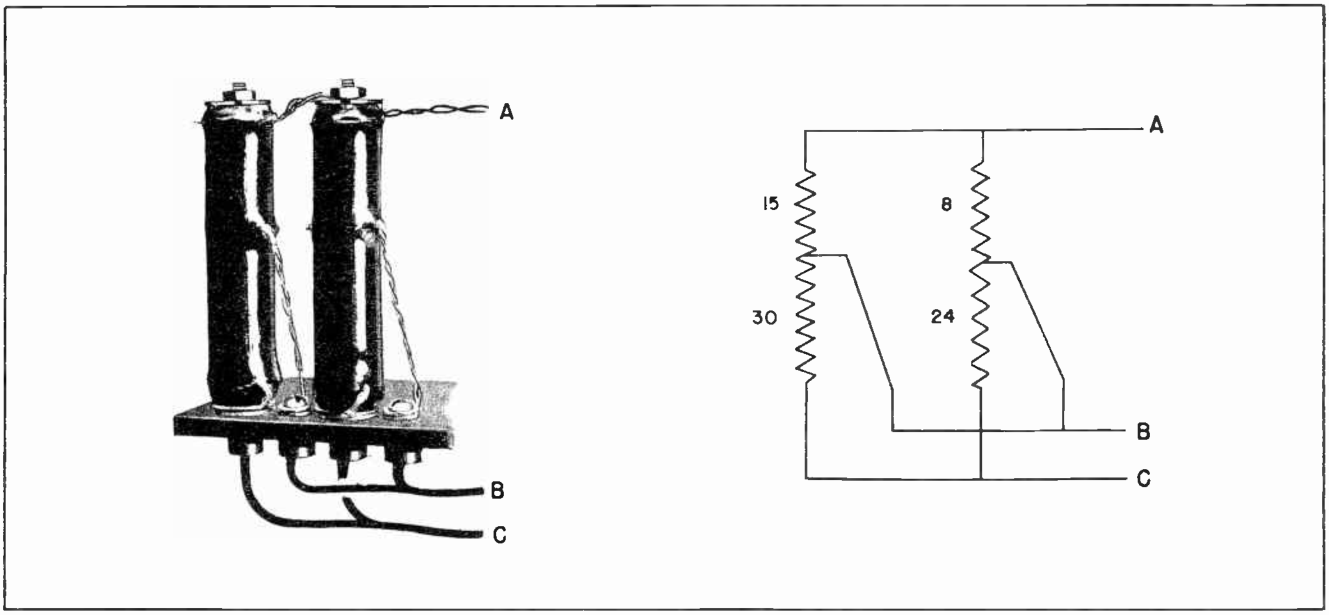


Fig. 15. Tapped Resistors forming two parallel circuits.

resistors. We want to learn the effective resistance from *A* through to *B*. We also want to learn the effective resistance from *A* through to *C*.

We may begin by examining the entire circuit to find just how its resistances are connected.

1. Current may flow from *A* to *B* through the upper left-hand resistance of 15 ohms.

2. Current may flow from *A* to *B* also through the upper right-hand resistance of 8 ohms.

3. Then between *A* and *B* we have two resistances in parallel, one of 15 ohms and the other of 8 ohms.

4. In tracing a path from *A* to *C* we find that current may pass through the two left-hand resistances, one after the other, in series. One of these resistances is 15 ohms, the other is 30 ohms. Thus their total series resistances is 15 plus 30, or 45 ohms.

5. We may trace another path from *A* to *C* through the two right-hand resistances. One is 8 ohms and the other is 24 ohms. These two are in series, so their total resistances is 8 plus 24, or 32 ohms.

6. We have between *A* and *C* two different current paths. One path has a total resistance of 45 ohms and the other has a total resistance of 32 ohms. This makes a parallel circuit having 32 ohms of resistance in one branch and 45 ohms in the other.

Now we actually have two separate parallel circuits. One is from *A* to *B*. It has one branch with 8 ohms of resistance and another branch with 15 ohms of resistance.

The other parallel circuit also has two branches. One branch has 32 ohms of resistance, and the other branch has 45 ohms.

For our first step we will determine the effective resistance between *A* and *B*. According to the rules for solving such a circuit by the reciprocal method, we first find the reciprocals of the resistance in each branch of the circuit. The reciprocal of 8 ohms is 1/8. The reciprocal of 15 ohms is 1/15. The lowest common denominator is 120. Changing 1/8 and 1/15 into fractions having a denominator of 120 we will have:

$$\frac{15}{120} + \frac{8}{120} = \frac{23}{120}$$

The reciprocal of $\frac{23}{120}$ is $\frac{120}{23}$.

Thus the effective resistance is equal to $\frac{120}{23}$ ohms.

Changing this improper fraction into a whole number and a decimal we merely divide the 120 by the 23. This will give us approximately 5.2 ohms. This means that the effective resistance between A and B is 5.2 ohms.

In the circuit from A to C we have two branches, one of which has a resistance of 32 ohms and the other a resistance of 45 ohms. This is solved in exactly the same way. First we find the reciprocals. The reciprocal of 32 is 1/32. The reciprocal of 45 is 1/45.

We add these two together, but to do so we must find a common denominator for each fraction. The common denominator in this case is going to be quite large. It is 1440. Our two fractions now become:

$$\frac{45}{1440} + \frac{32}{1440} = \frac{77}{1440}.$$

The effective resistance is equal to the reciprocal of this result. The reciprocal of

$$\frac{77}{1440} \text{ is } \frac{1440}{77}.$$

Thus the effective resistance of a resistor having 32 ohms resistance and one having 45 ohms, when the two are connected in parallel is,

$$\frac{1440}{77} \text{ ohms.}$$

It would be much more convenient to convert this fraction into a whole number and a decimal. To do this we would do just as before: Divide the 1440 by the 77. This will give us approximately 18.7 ohms. Thus the effective resistance of a 32-ohm resistor and a 45-ohm resistor connected in parallel is approximately 18.7 ohms.

Perhaps you have noticed that in every case of finding the effective resistance of two or more parallel resistors, the effective resistance has always been less than that of the smallest of the separate resistors. You can check back on this by reviewing the problems we have cited. This situation is always true and furnishes one check on the accuracy of your calculations. If you ever come up with an answer which shows the effective resistance to be greater than that of the smallest individual resistor, you will know you have made a mistake somewhere in your calculations.

As with most everything else connected with radio and other electrical work, there is a formula which shows how to find the effective resistance of two or more parallel resistors by the reciprocal method. Here is the formula:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \ldots \text{etc.}$$

What this means is that you can find the reciprocal of the total resistance (R_T) by adding the reciprocals of the individual resistors. Then once you have the reciprocal of the total resistance you merely find the reciprocal of that to obtain the actual effective resistance. It would be an excellent idea to jot this formula down in your note book where you will have it handy when you need it. You will not have to refer to your notes very long. You will be using the formula so much that it will soon become second nature to you.

Section 10. INCREASING THE RANGE OF A METER

There are so many ways the radioman uses his knowledge of parallel resistances, it is hard to point to any one use and say that one is more important than any other. One extremely useful application of the knowledge is in extending the range of a meter with which he has to work.

Very often the ammeter with which he is working does not have a range sufficiently great to read the current in some circuit with which he is working. Or perhaps it is a milliammeter -- the principle is the same. In order to do the job he is called upon to do, and yet use the instruments which are at hand, he must devise some means of extending the range of his meter.

Fig. 16 shows a meter such as he might be using. In this case, the meter has a full-scale reading of one ampere. This means that when one ampere of current is flowing through the meter, the scale will be deflected to its extreme limit. If an attempt is made to use the meter to measure more than one ampere, there is great danger of burning out the working mechanism, and ruining the meter. These meters are quite sensitive, and easily burned out if improperly used.

But the skilled radioman knows how he can extend the range of the meter, and safely measure a much higher current than the meter was designed to measure. First he determines the internal resistance of the meter. In this case the internal resistance is found to be 9 ohms.

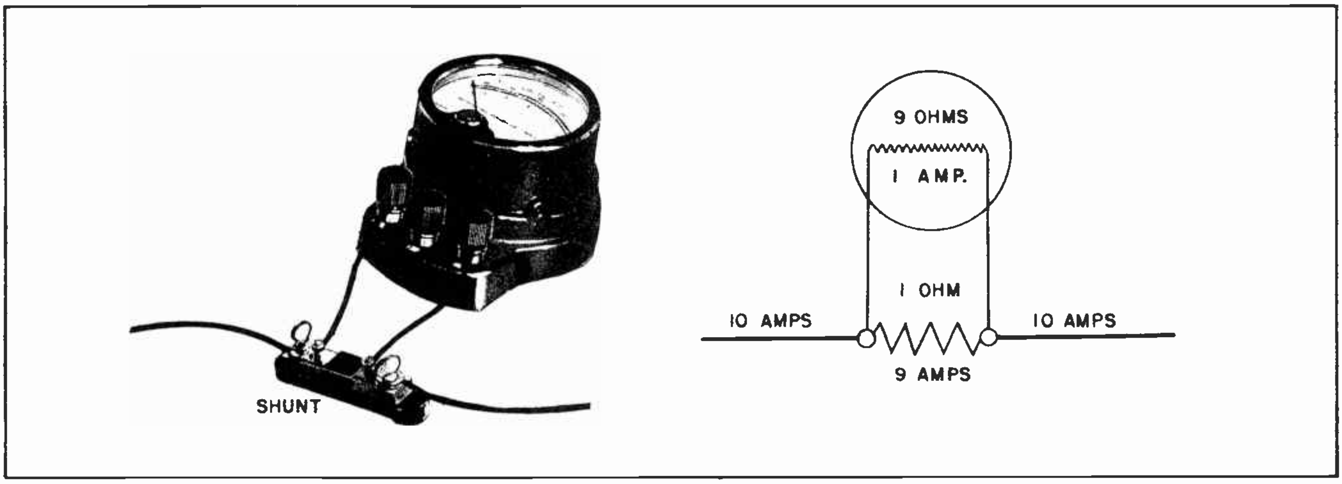


Fig.16. How a Meter Shunt Operates.

One of the first thing a radioman learns about parallel circuits, is that when two resistors are in parallel, and the value of the resistances are unequal, the resistor with the lowest resistance will pass the largest current, and the resistor with the highest resistance will pass the least current. To put this in the form of a rule we would say:

Two currents in parallel are inversely proportional to the resistances in which they flow.

If one resistance has 10 times as many ohms as the other, it will take only 1/10 the current that the other takes. If the resistance ratio is 100 to 1, the current ratio will be 1 to 100.

The meter in Fig. 16 is capable of measuring currents only up to one ampere. But suppose it is necessary to measure currents up to 10 amperes. To extend the range of the meter we will connect a resistor in parallel with the internal resistance of the meter. The resistor will be connected between the terminals of the meter. This resistor will have a resistance much smaller than that of the meter itself. The resistance is so much smaller than that of the meter that such a resistor is usually referred to as a *shunt*. This is because it is used to shunt the major portion of the current around the meter itself.

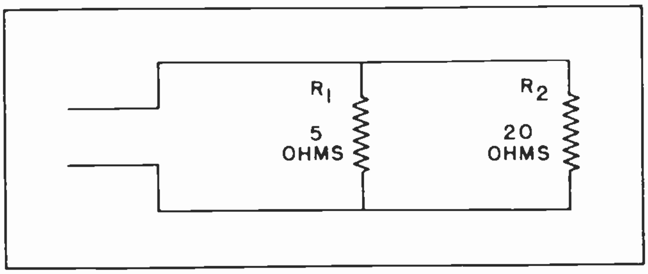


Fig.17. Two Resistors in Parallel.

Now in order to make the meter function accurately, the resistance of the shunt must be carefully calculated so as to shunt an exact amount of current around the meter, and yet let the proper amount pass through the meter so it will register properly. In the case of the meter with which we are working, we want to extend its range so we can measure ten times as much current as the meter was designed to measure. To accurately measure the larger amount of current we should design a shunt which will allow one-tenth of the total current to pass through the meter, and the other nine-tenths to pass through the shunt. Then when the meter reads 1/10 ampere, we will know one ampere is flowing in the main circuit. Likewise, when the meter reads .5 ampere we know that 5 amperes is flowing in the main circuit.

In this case we would place a shunt having 1 ohm of resistance across the terminals of the meter. The shunt has 1/9 the resistance of the meter, so it will pass nine times as much current as the meter. In other words, 1/10 of the total current will pass through the meter and 9/10 will pass through the shunt. Then to measure whatever current is to be measured, the reading is taken from the meter, then multiplied by 10. This will give the correct amount of current flowing in the circuit.

The subject of meter shunts and multipliers will be gone into at considerably greater length in a later lesson. It is a complete subject in itself, and is an important one to the radio man.

Section 11. ANOTHER METHOD FOR DETERMINING EFFECTIVE RESISTANCE

The reciprocal method is by far the most commonly used method for determining effective resistance. It is the only method to use when more than two resistors are in parallel if you are in a hurry to obtain your answer.

But there is another method which is quite commonly used when there are only two resistors in parallel. This method involves multiplication, addition and division. The two resistances are first multiplied together. Then they are added together. The sum obtained by adding them together is divided into the product obtained when they were multiplied together. The formula for this operation is written like this:

$$R_t = \frac{R_1 \, R_2}{R_1 + R_2}$$

Take the problem presented by the two resistors connected in parallel in Fig. 17. The formula:

$$R_t = \frac{R_1 \, R_2}{R_1 + R_2}$$

can be changed by the insertion of the actual values of the resistors to look like this:

$$R_t = \frac{5 \times 20}{5 + 20}$$

Multiplying 5 by 20 gives us 100, and adding 5 to 20 gives us 25. Our equation now looks like this:

$$R_t = \frac{100}{25}$$

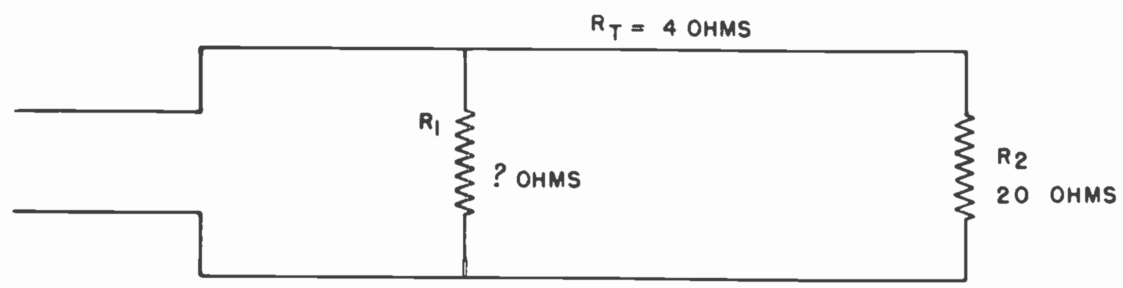
Changing the fraction into a whole number gives us the result: 4 ohms. This means that when a 5 ohm resistor is in parallel with a 20 ohm resistor their effective resistance is 4 ohms.

This method of obtaining the effective resistance is often used when there are only two resistors in parallel. It is possible to use it when there are more than two resistors, but the calculations become so complicated that it is far easier to use the reciprocal method.

Section 12. FINDING THE VALUE OF ONE PARALLEL RESISTOR WHEN THE OTHER IS KNOWN

Very often the radioman is faced with a problem where he knows what the total resistance is, or should be, and knows the value of one of the paralleling resistor. But he must figure out what the value of the other resistor is, or must be.

The problem might be a cathode resistor which he discovers has too high a resistance. Not having any smaller resistors handy, the radioman decides to lower the effective resistance in the cathode circuit by paralleling the existing resistor with another resistor. The problem is what value resistor to use in parallel.



$$R_1 = \frac{R_T \, R_2}{R_2 - R_T} \qquad R_1 = \frac{4 \times 20}{20 - 4} = \frac{80}{16} = 5 \text{ OHMS}$$

Fig. 18.

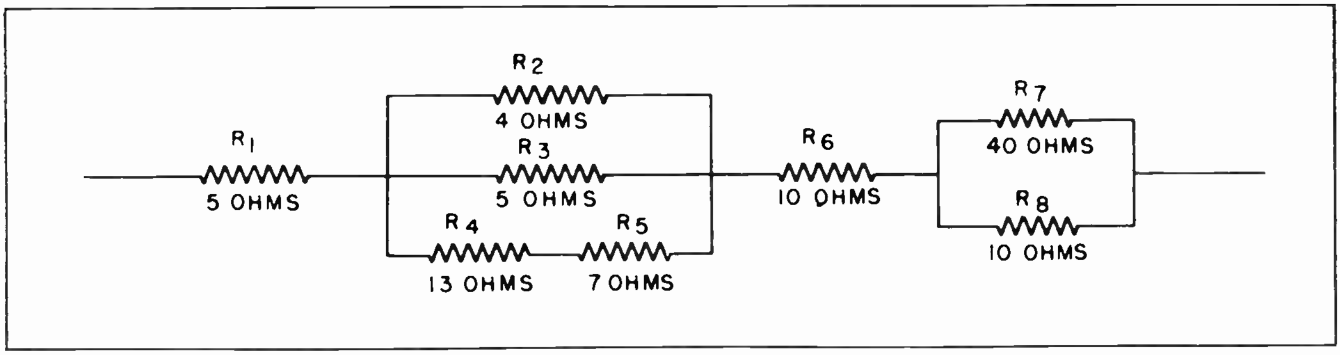


Fig. 19. An apparently complicated resistance network.

Other situations which often arise, involve the problem of paralleling one or more of the resistances of a voltage divider network, where the total resistance must not be upset, or the resistance network of a diode detector in a modern superheterodyne receiver.

The best method to use is to multiply the effective resistance by the value of the other resistance. This will give you one value. Next, subtract the effective resistance from the other resistance. This will give you a second value. Now divide the first value by the second value. This will give you the value of your unknown resistor.

The formula for this is:

$$R_1 = \frac{R_t \ R_2}{R_2 - R_t}$$

In order to see how this formula is used we will substitute the actual known value in Fig. 18 into the formula. R_t is equal to 4 ohms. R_2 is equal to 20 ohms. Our problem will now look like this:

$$R_1 = \frac{4 \times 20}{20 - 4} = \frac{80}{16} = 5 \text{ ohms.}$$

Thus we find that in order to have an effective resistance of 4 ohms when one of the paralleling resistors has a resistance of 20 ohms, the other resistor must have a resistance of 5 ohms. This formula is used over and over. It would be an excellent idea to jot this down in your little notebook also. Then you will have it handy whenever you want to use it.

Section 13. SERIES-PARALLEL CIRCUITS

In radio and television work, some of the circuits become quite involved. There may be two or more resistors in parallel with each other. Then in series with these, there may be one or two other resistors which may be connected either in series or in parallel. Sometimes these arrangements extend at great length.

To the unitiated -- that is, the untrained man -- it would seem to be almost hopeless to try to figure out just what was going on inside such an array of circuits. The trained man knows that regardless of how complicated a circuit may look, it can always be broken down into simple series circuits, or into simple parallel circuits. It does not make any difference what the arrangement of the resistors might be,

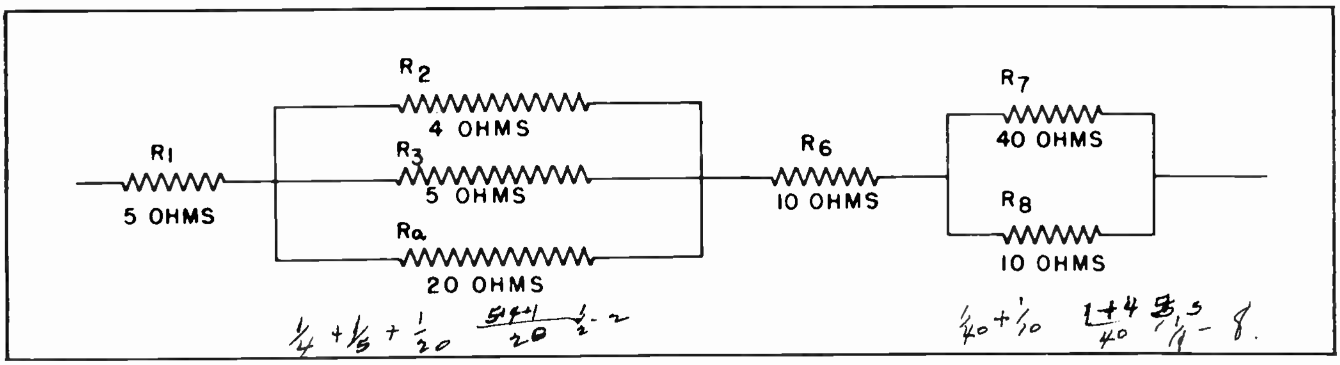


Fig. 20. The first step in simplifying a resistance network.

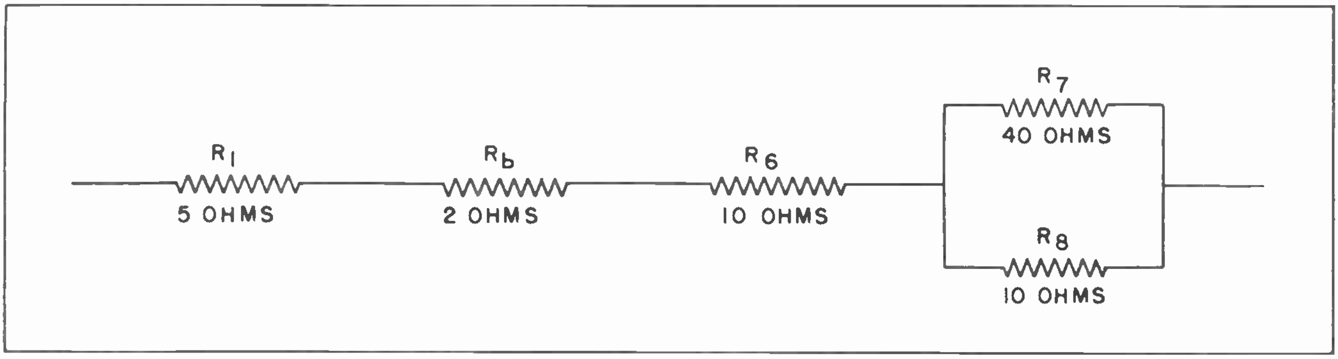


Fig.21. The second step in simplifying a resistance network.

by careful analysis they can be readily simplified.

There are only two basic circuits. The series circuit. And the parallel circuit. All other circuits, no matter how complex, are merely combinations of series or parallel circuits.

At first glance the circuit in Fig. 19 would seem extremely complicated. There are parallel circuits, and there are series circuits. And there are combinations of series and parallel circuits.

In solving such a circuit, the trained man attacks it methodically. He looks to see what he can combine to make the circuit a little more simple, then draws it again. In this case the trained man would note that resistors R_4 and R_5 are in series with each other. The first step would be to combine them into one resistor.

The circuit is then redrawn as in Fig. 20. Note that R_4 and R_5 have been combined into a single resistor which we have chosen to call R_a. It has a total resistance of 20 ohms. This is the sum of the values of R_4 and R_5, one of which had 13 ohms and the other 7 ohms.

The next step is to find something else to simplify. Probably the best thing would be to combine R_2, R_3 and R_a into one unit and determine their effective resistance. This we will do by use of the reciprocal method, and then redraw the circuit to fit this new condition.

The circuit is redrawn as shown in Fig. 21. Note here that R_2, R_3 and R_a have been combined. Their effective resistance is now represented by a single resistor which we have chosen to call R_b. It has an effective resistance of 2 ohms.

For our next step we could do either of two things. We could combine R_1, R_b and R_6, which are in series with each other, into one single resistance; or we could combine R_7 and R_8. It makes no difference which we do, but we shall choose to combine the parallel resistors, R_7 and R_8 into their effective resistance, and then redraw the circuit to show how it will then look.

Fig. 22 shows how the circuit looks when R_7 and R_8 have been combined into one effective resistance. We have chosen to call this effective resistance R_c in order to distinguish it from the other resistances. Now in Fig. 22 we have four resistances in

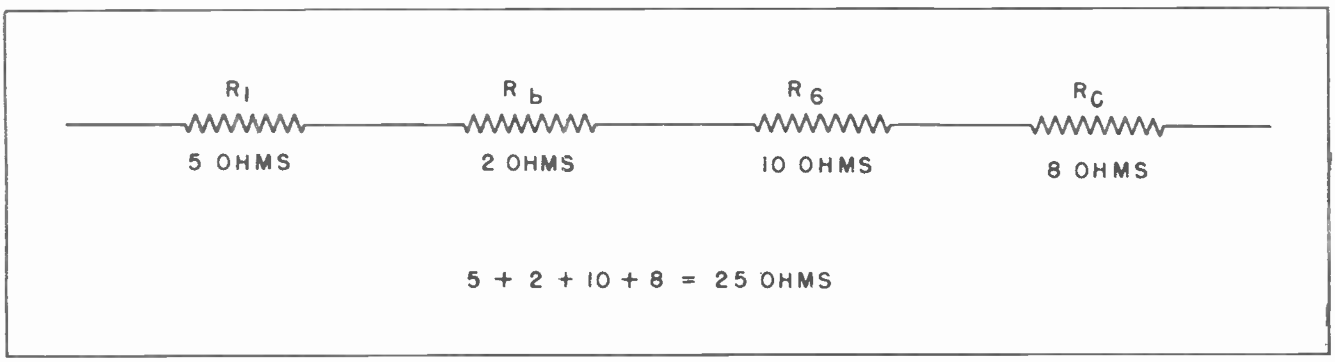


Fig.22. After the resistance network has been completely simplified into a simple series circuit.

series. The final step is quite simple. All there is to do is add these four resistances together and we will have the effective resistance of the network which looked so formidable just a few minutes ago. The sum of 5 ohms, 2 ohms, 10 ohms and 8 ohms is 25 ohms. Thus the network of resistors shown in Fig. 19 has an effective resistance to the flow of current equal to a 25 ohm resistor.

To obtain a little more practice in the solving of series and parallel circuits, we have shown such a circuit in Fig 23. The values of the various resistors are shown. It would be a good idea for you to solve this circuit. You will not find it to be a hard problem. As a hint, it is suggested that you first find the effective resistance of resistors R_2 and R_3. When this has been done, add this value to the resistance of resistor R_1. To check the accuracy of your work, the total resistance of the network is 30 ohms.

If you would like to tackle a little more difficult problem, you might try solving the circuit shown in Fig. 24. As a hint to you, it would be a good idea to find the effective resistance of R_1 and R_2 first. Then find the effective resistance of R_4, R_5 and R_6. After you have worked out this much of the circuit you will have the equivalent of three resistors in *series*. You already know what to do with resistors in series. In order for you to check the accuracy of your work, the total resistance of the network is 10 ohms.

Most of the problems we have shown you use such values that the resistance comes out in even values. Under actual working conditions, of course, the values with which you will be working are not quite so convenient. But while you are learning, it is the principles which are most important. The actual arithmetical numbers are entirely secondary.

$\frac{1}{80} + \frac{1}{20}$ $\frac{1+4}{80}$ $\frac{80}{5}$ 16

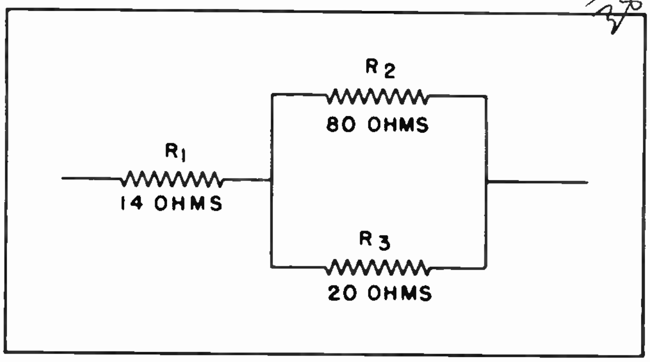


Fig.23. A simple series-parallel circuit to be solved.

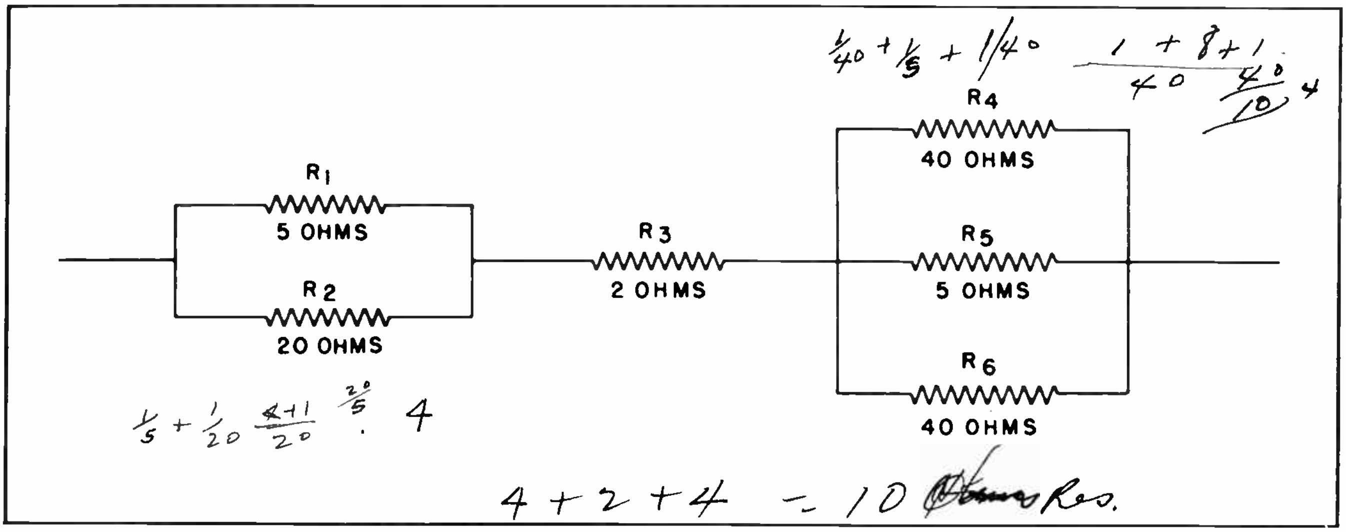


Fig.24. A more complicated resistance network.

(Reference Notes on the Page following)

NOTES FOR REFERENCE

Total current through resistors in parallel equals the sum of currents through the separate resistors.

The effective resistance of equal resistances in parallel is equivalent to the value of one resistor divided by the number of resistors.

When unequal resistances are in parallel, the one with the highest resistance will pass the least current, and the one with the least resistance will pass the greatest current.

The effective resistance of resistances in parallel is always less than the value of the smallest individual resistance.

Ohm's Law can be used to determine the effective resistance of several resistances in parallel.

The formula for finding the effective resistance by the reciprocal method is:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \; . \; . \; . \; . \text{ etc.}$$

Two currents in parallel are inversely proportional to the resistances through which they flow.

The formula for finding the effective resistance when only two resistances are in parallel is:

$$R_t = \frac{R_1 \; R_2}{R_1 + R_2}$$

The formula for finding the resistance of one branch of a parallel circuit when the effective resistance and the value of the other resistance are know is:

$$R_1 = \frac{R_t \; R_2}{R_2 - R_t}$$

NOTES

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Contents: Introduction - Relative Values of Anode Current - Dynamic Characteristic Curves - Phase Inversion - Methods of Obtaining Grid Bias - Cathode Bias - Degeneration - By-Pass Capacitor - Stage Gain - Power Amplifiers - Load Lines - Notes for Reference.

Section 1. INTRODUCTION

One of the principal uses for vacuum tubes such as the triode, the tetrode, the pentode, the beam power tube and still other types which we have not yet discussed, is in amplifier circuits. By "amplifier circuits" we mean circuits which will increase, or multiply, some electrical value.

By custom, vacuum tube amplifiers are divided into two general groups: The *voltage* amplifier, and the *power* amplifier. One is designed to take small voltages and increase them into much larger voltages without changing the wave form of the voltage, or changing the frequency at which it might be changing in strength, or *amplitude*. The other is so designed that it can take some substantial value of signal voltage which is applied to the grid and change it into sufficient power at the output of the anode that it can do whatever work is required. As mentioned before, this work might mean moving the cone of a loudspeaker or the operation of a relay. In other applications it might be used for some other purpose.

It should be remembered that *voltage alone*, when applied to the proper elements of a vacuum tube can bring about certain actions within and without the tube. But nearly all other electrical devices require *power* to operate them. The usual set up, then, is for a voltage amplifier to be used to raise small voltages up to a strength sufficiently great for application to the grid of a *power amplifier tube.*

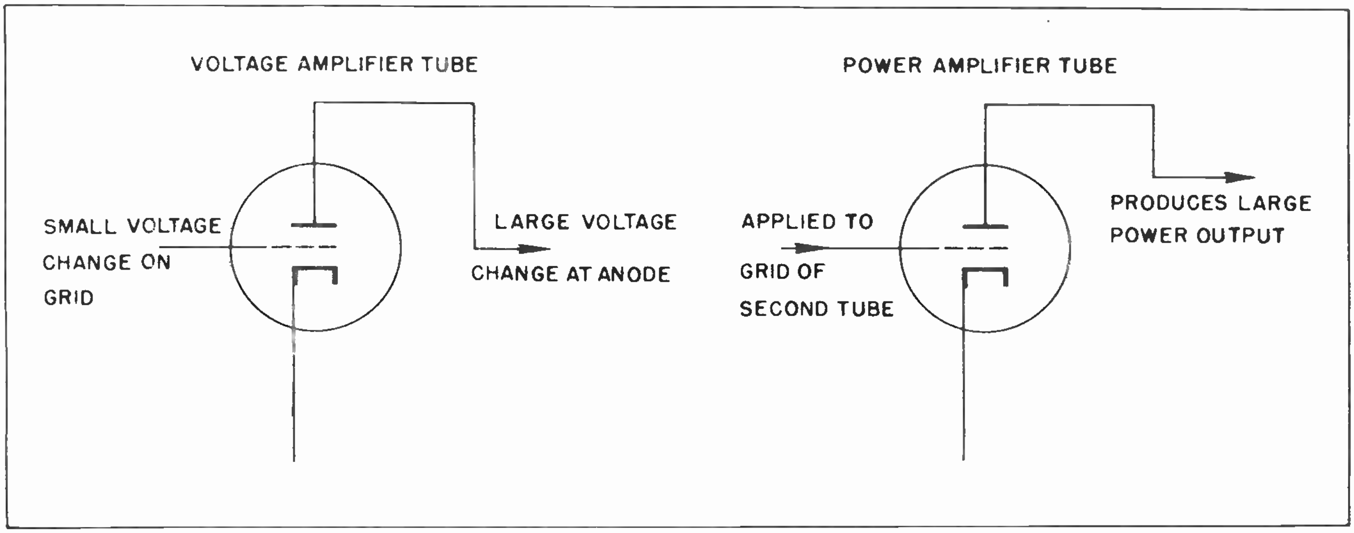

Fig. 1. Functions of the Voltage Amplifier and the Power Amplifier.

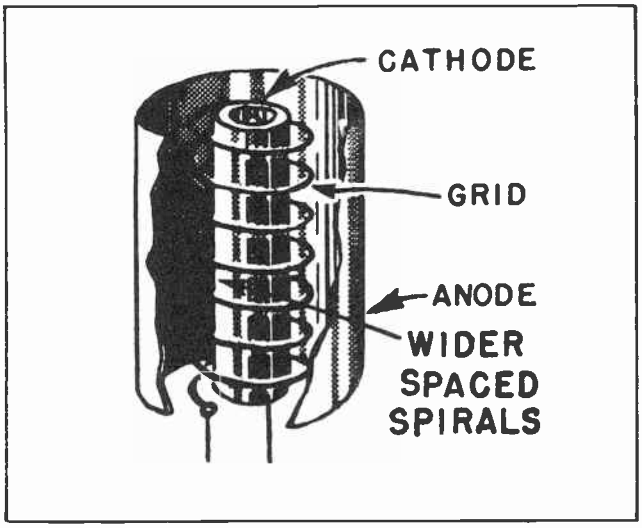

Fig.2. Power amplifier tubes have wide spaces between the spirals of the grid wires, permitting large current but requiring high grid voltages.

The output of the voltage amplifier is applied (through appropriate circuits) to the grid of a power tube. The power tube converts the signal voltage into sufficient power to operate whatever device the tubes are used with. (See Fig. 1.)

A triode tube can be used either as a voltage amplifier or as a power amplifier. The exact use to which it is put will depend very largely upon the internal construction of the tube. If the triode has been designed for power amplification it will be so constructed that reasonably abundant amounts of electrons can pass through the spiral wires of the control grid. This will mean that the spirals will be spaced rather widely apart as in Fig. 2.

We have mentioned previously that some triode grids had the spirals spaced widely apart but did not at that time explain why they were so constructed. At that time we did mention that tubes which had the grids widely spaced did not have as great an amplification factor as tubes with the grid wires closer together. Further than this, we said that when the wires were widely spaced, more grid voltage was required to materially affect the passage of the electrons. It is for these reasons that power amplifiers, especially triodes, require much more grid voltage than do the tubes which are used primarily as voltage amplifiers.

A triode tube which has been designed especially for use as a *voltage amplifier* will have the spiral turns of the grid wires much closer together, as in Fig. 3, and will probably have the grid somewhat closer to the cathode. The voltage amplifier tube will not pass nearly so many electrons as the power amplifier tube, but the grid will be able to exert a much higher degree of control over those electrons which are passed.

All this may give you the impression that in some mysterious way some vacuum tubes amplify voltage only, while others amplify power only. Such an idea, however, would be entirely wrong. Actually all operate on the principle that a change in the grid voltage results in a change in the anode current. The main difference between them lies in the fact that one vacuum tube with a high amplification factor may not pass enough current to operate any electrical device but its anode current *changes* can be changed into voltages which greatly exceed the original voltages applied to the grid, while another tube with a low amplification factor may not be able to greatly increase the output voltage over that applied to the grid, it will pass sufficient anode current to operate some electromechanical device.

Since the characteristics of one type of triode may lend themselves admirably to the job of increasing the signal voltage, that type is generally referred to as a *voltage* amplifier. And since the characteristics of the other type of triode are such as to make it better adapted for changing large voltage changes into large current changes it is called a *power* amplifier.

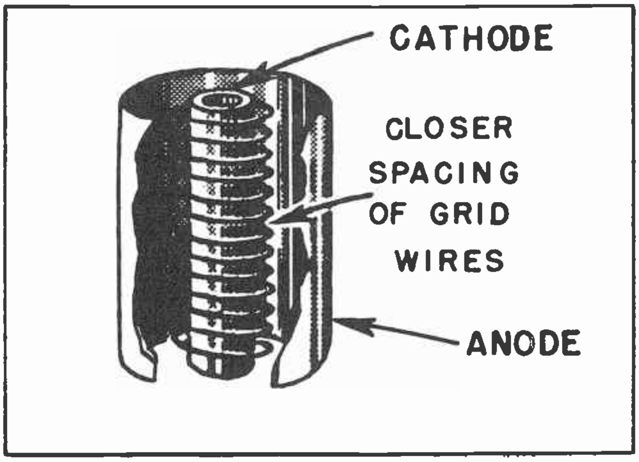

Fig.3. Voltage amplifier tubes have closer spacing of the grid wires, giving high amplification but allowing only a small current.

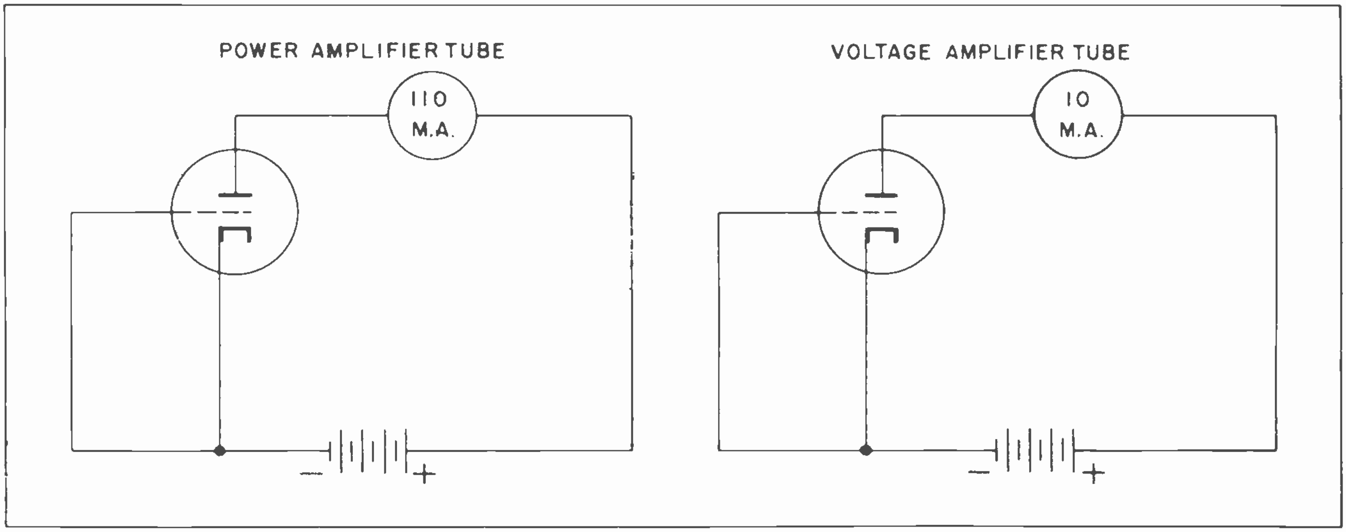

Fig. 4.

It should be remembered, however, that the basic essentials of each type of tube are the same. Each operates in exactly the same manner as the other. The difference between them is one of *degree* rather than of nature.

Perhaps it might seem we are giving a bit too much stress to something which may seem relatively unimportant. Unfortunately, it is easy for a newcomer into this field to fail to fully understand either the close similarities of the two types of tubes in some ways or recognize their dissimilarities in other ways. The really unfortunate thing is that some of the old timers fail to fully understand these things. A failure to understand will nearly always result in mental confusion, and is usually reflected in the quality of work one can turn out.

Section 2. RELATIVE VALUES OF ANODE CURRENT

In Fig. 4 are shown two vacuum tube circuits. The one at the left utilizes a power amplifier tube. The one at the right, a voltage amplifier tube. The same value of voltage is on the anode of each tube. The circuits are identical in every way except for the type of tube. The circuit which uses the power amplifier tube has a current of 110 milliamperes flowing in the anode circuit. The other circuit which uses the voltage amplifier tube has only 10 milliamperes of current in the anode circuit. These current values give an indication of the difference in the anode current values between these two types of tubes.

Even though both of these tubes operate essentially on the same principle, let's see why the tube at the left -- the power tube -- could not be satisfactorily used as a voltage amplifier. To control the large amount of anode current the grid would require considerable voltage. This is because the spirals of the grid wire are so wide apart. To reduce the anode current from 110 milliamperes to about 50 milliamperes would probably require about 25 volts on the grid, possibly a little more.

Fig. 5 repeats the circuit at the left of Fig. 4, that of the power tube. First is shown the circuit with a zero grid and an anode voltage of 350 volts. The load is 1000 ohms. When the 110 milliamperes of anode current flows through the 1000 ohm load there will be a voltage drop of 110 volts. At the right of Fig. 5 we have the same circuit except that a negative grid voltage of 25 volts has been added. With 25 negative volts on the grid, the anode current has been reduced from 110 M.A. to 50 M.A. There is a resulting voltage drop through the load resistor of 50 volts. This is a *change* of 60 volts across the load resistor.

Now let's see what we have. A *change* of 25 volts on the grid has resulted in a *change* in the voltage across the load of 60 volts, or a *gain* in voltage of 2 2/5ths. This is not very much *voltage gain* for one stage of vacuum tube amplification.

Next we will see what happens in the circuit using the vacuum tube at the right of Fig. 4. Here we have only 10 M.A. in the

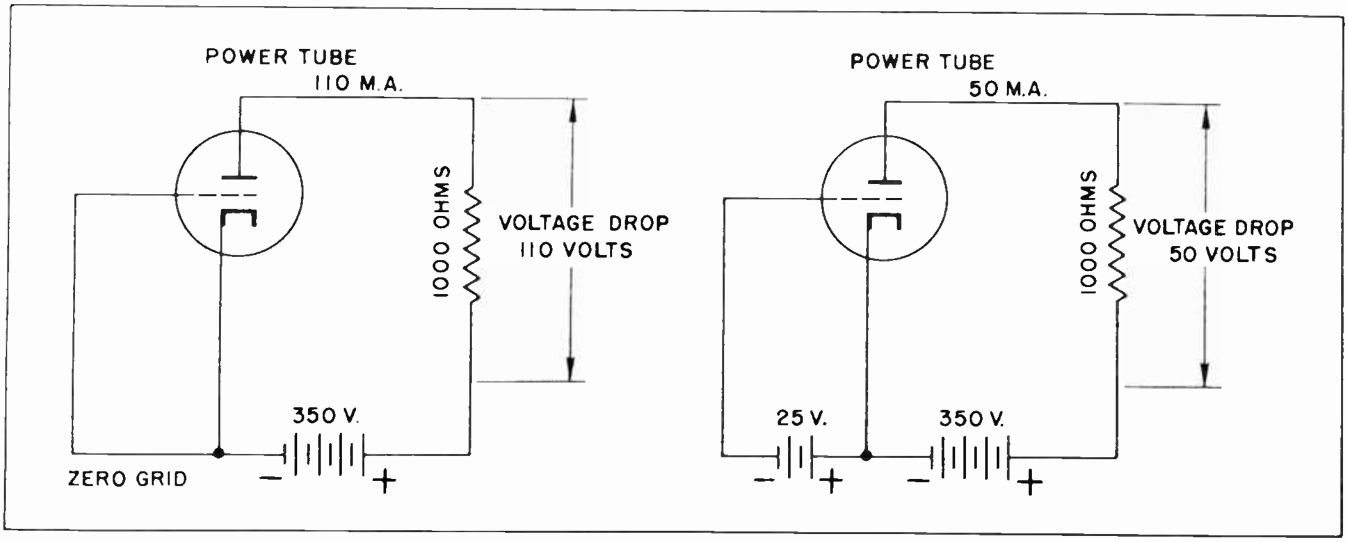

Fig. 5.

anode circuit. Where the anode current is small it is possible for us to use a high resistance for the load resistor. Instead of the 1000-ohm resistor we use for the power amplifier tube we will use 10,000 ohms. (See Fig. 6.)

Since this is a voltage amplifier tube, the spiral wires of the grid will be close together. A small grid voltage will have a material effect on the passage of electrons. 5 negative volts on the grid would probably result in reducing the anode current to about 4 milliamperes. 4 M.A. flowing across the load resistance of 10,000 ohms would result in a voltage drop of only 40 volts. This is a difference of 60 volts from that when the anode current was 10 M.A.

What we have here is a situation where 5 volts change on the grid results in 60 volts change across the load, a voltage *gain* for the amplifier tube stage of 12. This means the *output* voltage of the stage is 12 times greater than the input voltage.

Although the tube designed for power amplifier work could be so used that it would amplify the voltage 2 2/5ths times, a tube especially designed for voltage amplification would amplify it 12 times. For this reason it would not be feasible to use a power tube as a voltage amplifier tube. We already know why it is not feasible to use a voltage amplifier tube as a power tube -- the voltage amplifier tube does not pass enough anode current.

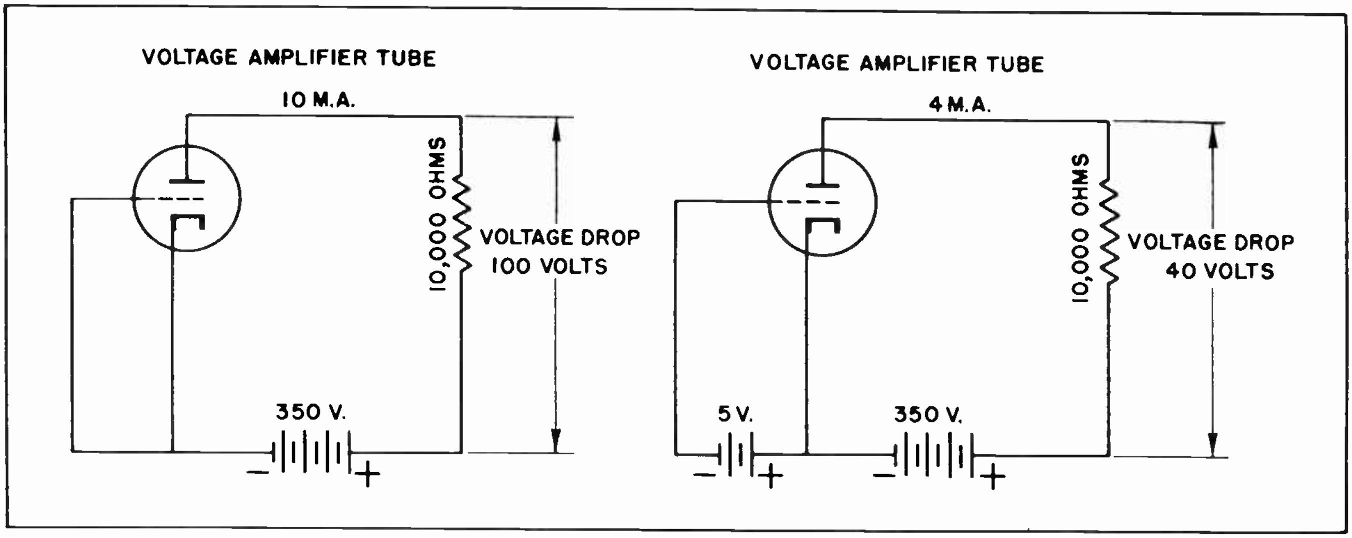

Fig. 6.

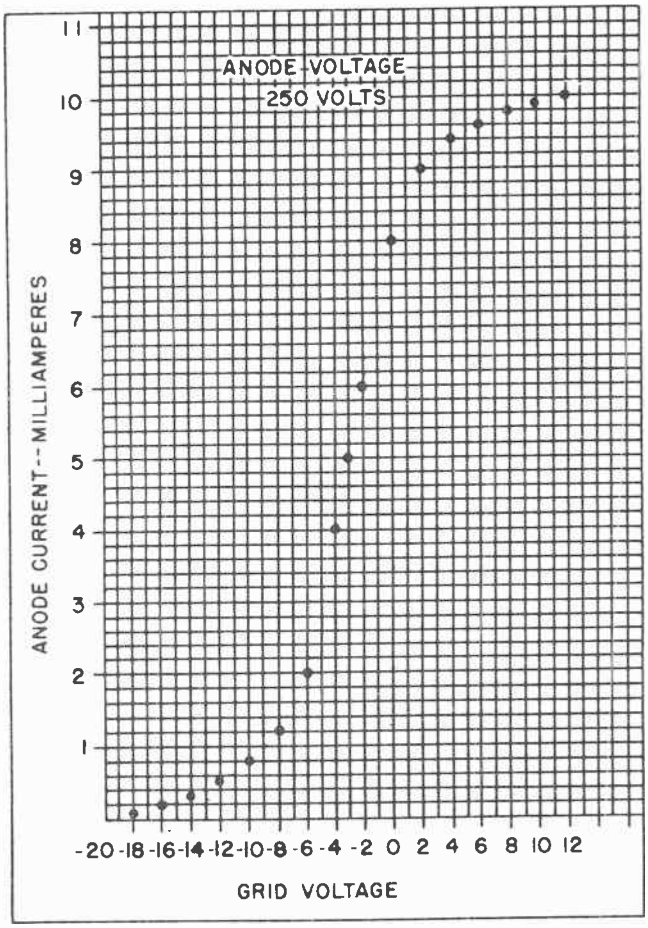

Fig. 7.

Section 3. DYNAMIC CHARACTERISTIC CURVES

In our study of the action of vacuum tubes we have created a number of "graphs" showing the action of one part of the tube when the voltage was varied on another part. This type of graph shows what is generally referred to as *static* curves of vacuum tubes. This name is given to them because it shows what will happen to the anode current, or some other feature of the tube, when there is *no load* in the anode circuit.

As we have intimated, the vacuum tube is nearly always operated with a load of some kind in the anode circuit. The load might be any of a number of different things. It might be a resistance, such as an ordinary carbon resistor, or it might be some other type of load. The point is, however, that the kind of *characteristic curve* we use for studying the operation of a vacuum tube when under load is somewhat different than the one we study when it is not under load. Where the curves of a tube not under load are called *static curves,* those of a tube which is operating into a load are called *dynamic curves*. Dynamic curves are generally used to determine exactly how a tube will operate in an actual operating circuit.

In order to use a dynamic curve we must first construct such a curve. In Fig. 7 we take the first steps toward doing just that thing. We have constructed the basis for a graph there. We have taken a vacuum triode and placed 250 volts on the anode, then connected a milliammeter in the anode circuit as shown in Fig. 8, and a voltmeter across the grid circuit. Then we have set up a voltage divider network across a battery so we can vary the voltage on the grid.

With the arrangement shown in Fig. 8 we have proceeded to take a variety of grid voltage and anode current readings. The results of these readings have been recorded on the graph in Fig. 7.

We start out by placing 20 negative volts on the grid of the tube. With such a high negative voltage on the grid no anode current is able to flow. So we place a dot on the graph on the -20 volt vertical line. But since no current is flowing, the dot is placed on the "zero" current horizontal line.

The next reading is taken at -18 volts on the grid. With this voltage on the grid a small amount of current begins to flow -- about 1/10th of a milliampere. Another dot is placed on the graph where the vertical -18 grid voltage line crosses the horizontal location which would represent 0.1 M.A.

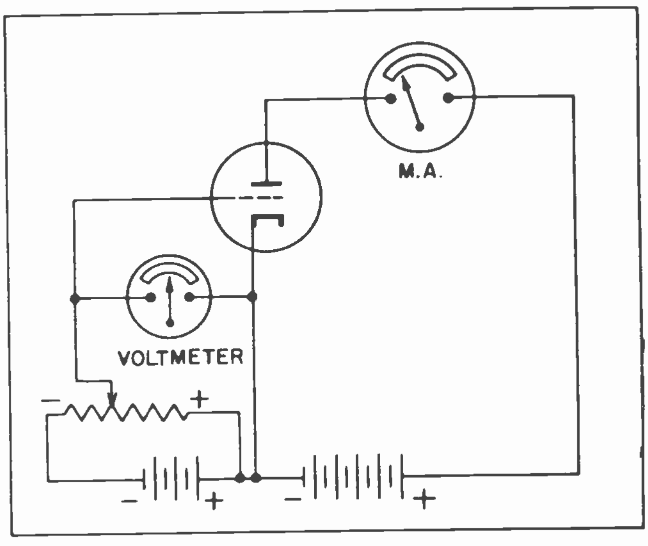

Fig. 8.

The next reading is -16 grid volts. With this voltage on the grid, 0.2 M.A. of current will flow in the anode circuit. Another dot is placed on the graph where the vertical -16 volt line crosses the horizontal 0.2 M.A. line.

The readings continue. -14 grid volts allows 0.3 M.A. to flow. -12 allows 0.5 M.A. of current; -8 volts allows 1.2 M.A. of current; -4 volts allows 4 M.A. of current. And so it goes until the readings have been taken up to 12 positive volts on the grid.

Note how the dots arrange themselves on the graph. When the grid is quite negative, any reduction in the negative voltage results in some increase in anode current, but not very much. But as the grid voltage is reduced some more, the anode current increases quite rapidly. In this region the line of dots rise on the graph paper in a very steep line. But after the anode current rises to about 8 M.A. the line of dots do not rise quite so steeply any more. Instead they incline toward the right. This indicates that decreasing the grid voltage no longer has as much effect on the anode current as it did before. When the anode current reaches values in this neighborhood it is approaching what we call *voltage saturation*. This is the same voltage saturation we encountered when studying diode tubes.

In order to see a little more plainly how the several meter readings are related to each other we can join all the dots together with a curving line as in Fig. 9. The graph in Fig. 9 shows several things very distinctly. The first thing to be noted is that when the grid voltage is in the region below about -6 volts we encounter what is known as a "non-linear" portion of the curve. By "non-linear" we mean that in the region where the grid voltage ranges from about -6 volts to about -20 volts a change in the grid voltage is not always reflected in a *proportional* change in the anode current. This non-linear portion of the curve is often called the lower "knee" of the curve.

As an example of this we can see by glancing at the graph that we will cause the anode current to change from 2 M.A. to 1.2 M.A. by changing the grid voltage from -6 volts to -8 volts. This is the section of the curve from point "A" to point "B". Thus we find that changing the grid voltage by 2 volts here, we change the anode current by 0.8 M.A.

But let's see what happens when we change the grid voltage from -8 to -10 volts. Here we again change the grid voltage by 2 volts, but we change the anode current from 1.2 M.A. to 0.8 M.A. or a change of only 0.4 M.A. This is the section of the curve from point "B" to point "C".

From *A* to *B* a change of 2 volts on the grid caused a change of 0.8 M.A. in the anode current, but from *B* to *C* another change of 2 volts on the grid resulted in a change of only 0.4 M.A. in the anode current. Thus the changes in this region of the curve are not *even*; they are not *proportional*.

But from point "A" to point "D" is virtually a straight line. A change of 2 volts on the grid anywhere along that portion of the curve will result in a change of 2 M.A. of anode current. This part of the curve, the straight portion, is called the "linear" portion of the characteristic curve. This is the part of the curve that we usually try to use for voltage amplifier work.

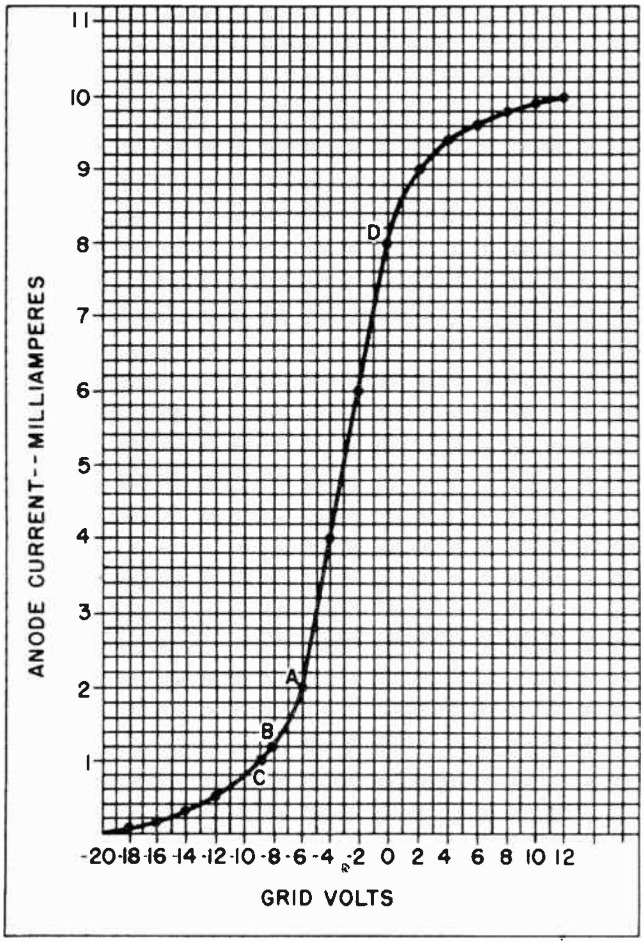

Fig.9.

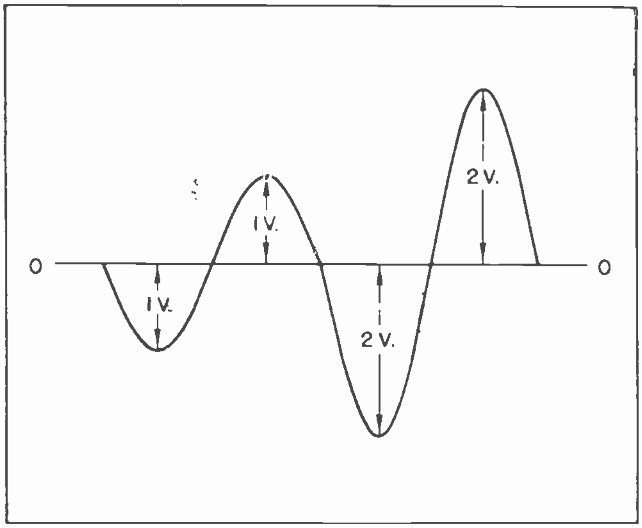

Fig. 10.

It should be noted that after the anode current reaches about 8 M.A. in the region of point *D* the curve is no longer straight -- it is no longer *linear*. In this region any voltage changes on the grid will not be reflected in proportional changes in the anode current. This non-linear portion of the curve is called the upper "knee" of the curve.

Operating a vacuum tube in the regions below point *A* or above point *D* will result in the signal becoming *distorted*. By distortion we mean that the output signal will not be a reproduction of the input. This is usually undesirable. In most applications we want the output signal to be an exact reproduction of the input signal, but greatly amplified. This is the reason we usually find it desirable to operate a tube between points *A* and *D*.

Usually the signal which is to be amplified is an alternating voltage. Now an alternating voltage, as we already know, is one which is alternately positive or negative with respect to some zero base. This is shown graphically in Fig. 10. One instant the voltage is in a positive direction; an instant later it is in a negative direction.

If it is desired to amplify a voltage such as the one shown in Fig. 10 we could do that very readily by means of a vacuum tube. All that is necessary is to provide some means of introducing the signal onto the grid of the vacuum tube.

Now suppose the grid of the tube had no negative voltage on it at all when the alternating voltage signal was placed upon it. If that were the situation there would be 8 M.A. of current flowing at that point. See point "D" in Fig. 9. Now we will apply the voltage of the wave shown in Fig. 10 to the grid of the tube which is graphed in Fig. 9. Placing 2 negative volts on the grid by means of the signal will reduce the current from 8 M.A. to 6 M.A.

But what happens when the positive half cycle of the wave comes along? That causes the anode current to increase. The anode current will rise from its normal value of 8 M.A. to 9 M.A. under the influence of the 2 positive volts.

Here we have an undesirable situation. The *negative* half of the input signal voltage wave placed on the grid will cause the anode current to drop *2* M.A., but the *positive* half of the voltage wave will cause the anode current to increase only *1* M.A. It is entirely obvious that the output signal would not be an exact reproduction of the input signal -- one-half of the voltage

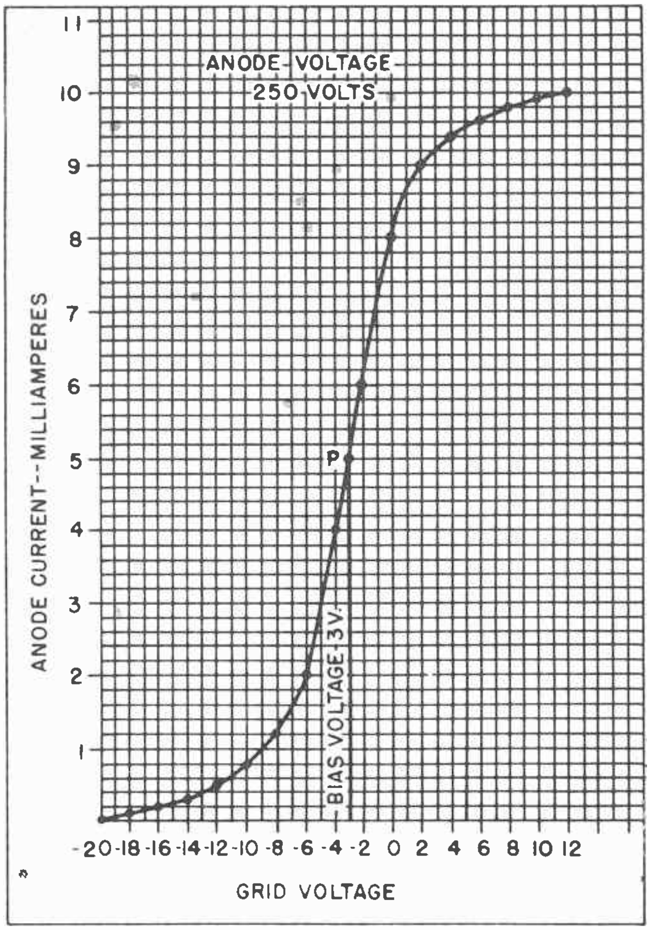

Fig. 11. The grid bias voltage determines the operating point of the tube.

wave will have been amplified just twice as much as the other half.

It becomes quite clear that we must do something to the grid in order to change the *operating point*. Before we do any thing we should study the graph and see just where we could operate the tube so it would reproduce the signal we want to place on the grid. A study of the graph will show us that if we could arrange it so the anode current would be about 5 M.A. when there was no signal on the grid, we could then apply a signal to the grid and the signal would be perfectly reproduced in the anode circuit.

In order to cause the tube to operate so that 5 M.A. of current will flow in the anode circuit when no signal is applied, we place what is called a "bias voltage" on the grid of the tube. A "bias voltage" is a negative voltage which is placed on the grid of the tube so as to place the operating point in the region on the linear portion of the curve which is most desirable.

In this case it would seem most desirable to operate the tube around point "P" in Fig. 11. In order to make the tube operate at that location we will place a negative "bias" of 3 volts on the grid of the tube. Doing this will reduce the anode current to 5 M.A. and place the operating point just about midway of the linear portion of the characteristic curve.

Suppose we now try our signal again. We will start it off in the positive direction as shown by Fig. 12. First the alternating voltage will move in a positive direction to

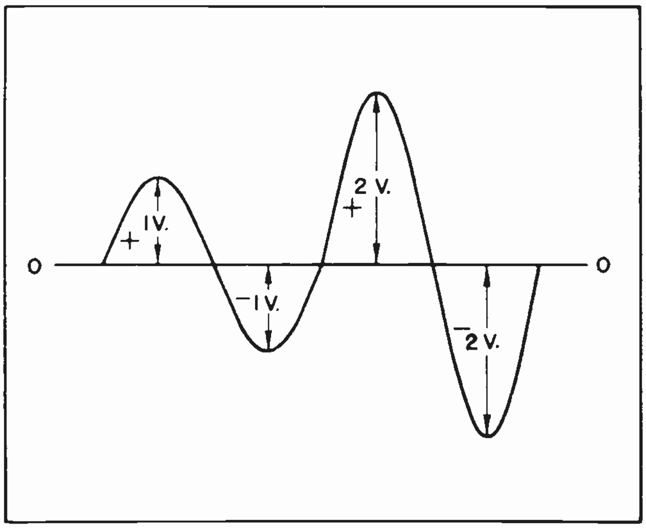

Fig. 12.

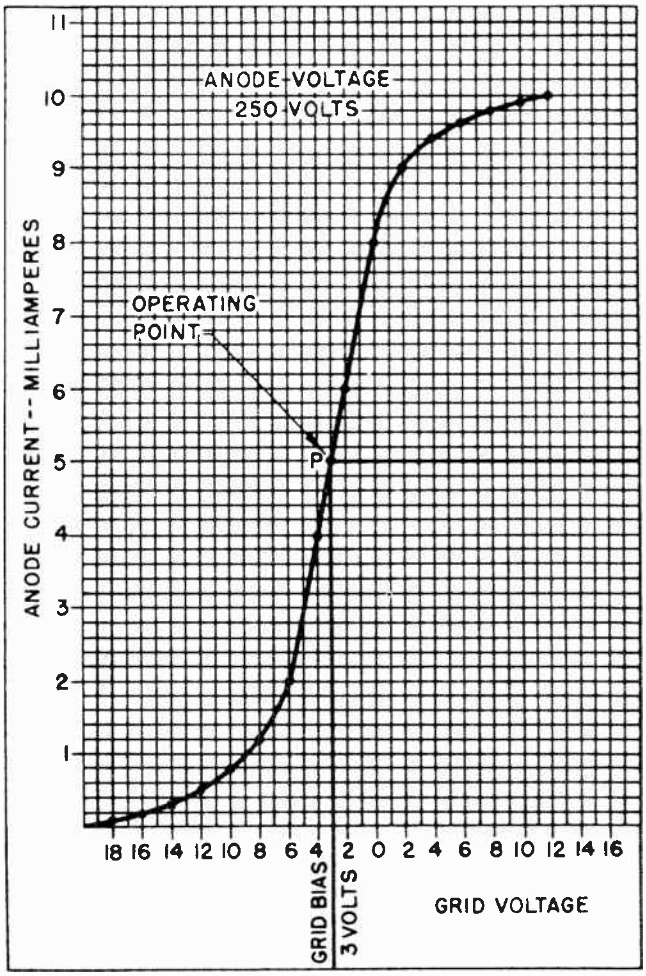

Fig. 13. Changes in the grid voltage results in changes in the anode current. The anode current can be graphed to the right of point "P".

a peak of 1 volt, then reverse itself and go in a negative direction to a peak of 1 volt. In the next cycle it will go to 2 volts positive, then 2 volts negative.

We will place the signal voltage on the grid, superimposing it on the negative "bias" of 3 volts. The alternating voltage will alternate back and forth around the biasing voltage shown in Fig. 13. The varying grid voltage will cause the anode current to increase or decrease around the operating point "P". The anode current will increase when the grid voltage goes in a positive direction and will decrease when the grid voltage goes in a negative direction. We can graph the varying grid voltage by using the vertical biasing point of Fig. 13 as the zero level for the signal voltage. Then we can graph the varying anode current on the line extending horizontally to the right from the operating point "P" in Fig. 13.

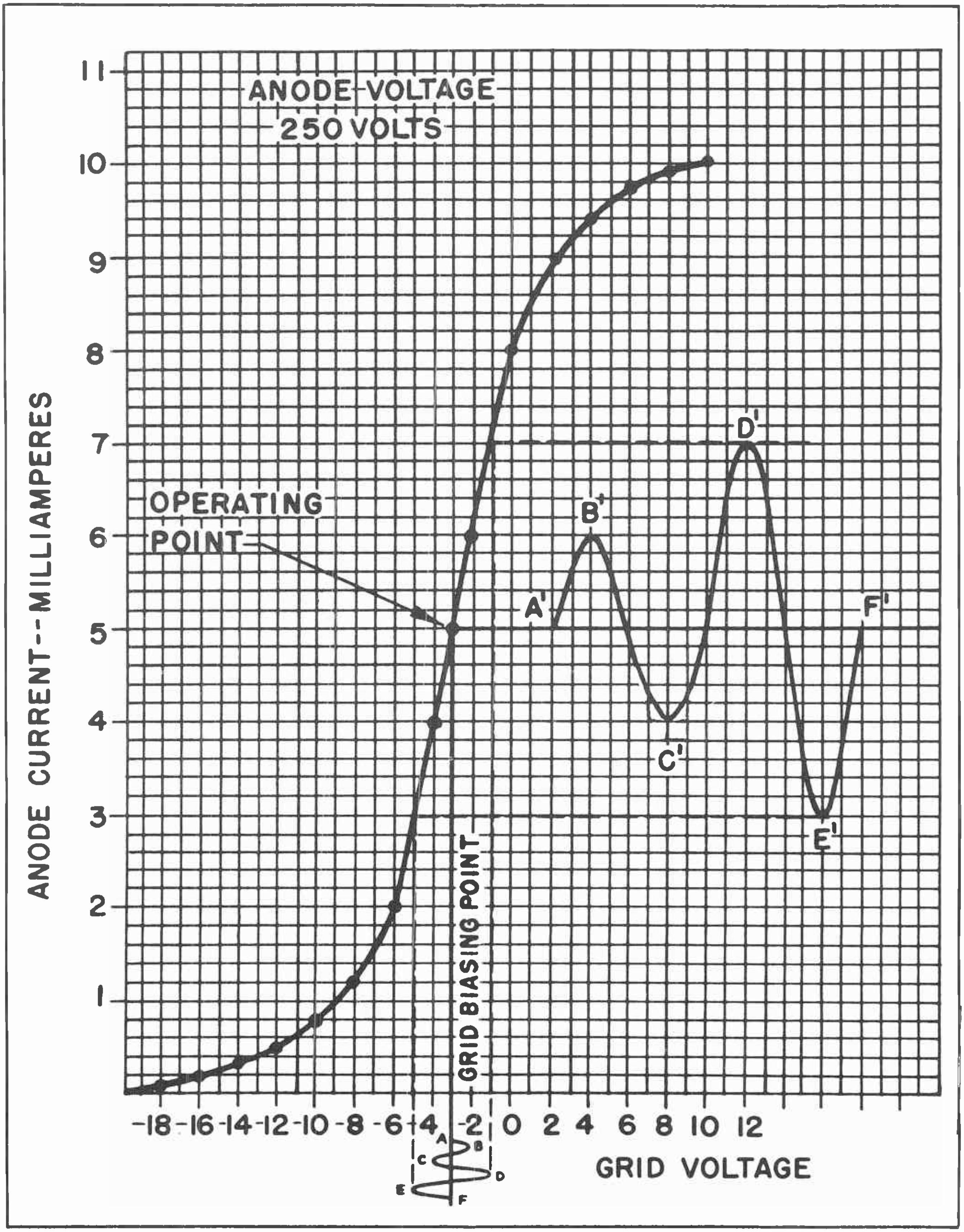

Fig.14. Changes in the grid voltage is reflected in changes in the anode current.

The graphing of the alternating signal voltage and the resulting anode current has been done in Fig. 14. Where the signal voltage in Fig. 12 has first moved 1 volt in a positive direction, we have marked that from point *A* to point *B* around the bottom of the grid biasing point line. When this 1 positive volt is superimposed on the 3 negative volts it causes the grid voltage to drop from -3 volts to -2 volts. This change in the grid voltage causes the anode current to rise from 5 M.A. to 6 M.A. which is shown as the curving line from A' to B' on the varying anode current graph.

Next the signal on the grid goes in a negative direction; it goes back to the normal bias of -3 volts, then continues going negative until it reaches -4 volts. This is from point *B* to point *C*. When the grid is negative by -4 volts the anode current is reduced to 4 M.A. as shown on the curve which graphs the changing anode current. This is the change from B' to C'.

In the next cycle of the signal voltage it goes 2 volts in a positive direction. This reduces the voltage on the grid to -1 volt. When the grid voltage is -1 volt the anode current will be 7 M.A. The graph of the grid voltage shows the voltage moving from point *C* to point *D*, and the anode current moving from point C' to point D'.

It will be noted that for every change in grid voltage there will be a change in the anode current which is directly proportional. When the anode current is exactly proportional to the signal voltage, the output signal will be an exact reproduction of the input signal.

The importance of obtaining an exactly proportional anode current can be better understood when it is realized that the anode current will flow across a load. Every change in the current across that load will result in a voltage change which is directly proportional to the value of the current. This follows from the application of Ohm's Law.

To illustrate this, suppose the anode current is flowing through a load resistance of 20,000 ohms. Such a circuit would be similar to Fig. 15. We have found that changing the grid one volt will change the anode current 1 milliampere. One milliampere flowing across 20,000 ohms results in a voltage drop of 20 volts. The ultimate result is that through the action of the tube the original signal voltage which was applied to the grid of the tube reappears across the load resistor magnified 20 times.

During the time when there is no signal on the grid of the tube -- only the 3 volts of negative bias -- the various currents and voltages in the tube circuits will be as in Fig. 15. With a battery voltage of 350 volts, a load resistance of 20,000 ohms, and 3 volts bias on the grid, there would be 5 milliamperes of anode current flowing. The 5 M.A. flowing through the load resistance would cause a voltage drop of 100 volts across that resistance, thus placing 250 volts on the anode of the tube.

To repeat, this is the situation in and around the tube at times when no signal is applied to the grid of the tube.

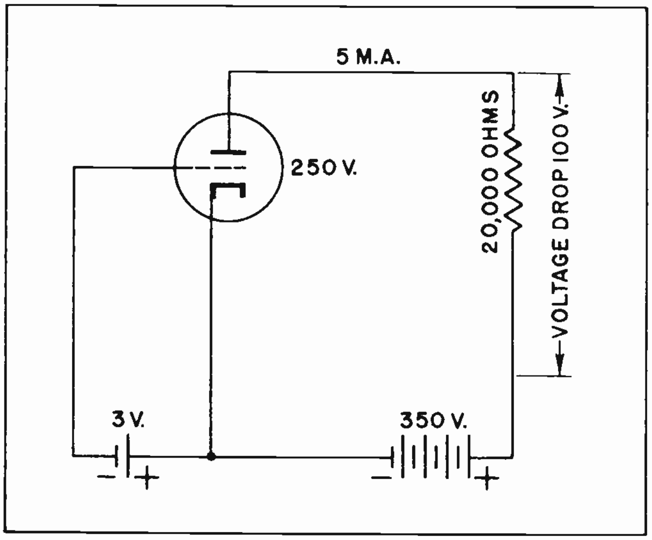

Fig. 15.

Now suppose we apply the signal which has been diagrammed in the graph of Fig. 14. There we find a signal which swings 1 volt each side of the zero line for one cycle and then swings 2 volts each side of the zero line during the next cycle.

We can apply the signal to the grid of the tube by means of a transformer coupling as shown in Fig. 16. The 3 negative bias volts can act directly on the grid through the conductor of the transformer secondary winding. But at the instant the upper end of the transformer is one volt positive, as shown in Fig. 16, this one positive volt will be subtracted from the 3 negative volts of the bias. This makes a total of 2 negative volts which are on the grid during that instant. With only 2 negative volts on the

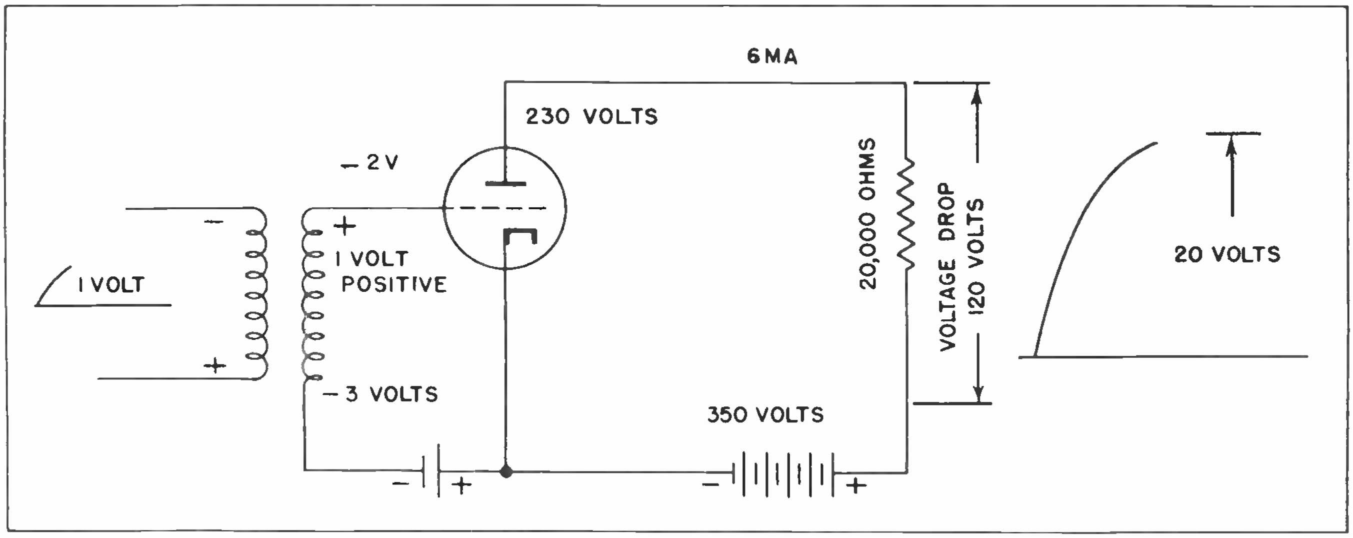

Fig. 16. The small signal voltage superimposed on the grid by means of the transformer reappears greatly enlarged across the load resistor.

grid we find by looking at the graph of Fig. 14 there will be 6 M.A. of current flowing in the anode circuit. When the 6 M.A. of current flows through the 20,000 ohms of resistance in the load there will be a voltage drop of 120 volts. This is shown in Fig. 16. When the voltage across the load increases to 120 volts, that reduces the voltage on the anode to 230 volts.

The main point is this: A change of one volt on the grid (from -3 to -2) causes a change of 20 volts (from 100 volts to 120 volts) across the load resistance. The 20 volts which we can tap off from across the load resistance is just as useful to us as the one volt applied to the grid. In fact it is much more useful -- it is 20 times larger. The *shape* of any voltage wave which might appear across the load resistance will be exactly the same as the voltage wave *shape* which is placed upon the grid, provided we are careful to keep the tube operating on the *linear* portion of the characteristic curve.

The same thing occurs when the input signal on the grid of the tube goes in the negative direction except the action will be reversed. When the input signal goes in the negative direction by 1 volt as shown in Fig. 17, the results will be as shown in the diagram there. Making the grid 1 more volt negative increases the negative voltage on the grid to -4 volts. The graph in Fig. 14 tells us that when the grid is

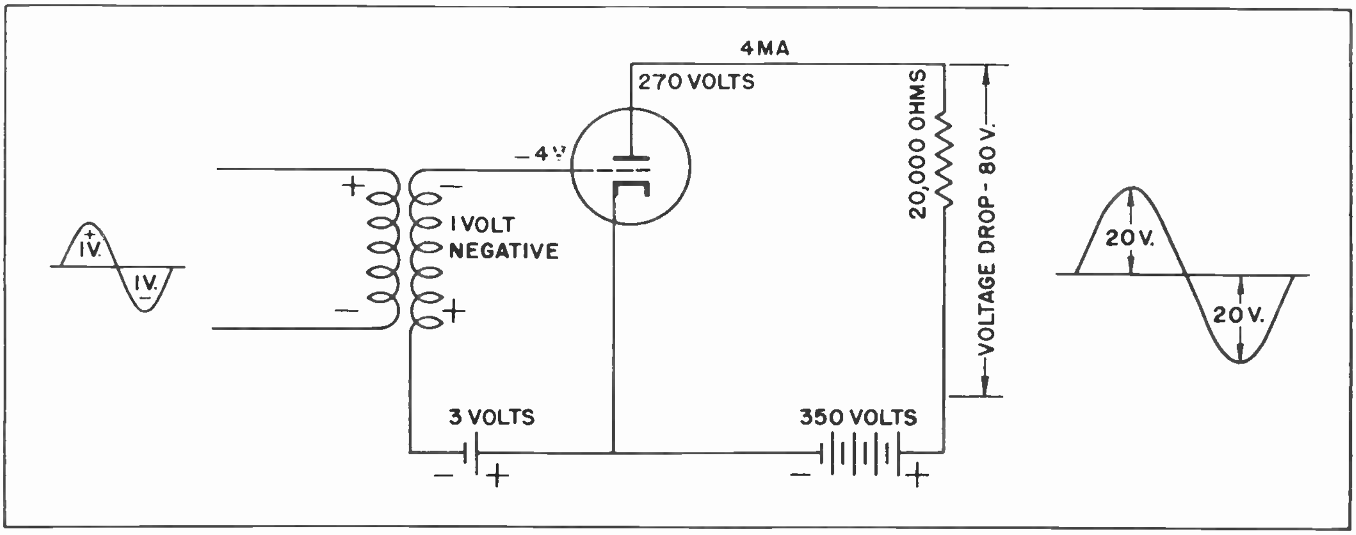

Fig. 17.

4 volts negative there will be 4 M.A. of current flowing in the anode circuit. 4 M.A. in the anode circuit will cause a voltage drop across the load resistance of 80 volts, a change of 20 volts from the normal condition when there are -3 volts of bias on the tube, and a change of 40 volts from that when the grid was only 2 volts negative.

Section 4. PHASE INVERSION

The step by step description of the action which takes place in a voltage amplifier circuit when a signal is being amplified is accurate except for one little point. The signal which appears as a voltage across the load resistance is an exact reproduction of the signal which was placed on the grid with one exception. *The signal is inverted.*

We did not show the inverted condition of the signal at the output of the tube at the time we were going through the amplification action because we did not want to distract your attention from the point then being described. But the matter of phase inversion should now be mentioned and described. It should be emphasized that in most radio or sound circuits the matter of inverting the phase is usually unimportant. Normally the ear could not detect such inversion. But inversion of the signal phase must be considered when working with video circuits. If phase inversion is not taken into consideration, the spots which should be white on the picture may come out black, and those which should have come out black may come out white.

Fig. 18 shows graphically how the signal is inverted. The grid voltage is at all times negative, but under the influence of the signal voltage it is sometimes more negative than at other times. When it becomes less negative as is the case when the signal is positive, the anode current will increase proportionately. More anode current creates a larger voltage drop in the load resistance but *decreases* the voltage on the anode. Thus, as the grid voltage becomes *more* positive, the anode voltage becomes less positive, and when grid voltage becomes *less* positive, the anode voltage becomes *more* positive.

The output signal will be exactly the same as the input signal except that it will be greater, *and will be inverted.* Technically this inversion is referred to as a signal *180^0 out of phase.* That is merely a mathematical expression commonly used in electronic work to express phase inversion. So that you will become accustomed to each of these expressions, we will use them both from time to time.

This is in line with our practice of trying to use all the expressions -- both technical and vernacular -- which you will encounter in your work in this field. It is a peculiar characteristic of electronic work that engineers and amateurs, as well as ordinary repairmen, all work side by side in perfect harmony. Engineers bring their technical terms into the shop where they are often picked up by the less highly skilled workers. The technicians and repairmen also have their own pet names for many things in the way of electronics. The

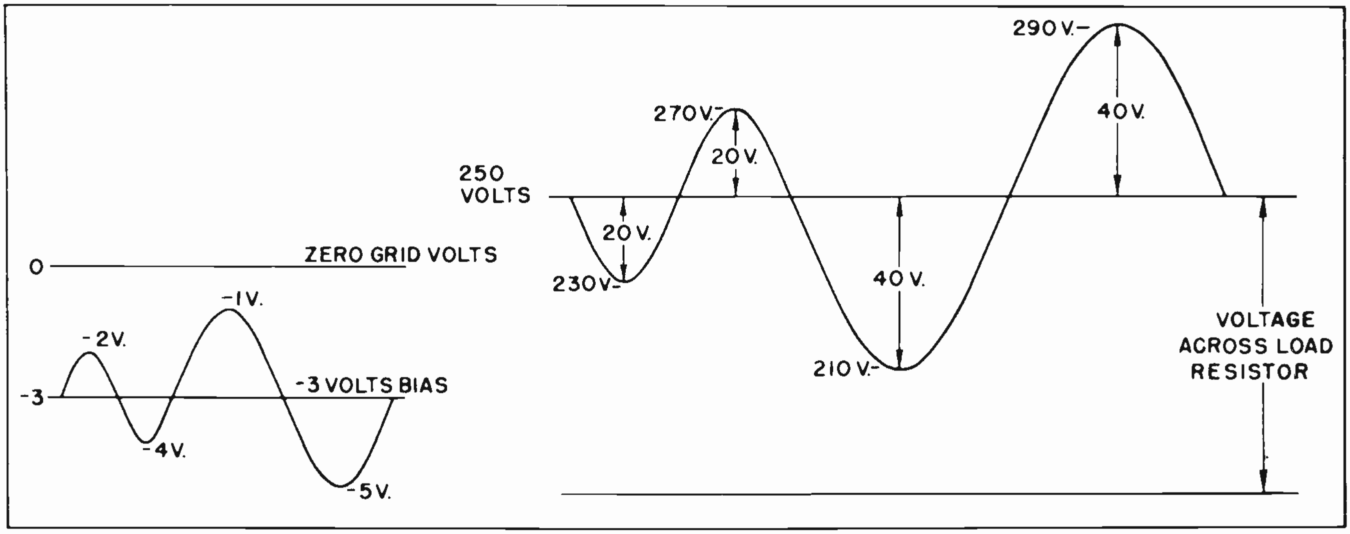

Fig. 18.

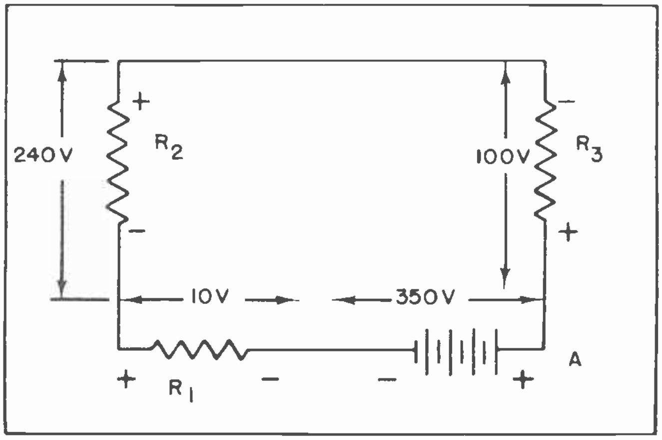

Fig. 19.

engineers in turn pick up this everyday slang and use it as commonly as the more technical expressions. This has resulted in two or more names for nearly everything in electronic work. Sometimes it is a bit confusing to the newcomer into the field, but even the rankest novice soon finds himself slipping into the habits of the more ancient workers, and adopting the expressions of the profession, then using them as his own.

Section 5. **METHODS OF OBTAINING GRID BIAS**

In our previous discussions of vacuum tubes we have acted on the assumption that a separate battery has been used to provide the *bias* needed for the proper operation of the vacuum tube. In many cases this is done. In the earlier days the battery was used almost exclusively.

But a battery has definite drawbacks when used for this purpose. For one thing, using a battery makes just one more thing which is subject to deterioration and need for replacement. This feature alone makes the battery unsatisfactory. Another objection is that a battery, even the smallest, is bulky. Usually we strive to keep all the components of an electronic device as small and compact as possible.

In broadcast transmitters and some other special applications we will find specially regulated grid voltage supplies. But since these types of biases do not concern us at the moment, we will describe the method which is in most common use in nearly all electronic devices you are likely to encounter.

In order to fully understand how such a bias operates, we will review very briefly the voltage drops which occur across resistances when current flows through the resistance. Suppose we set up a circuit similar to that shown in Fig. 19. Here we have a battery connected to three resistances in series. If we start from point *A* and go in a clockwise direction we will find the battery creating an electromotive force of 350 volts. The polarity of the battery is such that there will be a deficiency of electrons at point *A* and an over-supply at the other end of the battery.

The electromotive force of the battery will push some of the electrons through the resistance of resistor R_1. But in pushing the electrons through the resistance there will be a drop of 10 volts in the voltage. In other words, the right end of R_1 is more negative than the left end.

Even with a drop of 10 volts in the electrical potential we still have 340 volts left to push the electrons through the resistance of R_2. But in pushing the electrons through R_2 we drop the voltage another 240 volts. This leaves 100 volts with which to push the electrons through R_3. By the time the electrons have gotten through R_3, all the electromotive force has been used up and the electrons are back at the starting point.

Technically speaking, the battery raises the electromotive force. The voltage is then dropped as the current passes through each of the resistors. There will be a voltage drop across each resistor, depending upon the amount of resistance, and the value of the current.

Most worthy of note is that the right end of resistor R_1 is negative with respect to

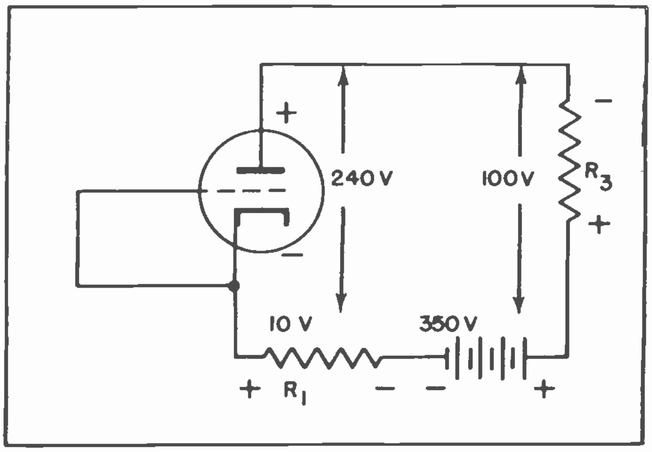

Fig. 20.

the left end. In this case the voltage difference between the two ends amounts to 10 volts.

In Fig. 20 we have redrawn the circuit of Fig. 19 but have substituted a vacuum tube for resistor R_2. The circuit will now be identical except for that one substitution; the voltage drop across R_1 will be the same, the voltage drop across R_3 will be the same, and the voltage drop across the tube will be the same as that across R_2 in Fig. 19. Note that in Fig. 20 the grid is tied directly to the cathode, and is of course at the same potential as the cathode.

Note also that that cathode is not at the same potential as the negative end of the battery. Instead, it is 10 volts more positive than the most negative part of the battery, although the anode is still 240 volts more positive than the cathode.

Now suppose we redraw the diagram again and connect the grid as in Fig. 21. The cathode is still 10 volts more positive than the negative end of the battery due to the action of R_1. But now we have the grid connected to the negative end of the battery. This means that the cathode is 10 volts more positive than the grid.

If the cathode is 10 volts more positive than the grid it is the same thing as saying the grid is 10 volts more negative than the cathode. It means the same thing. In our work we normally would say the grid is more negative than the cathode.

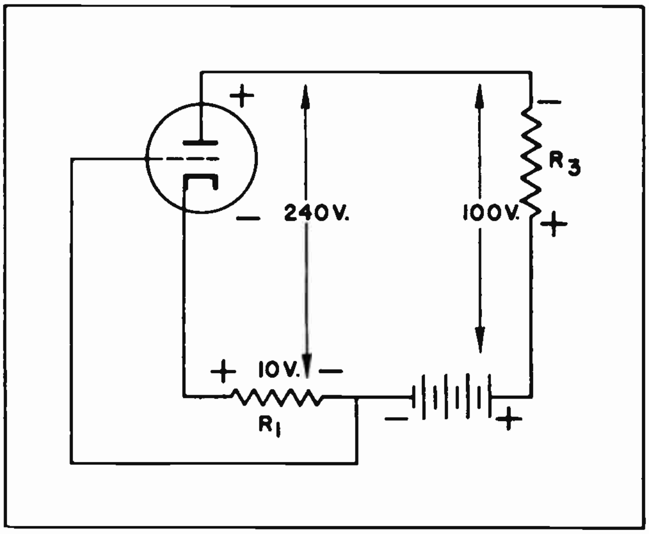

Fig.21.

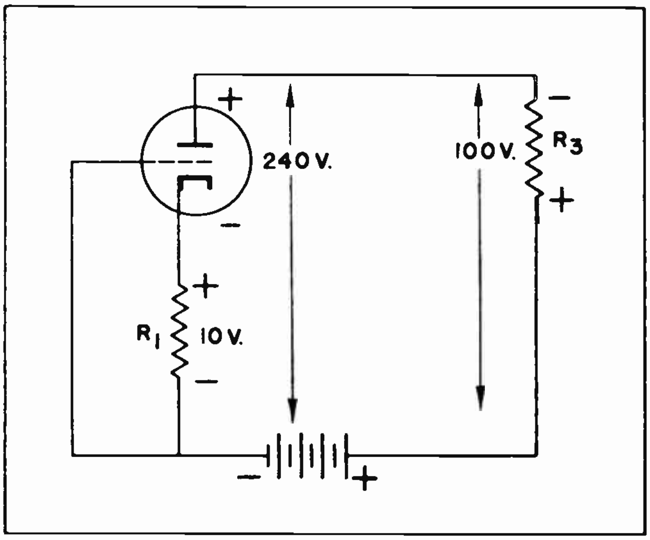

Fig.22.

Section 6. **CATHODE BIAS**

The more conventional method is to draw this circuit in the manner shown in Fig. 22. When resistor R_1 is connected as shown here it is usually referred to as the *cathode resistor*. Sometimes it is called the *cathode bias* resistor. Sometimes the *bias resistor*. When it is connected in this manner all the current which flows through the tube must pass through the cathode resistor. By selecting a resistor of the proper value it is possible to place whatever value of negative voltage on the grid that suits our needs or the requirements of the tube. In general, the current which will flow through the cathode resistor will be the same as that which flows in the anode circuit. In the case of tubes which use screen grids we will find slightly more current through the cathode resistor than is in the anode circuit. This is because the current which flows in the screen grid circuit must also pass through the cathode resistor.

We can place any value of grid bias on the grid which suits our fancy. As an example, we need 5 negative volts on the grid. We may know there are normally 5 milliamperes of current in the anode circuit. We can find the amount of resistance we need in the cathode resistor by dividing the 5 volts by the 5 milliamperes. By dividing 5 milliamperes into 5 volts we find we need 1000 ohms of resistance. (5 volts ÷ .005 amperes).

Then with 1000 ohms of resistance in the cathode circuit we will have a voltage drop across it of 5 volts when 5 milliamperes of current flows through it. This 5 volts can then be applied to the grid as was previously shown in Fig. 22.

Section 7. DEGENERATION

The thought has probably come to you that if the varying anode current which passes through the load resistor creates voltage fluctuations across that resistor, why does not the same varying current which flows through the cathode resistor cause voltage fluctuations across the cathode resistor? And if such varying voltages are created across the cathode resistor, what prevents them from being applied to the grid in the form of a varying signal which would interfere with the original signal applied to the grid?

Indeed, something like that would actually take place if the circuit where left as shown in Fig. 22. To see exactly what would happen, suppose we follow through a sequence of actions which would follow the placing of a signal on the grid.

First we will make the grid slightly more *positive* than normal. This will cause more current to flow through the anode circuit -- and the cathode resistor. More current through the cathode resistor would cause a *larger* voltage drop across the cathode bias resistor. A larger voltage drop across the cathode resistor means more *negative* voltage on the grid.

So -- the effect of placing more positive voltage on the grid immediately results in placing additional negative bias on the same grid, thus cancelling, or partially cancelling the signal voltage. Actually the fluctuating voltage applied to the grid from the cathode bias resistor will seldom or never be as great as the original signal voltage. But the fluctuating current which flows through the cathode resistor does very definitely cut down the effectiveness of the signal voltage. This cuts down, or limits, the *gain* which could be obtained through such a tube.

Reduction of the signal voltage, due to the action of the cathode resistor is known as *degeneration.* Although it limits the effectiveness of the signal voltage, such degeneration does have some advantages. Should any distortion creep into the amplified signal while passing through the tube and its immediate circuits, such degeneration will tend to radically reduce the distortion. For this reason many vacuum tube circuits are deliberately designed to have some degeneration in them. This aids in maintaining a high degree of *fidelity.*

By high fidelity we mean a reproduction of the original sound so that it appears to the ear to be the same. High quality radios, radio-phonograph combinations, F-M receivers and the better television receivers all strive for high-fidelity. In many of these sets a certain amount of degeneration is deliberately introduced into the receiver to improve its tone quality and fidelity.

Section 8. BY-PASS CAPACITOR

Where we have plenty of *gain* in a vacuum tube stage we can afford a reasonable amount of degeneration. But there are other times when we want the gain to be as high as possible. In that case it becomes necessary to arrange the cathode circuit in such a manner as to avoid as much degeneration as possible.

The *average* amount of current which flows through the cathode resistor will remain virtually stable, notwithstanding that there may be fairly wide swings from instant to instant. If we can devise a method of ironing out these wide swings, so to speak, and keep the actual flow of electrons through the resistor at a fairly constant level, we will be able to use the cathode resistor as a source of grid bias and yet not be bothered by the fluctuating voltage which is caused by the varying anode current.

In Fig. 23 we have added a "by-pass" capacitor to the cathode circuit. The by-

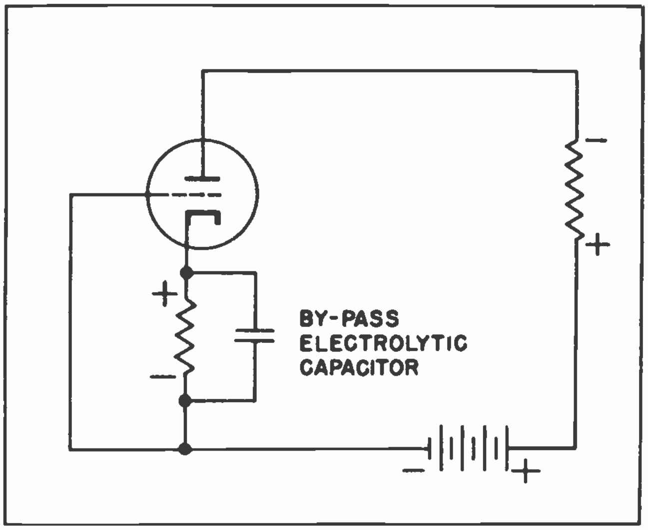

Fig. 23.

pass capacitor will absorb the varying voltage and current changes, "passing" the *A-C component* of the current in the cathode circuit along to the cathode. The actual *D-C component* will flow through the resistor as a steady, unfluctuating stream of electrons. The effect of the capacitor is to "by-pass" the fluctuations around the resistor, yet at the same time allowing the steady stream of electrons to flow through the resistor.

Such by-pass capacitors usually have fairly high capacity. Many of them are electrolytics. An electrolytic capacitor can be used in this application because of the polarized conditions under which it will operate. The use here is somewhat similar to its use in filter circuits with rectifiers.

Section 9. STAGE GAIN

The voltage amplification of a vacuum tube circuit is usually referred to as the *gain* of the circuit, or *stage*. A stage of amplification is measured from the input at the grid of a tube to the output at the load in the anode circuit. The amount of amplification which can be achieved in one stage depends upon several things. These things include the amplification factor of the tube, the plate resistance of the tube and the load resistance in the plate circuit.

The gain in a stage, or in a circuit, is commonly expressed by means of a formula. The gain itself is represented by the letter *A*, the first letter of the word *amplification.*

We should be careful to distinguish between the two terms "voltage amplification" and "amplification factor". *Amplification factor* is the measure of a tube's ability to amplify. *Voltage amplification* is the term used to signify exactly how much the voltage has actually been increased in one stage; usually this is somewhat less than the amplification factor of the tube used in the circuit. To say this in another way: We are seldom able to use a tube's ability to amplify to the limit of its efficiency.

Since the voltage amplification of any circuit depends upon the amplification factor (Mu) of the tube, the plate resistance of the tube, and the resistance, it would seem reasonable that we could combine all these factors into a formula, and be able to apply the formula to fit any existing conditions. This has been done. The higher the amplification factor, the greater the voltage amplification can be. The load resistance must be determined within reasonable limits or the circuit will not be satisfactory. Increasing the load resistance up to a certain value is usually beneficial to the proper operation of the circuit; increasing it beyond that point is detrimental. Thus in any formula it is reasonable that the load resistance must be considered in two or more places. Finally, the plate resistance is a limiting factor on the amount of voltage amplification which can be achieved.

The formula for determining the voltage amplification of a stage is given as:

$$A \text{ (voltage amplification)} = \frac{\mu R_L}{R_L + R_P}$$

To find the gain of a stage, then, we should multiply the *Mu* of the tube by the load resistance. The product of that multiplication will then be divided by the sum of the load resistance added to the plate resistance. It should be understood that by plate resistance we mean the *dynamic* plate resistance, the A-C plate resistance.

If you are mathematically inclined you will notice from observation of the formula that the larger we make the load resistance the nearer we will come to realizing the full advantage of the amplification factor of the tube. This is because the greater the value of the load resistance the less significance is attached to the plate resistance.

To see how this formula will work out in a practical circuit, suppose we select a vacuum tube which has a *Mu* of 20. By looking in a tube manual we can learn the plate resistance of the tube from the manufacturer's published data. In the case of this tube we find the plate resistance is 10,000 ohms. We place these values in our formula and find that it looks like this:

$$A = \frac{20 \times R_L}{R_L + 10{,}000}$$

All we have to do now is to select a load resistance. This is a factor over which we have complete control. We can put in whatever value resistance strikes our fancy.

But if the circuit is going to work properly we must make the load resistance a value which will give us a good gain, yet not create distortion in the signal as it passes through the stage. We can tell by looking at the formula that the higher we make the load resistance, the greater will be the gain. For this reason we will select a resistor having 100,000 ohms of resistance as the load for the tube. Putting that into our formula it will look like this:

$$A = \frac{20 \times 100{,}000}{100{,}000 + 10{,}000}$$

Which is equivalent to

$$\frac{2{,}000{,}000}{110{,}000}$$

Which can be solved still further and we come up with a figure of approximately 18.2.

This is large amount of gain for a tube with a Mu of 20. Furthermore, we will find that if the load is made too high, distortion will be found in the output of the stage. The anode current will be held to such a low value the tube will operate in the non-linear portion of its characteristic curve, and other elements will enter into the picture to affect the fidelity of the output signal. For this reason it is not practical to use load resistances as high as we have here.

Practical experience has shown that best gain can be obtained, together with the least distortion by using a load resistance which is approximately equal to the plate resistance of the tube. Suppose we try our formula with the same tube but with only 10,000 ohms of resistance in the load. Our problem will now look like this:

$$A = \frac{20 \times 10{,}000}{10{,}000 + 10{,}000}$$

Which, of course is equal to:

$$\frac{200{,}000}{20{,}000}$$

This, then will figure out to a total gain of 10 for the entire circuit.

Experience has also shown, however, that it is possible to use load resistances somewhat higher than the value of the plate resistance. When the load resistance exceeds the plate resistance, some distortion will be introduced, but until the load resistance reaches a value that is double the value of the plate resistance, the distortion is not noticeable to the human ear. The distortion can be readily detected by use of instruments, and would be troublesome in video circuits. But in the case of sound the distortion can be tolerated by the ears without being objectionable.

We will now try a load resistance in our hypothetical circuit which has a value of 20,000 ohms, just double the plate resistance of the tube. Placing this new value in our formula, we have:

$$A = \frac{20 \times 20{,}000}{20{,}000 + 10{,}000}$$

Which is equal to:

$$\frac{400{,}000}{30{,}000}$$

This figures out to a gain of about 13.3. And this is just about the maximum amount of gain which can be secured from a stage without introducing too much undesirable distortion.

If the voltage amplifier stage is to be used in an industrial circuit where high fidelity is of little concern, the gain can be stepped up much higher by the use of higher load resistances. But for sound or video work we must be satisfied to sacrifice some of our gain for a better fidelity.

Section 10. POWER AMPLIFIERS

In working with vacuum tubes which are designed for use as power amplifiers, we are concerned with somewhat different things than when working with tubes used to amplify voltages. Now we are going to be concerned with tubes which have relatively large currents flowing in the anode circuit, currents large enough to do some work. These tubes will probably require much higher voltage swings on their grids than the tubes we have been working with previously, but if these tubes are preceded

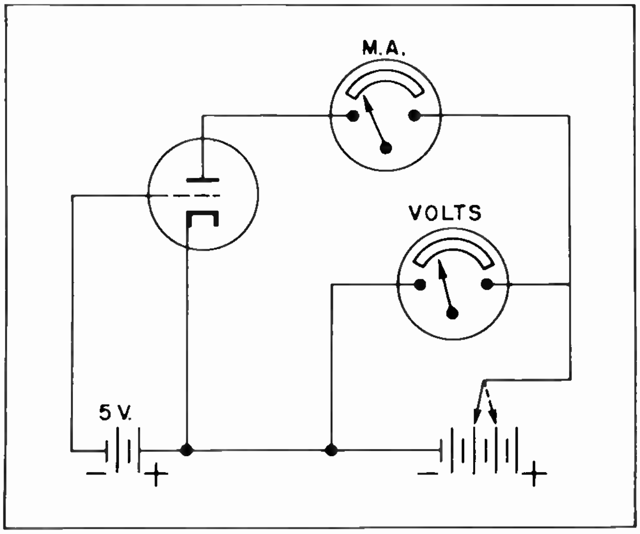

Fig. 24.

by voltage amplifier stages we will have available the necessary grid voltage. Furthermore, since we are dealing with relatively large anode currents we must limit the load resistance to values considerably smaller than was the case with voltage amplifiers. In fact, one of the biggest problems we must face in dealing with power amplifiers is to select the load resistance which will prove most satisfactory; that is, deliver the most power with respect to the value of the voltage on the grid.

In studying the characteristics of a power tube we use a somewhat different "family" of characteristic curves than we use with tubes intended for voltage amplifiers. To create them we will set up a circuit such as that in Fig. 24. In this circuit we will maintain a steady negative bias of 5 volts on the grid. Then we will measure the anode current by means of the milliammeter as we vary the anode voltage.

Our first attempt to obtain anode current will use 25 volts on the anode. Here we

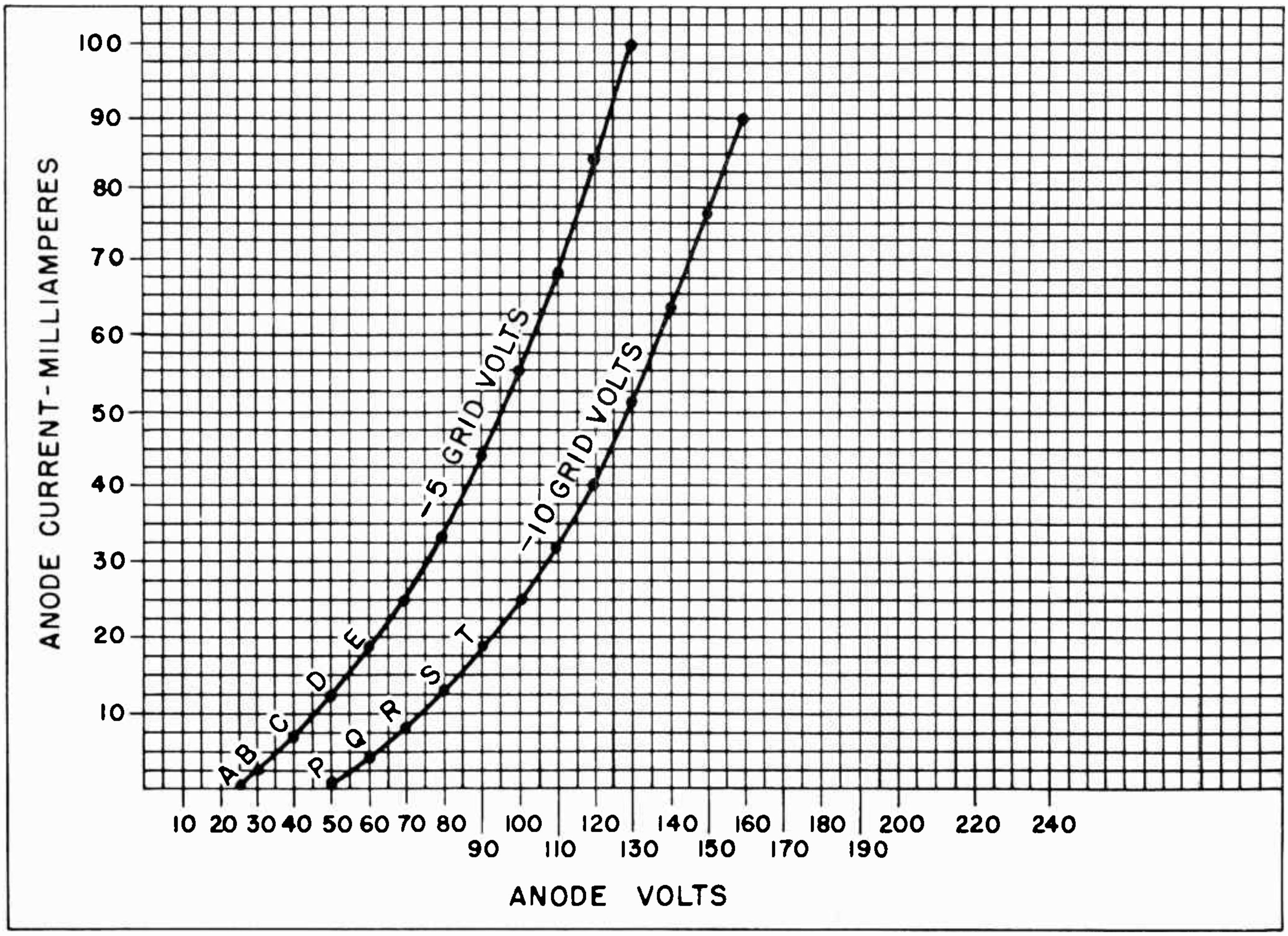

Fig. 25. Graph of the anode current when the anode voltage is varied. One curve represents a grid bias of -5 volts, the other -10 volts.

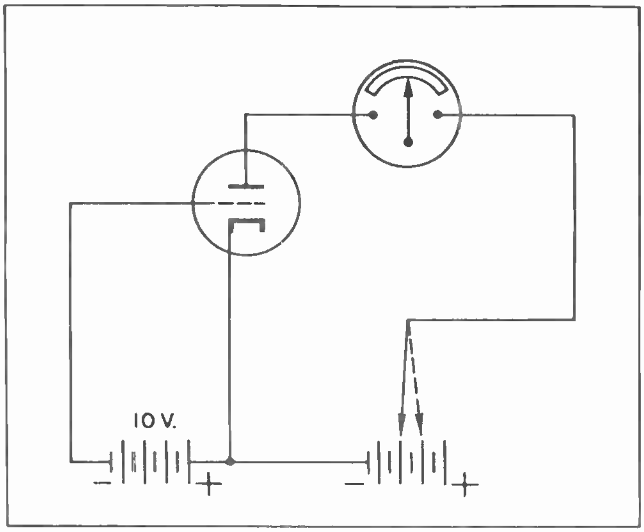

Fig. 26.

get no current so we place a dot at point *A* on the graph in Fig. 25. Then we will increase the anode voltage to 30 volts.

Now we find we have approximately 2-1/2 milliamperes of current.

Note that we are already beginning to get considerable anode current with low anode voltage even though there are 5 volts of bias on the grid. To refresh your memory you might check these values against those of a tube used for voltage amplification.

Continuing our readings we find that 40 volts on the anode will cause almost 8 milliamperes of current to flow in the anode circuit, 60 volts will cause 19 milliamperes of current to flow, which is marked with *E* in Fig. 25.

These readings will continue until we can draw a complete curve as is shown on the graph in Fig. 25. This is the curve marked "-5 grid volts".

Our next step will be to change the grid voltage to 10 negative volts as in Fig. 26.

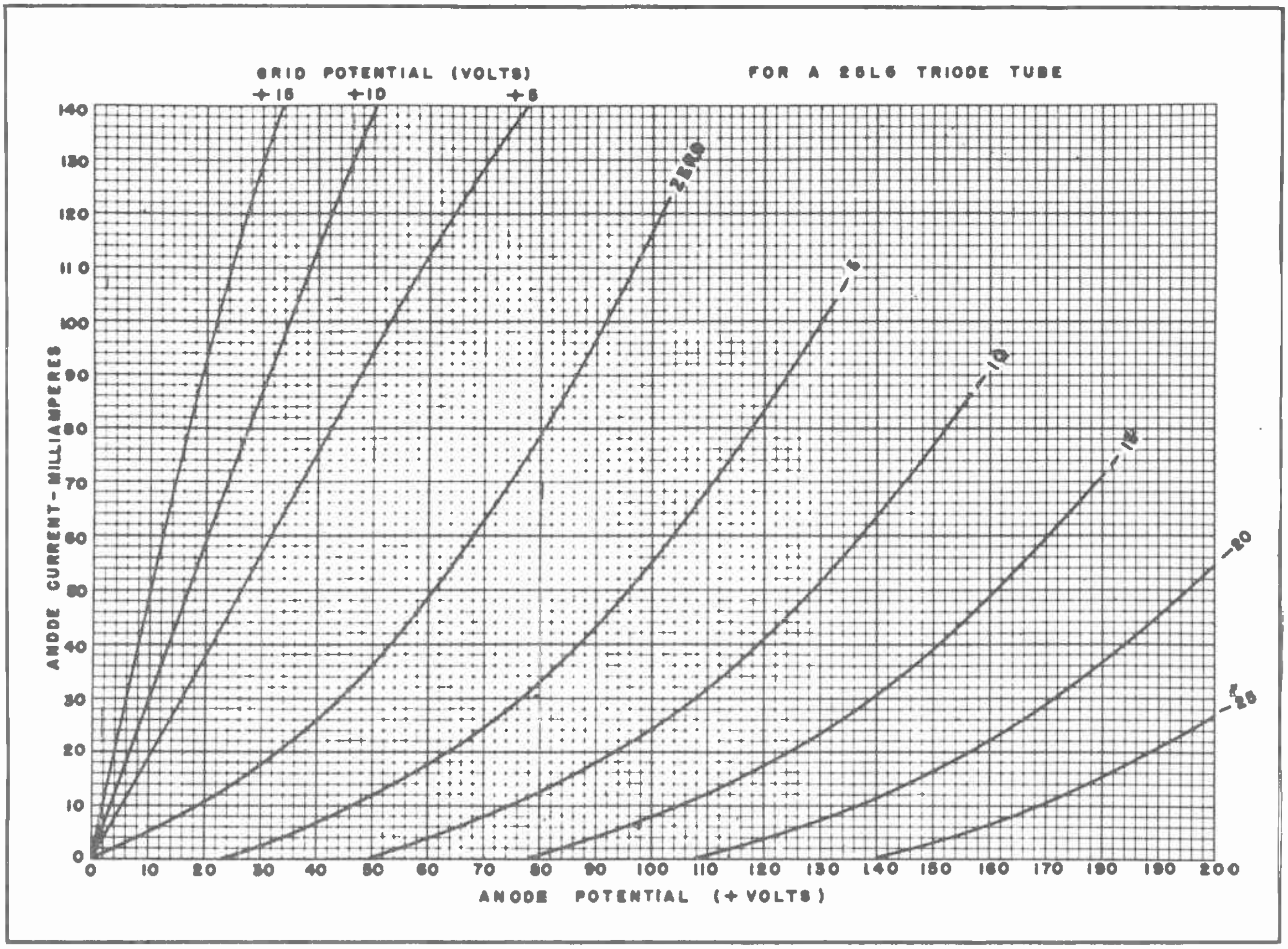

Fig. 27. A family of curves, each curve representing a different value of grid bias.

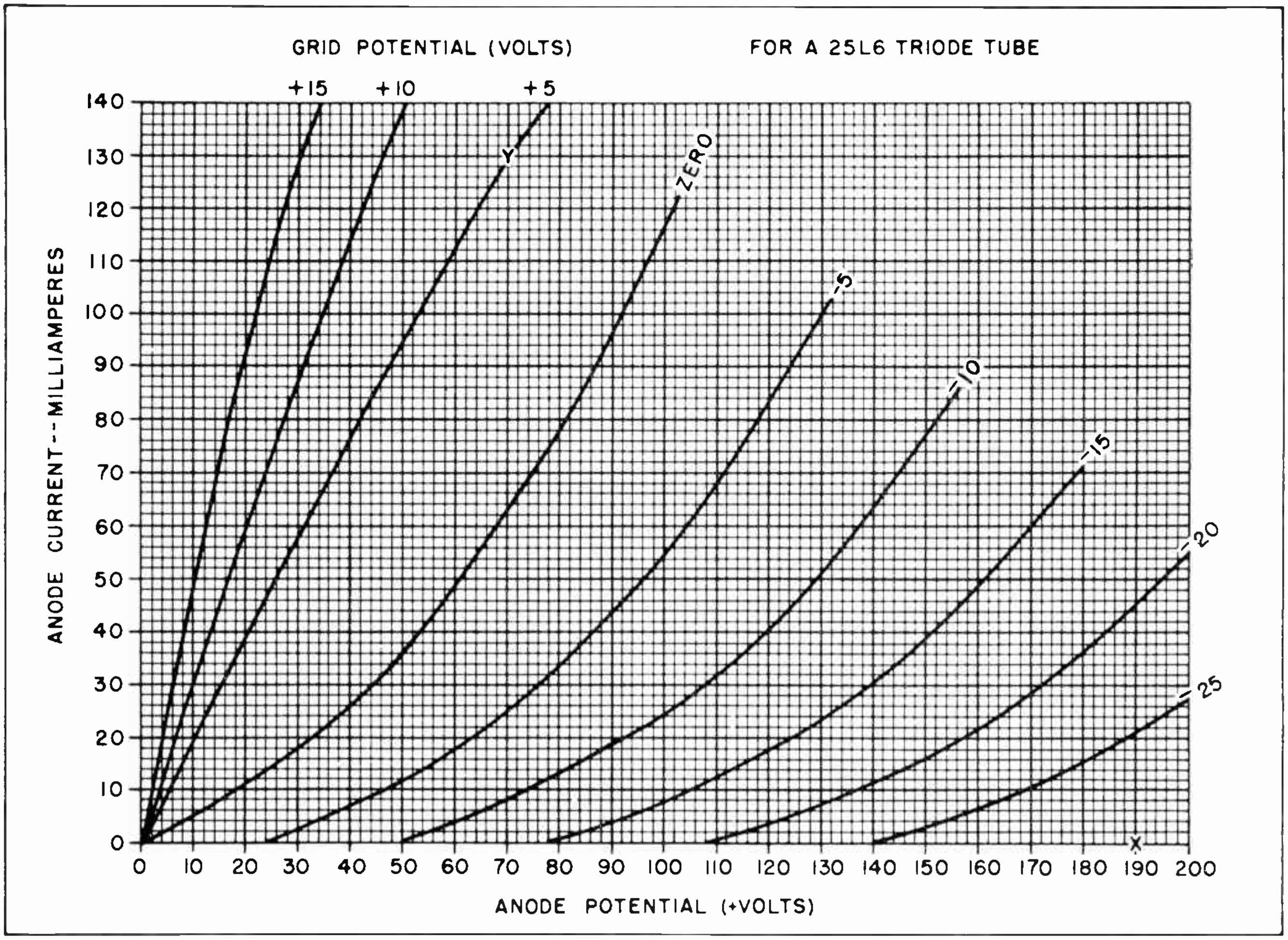

Fig.28. A load line is laid out by first marking off a point on the zero current line as at "X", and another at some larger current, as at "Y".

Then we will again start with a low anode voltage and gradually raise it, keeping a record all the time of the anode current readings. This record is kept on the same chart in Fig. 25 as was used to record the anode current when the grid was 5 volts negative.

When the grid is 10 volts negative we find that we are unable to secure any anode current until the anode voltage is raised above 50 volts. We will start at 50 volts and place a dot on the zero current line at point *P*. The next reading will be 60 volts on the anode. This results in anode current of almost 5 milliamperes. 70 volts gives us 8 milliamperes at point *R*; 90 volts gives us 18 milliamperes at point *T*. All these results are recorded on the graph and when all the readings have been taken up to 160 volts, a smooth curve is drawn to join the dots. This results in the curve marked "-10 grid volts".

The next step is to draw other curves to show the anode current and voltage relationships when the grid bias is 15 volts negative, 20 volts negative, and 25 volts negative. Then to complete the "family of curves" we will use a zero bias on the grid, then some positive biases. When all these readings are recorded on the same sheet of graph paper we will have the family of curves shown in Fig. 27.

Section 11. LOAD LINES

The thing we are actually most interested in is finding the best load into which we can work our tube. By this we mean we are trying to select a load resistance which will give us the best results when using the tube under consideration.

We could find the proper value by a series of experiments on a hit or miss basis. We could actually conduct all the experiments we describe in Figs. 24 through 27. But this would take a lot of time. Further than this it is unnecessary. The tube manufacturer has already conducted all these experiments for us and drawn the family of curves as shown in Fig. 27. These families of curves are readily obtainable from the manufacturer, and are usually included in most tube manuals and handbooks. Since there are more than a thousand different types of tubes, it would be a most exhausting job if you had to run all these experiments on every tube you might want to use. Fortunately, all you have to do is refer to your tube manual and utilize the graphs the manufacturer has provided for you there. What we are trying to do here is explain to you how these graphs can be used.

Since we have the graph of a family of curves supplied to us by the manufacturer, we might just as well make use of it. In using these family of curves the rules say we must find a location on the anode voltage side of the graph where there is no current flowing, and place a mark there. Then we must select some value of current somewhere on the chart and place another mark on it. Then draw a straight line between the two marks and it will give us the load line and the resistance for that load.

That all sounds very good, but at first glance it is somewhat difficult to understand. Fortunately this is one of the things we do not need to understand right at the beginning if we learn the steps of procedure which are laid out for us. After we have gone through these steps a few times, it will gradually dawn on us what the manufacturer is trying to tell us.

The first step is to locate some point on the anode voltage line where the current is zero. Well, the current is zero all the way across the graph at the bottom. What is meant is that we should choose some spot where the grid voltage is so high it has cut off all current flow for that particular anode voltage.

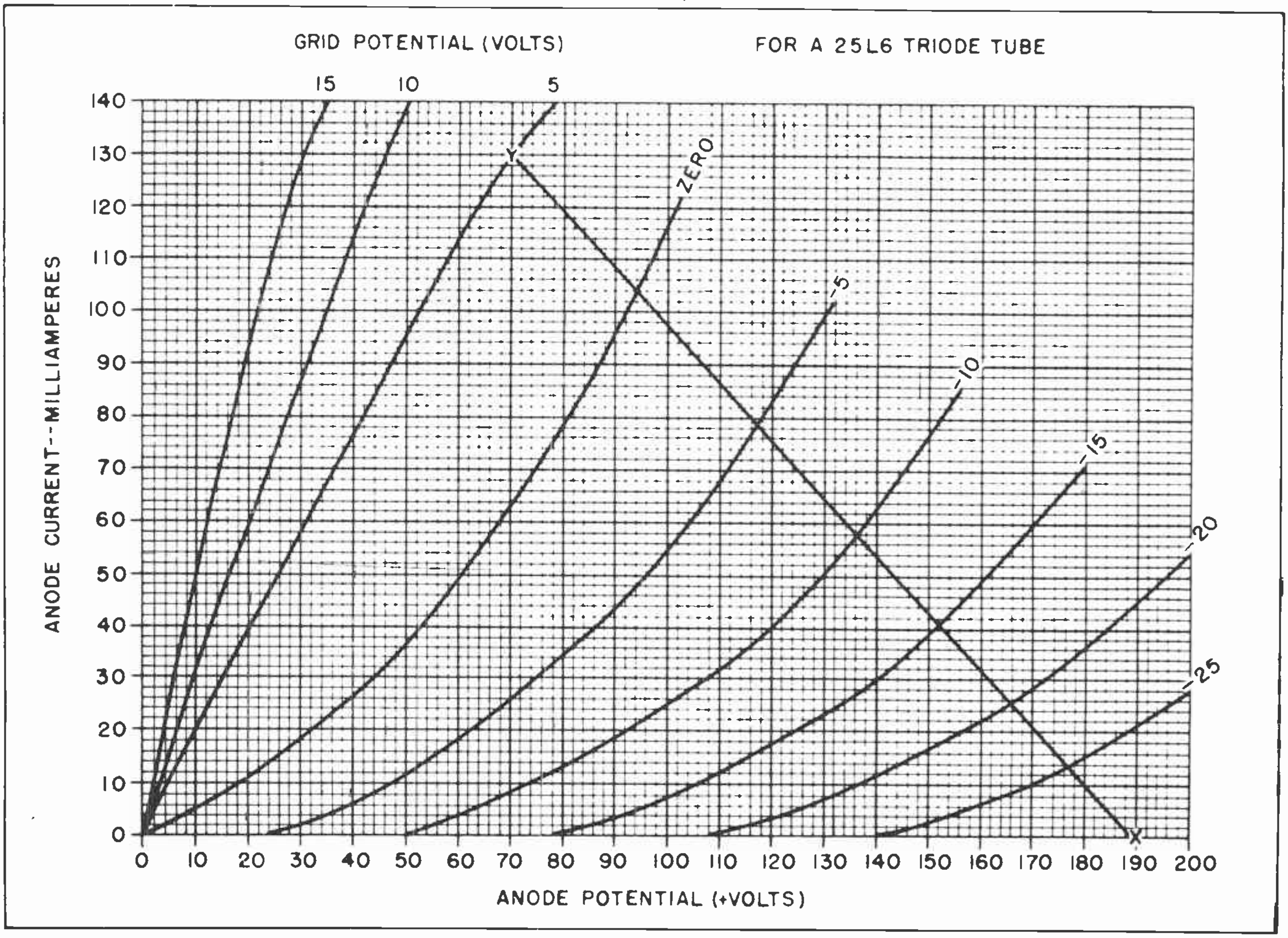

Fig.29. Drawing a straight line between "X" and "Y" completes the load line.

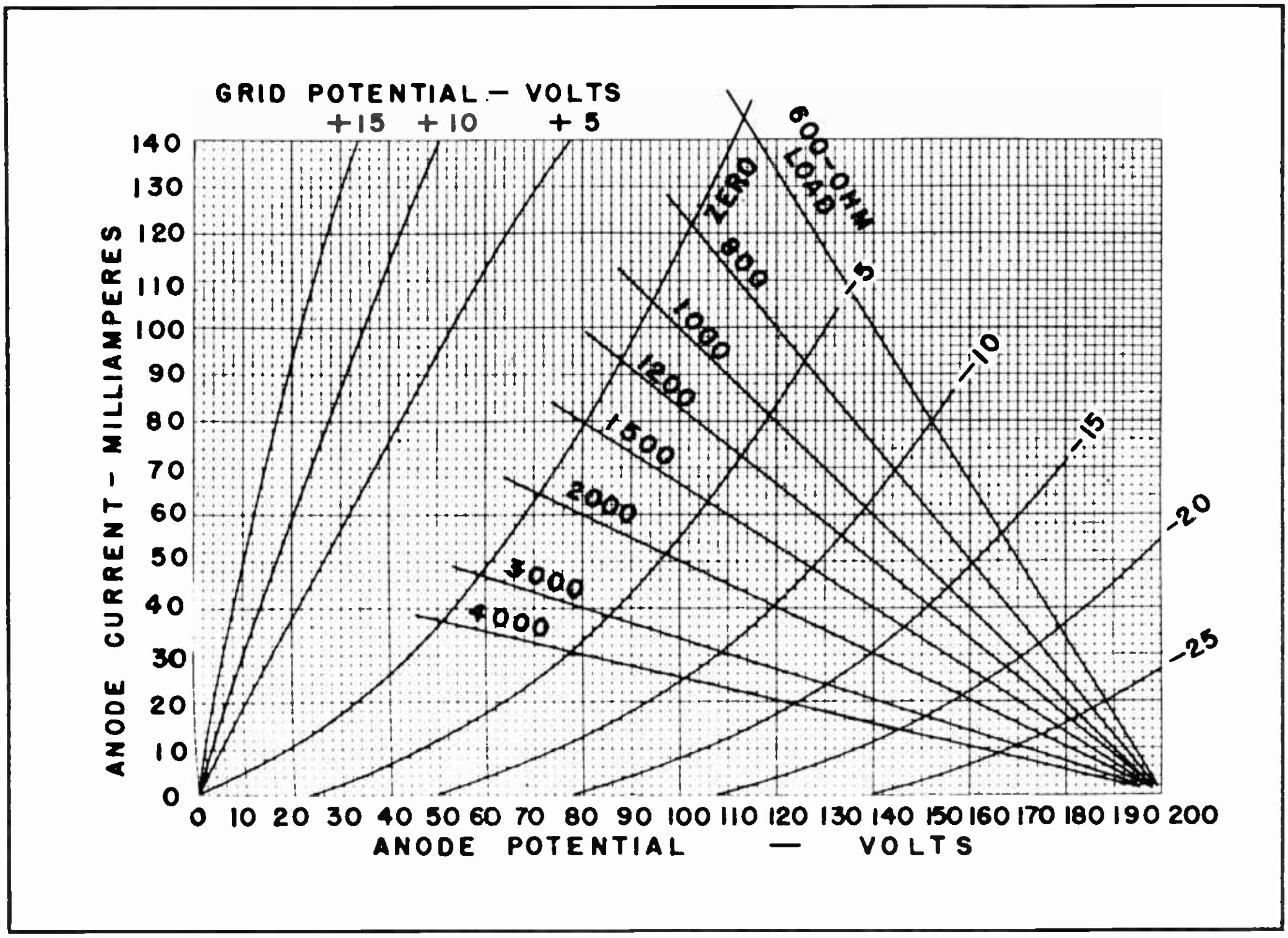

Fig.30. A variety of load lines for a variety of load resistance.

Suppose we have a supply voltage of 190 volts. This would be the same as the "B-voltage" we have mentioned several times, the battery voltage.

If no anode current is flowing, there would be no voltage drop across the load. This would be true regardless of what the value of the load might be. So if we have a supply voltage of 190 volts and there was no voltage drop across the load, there would be 190 volts applied to the anode of the tube. So our first move will be to place a dot on our graph where it is marked "X" in Fig. 28. This is the first step.

Next the rules say locate some value of anode current somewhere on the graph and place another mark on it. Actually it makes little difference where this second mark is placed so long as it is somewhere on the chart. For the sake of convenience, we will place a mark at point "Y" in Fig. 28. This represents 70 anode volts and 130 milliamperes of anode current.

Now these two values -- 70 volts and 130 milliamperes -- have a real meaning. The 130 milliamperes flows through the load, and in doing so causes a voltage drop. But we don't know how much that resistance is -- that is, what we are trying to find out. But we do know the voltage drop across the load must be the difference between 190 volts and 70 volts. (We know this because we are supplied 190 volts by the power supply, yet only 70 volts are applied to the anode. The balance *must be* the voltage drop across the load.) The difference between 190 volts and 70 volts is 120 volts.

This gives us more information. We still do not know the resistance of the load. But we know the value of the current which flows through the resistance, and we know the voltage drop across the load. We can find the resistance by using Ohm's Law. 120 volts divided by 130 milliamperes gives us approximately 920 ohms of resistance.

The final step is to draw a straight line between points "X" and "Y" in Fig. 28. This has been done in Fig. 29. This straight line is called the "load line". It shows exactly how much anode current will flow for any *value of grid voltage* when the supply voltage is 190 volts and the load resistance is 920 ohms.

Fig. 30 shows loads of several resistances drawn on the same graph where the anode voltage is 200 volts. Note that as the anode current decreases the voltage always approaches the 200-volt mark on the bottom line. Note also that as the resistance is increased, the amount of anode current which can flow becomes less and less. If the load resistance becomes too great there is a tendency for the tube to work in the region where distortion will be created. This is in the lower part of the family of curves where the curves are not linear. For this reason it is not a good practice to use a load resistance which is too high.

Further than that, note that the current swings are not very great. Take the case of the load line for 4000 ohms, the bottom line. Even when the grid voltage has been reduced to zero the anode current does not exceed 40 milliamperes. Using a load resistance as high as 4000 ohms prevents the tube from delivering to its full capabilities. A lower resistance will give a much greater *swing* in the anode current.

But there are also practical limits beyond which it is not wise to go in reducing the amount of resistance in the load. Remember the anode current is flowing in both the tube and the load. In the load the high voltage and the high current are capable of doing work, delivering power. But there is power being dissipated inside the tube also. The more electrons which bombard the anode as the current through the tube rises, the hotter the anode becomes. There is a practical limit to the power which the anode of each tube can dissipate. If the tube is driven too hard, the anode becomes too hot, and eventually the tube will burn up. (See Fig. 31.)

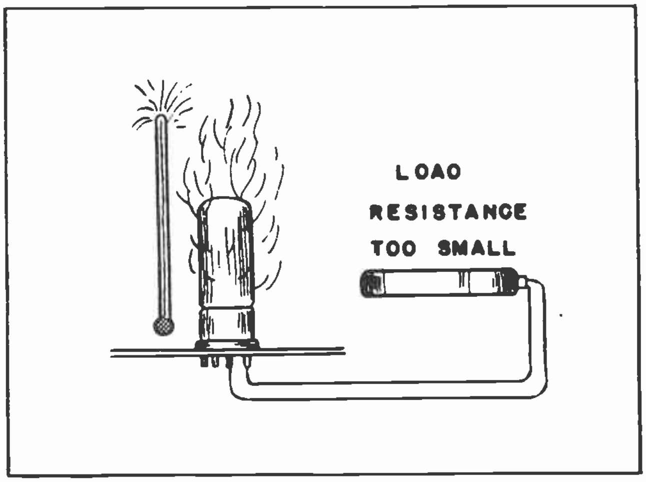

Fig.31. Too small a load will overheat the anode and cause the tube to burn up.

The manufacturer, fortunately, has experimented with his tubes and has determined how much power can be dissipated by the anode. This is called the "plate dissipation" of the tube, and is given in the tube manual by the manufacturer along with the other data concerning the tube.

In running the load lines for any particular tube you should keep in mind this matter of "plate dissipation" and be careful to choose a load resistance of such value that the tube will not be damaged by too small a load.

The lines representing the various values of loads in Fig. 30 which would be most desirable would be those of 1200 or 1500 ohms. These load values give a reasonable swing in the anode current. The 1500-ohm load allows the anode current to swing from a little over 80 milliamperes to zero current, depending upon the swing of the grid voltage, which the 1200-ohm load allows a swing from almost 100 milliamperes to zero, again depending upon the swing of the grid voltage. These values of load resistance are low enough to permit reasonably wide swings in the anode current, yet are large enough to prevent too much power from being dissipated inside the tube, and thus damaging it.

NOTES FOR REFERENCE

There are two general types of vacuum tube amplifiers -- voltage amplifiers and power amplifiers.

Voltage amplifiers deliver relatively little anode current, and a small grid voltage greatly affects the anode voltage.

(over)

Power amplifiers deliver large anode currents but need considerable voltage on the grid to control the flow of anode current.

Data concerning the characteristics of tubes can be secured from the manufacturers or from tube supply houses. This data is included in "tube manuals". These manuals are being constantly changed by the manufacturers. Their cost in nominal.

Characteristic curves are used to place the operating point of voltage amplifiers.

Families of curves and load lines are used to determine the best load for a power amplifier tube.

The following chart shows the various values of volts in the load and the tube, the power dissipated in the load and in the tube, and the percentage of work done in the load and in the tube for the power amplifier tube graphed in Fig. 30.

OHMS	AMPERES	VOLTS		WATTS		PERCENT OF WORK	
In Load	Zero Grid	In Load	In Tube	In Load	In Tube	In Load	In Tube
600	0.145	87	113	12.61	16.39	43.5	56.5
800	.122	97.5	102.5	11.90	12.50	48.8	51.2
1000	.1055	105.5	94.5	11.10	10.00	52.6	47.4
1200	.093	112	88	10.42	8.18	56.0	44.0
1500	.0795	119.5	80.5	9.50	6.40	59.8	40.2
2000	.064	129	71	8.22	4.58	64.2	35.8
3000	.047	141	59	6.62	2.78	70.5	29.5
4000	.037	149	51	5.51	1.89	74.5	25.5

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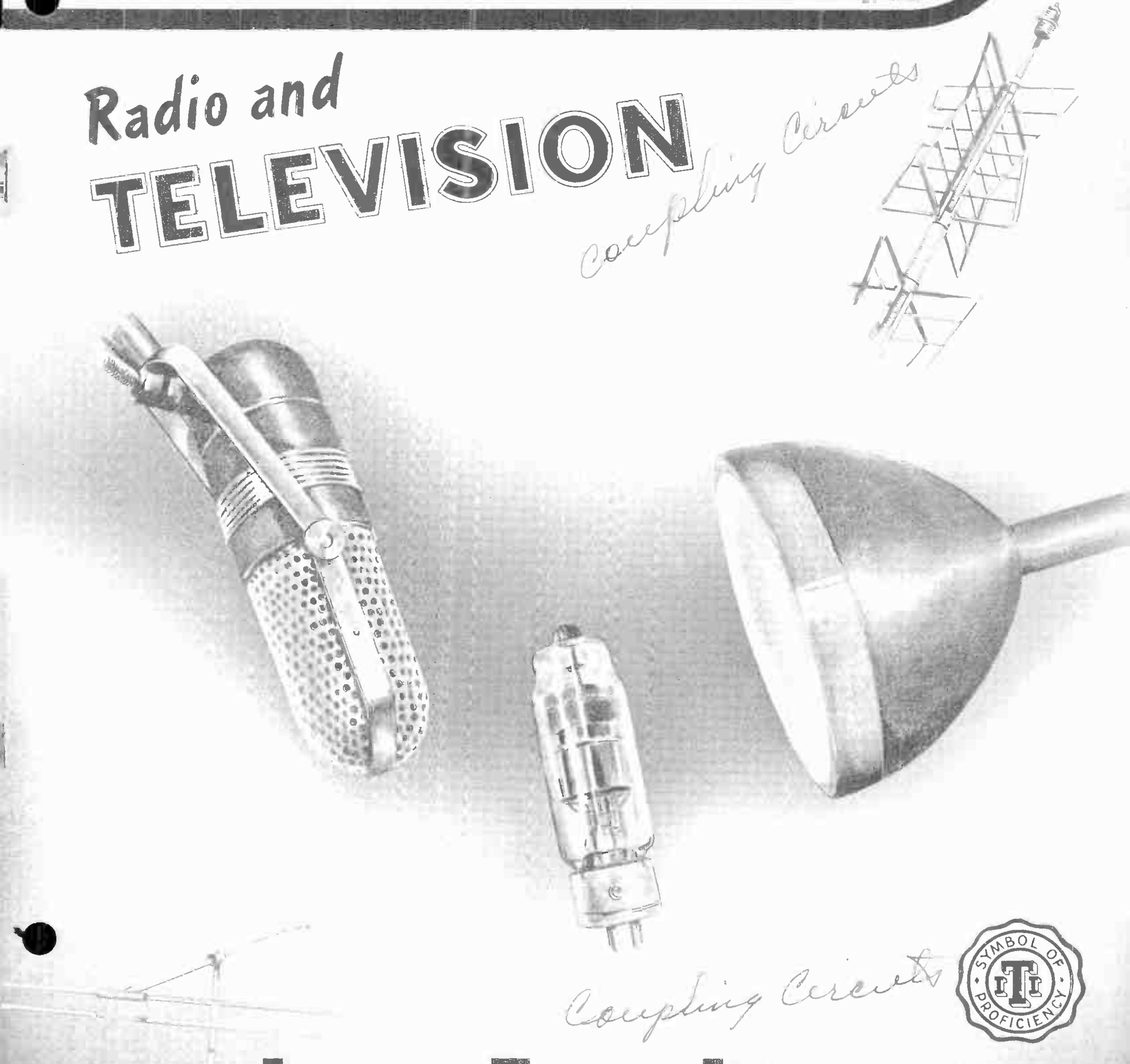

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COUPLING CIRCUITS

Contents: Introduction - Types of Coupling - How Transformers are Used for Coupling - A-C Component and D-C Component - Step-Up Coupling Transformers - Limits to Stepping Up the Amplification - High Frequencies and Low Frequencies - Resistance Coupling - Using a Capacitor - Advantages and Disadvantages of Resistance Coupling - Where Transformer Coupling is Always Used - Resistance Coupling Action, Step by Step - Successive Stages of Amplification - Impedance Coupling - Cathode Follower - Notes for Reference.

Section 1. INTRODUCTION

There is something unbelievably fascinating about working with vacuum tubes. Few men who have once been bitten with the bug through contact with them have ever been able to break away into some other line of work and be completely happy. Almost without exception those men who have been promoted into jobs where they are no longer required to maintain daily contact with vacuum tube work have deliberately gone out of their way to create some means for maintaining such contact. Most often this has been accomplished by entering (or remaining in) the ranks of radio amateurs.

In other instances men who have risen through the ranks to a desk job have been able to spend enough time in the engineering rooms of laboratories to satisfy their compelling inner urge for continued personal contact with vacuum tubes and their many types of circuits. Usually a way is found by which a man can continue to delve into the seductive mysteries of radio and television which seem to abound on every side.

A vacuum tube, or several vacuum tubes in combination, can be caused to do so many things there seems to be no end to their possibilities. Which brings us to a subject which we have not yet touched upon although we have skirted it quite closely several times. This is the matter of connecting two or more vacuum tubes together so they can all work as units of a whole.

When we discussed how one or more vacuum tubes could be used to amplify the tiny voltages which are picked out of the air, and are then used to supply the grid voltage for operating a power amplifier tube you must have wondered just how one tube could be connected to another. One tube cannot be connected to another by merely tying them together with a piece of wire. Note, for example, the situation of trying to

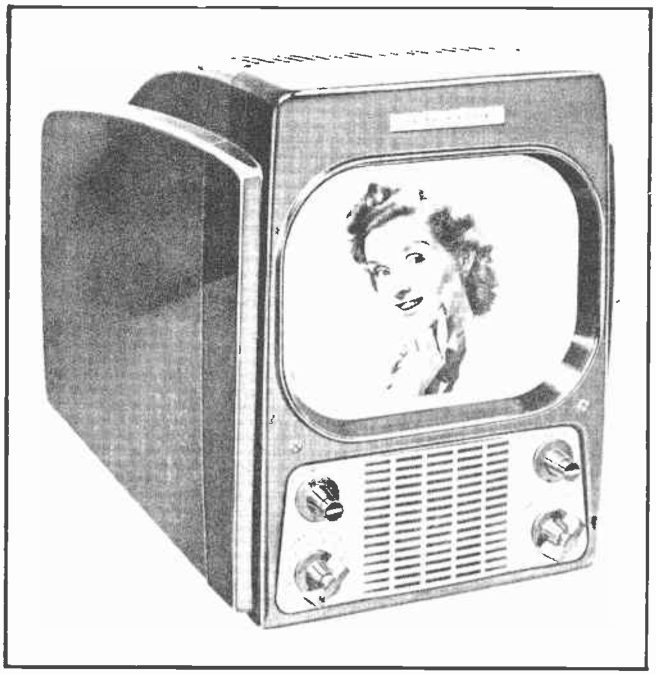

Fig.1. Table Model Television Receiver. (Courtesy of General Electric)

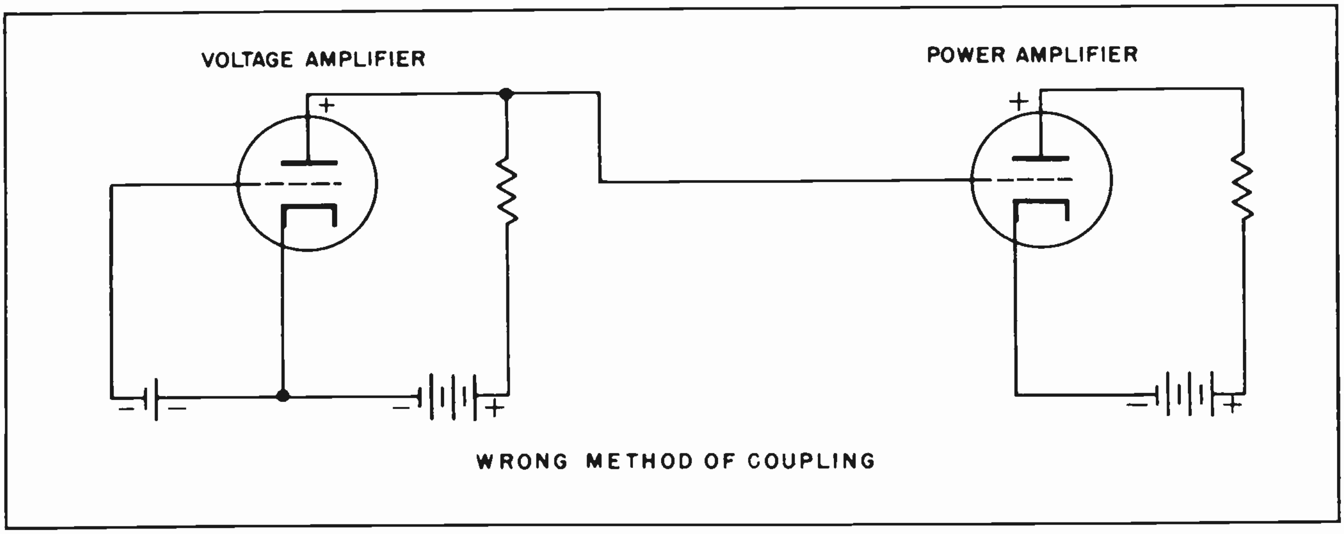

Fig. 2.

connect the anode of the voltage amplifier tube in Fig. 2 with the grid of the power tube. Even the most casual inspection will disclose that the high positive voltage on the anode of the voltage amplifier has now been placed on the grid of the power amplifier tube. From our studies of vacuum tubes we know very well we do not want a high positive voltage on the grid of a tube. Quite the reverse. This calls for a bit of thought.

Although we cannot tolerate the *high positive voltage* normally on the anode of the voltage amplifier on the grid of the power amplifier, we do want the amplified *signal voltage* which appears on the anode placed, in some manner, on the grid of the power tube. Obviously, connecting a simple piece of wire is not going to do the job. This brings us to the subject of *coupling*.

Section 2. TYPES OF COUPLING

Connecting one vacuum tube stage to a succeeding stage is accomplished by means of what is called *coupling*. There are three general methods of coupling. These methods are called:

Resistance coupling
Transformer coupling
Impedance coupling

Since you are already familiar with the operation of a transformer we will take up a discussion of transformer coupling first. Transformer coupling was once used almost exclusively for connecting one stage to another. The earlier radios frequently used many stages of transformer coupling in order to bring the signals up to a strength where they were useful. Transformer coupling is still used extensively in high power audio systems where a lot of power is needed to drive large loudspeakers. Furthermore, many coupling transformers will be found in radio transmitters.

Section 3. HOW TRANSFORMERS ARE USED FOR COUPLING

In transformer coupling we use the primary of the transformer as the load for the anode of one tube and place the secondary in the grid circuit of the following tube. (See Fig. 3.) The grid of the second tube is thus effectively isolated from the high positive voltage on the anode of the first tube. Nevertheless, every *change* in the anode current of the first tube is instantly reflected as a *change* in the voltage which is placed on the grid of the second tube. This is accomplished by the normal action of the transformer which causes a voltage change in the secondary whenever the current through the primary changes.

Section 4. A-C COMPONENT AND D-C COMPONENT

It is time we called attention to something which you have probably already noticed but which we have not emphasized. There are *two* kinds of current flowing in the anode circuit of the voltage amplifier tube (or any vacuum tube, for that matter.) First, there is the reasonably steady flow of current through the tube and the anode circuit which is its normal state. This is what we call the *D-C component.* Second, we have the fluctuations which occur in the anode current due to the fluctuating signal voltage on the grid. This we call the *A-C component* of the anode current.

The high positive voltage on the anode, and the steady D-C current, are necessary to the proper operation of the tube. However, we do not want any of this to reach the grid of the next tube. But the fluctuating portion of the anode current is another matter. This has been brought about as a result of signal changes on the grid, it is an enlarged reproduction of the original signal. In short, this is what we want to pass along to the grid of the next stage.

The problem of separating the D-C component from the A-C component, and passing the A-C component along to the next tube, is an ideal job for a transformer. The steady D-C component can flow through the primary of the transformer without affecting the secondary in any way. But the A-C component of the anode current will induce A-C voltages in the secondary which are exact reproductions of the original signal voltage. The transformer can even be designed to actually increase these voltages.

It is understandable that any transformer can be designed to step up the voltage, or to step it down, or to merely pass it along from the primary to the secondary without being changed in any way. When a transformer is used to couple one vacuum tube stage to another, and the only function of the transformer is to isolate the high voltage of one anode circuit from the grid of the next circuit, the transformer is often designed with a 1:1 turns ratio. In such a transformer the output voltage will be the same as the input voltage. Such a transformer will pass the signal along with high fidelity. Such transformers are commonly used in radio transmitters where high fidelity is an important consideration, in high power audio circuits such as public address systems, and in the audio system of some high quality radio and television receivers.

Section 5. STEP-UP COUPLING TRANSFORMERS

It is also possible to use transformer coupling to actually "step-up" the voltage from one stage to another. Advantage of this feature of transformer coupling was taken in the early days of radio. In those days the only amplifier tubes were triodes; they had relatively low amplification factor. By using a triode to amplify the signal voltage some 20 times within the stage and then using a step-up transformer with about a 1:3 ratio it was possible to obtain a voltage gain of about 60 in one stage of amplification. (See Fig. 4.) Several such stages could result in considerable amplification of the tiny radio signal.

Section 6. LIMITS TO STEPPING UP THE AMPLIFICATION

It might be asked: If the signal could be stepped up some three times by means of an interstage coupling transformer with a 1:3 step-up ratio why not increase the turns

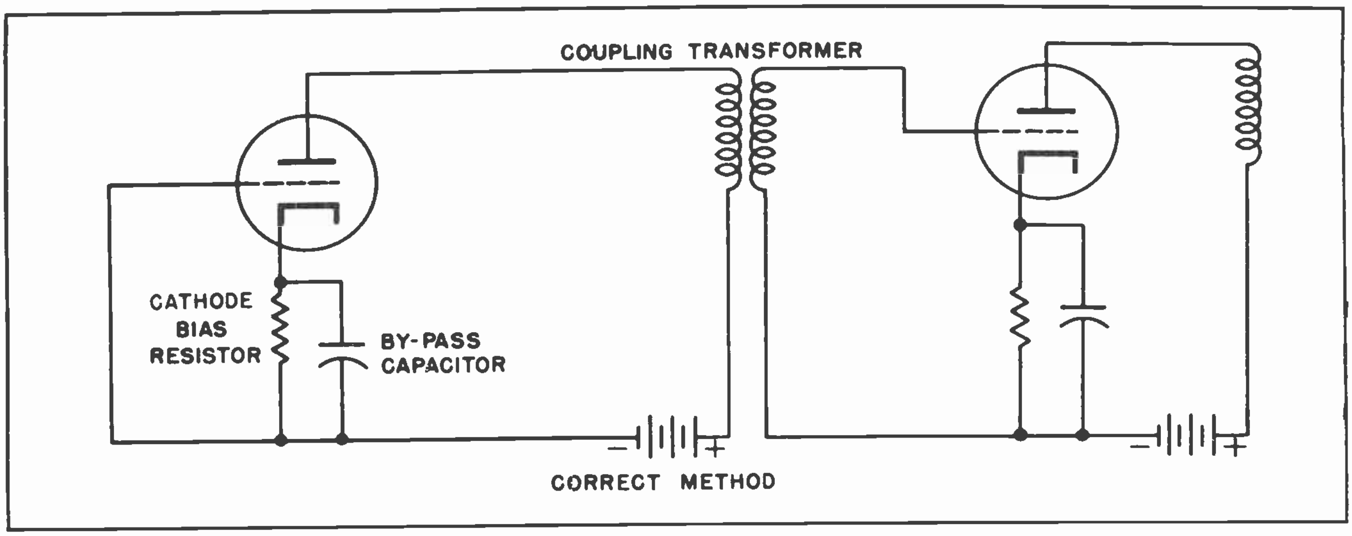

Fig.3. Interstage coupling by means of a transformer.

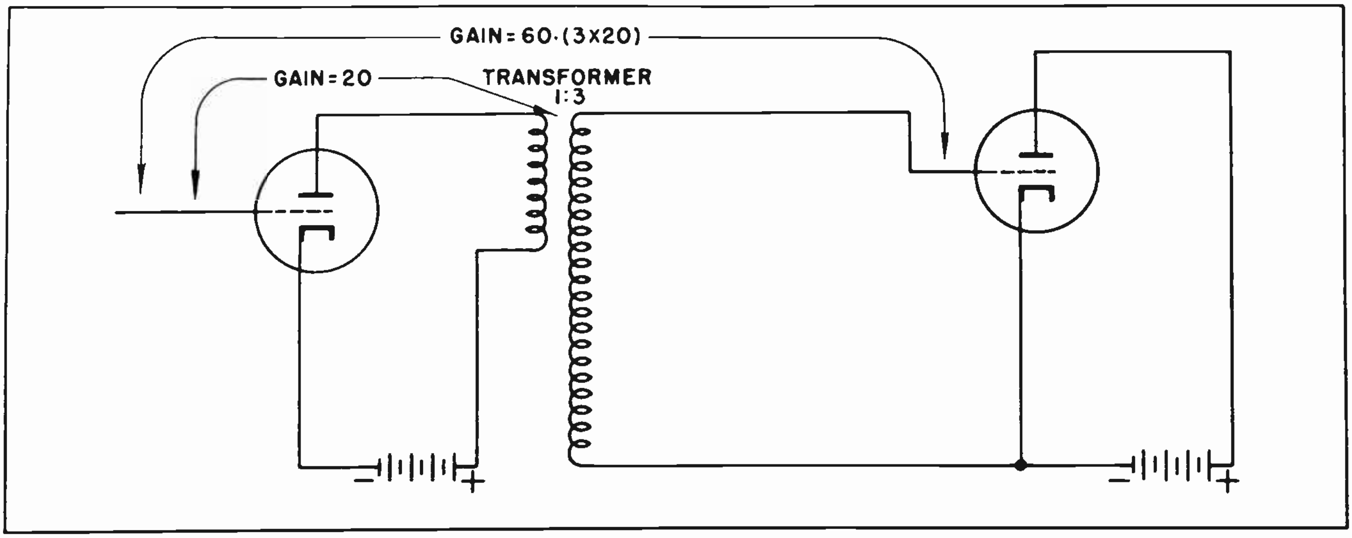

Fig.4. How gain can be increased by using a transformer.

ratio on the transformer and step the voltage up some 10 or 20 times?

If a signal of only one frequency, such as 100 cycles or 1000 cycles, were to be amplified through the transformer coupling such a high step up ratio would be perfectly feasible. But unfortunately such is not generally the case in vacuum tube circuits where the transformer coupling would be used.

If we pause for a moment to analyze the signal which would pass through such a transformer we will find that much of it would represent frequencies created originally by a voice or musical instruments. In the case of the human voice the frequencies would probably range from perhaps 100 cycles to around 1000 cycles. The musical instruments will produce frequencies from less than 100 cycles up to several thousand cycles. If we expect to reproduce the original sounds in such a manner that they closely resemble ones originally created it is necessary to amplify each of the various frequencies by the same amount. It would not do to amplify the sound of the drum or the bass viol by large amounts and the sound of the piccolo by a much lesser amount. The result would not be satisfactory. Neither would we want to over-emphasize the deep voice with the lower pitch over the higher pitched one. That would not be satisfactory either.

The natural question could be: Why should the frequency of the signal make any difference in its amplification? You probably already know the answer if you think it over for a moment.

Remember in our study of inductance we found that an alternating current of high frequency would encounter more opposition -- or reactance -- in a coil than an alternating current of lower frequency. We found the opposition met by the alternating current would increase as the frequency increased. This is indicated by the formula:

$$X_L = 2\pi fL.$$

Section 7. HIGH FREQUENCIES AND LOW FREQUENCIES

Now the varying currents and voltages in the anode circuit of a vacuum tube are nothing more nor less than alternating currents and voltages of varying frequencies. If the signal voltage and current has a relatively low frequency, such as the voice of a man or a note from a drum or bass viol, such signal will meet low opposition in the primary of the transformer. The signal will be passed through to the secondary circuit with full strength.

But suppose the signal voltage and current has been originally produced by a high violin note, or by a piccolo. In this case it will have a frequency many times higher than before. The higher current and voltage frequency in the anode circuit of the tube will meet considerably more opposition in the primary of the transformer than did the lower frequency. It will be passed through to the secondary in greatly reduced volume.

Now the natural question is: If all this is true how can *any* transformer be used to couple between vacuum tube amplifier stages by using *any* turns ratio. The answer is that design engineers have been able to create transformers which will pass a *band* of frequencies without discriminating against any of the frequencies within that band -- provided, the turns ratio between the primary and the secondary does not exceed 1:3. In designing such transformers an electrical property known as *impedance* plays a very important part. We have paid little attention to impedance so far but we will be giving it much consideration soon. Impedance is a combination of resistance and reactance.

Resistance and reactance in a circuit cannot be added together like adding a bushel of apples to a barrel of apples, or a quart of water to a gallon of water. But there are ways by which these two quantities can be combined to determine the total opposition in an electrical circuit. It is by taking advantage of the peculiarities of impedance that engineers have been able to create highly practical coupling transformers.

It should be mentioned that gain through the transformer will normally fall off at very low frequency due to lack of sufficient inductance in the primary of the transformer. Further than this there will be a very sharp falling off of amplification at very high frequencies due to the distributed capacitance between the windings of the primary coil. But over a reasonably wide range, or *band*, of frequencies the amplification will be substantially constant. This is particularly true if no attempt has been made to obtain too much voltage gain through the transformer.

Transformers have the advantage of aiding the vacuum tubes in providing additional gain in a stage. This was very important when the amplification factor of all tubes was low, and accounts for the former widespread use of transformer coupling. Furthermore, if properly designed the transformer coupling will provide a high degree of fidelity in the receiver where it is used.

However, transformer coupling is not an unmixed blessing. Transformers are bulky and heavy, especially those designed for audio work, and are relatively expensive. A good audio transformer may weigh several pounds, take up considerable space on the chassis, and cost several dollars. Because of these reasons transformer coupling is not used nearly so widely now as it once was. This is not to say, however, that transformer coupling has disappeared from the scene. Far from it. It is still used, especially in large power units and in transmitters.

Section 8. RESISTANCE COUPLING

Resistance coupling is by far the least expensive method of connecting one vacuum tube stage to another, and takes up the least room. We have discussed resistance coupling operation in our lessons of vacuum tube amplifiers without actually explaining what it was.

Resistance coupling, essentially, is the placing of a resistor in the anode circuit of a vacuum tube, then tapping off the varying voltage which develops across the resistor as a result of the varying anode current. Yet the problem is not solved quite so easily as that either. (See Fig.2.)

If we are to tap off the voltage which is developed across the load resistor in Fig. 5 we must do it in some manner other than that of Fig. 2. Our problem now is to find some method of passing the A-C component of the anode circuit signal along without passing the D-C component. We have already seen that this problem can be solved by using a transformer, but we need a method less expensive, less heavy and less bulky than the transformer.

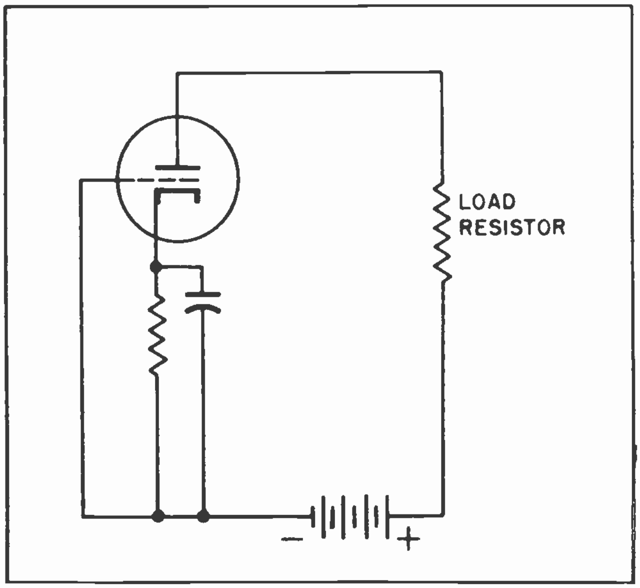

Fig.5.

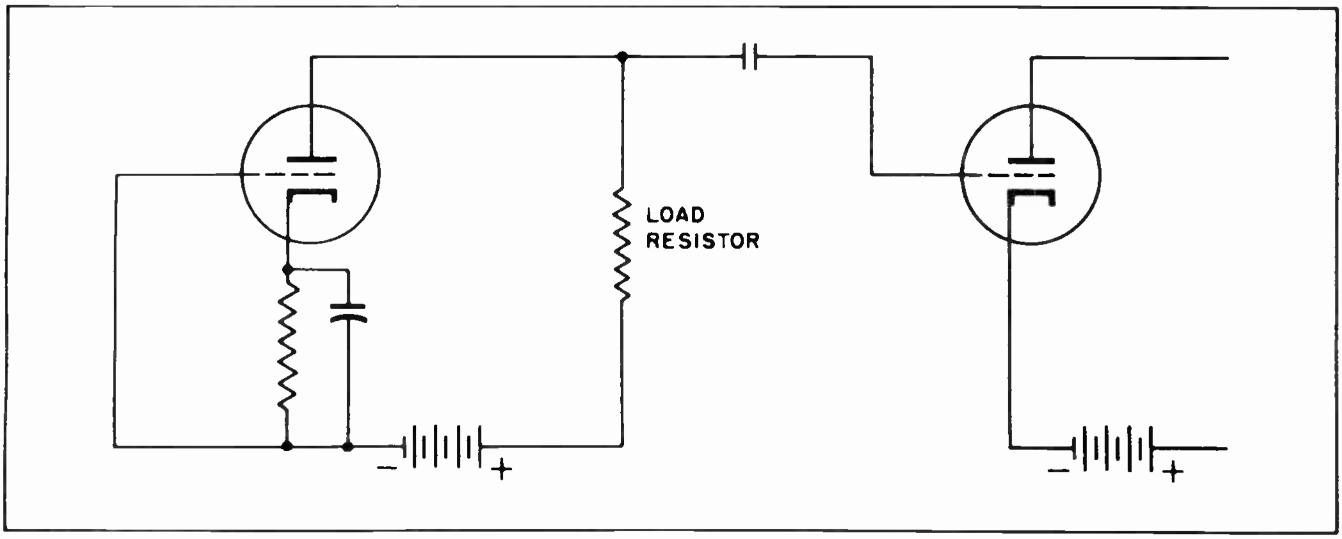

Fig. 6.

Section 9. USING A CAPACITOR

Another method of separating the D-C component from the A-C component is by using a capacitor. The D-C cannot pass through the capacitor, but the varying A-C component can pass through with little difficulty.

So we will try placing a capacitor between the anode of the first tube and the grid of the second tube as in Fig. 6. At first glance this looks like it might be the solution. But a little more study brings home the fact that the voltage on the grid of the second tube may be changing with respect to something or other but there is no reason to believe it is changing with respect to the *cathode* of that tube. For all we can tell the voltage on *all* the elements of the second tube will be changing together, and not changing with respect to each other. We must tie the cathode of the second tube down to some basic value, some neutral value, so the voltage changes on the grid of that tube can change with respect to it.

Suppose we connect the cathode of the second tube to the opposite end of the load resistor from where the capacitor is connected. (See Fig. 7.) Would this circuit work?

Yes, the circuit would probably work without too much trouble, provided we were prepared to use a separate battery, or other voltage source, for each tube. But it would be very extravagant to provide a

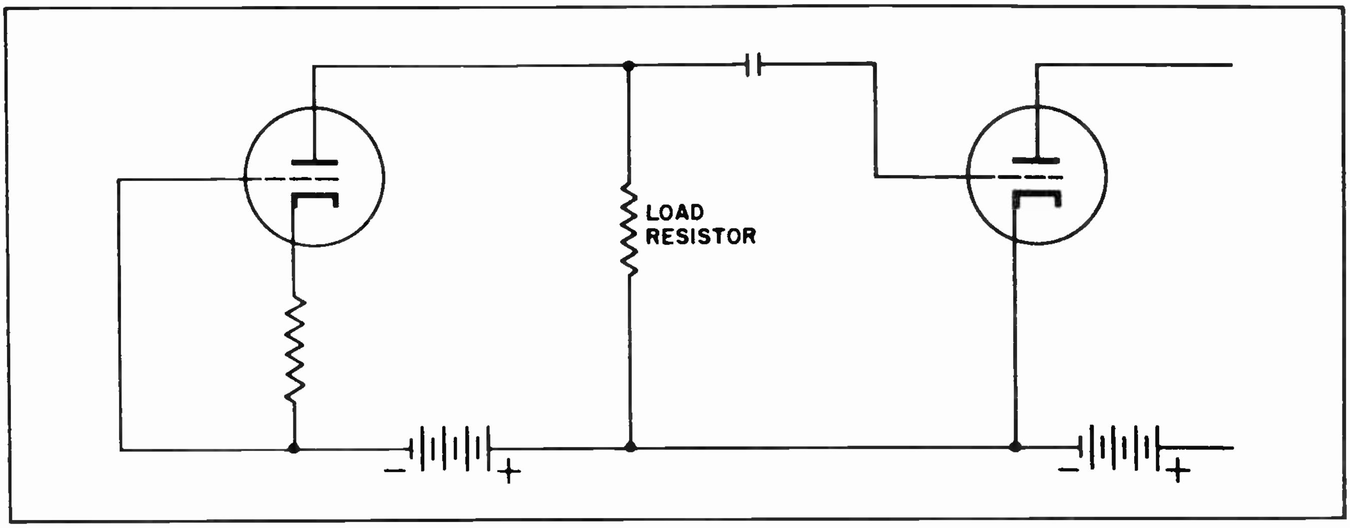

Fig. 7.

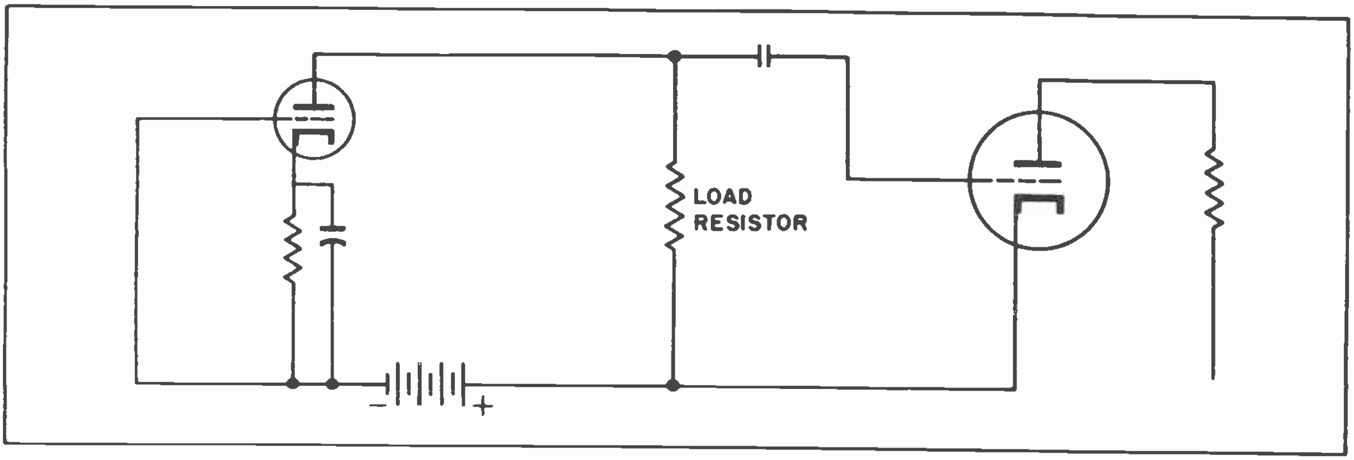

Fig.8.

separate battery for each tube when one battery could furnish the necessary power for all the tubes.

We have connected up a circuit in Fig. 8 exactly like that in Fig. 7 except we have not provided any power for the second tube. It will be noted that in Fig. 8 the cathode of the second tube is connected to the positive side of the battery just as in Fig. 7. But now we do not have a second battery.

If we are going to use the same battery for both tubes where are we going to connect the anode circuit of the second tube? We cannot connect it to the positive side of the battery too. Both the anode and the cathode would then be at the same potential. There would be no more working potential on the tube than there would be if no battery at all was connected. It will do no good to connect the anode of the tube to the other end of the battery. That would place a negative voltage on the anode.

It is entirely evident that we must connect the cathode of the second tube some where else. Suppose we try connecting the cathode of the second tube to the negative end of the battery as in Fig. 9. Will this provide us with a base for the cathode of the second tube so the varying voltage on its grid will vary in magnitude with respect to the cathode? Of course. Any voltage fluctuations across the load resistor will now be reflected immediately on the grid of the following tube through the coupling capacitor. But how to get a positive voltage on the anode of the second tube?

Fig. 10 shows the proper method of using the same battery, or other power source for two or more vacuum tubes. Note that

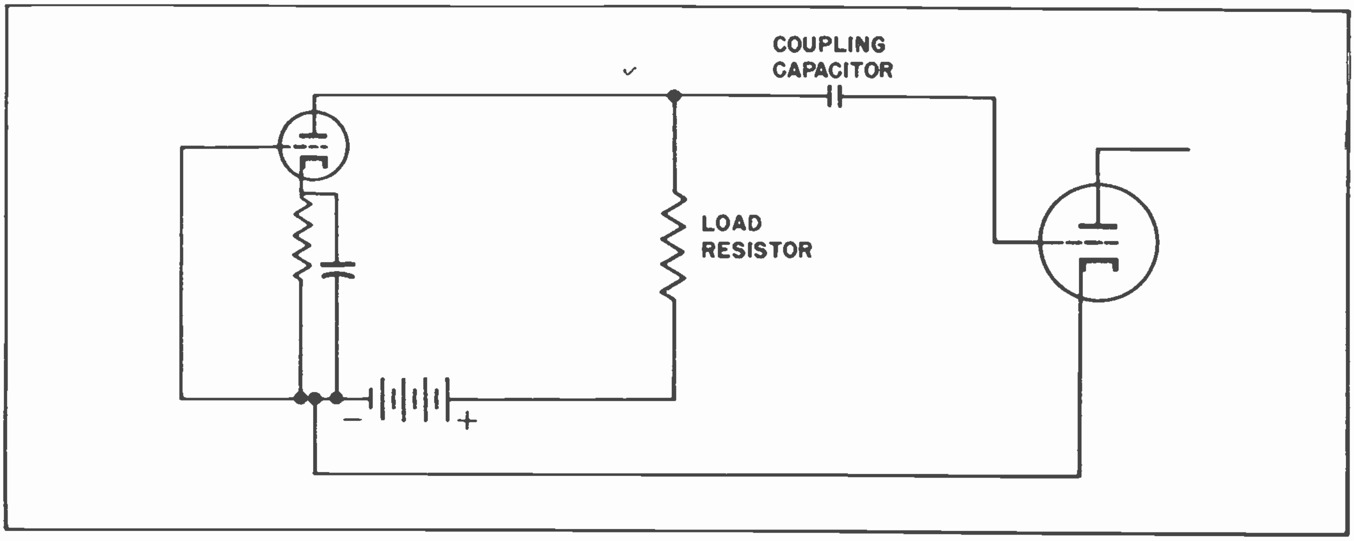

Fig.9.

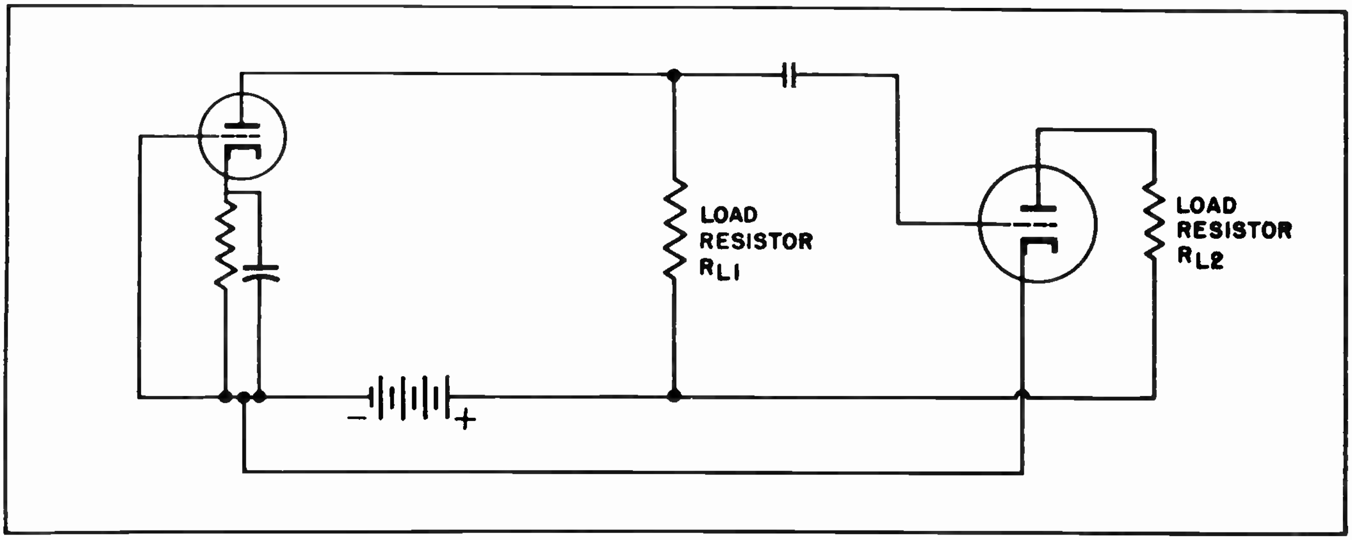

Fig. 10.

the cathode of the second tube has been connected to the battery in the same manner as in Fig. 9. Now the anode circuit has been brought out through load resistor No. 2 (R_L2) to the positive side of the battery. The battery can now place a positive voltage on the anode of each tube. Any voltage fluctuations across load resistor No. 1 (R_L1) will instantly appear on the grid of the second tube where they will be amplified still more to appear again across the second load resistor.

But is this circuit perfect? Insofar as the information we have given you is concerned the circuit should work. But there is one additional little item we have not previously mentioned. This refers to grid "blocking".

Grid blocking is a situation which occurs when electrons passing from the cathode to the anode of a tube accidentally hit the wires of the control grid and become trapped there. It should be understood that it is not intended that any electrons should strike the grid and become trapped there. But remember, the grid is right in the path of electrons which are emitted from the cathode. The grid is negative and should not attract any electrons. But there are billions of electrons clouding around in

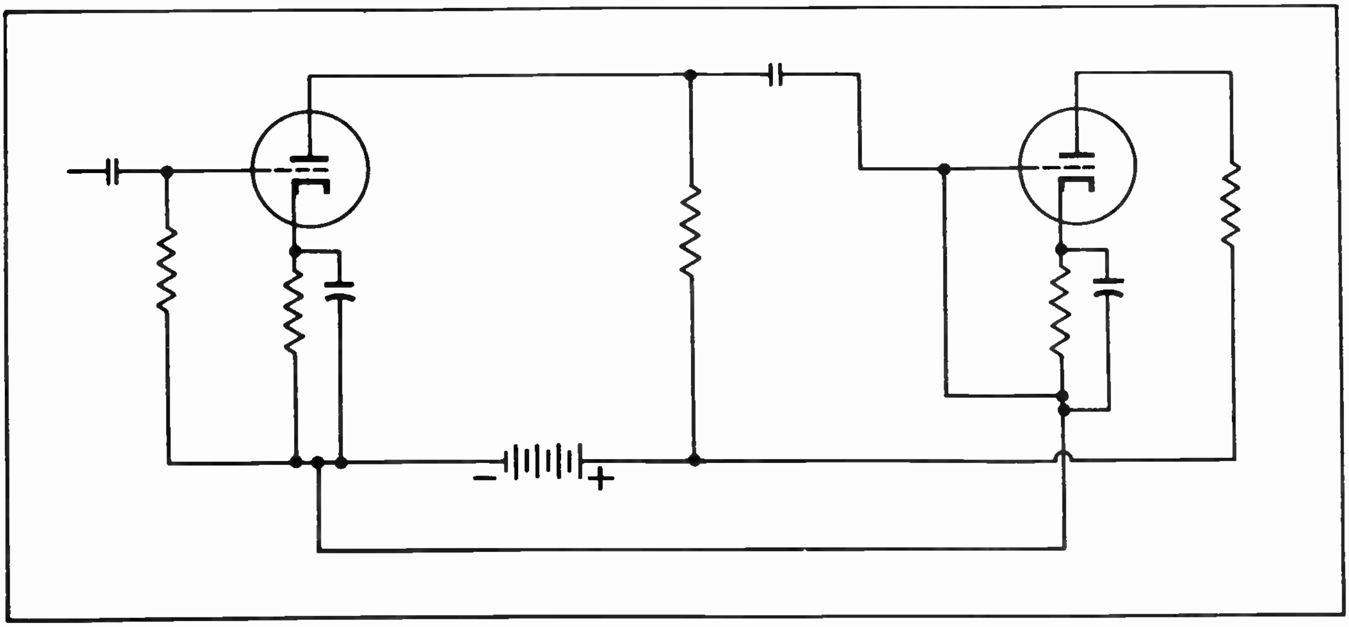

Fig. 11.

the space between the grid and the cathode. Each of them are repelling each of the others. It is inevitable that some of the electrons, under the influence of repulsion of other electrons, will attain considerable velocity in the direction of the grid wire, and before they can swerve aside will strike the grid.

Once the electron strikes the grid it is trapped. It cannot escape from the grid except through thermionic emission or secondary emission. The grid is not heated and the chance of secondary emission is remote at best. It is forced to remain on the grid. But each additional electron which strikes the grid makes the grid just that much more negative. If this condition continues the grid will soon become so negative it will prevent any electrons from passing through to the anode.

It is imperative that some means be provided to allow the electrons which are trapped on the grid a means of escape. We cannot make any kind of connection between the grid and the anode. That would result in a positive voltage reaching the grid. Such is not desirable. Suppose we connect the grid with the cathode as in Fig. 11, which is similar to many other previous diagrams we have drawn. Would this work?

The answer to this question is to ask another. If the grid is connected directly to the cathode will the applied signal create any voltage difference between the grid and the cathode? It is rather obvious that it will not. The signal reaching the grid through the coupling capacitor will effect the grid all right, but it will place exactly the same voltage on the cathode. For all practical purposes there will be no difference in the voltage on the grid and that on the cathode except for the cathode bias, and we can discount that. The resistance of the cathode bias resistor is too low to offer any real opposition to the signal voltage.

It is evident that we must do something to correct this situation. The question is, what? Fig. 12 provides the answer. For the direct connection between the grid of the second tube and the cathode of that tube in Fig. 11 we have substituted a resistor. This resistor is called a *grid leak resistor*. The resistance of this resistor must be quite high to prevent the signal voltage from the coupling capacitor from leaking through it to the cathode of the second tube where it is not wanted. Since the electrons which are normally trapped on the grid are relatively few in number, it is perfectly feasible for the resistance of the grid leak resistor to be quite high -- the few electrons on the grid will be able to make their way through it.

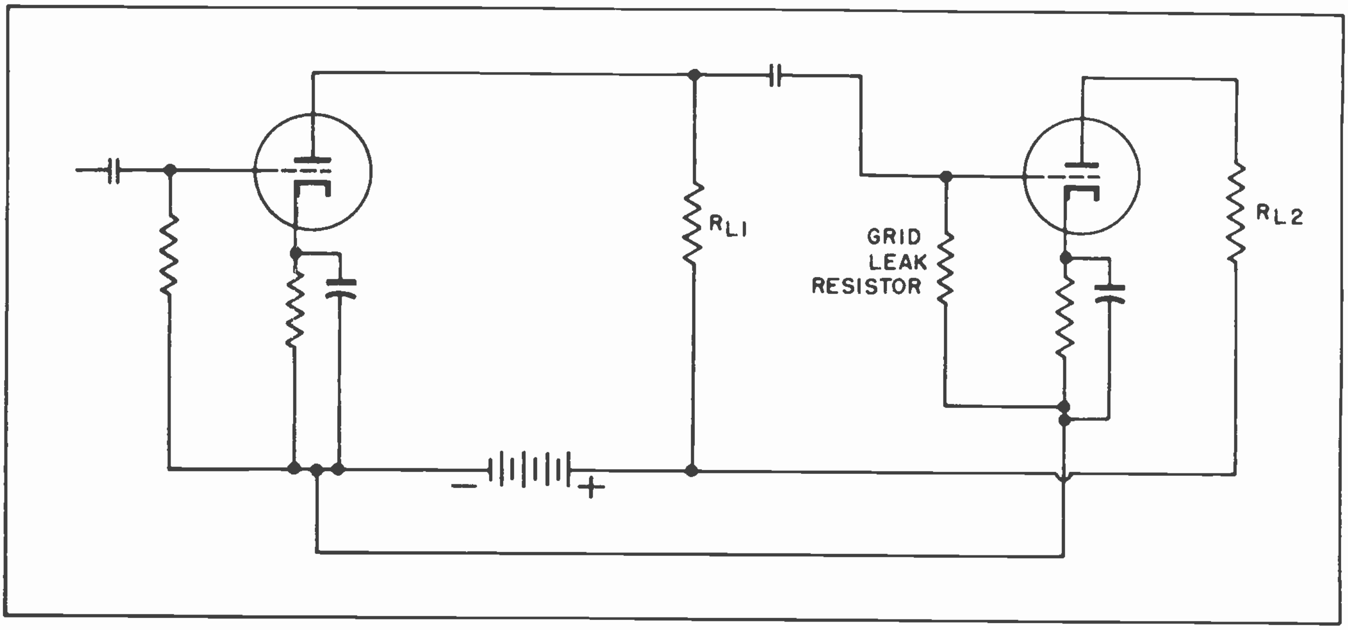

Fig.12.

The ohmic resistance of the grid leak resistor ranges from 250,000 ohms up to several megohms. A very common value for many voltage amplifier tubes is 500,000 ohms, or 0.5 megohm. The resistance must be so high as to be virtually an open circuit for the alternating signal voltage coming through the capacitor from the anode circuit of the preceding tube, yet the resistance must not be so high as to make it impossible for the electrons trapped on the grid to leak off.

Section 10. ADVANTAGES AND DISADVANTAGES OF RESISTANCE COUPLING

Resistance coupling is used more frequently today than any other type of coupling. It has the advantage over transformer coupling of being much less expensive, less bulky, and weighing much less. Two resistors and one capacitor comprise the total number of parts needed to connect one stage of amplification to another by means of resistance coupling. The two resistors together probably will not cost more than five cents, and on a quantity basis even less. The capacitor would not cost more than ten cents.

Compare these costs with that of an audio transformer to be used for coupling two stages of audio together. The transformer might cost considerably more than a dollar.

But these are not the only advantages of the resistance method of coupling. A chassis for mounting the parts for a radio receiver using resistance coupling can be much smaller than one using transformer coupling. If the coupling is to be by means of transformers between all the stages, a place must be provided on the chassis for mounting the transformers. If resistance coupling is to be used, however, the resistors and the capacitor can be mounted directly to the tube socket lugs. No special provision need be made on the chassis for these small components.

But the advantages of resistance coupling is not all one-sided. Resistance coupling does have the disadvantage of being unable to utilize the full amount of the amplification factor of the tube as can the transformer method of coupling. In fact a stage of resistance coupling is unable to use much more than 55% to 60% of the full amplification factor of the tube and still retain high fidelity. The use of resistance coupling with tubes having low amplification factor is not advisable, and is the reason it was not widely used in the early days of radio. In those days the vacuum tubes had so little gain none of it could be sacrificed. For that reason transformer coupling was used almost universally in those days. But at the present time our high-gain tubes have such high amplification factor we can afford to sacrifice some of it to obtain the other advantages of resistance coupling.

In general, if the load resistance does not greatly exceed the plate resistance of the tube little or no distortion will be introduced by use of resistance coupling. By introducing a small amount of degeneration into the stage it is possible to eliminate any distortion which might appear.

Section 11. WHERE TRANSFORMER COUPLING IS ALWAYS USED

There is one place where the transformer has advantage over the resistance method of coupling, and is one which is found in nearly every type of radio or television receiver, whether new or old. This is where it is desirable to couple a "high-impedance" circuit, such as that of a vacuum tube anode, to a low impedance circuit. An example of this is connecting the anode circuit of a power amplifier to the "voice coil" of a loudspeaker.

The normal situation in the anode circuit of a vacuum tube, even a power amplifier, is to have a high voltage and a relatively low current. The voltage may be on the order of 100 volts on up, and the anode current from about 45 or 50 M.A. up to something like 100 M.A. Often it is desirable to connect this output to a load where a much lower voltage would be suitable but a higher current would

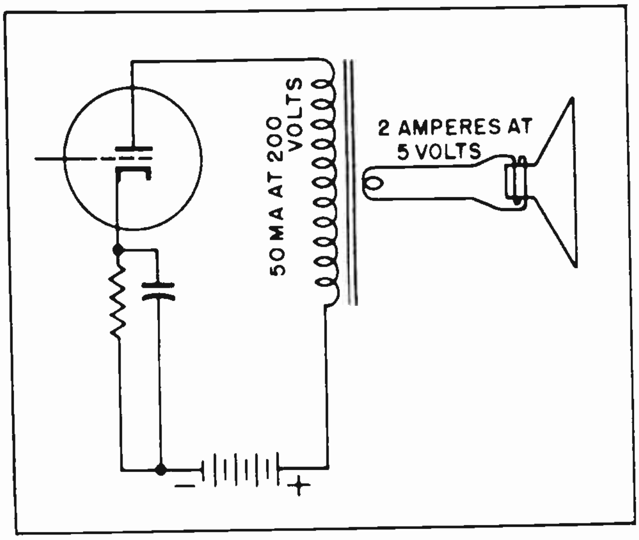

Fig.13. Transformer coupling between output tube and loudspeaker.

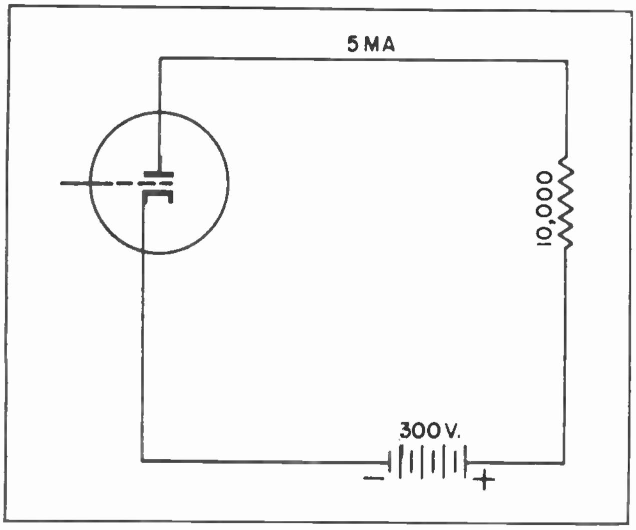

Fig.14.

be desirable. This is the condition we encounter in the operation of a loudspeaker from a vacuum tube power amplifier.

In Fig. 13 is a diagram of a vacuum tube driving a loudspeaker. The anode circuit is what is known as a "high-impedance" circuit. The voltage is high and the current relatively low. The "voice coil" circuit of the loudspeaker is what we call a "low-impedance" circuit. The voltage is low but the current is high. The need for high current is brought about by reason of the fact the voice coil operates within a magnetic field. Any changes in the current in the voice coil itself will react with the magnetic field and cause the cone of the speaker to move. This action changes the electrical impulses into mechanical movement which sets up sound waves in the air. The transformer is an ideal device for connecting the "high-impedance" of the anode circuit to the "low-impedance" of the voice coil.

It is not our purpose to explain the operation of a loudspeaker at this time. The loudspeaker is such an important subject that an entire lesson is devoted to that one subject alone. But this does serve as an illustration of one place where the transformer still rules supreme over resistance coupling, although resistance coupling seems to have taken over most every other place.

Section 12. RESISTANCE COUPLING ACTION, STEP BY STEP

We are already familiar with the voltage drop which occurs across a resistor when current flows through it. This situation is taken advantage of in resistance coupling to change the current changes in the anode circuit of a tube into voltage changes which can be impressed upon the grid of a following tube. This has been discussed before.

In Fig. 14 we have set up a circuit which contains the first essential components for a resistance coupling network. We have the vacuum tube, a source of power and a load resistor. The tube is such that 5 milliamperes of current will flow under normal conditions. The load resistor has a resistance of 10,000 ohms. The power supply delivers 300 volts.

Rearranging the circuit as in Fig. 15 we can readily see there will be a voltage drop

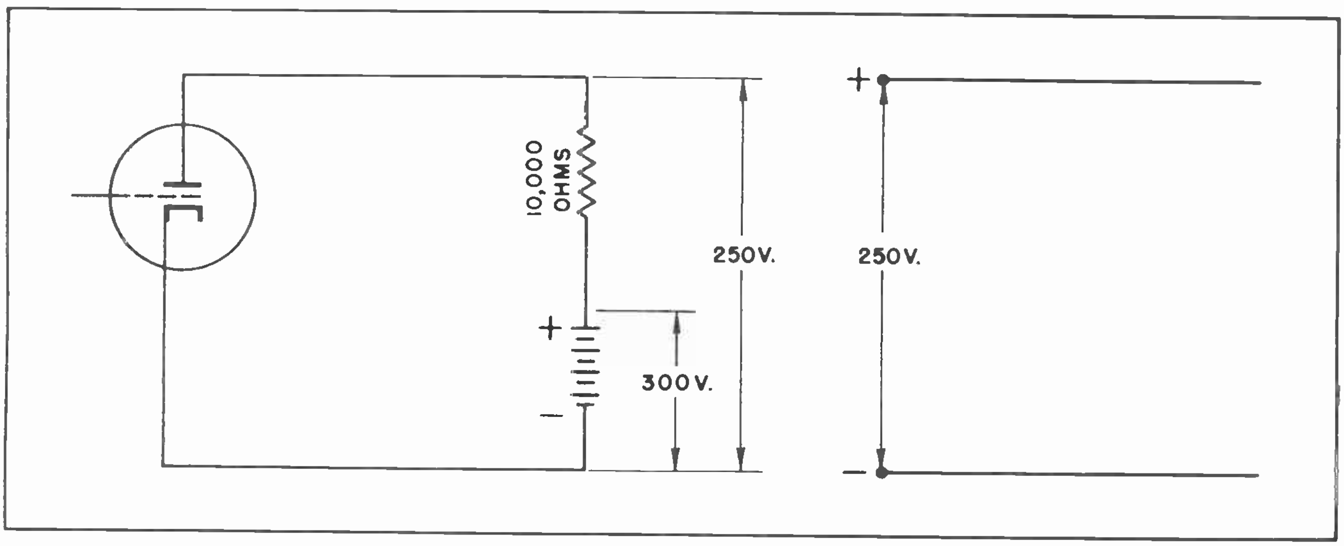

Fig.15.

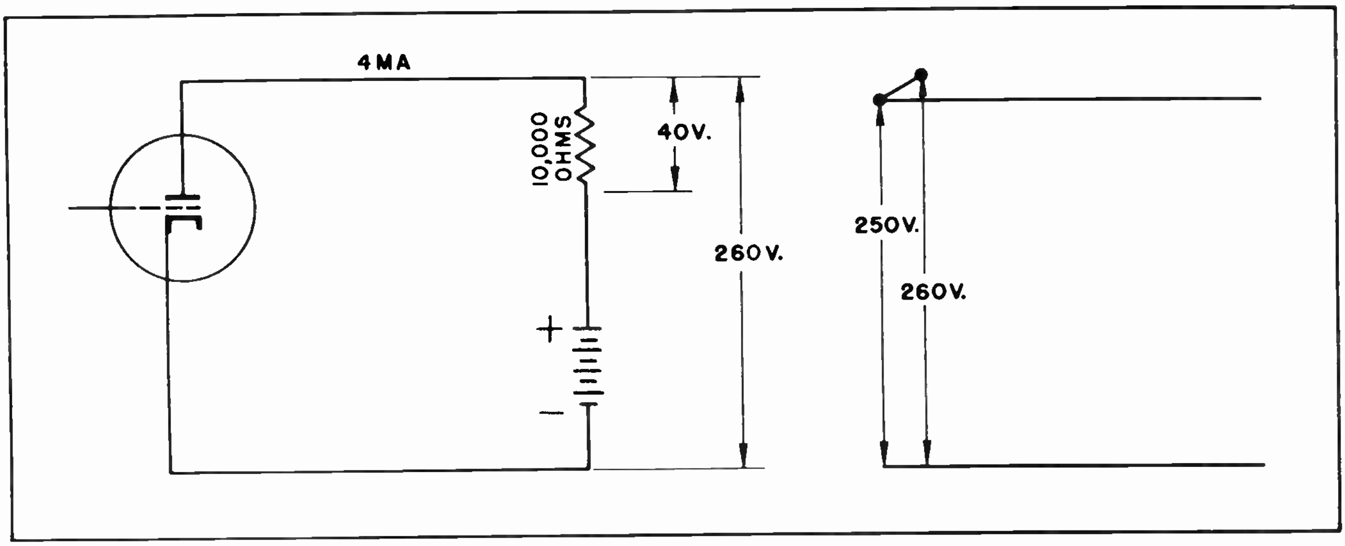

Fig. 16.

across the resistor under the normal condition when there is no signal on the grid of the tube. The graph at the right shows there is a voltage difference between the zero end of the battery and the upper end of the load resistor of 250 volts at that time.

In Fig. 16 we find the negative voltage on the grid of the tube has been increased sufficiently to reduce the anode current to 4 milliamperes. The 4 M.A. flowing across the load resistor causes a voltage drop of 40 volts as is indicated.

Since there are only 40 volts drop across the resistor the voltage between the negative end of the battery and the upper end of the resistor is now 260 volts. The change is recorded on the graph at the right.

In Fig. 17 the grid voltage has been increased again, dropping the anode current to 3 milliamperes. The anode current through the load resistor now causes only 30 volts drop across it, making the voltage between the negative end of the battery and the upper end of the resistor 270 volts. This has also been recorded on the graph.

Other changes are made in the grid voltage in the readings recorded on the graph in Fig. 18.

At *D* we record another voltage reading between the upper part of the load resistor and the negative end of the battery when the anode current was again 4 milliamperes, and at *E* with the anode current back to normal 5 milliamperes.

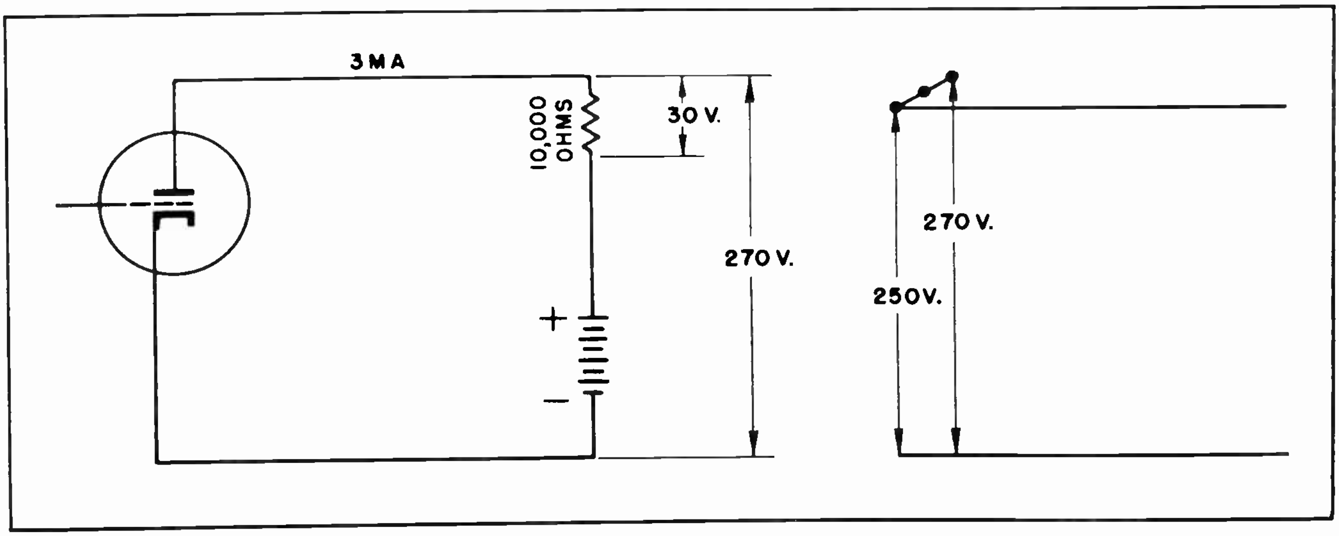

Fig. 17.

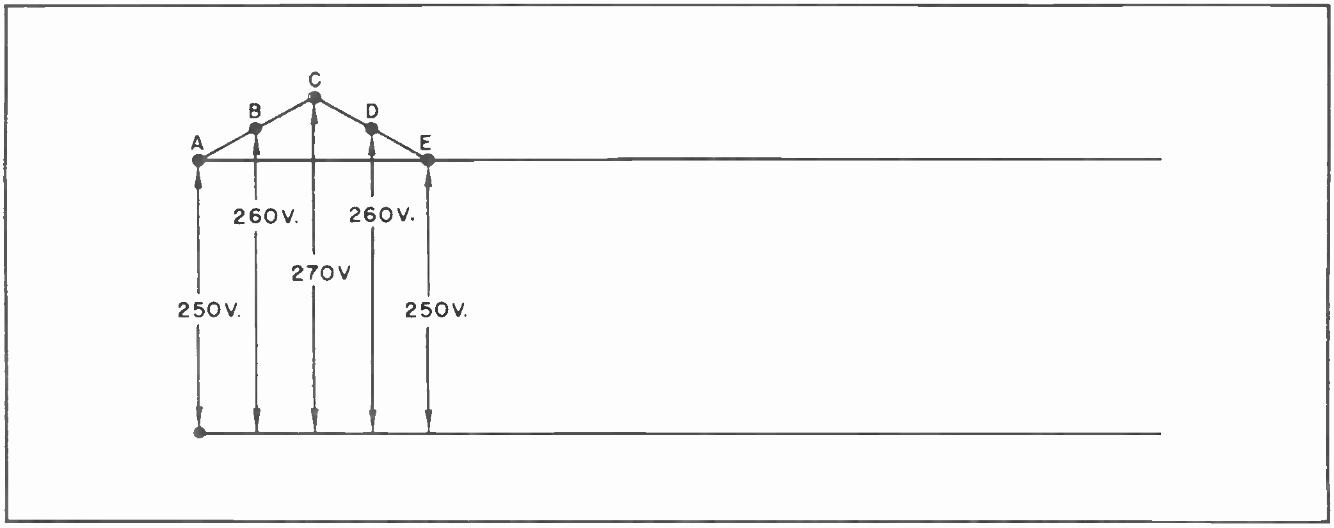

Fig.18.

In Fig. 19 we find the anode current increased to 6 milliamperes. This current causes a voltage drop of 60 volts across the load resistor and reduces the voltage between the upper part of the load resistor and the negative end of the battery to 240 volts. These values have also been recorded on our graph at the right.

In Fig. 20 the anode current has changed to 7 milliamperes. This causes a voltage drop of 70 volts across the load resistor and reduces the voltage between the upper end of the load resistor and the negative end of the battery to 230 volts. The result is recorded on the graph at the right.

Fig. 21 shows how the changing voltage which appears across the load resistor can be tapped off as an alternating voltage and applied through the coupling capacitor to the grid of the following tube. The capacitor will present relatively little opposition to the passage of this alternating voltage, but the 500,000 ohm grid leak resistor will present a large amount of opposition. The result is that nearly all the voltage which appears across the load resistor can be applied directly to the grid of the following tube.

Section 13. SUCCESSIVE STAGES OF AMPLIFICATION (CASCADE)

Fig. 22 shows how a signal is magnified through several stages of resistance coupling between the input to the first stage and the output at the loudspeaker. A small

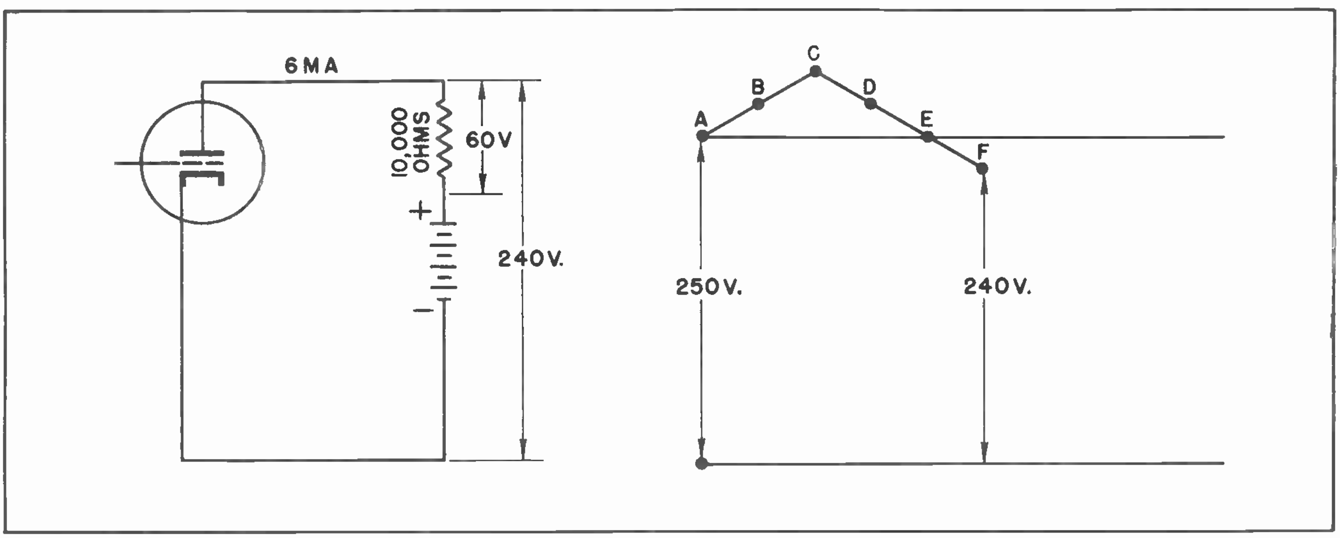

Fig.19.

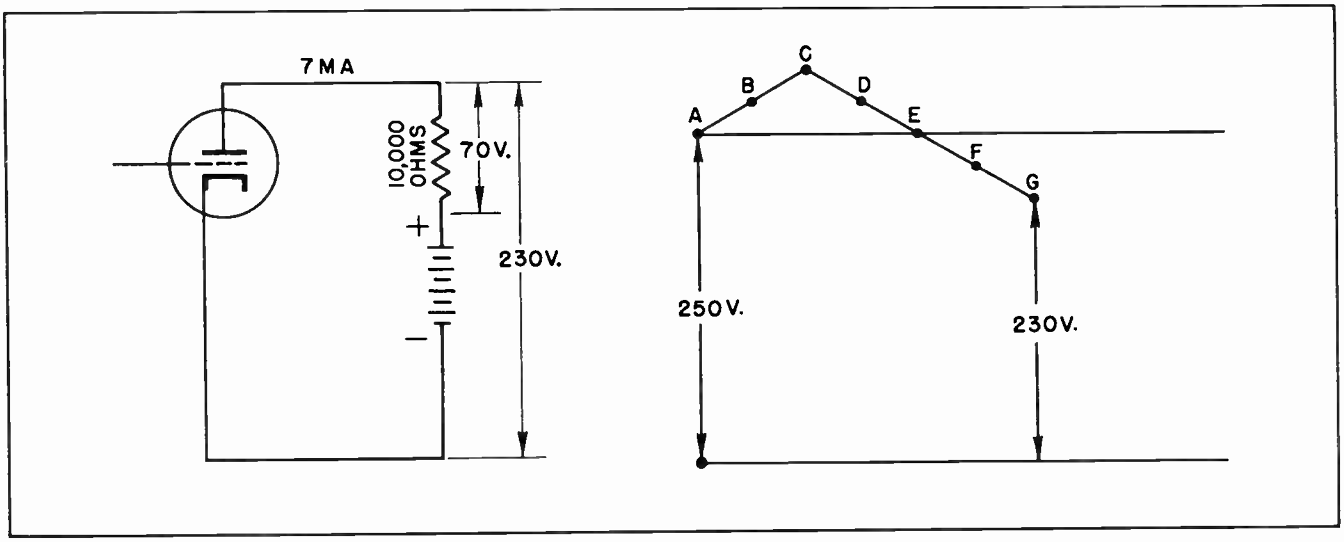

Fig. 20.

signal having a swing of 0.1 volt is placed on the grid of the first tube. The output of that tube is tapped off at the load resistor and applied to the grid of the following tube. The action of the first stage has amplified the signal voltage from 0.1 volt to 2.25 volts.

The signal is then placed on the grid of the second tube and again amplified. It appears across the output of the second stage and is applied to the grid of the final tube, the *output power tube.*

The voltage has been amplified now until it has reached the value of 50.5 volts when it is applied to the grid of the final output power tube. The main purpose of the final tube is not to amplify the voltage

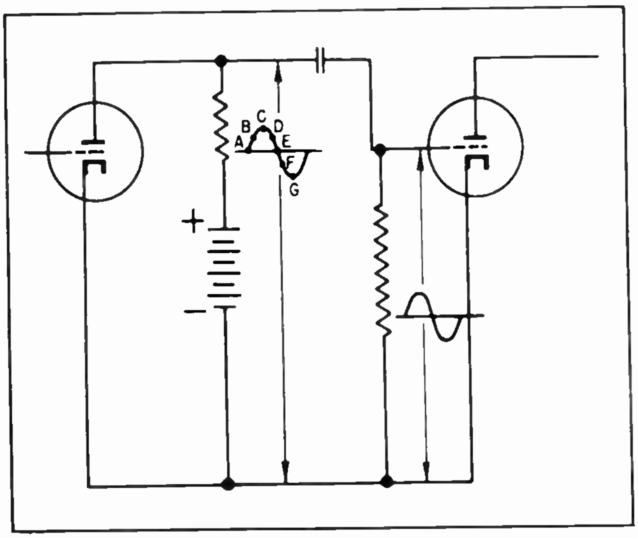

Fig. 21.

again. However, it does amplify the signal some -- to the value of 100 volts.

The voltage gain of this final tube, however, is merely incidental. The main purpose here is *power*. The output of the final tube is connected to the primary winding of an output power transformer where the output of the tube is matched to the voice coil of the speaker. This diagram serves to illustrate the uses for both resistance coupling and transformer coupling and further serves to show typical gains which can be expected in the several stages of amplification. Successive stages of amplification is called "cascading".

Section 14. IMPEDANCE COUPLING

There is a third type of coupling called "impedance coupling". Instead of resistance in the anode circuit of the tube an inductance is used. The main components of the impedance circuit are shown in Fig. 23.

Impedance coupling was once used to a limited extent in audio circuits of radio receivers. However, the impedance method of coupling possessed no particular advantages over resistance coupling while the components were considerably more bulky and expensive. The choke needed for audio work was comparable in size, cost and weight with the transformer used for transformer coupling, but lacked its gain. All things considered, the impedance method of coupling had little to commend its use in audio work.

It is used to some extent in the radio frequency sections of radio receivers, and

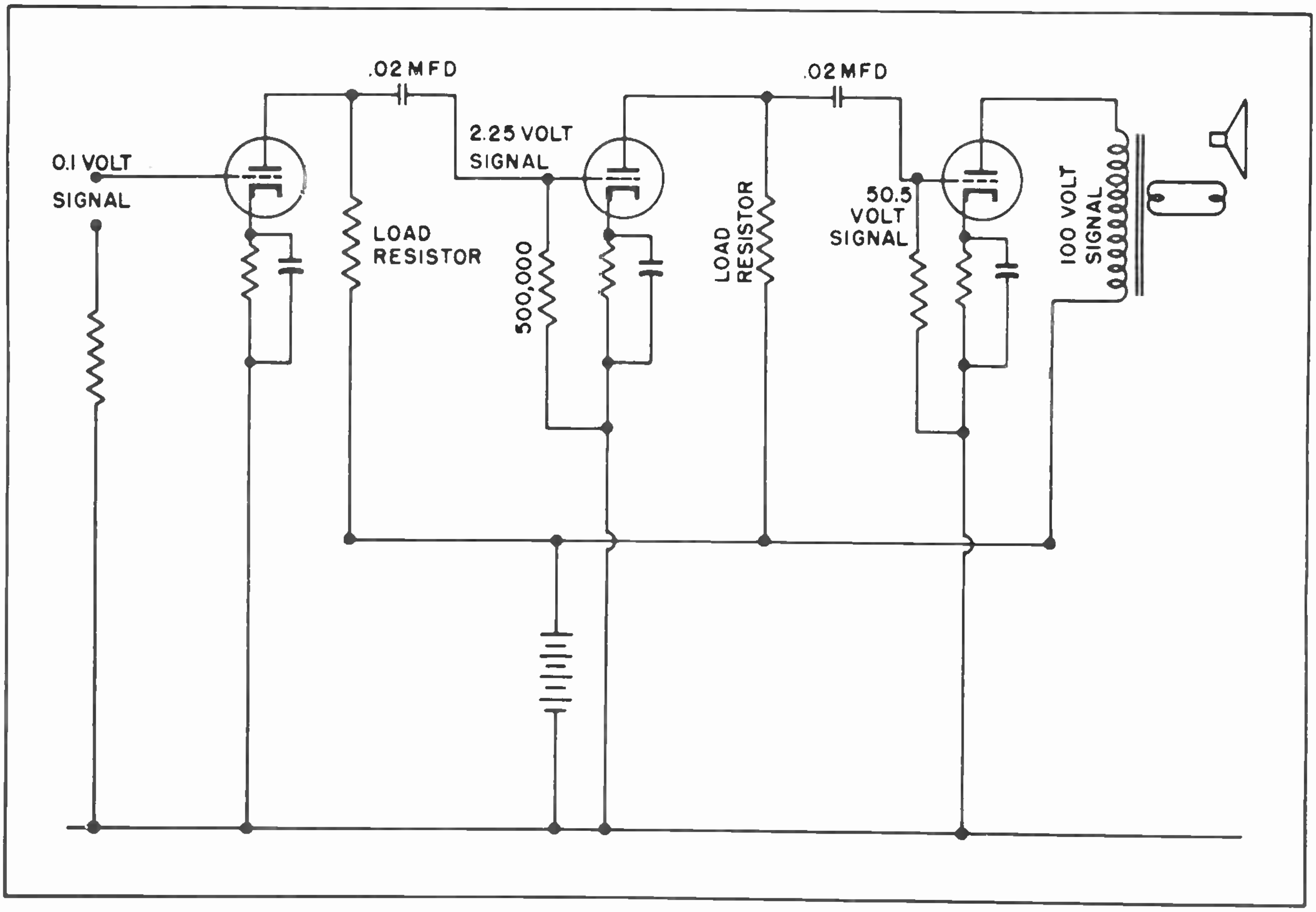

Fig.22. How resistance coupling and transformer coupling are both used in same amplifier unit.

will be often found in both the RF and IF sections of television.

Section 15. CATHODE FOLLOWER

There are instances in television work where it is necessary to couple one circuit to another for the purpose of "matching" impedances. Sometimes the circumstances are such that it is not convenient, or possible, to use a transformer for that purpose. It might be mentioned that at high frequencies it is not always possible to design a transformer which will give exactly the

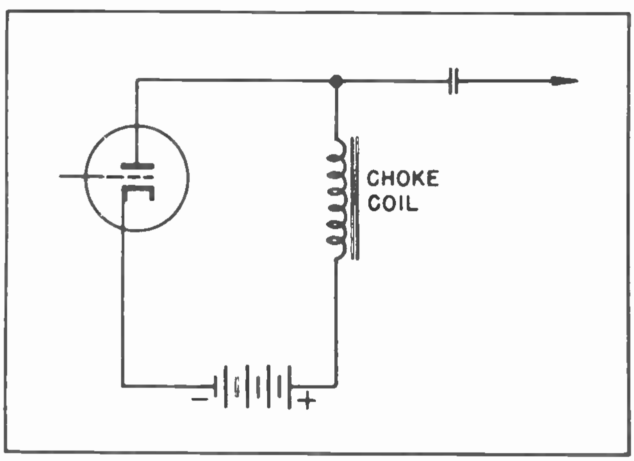

Fig.23. Impedance coupling.

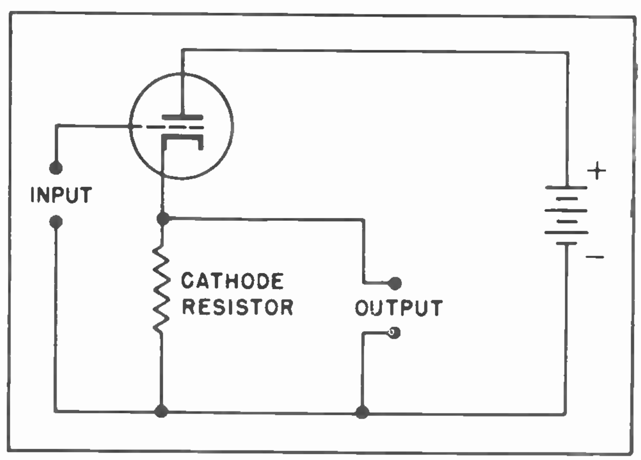

Fig.24. Cathode follower coupling.

performance desired. To overcome the difficulties which sometimes arise in matching two such circuits we sometimes resort to what is called the "cathode follower". Such a circuit is shown in Fig. 24. Such a vacuum tube circuit and stage will not provide any amplification. But the elements of the vacuum tube will effectively isolate one circuit from the other in one respect while permitting the signal to pass without any trace of distortion. The cathode follower is commonly used to couple Television Video Circuits.

The input signal is placed on the grid of the tube in the normal manner. But instead of tapping off the output across the load resistor as in the case of resistance coupling the output is tapped off across the cathode resistor. The signal comes out at the same magnitude at which it entered the circuit, but the output can be either high or low impedance and so can the input. Usually one is high impedance and the other is low impedance. It is to match the two impedances that this circuit is found most useful.

NOTES FOR REFERENCE

A vacuum tube amplifier is connected to a following stage by means of *coupling*.

Transformer coupling has the advantage of using the full gain of a tube plus some gain of its own. It has the disadvantage of high cost, bulky and considerable weight.

Resistance coupling is inexpensive and compact. It has the disadvantage of being unable to utilize the full gain of a tube.

NOTES

NOTES

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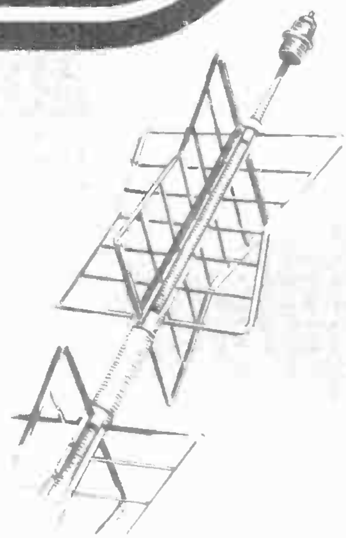

Nina Lee Bottoms

Oscillators

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RADIO TELEVISION

OSCILLATORS

Contents: Introduction - The Armstrong Oscillator - Feedback - Oscillator Frequency - Oscillator Grid Bias - Hartley Oscillator - Hartley Series Fed Oscillator - The Electron Coupled Oscillator - Comparing Frequencies - Notes for Reference.

Section 1. INTRODUCTION

No conversation with a radioman or television technician can last for more than a few moments without the word "frequency" creeping into it in some way. The radio and television man is constantly dealing with frequencies. Everything he does involves work with some kind of frequency.

At one moment he will be working with low frequencies. The next, perhaps, it will be high frequencies. He also has audio frequencies to deal with -- and radio frequencies. In the superheterodyne receiver he has the intermediate frequency and the oscillator frequency.

The man who has occasion to work with communication receivers, such as those used by radio amateurs and commercial radio operators, also has to deal with "beat frequency oscillators", ultra high frequencies and very high frequencies. The television man must always consider video frequencies.

All frequencies with which radio and television men deal are alternating currents or voltages. With the exception of the ordinary electrical power, found in most homes, and the audio speech frequencies these alternating currents or voltages are going through their cycles far faster than is perceptible to any of the human senses.

The human eye can perceive changes which do not exceed about 16 changes per second. This peculiarity of the human eye is utilized by the moving picture projector by means of which it is possible to project a series of still pictures, each of them slightly different from the others, on a screen. The series of still pictures follow each other in such rapid succession they appear to the human eye to blend into each other and thus create the illusion of movement. Since the still pictures are projected at the rate of 16 each second, or at a somewhat higher rate, the human eye is unable to see them as individual pictures.

From this it follows that the human eye could detect no change which resulted from

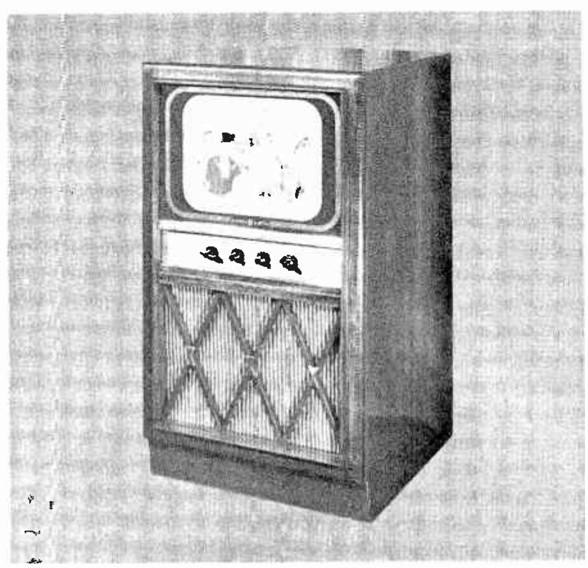

Fig.1. A Television Receiver Uses Several Types of Oscillator Circuits. (Courtesy General Electric)

changing voltages or currents which had a frequency much greater than 15 or 16 cycles per second.

The human ear can detect changes considerably higher in frequency than would affect the eye. But there is a very definite limit beyond which even the ear does not respond to sound created by changing voltages or currents. The average human ear hears *best* when the frequencies range from a little more than 100 cycles per second up to a little more than 1000 cycles. But most people can readily perceive frequencies up to about 5000 to 8000 cycles. Those with hearing somewhat better than the average can hear up to 12,000 cycles, or even a little higher. There are exceptional persons whose ears respond to frequencies up to about 18,000 or 19,000 cycles. It is a rare person indeed who can hear frequencies higher than that.

Yet in radio and television work we are constantly dealing with frequencies many times higher than any of these. Frequencies ranging up into the hundreds of thousands each second, yes even into the millions, are commonplace in ordinary radio broadcast work. Television involves frequencies which range up into the hundreds of millions each second.

These numbers seem almost staggering to the person who first makes their acquaintance. They seem so unrealistic as to verge on the fantastic. One is often tempted to doubt that the experts themselves actually know what they are talking about. It seems incredible that any object could move so fast as to create such frequencies. One wonders what kind of device could be constructed which would operate fast enough to create such unbelievably high frequencies without being subjected to a prohibitively high rate of wear.

As a matter of fact these high frequencies are not created by any kind of mechanical device. The highest frequencies created by mechanical means are those used for heavy duty induction heating, and these do not exceed about 12,000 to 15,000 cycles per second. These frequencies are just about the limit which can be reached through the use of mechanical generators.

When frequencies higher than these are needed, we must resort to what is called *vacuum tube oscillators*. In ordinary conversation it is customary to drop the "vacuum tube" and merely use the word "oscillator". The vacuum tube oscillator is capable of generating alternating currents and voltages of virtually any frequency which might be desired. In radar work specially designed vacuum tubes commonly generate frequencies which range up to many *billion* cycles per second.

What is an oscillator?

An oscillator is an electronic circuit which is specially designed so it will be capable of generating alternating currents or voltages. It should be noted that an oscillator is an "electronic circuit". This means it includes a vacuum tube, plus some other components.

Occasionally even experienced radio and television men get the false idea that an oscillator consists of the vacuum tube alone. This is not correct. An oscillator consists of the tube *and* its associated circuit. This point may seem rather minor, yet it is often important.

Since the vacuum tube is such an important factor in an oscillator circuit, and since we more frequently refer to the "oscillator tube" than to any of the other components of the oscillator circuit we fall into the habit of thinking of the tube as being *the* oscillator. But the tube alone will not "oscillate". It must have the other essential components which go to make up a complete oscillator circuit.

There are many types of oscillators. Each has its own advantages and disadvantages. None can do *every* job an oscillator is called upon to do. Some oscillators are designed to do a very specialized job. But there are other jobs which can be done by any of several types of oscillators. We will discuss some of the more important types in this lesson, and point out the things each is best capable of doing, and where it is most frequently used.

It is impossible to cover every type oscillator ever designed. Many specialized circuits have been designed -- some in foreign countries -- which are never encountered by the average radio or television man. It would serve no purpose to waste your time describing them all. The ones which are included in this lesson will probably meet every one of your immediate needs. Others will be discussed as need for them arises.

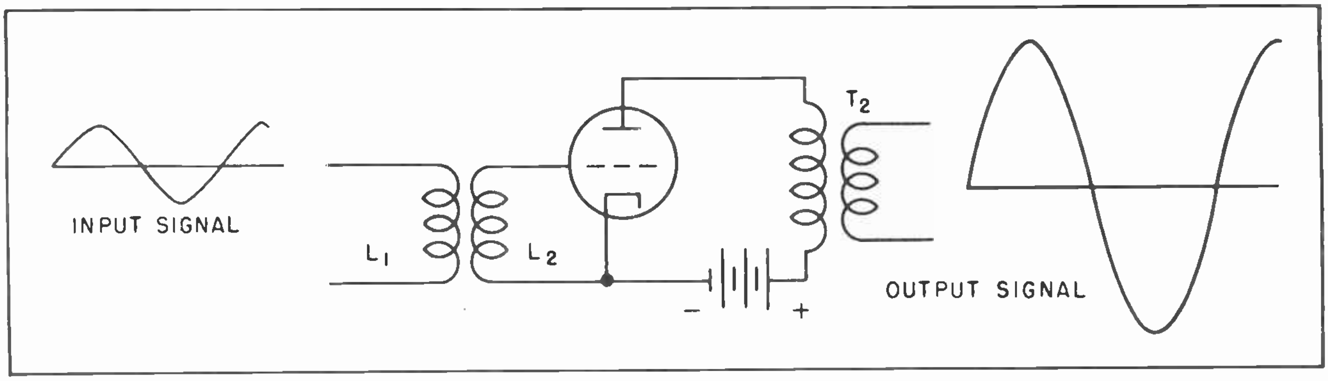

Fig.2. A Transformer Coupled Amplifier Circuit.

Section 2. **THE ARMSTRONG OSCILLATOR**

One of the oldest oscillator circuits, and the one which was once the most widely used of all, is the Armstrong oscillator. It was designed by Major E. H. Armstrong, who, many years after designing the oscillator, introduced Frequency Modulation radio, the modern F-M.

The Armstrong oscillator is still quite commonly used by amateurs and experimenters but is seldom found in modern radio receivers. However, it is one of the easiest oscillators to understand. For that reason we will present a description of it first, and using our knowledge of it go on to the other types which are somewhat more difficult

As a preliminary it should be emphasized that a vacuum tube's ability to generate alternating current -- to act as an oscillator -- results directly from its ability to amplify.

There are times when a tube's amplifying ability will generate oscillations where they are not wanted. Yet the essential fact is that its ability to oscillate depends upon its ability to amplify.

In Fig. 2 we have drawn a simple amplifier circuit. We have the input signal which is applied to the inductance L_1 which is also the primary of a transformer. By transformer action the signal is passed along to the grid of the vacuum tube. The vacuum tube amplifies the signal and it appears again on the primary of transformer T_2. From there it can go on to another stage of amplification.

In all our studies of vacuum tubes we have assumed the signal has been obtained from some outside source. We have never been concerned with the source, sometimes it has been the signal picked up by the antenna of a radio or television receiver. Other times it might have come directly from a microphone or a phonograph pickup. We have never considered the source. With this in mind notice the difference in the strength of the output signal from that of the input signal. The output is much larger than the input. Of course, this is no different than we would expect. We know the normal use to which vacuum tubes are put is to amplify a small signal into a much stronger, or larger, one. The main point is that the signal at the output of the anode circuit is much larger than is needed to drive the grid of the tube.

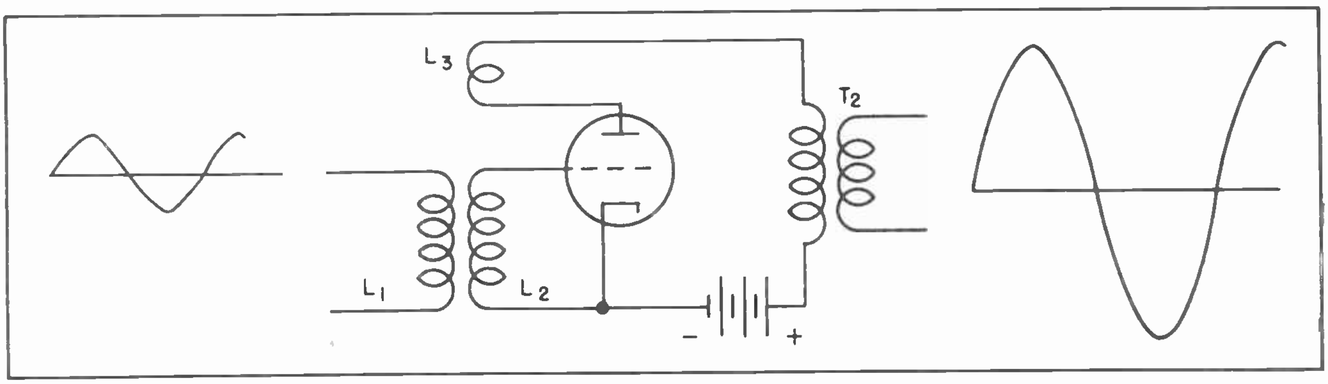

Fig.3. Feeding Some of the Output Signal Back to the Input.

Now suppose we run the anode current of the tube through a small coil such as L_3 in Fig. 3 before the current passes through the primary of T_2. If L_3 is placed adjacent to L_2 it will act like the primary of a transformer, with L_2 acting as the secondary.

Now we have a situation where a signal on the input to L_1 sets up a voltage in L_2. L_2 then places the signal on the grid of the vacuum tube. The signal is amplified by the vacuum tube and causes a current to vary in the anode circuit of the tube. The varying anode current will flow through L_3 and set up moving lines of magnetic force in the space surrounding the coil. These moving lines of force are able to cut across the coils of L_2, inducing more voltage in L_2 which in turn is placed on the grid of the tube, which again affects the anode current, etc., etc.

Before going any further suppose we take a specific example of a voltage on the input. Let us say there is a change in the input signal which results in the grid becoming slightly more positive. A "positive-going" grid will cause an increase in the anode current. An increase in the anode current will create expanding lines of magnetic force around L_3 and the primary of T_2. For the moment we can ignore T_2 but we are definitely interested in L_3. The expanding lines of force from L_3 cut across the coils of L_2 inducing even more voltage in L_2. This additional positive voltage in L_2 is immediately applied to the grid of the tube.

As the increased positive voltage is placed on the grid even more anode current flows through the anode circuit. This

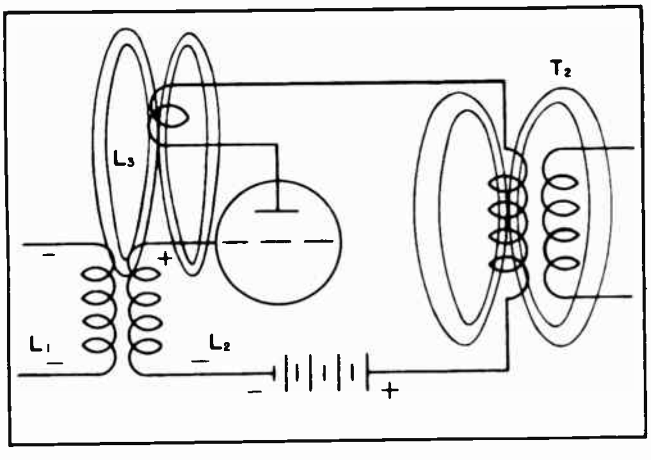

Fig. 4. Magnetic Lines of Force Around the "Tickler Coil".

in turn causes the grid to go even more positive, which causes more current to flow etc., etc. Now the question is: how long will this condition continue?

The grid will continue to become more and more positive, and the anode current will continue to increase until the anode is receiving all the electrons it can receive from the cathode. In other words the anode current will increase until the "saturation" point is reached.

When the tube reaches saturation it makes no difference how much additional positive voltage is placed on the grid there will be little or no additional increase in the anode current. When the anode current ceases to *increase*, the anode current will cease to *change*. When the anode current ceases to change, the magnetic lines of flux will cease expanding -- or moving out from -- L_3. When these magnetic lines of force stop moving they will no longer be cutting across L_2, and will thus be no longer inducing a positive voltage in L_2. The instant the positive voltage is removed from L_2 the grid will become *less positive*, which is the same as saying the grid will become more negative.

Now we have a situation which is exactly opposite to that we had a moment before. As the grid becomes more negative -- that is, less positive -- it will affect the anode current. The anode current will decrease. As the anode current decreases the current through L_3 decreases, and as the current through L_3 decreases the magnetic lines of force which have surrounded L_3 will begin to contract. As these lines of force contract they will again cut across the coils of L_2. But this time they will cut across in the opposite direction. Their cutting will now cause the grid to go more negative. And, of course, as the grid becomes more negative less anode current will flow.

Here, again, we can ask the question: how long will this condition continue? It will continue until the grid is driven so negative that all current is cut off the anode. When this happens the collapsing lines of force will no longer be driving the grid negative. When the negative voltage is removed from the grid the natural action is for the grid to become more positive. If something is *less negative* it is exactly the same as saying it is more positive.

Now we have the situation where the grid is becoming more positive again, and, of course, this will start the anode current flowing again. When this happens the entire cycle starts all over again.

Let's go back and review the whole action very briefly and make certain we understand what is going on. When the first tiny positive voltage is placed on the grid of the tube the anode current will increase slightly. The slightest change in the anode current will set off a series of events which will drive the anode current to saturation before it can be stopped. When the anode current reaches saturation and is no longer increasing the high positive voltage will be removed from the grid. Removing the positive voltage from the grid causes the anode current to start decreasing. When this happens the current will keep right on decreasing until the tube reaches cut-off.

When the tube reaches "cut-off", of course, no current will be flowing. When this happens the negative voltage will be removed from the grid. This, in turn, starts the grid in a positive direction again, and sets off the whole cycle of events again.

This entire action will be repeated over and over indefinitely. We will alternately have a large current flowing in the anode circuit, then no current. The anode current is also flowing through the primary of transformer T_2. A continuous alternating voltage can then be tapped off the secondary of that transformer.

Section 3. **FEEDBACK**

It has probably already occurred to you that we could now remove the original input through L_1 and the circuit would continue to oscillate, operated only by its own *feedback*. (See Fig. 5.) By feedback we mean the little bit of energy we have used from the output circuit and fed back into the grid circuit. Such a thing would be entirely feasible. Let us study this matter of feedback a little further for a moment. If the overall gain of the tube circuit was 10 we could apply 1 volt to the grid and have it amplified to 10 volts at the anode output.

If we took one volt of the output and fed it back into the input we would still have 9 volts left in the output circuit to accomplish some useful purpose. This sounds entirely reasonable; it does not conflict with anything we have learned about vacuum tube amplifiers, and is exactly what happens in this type of oscillator.

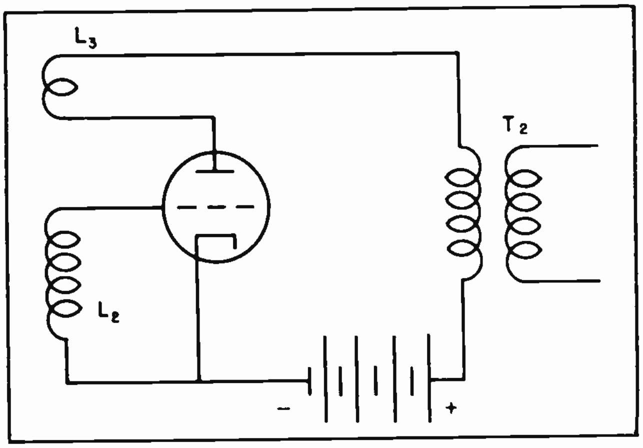

Fig.5. The Original Signal Can be Eliminated.

In any type of oscillator we will find a small amount of the output fed back, in some manner, to the grid of the vacuum tube. This small *feedback* signal is then amplified again, keeping the oscillations from dying out.

Once we have an oscillator circuit functioning properly it is not hard to understand that it can be kept oscillating indefinitely. Now we come to the problem of starting the oscillations. They could, of course, be started each time the circuit was put into operation in the same manner we have previously described. That is by applying some kind of signal to the grid of the vacuum tube as has already been described.

However, it should be remembered that frequently the devices which use oscillators are operated by persons without any technical training. A radio receiver, or a television receiver, furnishes the best example of this condition. It is a little too much to expect that every person who owns or operates one of these receivers must know how to start an oscillator oscillating.

Fortunately, it is not necessary to apply any outside signal to an oscillator to start it oscillating. The mere presence of the tube itself is usually sufficient. It should be remembered that electrons are normally moving from the cathode to the anode in any vacuum tube which has its filaments heated and a positive voltage applied to the anode. With any given anode

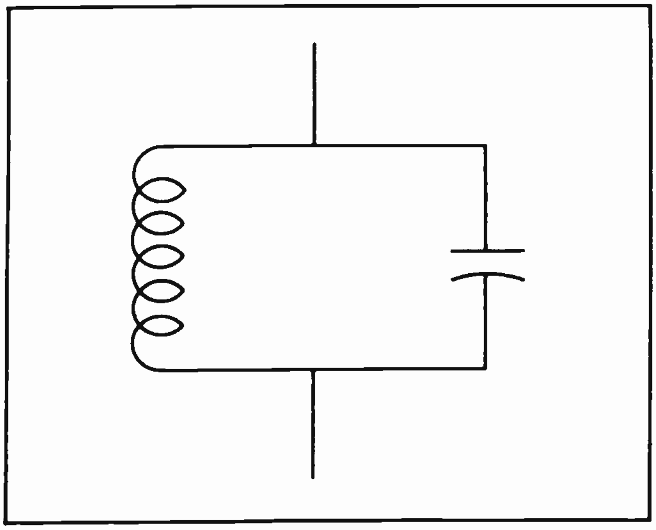

Fig.6. The Essentials of a "Tuned Circuit".

voltage, a given grid voltage and a given temperature on the cathode there will be a given amount of anode current flowing through the anode circuit. This we have learned, and this is true -- *within limits.* Even a delicate milliammeter placed in the anode circuit would detect no variations in the value of the anode current.

But the truth is that the anode current *is varying* -- very slightly -- at all times. The current itself is composed of a stream of electrons. There are untold thousands of electrons in the stream at all times. The total quantity will not vary noticeably under any given set of conditions -- but it will vary some.

For example, there may be 1,000,000,000 electrons flowing from the cathode to the anode each second. If the actual number of electrons varied some three or four thousand either way from 1,000,000,000 few instruments are delicate enough to detect the variation. *But the vacuum tube grid would detect the difference.* Any current change in the anode circuit would be instantly reflected to the grid. And once the grid of an oscillator tube starts changing -- either positive or negative -- it keeps on changing until the tube reaches either cut-off or saturation, depending upon whether it starts changing in the positive direction or in the negative direction.

From this it is evident the oscillator is self-starting. Any change in the value of the current in the anode circuit, or any change of voltage on the grid of the vacuum tube is enough to start the circuit oscillating. A little reflection is enough to point out that even this peculiar action of a vacuum tube is not needed to start a circuit oscillating. Suppose the cathode is not heated, nor is there any voltage on the anode. If heating current is applied to the cathode, electrons will soon start leaving the cathode. As the cathode becomes increasingly hotter more and more electrons will be emitted. This very condition is enough to cause a change in the anode current once the voltage is applied to the anode.

If the cathode is already heated before the anode voltage is applied, the mere application of the anode voltage is enough to start a *change* in the anode current. And remember, *any* change in the anode current is enough to start an oscillator circuit oscillating.

As a matter of fact, if all the elements of an oscillator circuit are present we need never worry about the circuit starting to oscillate. In fact we usually have more trouble keeping other circuits from oscillating than we have in getting an oscillator circuit to start oscillating.

If, by any chance, an Armstrong oscillator does not oscillate it would be well to check the "phasing" of the tickler coil and the main inductor coil of the tuned circuit. By "phasing" we refer to the windings with respect to each other. As an example of this we normally expect a current flowing in one direction in the

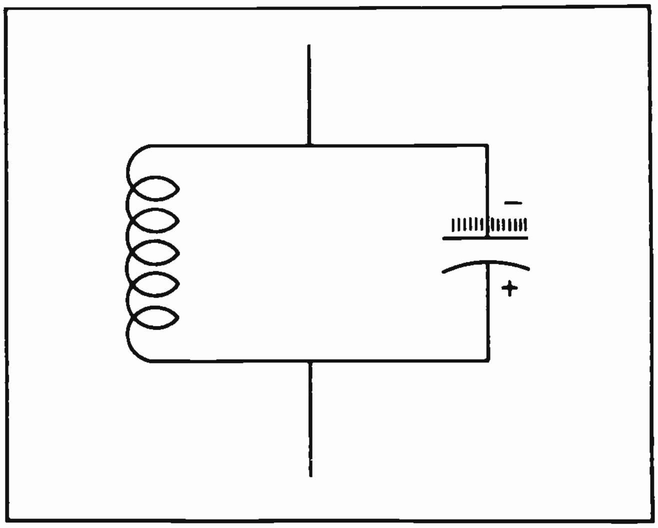

Fig.7. A Charge has been Built Up on One Plate of the Capacitor.

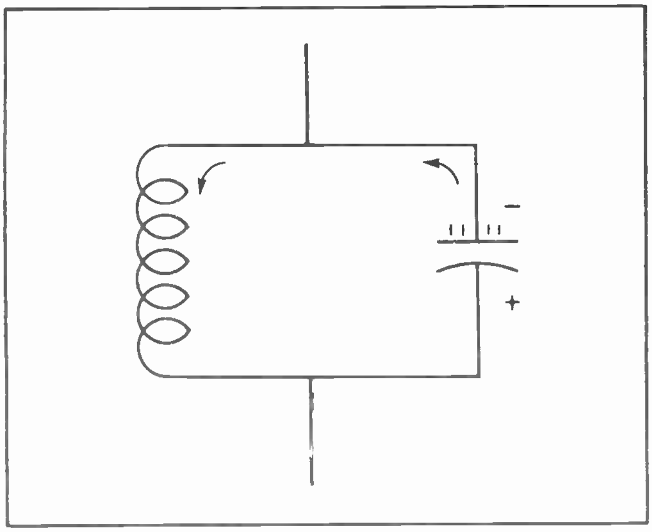

Fig.8. The Capacitor Discharges Through the Coil.

primary coil to induce an opposite voltage in the secondary.

Now it is possible to connect one of the windings so it will be just the reverse of what it would normally be. When this happens the secondary voltages will be just opposite that expected.

In the case of the Armstrong oscillator we expect the induced voltage in the tuned inductor coil to place a positive voltage on the grid of the tube as the anode current increases. Such a situation is necessary to maintain oscillation.

Should the tickler coil be reversed, however, an increase in the anode current will cause the grid to become negative instead of more positive. Such action will prevent oscillation. This condition is readily corrected. All that is necessary is to reverse the connections to the tickler coil.

Section 4. OSCILLATOR FREQUENCY

We have already mentioned that the main purpose of an oscillator circuit is to produce alternating currents or voltages. We have also intimated that an oscillator circuit is capable of providing a very wide range of frequencies of alternating current or voltage. The point which now confronts us is how to control the frequency -- how to design an oscillator circuit which will deliver the frequency we need and not some other frequency differing greatly from our needs. The frequency of any oscillator circuit is determined by its "tuned circuit". And since every oscillator must have a "tuned circuit", it is necessary that we pause in our description of the oscillator and first explain the peculiarities of a tuned circuit.

A *tuned circuit* is nothing more nor less than an inductor and a capacitor connected as in Fig. 6. The value of the inductance and the capacitance will determine the frequency of the oscillator. It is all as simple as that.

Suppose that in some manner the capacitor of Fig. 6 becomes charged up as in Fig. 7. The upper side of the capacitor is highly negative while the bottom is highly positive. We need not worry for the moment as to how the capacitor has happened to obtain the charge, let's accept the fact it has. Obviously the capacitor is not going to remain charged as in Fig. 7 for very long. It is too easy for the electrons to leak off the negative plate of the capacitor, flow through the inductor and onto the other plate of the capacitor.

In Fig. 8 we can see the electrons starting to flow from the capacitor toward the coil of the inductor. As the electrons flow through the inductor coil in the form of an electrical current they will cause magnetic lines of force to expand outward from the coil. This is the same thing that always happens when an electrical current flows through a coil. The first effect is for the expanding lines of magnetic flux to set up a counter voltage to oppose the flow of the current as shown by the dotted arrow.

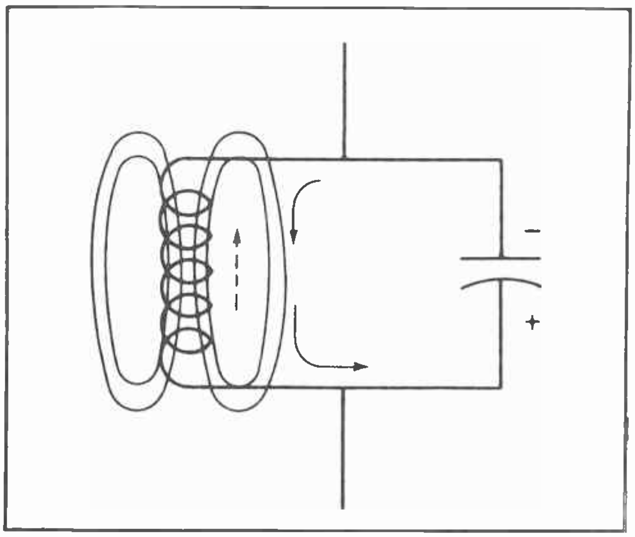

Fig.9. Magnetic Lines of Force are Built up Around the Coil.

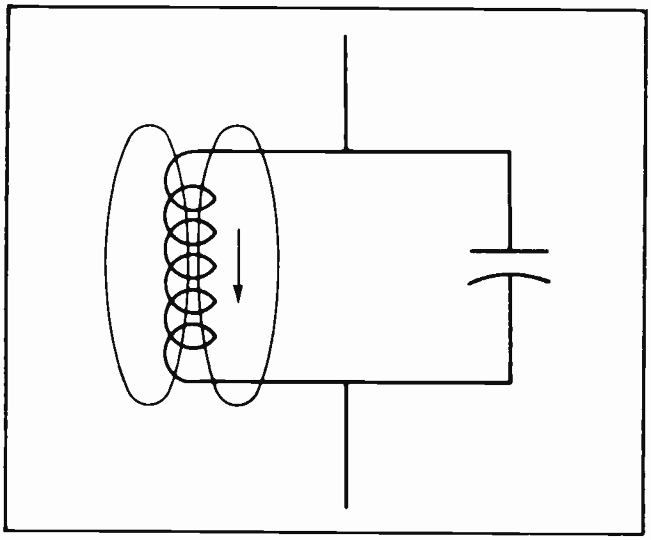

Fig.10. The Collapsing Lines of Force Induces a Voltage in the Coil.

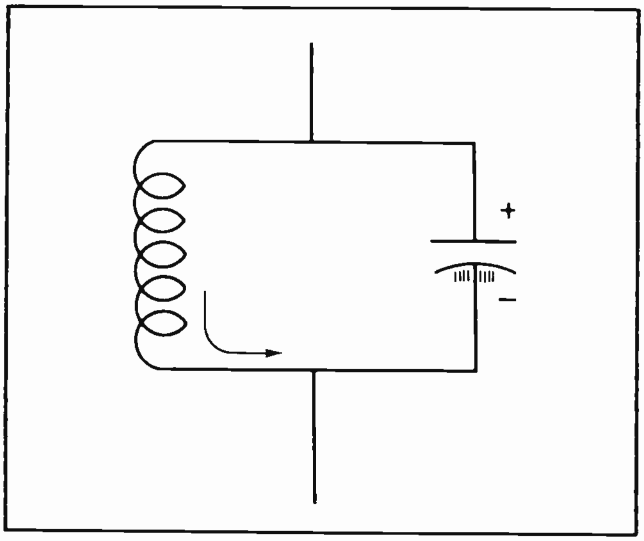

Fig.11. The Voltage Induced in the Coil Charges up the Capacitor.

But once the lines of force have been fully expanded the current can flow quite freely.

But the amount of current which can flow from the capacitor through the inductor is strictly limited. The capacitor can hold only a limited number of electrons. As the current begins to slacken, the lines of force begin contracting into the coil. These contracting lines of force induce a new voltage which tries to keep the current flowing. This new voltage is in such direction as to send a charge toward the other side of the capacitor. (See Fig. 10.) The current flowing under the pressure of the newly induced voltage flows toward the lower side of the capacitor, charging it up in a direction opposite to the charge it held only an instant before.

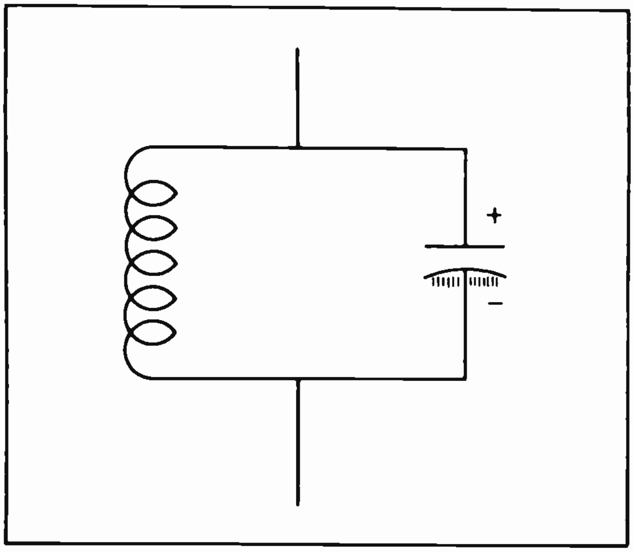

Fig.12. The Capacitor is Charged as Shown by the Polarity Signs.

By the time the voltage caused by the collapsing lines of force has died to zero the voltage on the capacitor will be built up to full value as shown in Fig. 12. At this instant the capacitor is fully charged. But now it is charged oppositely to what it was in Fig. 7.

It is entirely obvious again that the capacitor is not going to remain charged as in Fig. 12. It is going to start discharging again, and since the only way it can discharge is back through the inductor it will do that. (See Fig. 13.) Again, as the current starts to flow through the inductor a magnetic field will be built up around the inductor coil.

Then as the magnetic field collapses it will again induce a voltage which will send the current toward the upper plate of the capacitor, once again charging up the capacitor. (See Fig. 14.) This will be the same as in Fig. 7.

Once the capacitor becomes charged up in that direction, and the magnetic field around the coil has completely collapsed, the discharging capacitor will send the current back through the inductor again. This action continues over and over. The capacitor discharging through the inductor builds up a magnetic field around the coil. When the current decreases the collapsing field induces a voltage in the coil which sends the current to the other side of

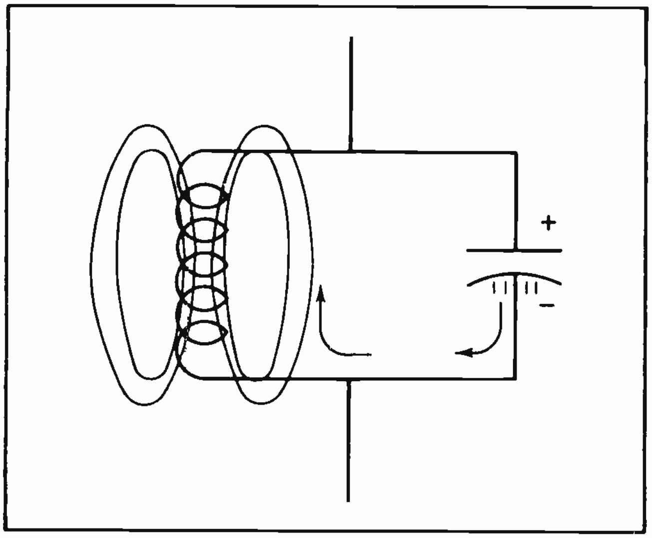

Fig.13. The Capacitor Again Discharges Through the Coil Causing Magnetic Lines of Force to Build up Around the Coil.

the capacitor, charging the capacitor up in the opposite direction.

The rate at which the capacitor will charge up and discharge will depend upon its capacity. If the capacitor is quite large it will take longer for it to build up a charge and for it to discharge. It is understandable that if the capacitor is large the frequency will be lower than if the capacity was small.

Likewise, if the inductance of the coil is large it will slow down the building up of the magnetic field, and will take longer for it to collapse. Furthermore, if the inductance is high it will induce a higher voltage when the field collapses, and in doing so will charge up the capacitor to a higher voltage. It is reasonable that a large inductor will slow down the passage of current more than would a small inductor. For these reasons it is easy to see that if the inductance is large the frequency will be much lower than if the inductance was smaller.

We have two things now which influence the frequency of the oscillations: the value of the capacitance and the value of the inductance. The larger either of them are, the lower will be the frequency of oscillation.

If it is desirable to create an A-C voltage with a low frequency -- perhaps an audio frequency which can be heard in a pair of earphones or in a loudspeaker -- we would use an inductor which had a high inductance. It would probably be an iron-core inductor, which would have a much higher inductance than an air-core inductor. The capacitor would probably have a fairly high capacitance also.

However, if it was desirable to generate a frequency in the radio-frequency range, something over 500,000 cycles per second, we would use an air-core inductor and possibly a capacitor which used air as a dielectric. Such a capacitor might even be variable as in Fig. 15. If it were variable it would be possible to generate a wide range of frequencies with the one oscillator merely by moving the "rotor" of the capacitor, and thus changing the capacitance of the capacitor. Variable capacitors similar to those illustrated in Fig. 15 are used in all radio and television receivers.

Variable capacitors similar to those in Fig. 15 are used with oscillators which are designed to generate test signals. In all radio and television receivers are circuits which are designed to operate best on one certain frequency, or "band of frequencies".

To test these circuits to determine if they are functioning properly it is necessary to apply an alternating current or voltage to them of the proper frequency. Specially designed oscillators, called "signal generators" are used to apply the needed signal to the circuit under test.

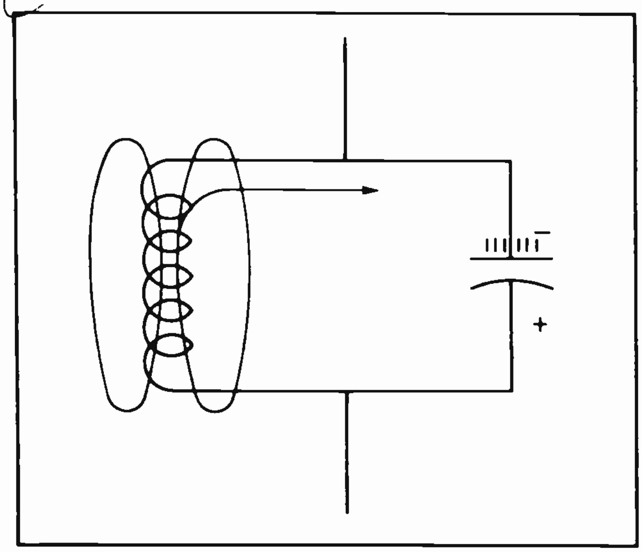

Fig.14. The Collapsing Lines of Force Charge up the Capacitor Again.

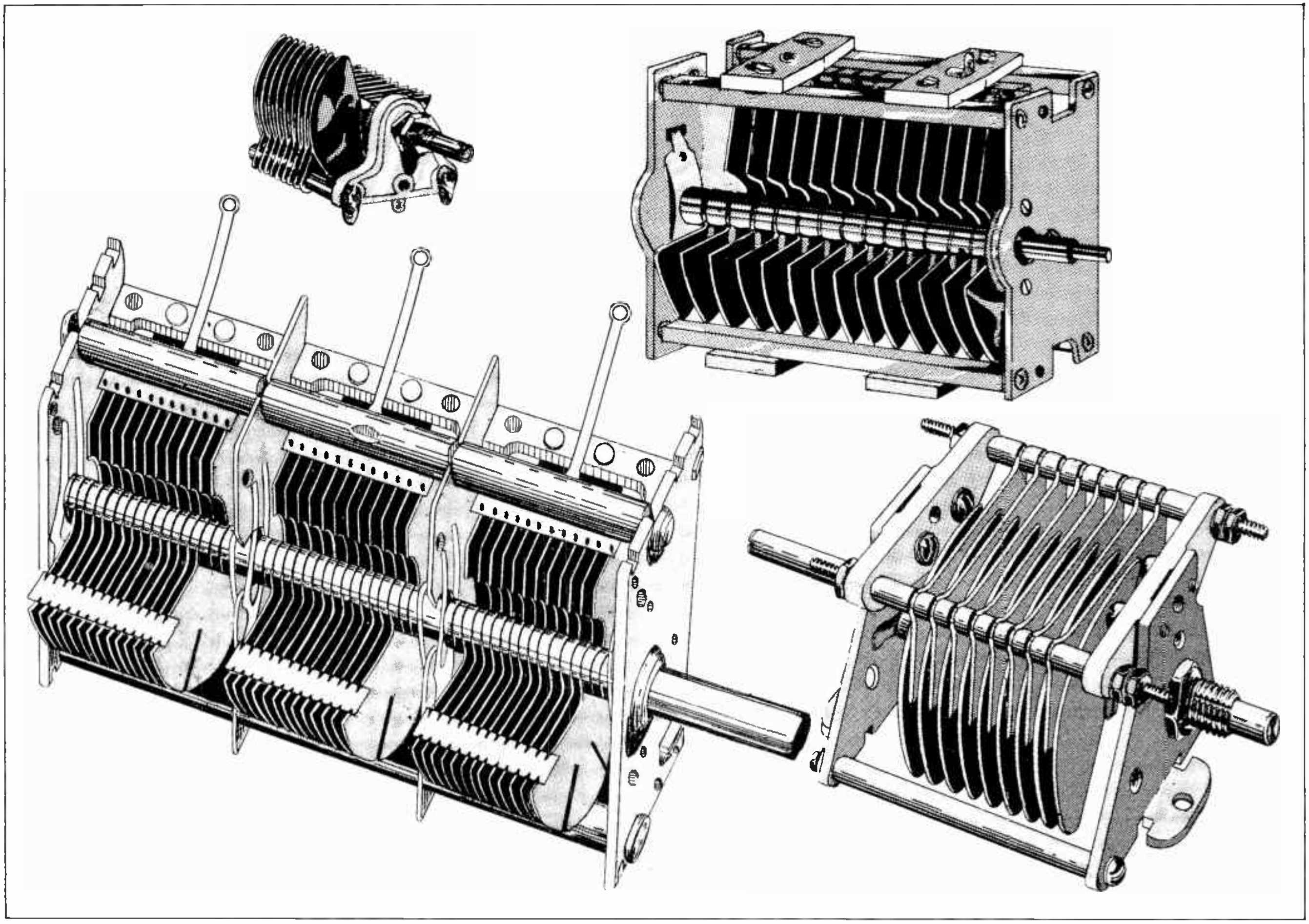

Fig.15. Four Types of Variable Air-Tuned Capacitors. One has Three "Gangs".

Section 5. **OSCILLATOR GRID BIAS**

For reasons which it is not necessary for us to go into at this time oscillator circuits work best when the grid of the vacuum tube is biased so heavily that no anode current can flow when no signal is applied to the grid. This is a special class of operation called "Class C" operation, of which much more will be said later. With the tube so biased, current will flow heavily when the grid is receiving the positive portion of the signal, but no current will flow when there is no signal, or when the signal is in the negative direction.

But what about the situation when there has been no signal, but it is desired to start a circuit oscillating? If the tube is biased at "cut-off", that is with so much negative bias that no anode current can flow, how are we going to obtain the *change* of anode current so necessary to start the circuit oscillating?

Obviously we could not start it. For this reason it is not possible to use "cathode bias" or "fixed bias", as we did with other types of vacuum tube amplifiers.

But we do have to have some kind of grid bias. To obtain the needed bias we resort to what is called "Grid-leak bias". Fig. 16 shows a diagram of an oscillator circuit with a grid-leak bias resistor by-passed with a by-pass capacitor. It also has a regular tuned circuit.

Now to see how this circuit operates. Suppose that at a given instant the upper part of the capacitor in the tuned circuit is positive as in Fig. 17. This will place a positive voltage on the grid of the tube. (This is acting on the supposition that the grid at that instant has no *bias* on it).

Placing a positive voltage on the grid will cause a heavy anode current to flow. Furthermore, since the grid itself is somewhat positive it will also attract some

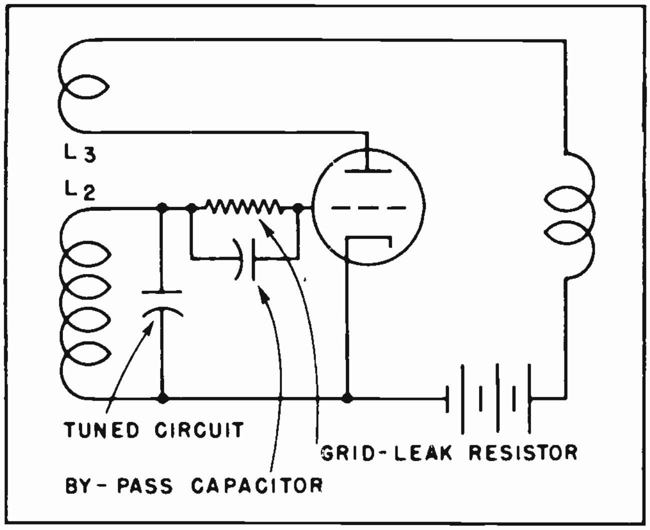

Fig.16. Grid-Leak Bias Circuit.

electrons. The instant the grid acquires some electrons it will become negative until the electrons can leak through the grid-leak resistor. The upshot of it is that the original positive voltage on the grid will attract electrons to the grid, changing the grid from positive to negative. The grid becomes fully negative just about the time the anode current has reached its maximum value.

When the anode current begins to decrease it would normally send the grid into the negative direction. The newly acquired electrons do the same thing. Thus the grid-leak resistor aids in making the grid highly negative until the tube actually goes to cut-off. Then the voltage in the tuned circuit starts building up in the positive direction again. By this time some of the electrons have leaked through the grid-leak resistor, although not all of them. But the positive voltage impulse from the tuned circuit can pass through the by-pass capacitor, making the grid momentarily positive again. This lasts just long enough for the grid to acquire a few more electrons from the space charge within the tube.

The combination of the tuned circuit, the grid-leak resistor, and the feed-back voltage keeps the oscillator circuit delivering a stable alternating current and voltage for whatever purpose it might be needed. The addition of the grid-leak resistor and its by-pass capacitor aids materially in keeping the oscillator operating, and keeping it operating at the same frequency. The tuned circuit is mainly responsible for determining the frequency, but the grid-leak resistor and its by-pass capacitor aids in keeping the frequency stable.

The resistor must not have such low resistance that the electrons can leak through it with little trouble. If they could do this there would be little point in having the resistor in the circuit at all. On the other hand the resistor cannot have too high resistance. If this should happen there would soon be so many electrons on the grid it would become "blocked". That is the grid would quickly become so negative it would prevent the passage of any electrons through the tube to the anode.

The exact value of the grid-leak resistor will depend very largely upon the type of tube being used. If the tube is a triode similar to those commonly found in radio and television receivers it would probably be about 500,000 ohms. If the tube was a large one such as is used in transmitters the resistance would be much lower, possibly only 10,000 to 25,000 ohms.

The value of the by-pass capacitor will depend largely upon the frequency the oscillator is designed to generate. If the frequency is high the capacitor would be quite small; if the frequency is low the value of the capacitor would be somewhat larger.

Section 6. **HARTLEY OSCILLATOR**

The Armstrong, or tickler-feedback, oscillator was probably the first in general use. At one time it was the only type used. But it has some definite drawbacks which makes it unsuitable for most commercial operations today. About the only place the Armstrong oscillator will now be found is in the home-made circuits of amateurs

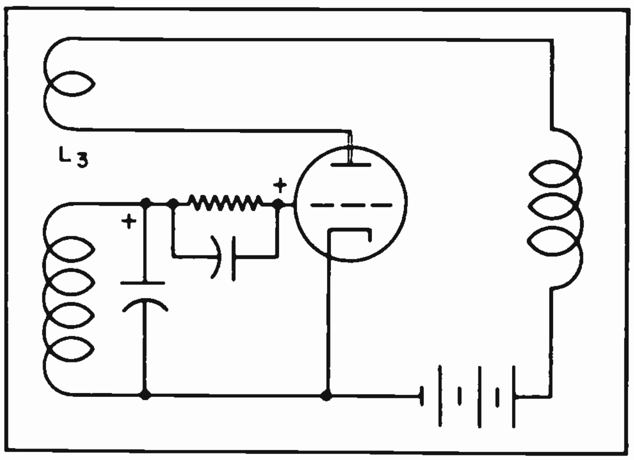

Fig.17.

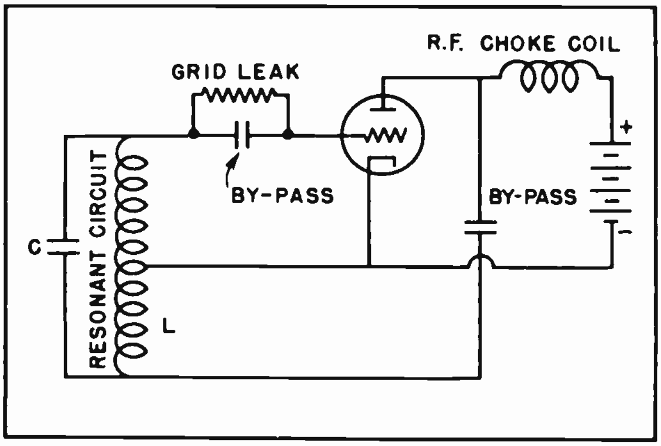

Fig.18. Hartley Shunt-Fed Oscillator.

and in portable receivers. However, it is much easier to understand the operation of oscillators when the Armstrong is the one used as a demonstration.

One of the most widely used oscillators today is the Hartley oscillator. Actually there are two types of the Hartley oscillator, the series-fed oscillator and the shunt-fed oscillator. The series-fed is seldom used but the shunt-fed oscillator is universally used. Fig. 18 shows the diagram of the Hartley shunt-fed oscillator. Note the tuned circuit, which is also called "resonant circuit". It will be noted that this circuit is in no way different from that of the Armstrong oscillator in Fig. 16. We have the inductance "L", and the capacitor "C". These two components of the tuned circuit operate exactly as the inductance and capacitance in the series of illustrations from Fig. 6 to Fig. 14.

The grid-leak resistor assists in furnishing a grid bias in exactly the same way as that in the Armstrong oscillator, and the by-pass capacitor serves the same purpose as in the other. But notice the difference in the method of obtaining feedback. In the Armstrong oscillator the feedback was by means of a tickler coil. No tickler coil is used with the Hartley oscillator. The R.F. choke prevents the alternating voltages from going through the battery. The by-pass capacitor on the right side of the diagram furnishes a path for the alternating currents and voltages from the anode of the tube to the bottom of the tuned circuit.

Note that the alternating currents and voltages can pass through the capacitor on the right, go to the bottom of the tuned circuit, flow through the lower part of the inductance coil to the midway tap, and from there to the cathode of the tube. This makes a complete circuit.

The next thing to note is that the alternating currents flowing through the lower part of the coil set up magnetic fields around the coil. Since the upper part of the coil is placed very closely to the lower part -- is, in fact, part of it -- any magnetic lines of force surrounding the lower part of the coil also cut across the turns of the upper part of the coil. This induces a voltage in the coil which acts to charge up the capacitor in the tuned circuit. From that point on, the tuned circuit acts the same as any other tuned circuit. A small part of the output signal fed into the lower part of the inductance coil is enough to start the oscillations and keep the circuit oscillating.

Section 7. HARTLEY SERIES FED OSCILLATOR

The Hartley series-fed oscillator is very similar to the shunt-fed type with one minor exception. In the shunt-fed oscillator it will be noted that the D-C portion of the anode and cathode current flows directly from the anode to the battery, and directly from the battery to the cathode. None of the D-C component flows in any part of the oscillatory circuit. The alternating current is by-passed from the anode circuit directly to the oscillatory circuit.

In the series-fed oscillator, however, the anode-cathode D-C current flows through the lower part of the inductor which forms the oscillatory circuit. The A-C portion of the anode current is by-passed around the battery, but it does flow through a part

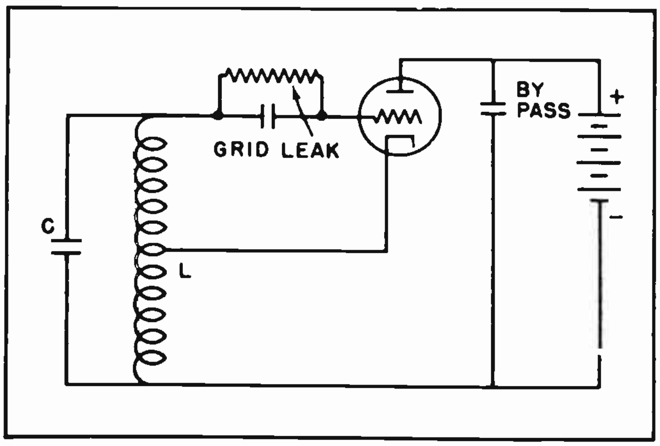

Fig.19. Hartley Series-Fed Oscillator.

of the tuned, or oscillatory, circuit. In some cases it makes little difference whether the D-C component is in the tuned circuit or not. But there are other applications where it is not desirable. Normally it is possible to obtain more stable operation if the D-C component is not allowed in the tuned circuit. Since it is just as easy to connect up the circuit for shunt feed as for series feed, and since the shunt feed usually gives better, more stable, operation the shunt-fed oscillator is by far the most widely used. The Hartley oscillator will be encountered in nearly every type radio or television receiver.

Section 8. THE ELECTRON COUPLED OSCILLATOR

A variation of the Hartley shunt-fed oscillator is the electron coupled oscillator. The electron coupled oscillator, or *E.C.O.* as it is commonly called, retains all the good points of the Hartley oscillator and adds a few others peculiar to itself. It is unbelievably stable in its operation, and a variation of the load into which it feeds does not affect the frequency of its oscillations.

It will be noted, by referring back to Fig. 18, that if a portion of the anode voltage is tapped off and fed into another vacuum tube there is a possibility of affecting the stability of the operation. Perhaps this is not readily apparent, but it is understandable that any change in the load can readily affect the voltage on the anode, and this in turn could affect the frequency of operation.

In the E.C.O., however, the anode load circuit is completely isolated from the oscillatory circuit. (See Fig. 20.) The oscillatory circuit is composed of the screen grid, which acts as the anode for the oscillatory circuit, and a tuned circuit which is very similar to that of the shunt-fed Hartley oscillator.

The load is tapped off the anode circuit. The load can be varied in any of several ways without affecting the frequency in any way.

It will be noted that the cathode, the control grid and the screen grid are the only tube elements which figure in the oscillator circuit. When the control grid cuts down the current to the screen grid it also cuts down the current to the anode. Likewise, when the grid increases the current to the screen grid it also increases the current to the anode. This means the current which flows in the anode circuit is completely controlled by the oscillations in the oscillatory circuit. But changes in the anode circuit are in no way reflected back into the tuned circuit, the grid or any other part which forms the oscillatory circuit.

For these reasons the E.C.O. is extremely stable. Where it is necessary to generate very high frequencies -- up to several million cycles per second -- the E.C.O. is nearly always used.

Section 9. COMPARING FREQUENCIES

If an oscillator is generating an alternating current and voltage with a frequency

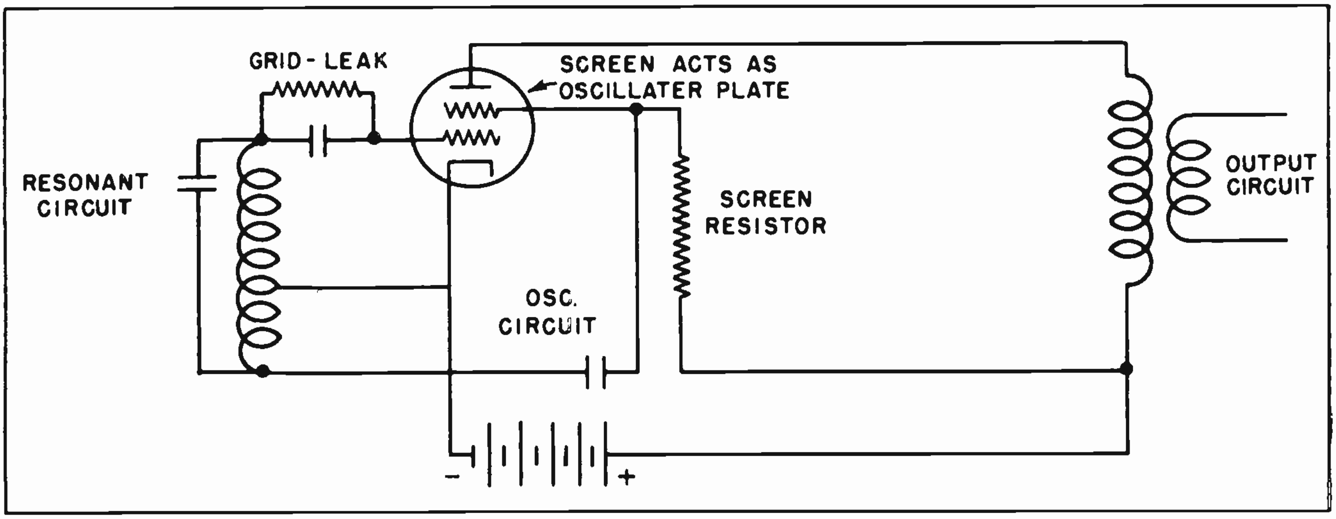

Fig.20. Electron Coupled Oscillator.

of 500,000 cycles per second it cannot be heard by the human ears. If another oscillator is generating another signal with a frequency of 495,000 cycles per second the signal from this second oscillator cannot be heard either.

If these two frequencies are mixed together in the proper vacuum tube circuit these same two frequencies will emerge at the anode of the tube. But in addition to them there will be a third signal which is equal to the *difference* between the two frequencies, or 5000 cycles. This third frequency *is* audible to the human ears.

This third frequency is called the "beat frequency". It is so-called because it is obtained by beating together the other two frequencies. It is this peculiarity of the various frequencies which makes it possible to measure the exact frequency which might be on the air. In measuring such frequencies it is the common practice to generate a known frequency by means of a calibrated signal generator. Then this signal is mixed with the unknown signal. The frequency of the known signal is slowly varied until a beat frequency can be heard.

After the beat frequency is heard the known frequency is slowly varied some more until the note of the beat frequency becomes lower and lower, thus signifying the known and unknown frequencies are coming closer and closer together. The beat frequency will become lower and lower in tone until it will completely disappear. When this happens we know that both the known and the unknown frequencies are at the same frequency. Since we already know the one frequency it stands to reason that the formerly unknown frequency is the same as the known, so that now the frequency of the unknown signal has become known.

This matter of measuring frequencies will be discussed at much greater length in future lessons. We merely wanted to show how we could always determine the exact frequency of any signal. All that is needed is some calibrated oscillator frequency. It is possible to purchase calibrated signal generators which are highly accurate. By using them any frequency can be measured. In this lesson we have barely scratched the surface of the subject of oscillators. It is not our intention to plunge into the subject too deeply at this time. Many other types of oscillators will be taken up in good time. Many of them will be discussed at the time we discuss their actual applications.

To mention a few other types of oscillators not discussed in this lesson we can mention the Colpitts oscillator, the tuned-grid-tuned-plate oscillator, the multi-vibrator oscillator, the Meissner oscillator, the crystal controlled oscillator, the blocking oscillator, the flip-flop oscillator and many others.

The multi-vibrator oscillator is used for many purposes in television and radar. It is used in many television receivers as the control medium in the sweep circuits which guide the electron beam in the picture tube as it paints the picture on the screen. Blocking oscillators are also widely used in television receivers.

In another lesson we will go into detail concerning the crystal controlled oscillator. This is the oscillator which is used to maintain the exact frequencies of radio and television broadcast stations. Under the Federal Communications Commission's regulations radio broadcast stations must not deviate more than 20 cycles above or below their assigned frequency. For example, a broadcast station which is assigned a frequency of 1,000,000 cycles shall not permit its frequency to exceed 1,000,020 cycles, nor drop below 999,980 cycles. You can readily understand that when the limits of frequency drift are as narrow as this the operator of the station must be able to check his frequency at all times, and *know* exactly what his frequency is. The FCC does not accept excuses.

In superheterodyne receivers there is a local oscillator within the receiver which generates a frequency to "beat" with the incoming radio signal. This beating, or "heterodyning" is an interesting subject. But it cannot be touched upon until after you are familiar with oscillators. Nearly all radio receivers, and all television receivers use the superheterodyne principle of signal amplification.

(Reference Notes on the page following)

NOTES FOR REFERENCE

An oscillator is an electronic device for generating alternating currents and voltages.

An oscillator depends upon a vacuum tube's ability to amplify.

In every oscillator a small part of the output of the circuit is fed back into the input of the circuit

The Armstrong oscillator, also called the "tickler feed-back oscillator", is often used by amateurs and other experimenters, but is found in few commercial receivers.

The Hartley oscillator is very widely used.

The Electron Coupled Oscillator is widely used at higher frequencies or where a high order of stability is necessary.

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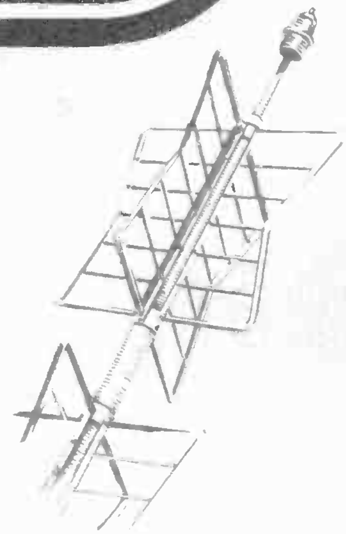

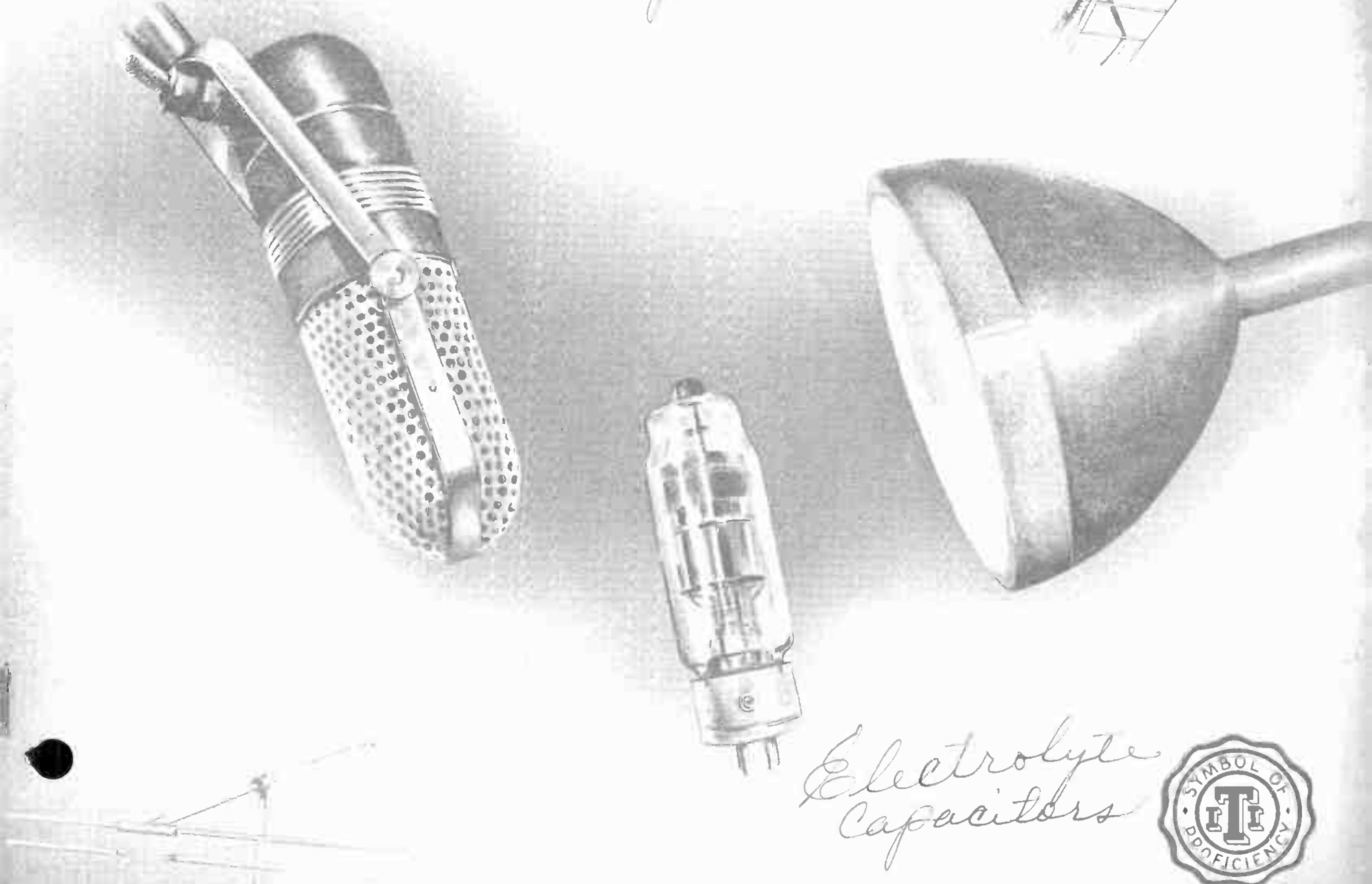

Electrolyte
Capacitors

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RADIO TELEVISION

ELECTROLYTIC CAPACITORS

Contents: Introduction - Special Features of the Electrolytic Capacitor - The Factors of Capacity - Capacity Factors in an Electrolytic Capacitor - Voltage Breakdown - The "Forming" Process - The Electrolytic Capacitor at Work - The Electrolytic Capacitor as a Filter - Action of C-2 - Action of C-1 - Current Through the Load - The Electrolytic as a Cathode By-Pass - Multiple Section Electrolytics - Power Factor in Electrolytics - Defective Electrolytics - Testing for Defective Electrolytic - Notes for Reference.

Section 1. INTRODUCTION

In a previous lesson we have discussed capacitors in general. There we learned the essential elements of any capacitor, or "Condenser" as they are also commonly called, are two electrical conductors separated by a non-conductor.

We also learned that an electrostatic charge could be stored in a capacitor. The amount of such charge would depend upon the size of the electrical conducting "plates", the kind of insulator or "dielectric", and the distance between the plates.

It was explained how the capacitor, by its very nature would act to block the passage of direct current. However, it has the ability to apparently "pass" alternating current, and for all practical purposes does pass it.

In this lesson we take up the study of a very special type of capacitor. It is one which has several important uses in Radio and Television work, and is widely used. When used properly it is highly useful but, like many other things, it has its limitations. This capacitor is called an *electrolytic capacitor.*

Section 2. SPECIAL FEATURES OF THE ELECTROLYTIC CAPACITOR

Electrolytic capacitors have two special qualities which make them indispensable to modern commercial radio and television circuits.

(1) They have a lot of capacity.

(2) They can be constructed to contain this high capacity in a comparatively small physical space.

These two qualities are really interlocked. Before electrolytic capacitors were made, it was possible to make capacitors of high capacity, but they occupied a lot of valuable space. Likewise, physically small capacitors were made and used, but they had extremely low capacity and hence their usefulness was definitely limited.

Electrolytic capacitors also have serious limitations. They must be *polarized* in most

Fig.1. Electrolytic Capacitor.

TABLE I	
MATERIAL	DIELECTRIC CONSTANT
Air	1.0
Ebonite	2.7
Glass (flint)	9.9
Glass (hard crown)	7.0
Glass (lead)	6.6
Gutta Percha	4.1
Mica	5.8
Paraffin (waxed paper)	2.1
Shellac	3.1
Acetone	26.6
Alcohol (at 0° C)	
amyl	17.4
ethyl	28.4
methyl	35
Ammonia	22
Benzene	2.3
Glycerine	56.2
Petroleum	2.1
Pure Water	81

applications, and the voltage they can withstand without breakdown is limited, rarely exceeding 800 volts. Moreover, they must be made by a special process; they deteriorate with the passage of time and they are affected by excessive temperature and humidity conditions.

Yet in both radio and television receiver circuits, their limitations do not seriously hamper their effectiveness in performing certain specialized functions safely and economically over a period of years.

Section 3. THE FACTORS OF CAPACITY

In any capacitor, the capacity is determined by three factors:

1. The total area of the plates.
2. The distance between the plates, or the thickness of the dielectric.
3. The nature of the dielectric. This is expressed as the *dielectric constant*, which is the *ratio* of the capacitor using a given dielectric to the capacity of the same condenser using air as a dielectric.

Note

In most cases, of course, it would be extremely difficult to remove the dielectric from a capacitor and use air as the dielectric instead. However, with the area of the plates and their distance apart known, it is a simple matter to compute the capacity using any dielectric whose constant is known. The constants of the more common dielectrics are compiled in tables. Computations may be made by the use of the following formula:

$$C = \frac{8.84\ KA}{10^8 \times L}$$

where: C is the capacity in *microfarads.*

K is the dielectric constant.

A is the area, in square centimeters, of the plates *actually facing each other.*

L is the thickness of the dielectric in *centimeters.*

Table I gives the dielectric constant of various materials, and comparison may be made with the dielectric constant of air, which is unity.

Section 4. CAPACITY FACTORS IN AN ELECTROLYTIC CAPACITOR

Obtaining high capacity in an electrolytic capacitor is achieved by a process which miraculously reduces the inter-plate distance to a microscopic value. This distance is barely a molecule or two thick! So small is it, in fact, that the other capacity-determining factors, such as plate area, and dielectric constant, may be quite unimportant in comparison to the very small distance between the plates. In this manner manufacturers are able to produce midget-sided electrolytic capacitors with capacities of 1000 microfarads or more. Such capacity values in small capacitors were unheard of before the development of the electrolytic. Today they are common values in scores of radio and television circuits.

In the electrolytic capacitor, the area of the plates is left much the same as in other types of capacitors; in fact, the plate area is often *reduced* considerably, but this reduction is quite permissible because of the closeness of the plates made possible in the electrolytic type. The closeness of the plates has increased the capacity so much that we can easily afford to make the *area* of the plates conveniently small.

In electrolytic capacitors, likewise, the dielectric constant is roughly the same as in other capacitors. Here, too, the closeness of the plates is so effective in increasing capacity that we can easily afford to use a material whose dielectric constant is even lower than that of air.

Section 5. VOLTAGE BREAKDOWN

In the lesson on "Capacitors", emphasis was placed on still another characteristic of capacitors. This is the matter of voltage breakdown.

The ability to withstand a certain amount of impressed voltage without becoming damaged by a spark jumping through the dielectric is a measure of the *voltage rating* of a capacitor. This characteristic is also known as the dielectric strength of the material used in the capacitor, and is generally expressed in volts per unit of thickness.

The following table will permit you to compare the dielectric strength of various common materials, most of them used in capacitor construction.

TABLE II

MATERIAL	DIELECTRIC STRENGTH (in volts per centimeter)
Air	30,000
Bakelite	210,000
Ebonite	700,000
Glass	350,000
Gutta Percha	140,000
Mica	500,000
Paraffin (waxed paper)	290,000
Transil Oil	100,000

To compute the voltage rating of a given capacitor, it is only necessary to determine the material used, measure its thickness in centimeters, and divide this dimension into the dielectric strength of this material. (It may not be an easy matter to measure the thickness of a given dielectric without the use of micrometers. Fortunately the actual construction of a capacitor is a problem for the engineer.)

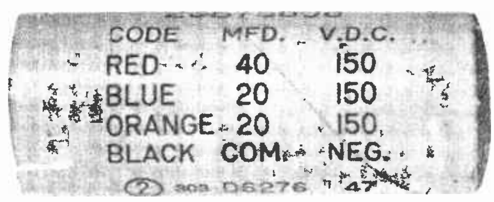

Fig.2. Voltage and Capacity are Marked on Electrolytics.

The voltage rating of capacitors, fortunately, is supplied by the manufacturer, and is almost universally printed or represented in color code in legible form upon the body of the capacitor itself, along with the microfarad capacity rating. Except where there may be some doubt as to whether the capacitor has changed value, we may take the manufacturer's voltage and capacity rating as correct. (See Fig. 2.)

You will probably think of the following question at this time: "If an electrolytic capacitor reduces the distance between the plates to such a small quantity, won't a capacitor of this type necessarily be limited in its voltage rating?"

In the case of non-electrolytic capacitors, the answer is of course, "yes", but in the electrolytic capacitor, this answer must be qualified in an important way. This is because the electrolytic capacitor uses a dielectric which has a peculiar unidirectional character.

Fig. 3 gives a much-enlarged view of the essential construction of an electrolytic capacitor. Let us first notice the *polarity* of the terminal leads, marked *positive* at the aluminum plate and *negative* at the metallic container. The electrolyte acts as one of the plates of this capacitor. The electrolyte, which is a good conductor of electricity, is in contact with the metallic container, which may also be made of aluminum, as well as with the thin film of oxide on the positive aluminum plate. Thus we have the basic requisites for a capacitor: Two conductors separated by a non-conductor, which in this case is the oxide film.

Since the oxide film is very thin, on the order of *millionths of an inch*, the two conductors are considered to be very close to

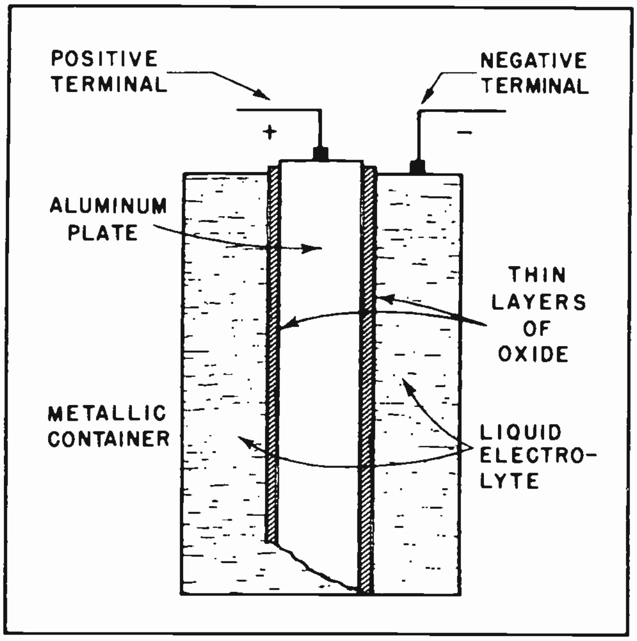

Fig.3. Construction of Electrolytic.

each other, a fact which seems rather obvious. However, this oxide film is a non-conductor only in one direction. If we try to make current flow from the negative terminal of the capacitor through the electrolyte and the oxide film to the positive terminal, the oxide, being a non-conductor in this direction, will prohibit such current flow. If, on the other hand, we drive current from the *positive plate* through the oxide and the electrolyte to the *negative* terminal, the oxide will permit this current to flow, and the unit no longer acts like a capacitor. This is because we no longer have two conductors separated by a non-conductor.

What we do have, instead of a capacitor, with the wrong polarity of applied voltage, is a short-circuit, the total conducting path of current consisting of three good conductors: the aluminum plate, the oxide, and the electrolyte. When incorrectly polarized, therefore, an electrolytic capacitor will act like a short circuit; it will heat up considerably, it may even explode, and is likely to seriously damage other components in its circuit. It may even result in serious bodily harm to the technician, if placed in a circuit in the wrong polarity.

Section 6. THE "FORMING" PROCESS

In order to produce the thin oxide film in an electrolytic capacitor, a process known as "forming" must be applied. This process, done under very carefully controlled conditions, is simple in principle.

After the aluminum plate, the electrolyte (which may be either in liquid or in paste form), and the metallic container are assembled, a voltage is applied to the unit. This voltage is D-C in nature, and is of a value corresponding to the desired breakdown voltage of the finished capacitor. If a 450-volt electrolytic capacitor is to be "formed", this value of D-C voltage is applied with the positive pole of the D-C source connected to the aluminum plate of the capacitor and the negative pole of the source connected to the negative terminal. The chemical action which then takes place is not fully understood, but it results in the oxidation (a chemical union) of the electrolyte in the form of a thin film deposited upon the aluminum plate. This film, as was mentioned earlier, is only a few molecules thick, its exact thickness depending upon the applied voltage and upon the length of time this voltage is applied. Experiment has shown that the breakdown voltage of the "formed" capacitor will be about equal to the voltage applied in "forming" it. Moreover, the polarization of the finished capacitor will be the same as the polarity of the applied voltage.

By the proper selection of applied voltage values, and the time interval of the forming process, electrolytic capacitors can be made with any reasonable degree of capacity and voltage rating. For instance, by adjusting the voltage and time factors in the forming process, capacitors may be made with a capacity of 20 mfd and a voltage rating of 150 volts. This would be referred to as a *20-150 electrolytic.* Or, by adjusting the voltage and time elements, a capacitor could be made with a capacity of 20 mfd and a voltage rating of 450 volts, which would be known as a *20-450 electrolytic.*

While there is no practical limit to the smallest voltage rating of an electrolytic capacitor, the upper limit seldom exceeds 800 volts.

While not a rigid rule, the general statement can be made that the lower the voltage rating of an electrolytic capacitor, the higher its capacity. This general relationship is evident when we consider that while the closeness of the plates adds capacity to the capacitor, it also reduces the voltage rating by virtue of the closeness of the plates.

Examples of this relationship can be seen when one thumbs through the pages of a radio and television parts catalogue, where capacity and voltage rating of the merchandise are specified. We find, for instance, that the 1000 mfd units are rated at 6 volts, the 100 mfd units at 10 volts, the 50 mfd units at 50-150 volts, the 20 mfd units at 150-450 volts, and the 8 and 10 mfd units at 600-800 volts. This is not a complete list, and there are many values of intermediate voltages and capacities. Yet this abbreviated list will indicate the tendency for the higher capacity electrolytic capacitors to conform to the lower voltage breakdown ratings, and for the higher voltage ratings to correspond to lower capacities.

Section 7. THE ELECTROLYTIC CAPACITOR AT WORK

Because of the character of an electrolytic capacitor, its usefulness within its limitations is very great. This usefulness rests upon the ability of the electrolytic capacitor to combine two important characteristics in one unit; high capacity and small size.

The applications of the electrolytic capacitor in electronic circuits may be considered under several different groups:

(1) It will effectively remove the 60- or 120-cycle hum which is usually present in a rectified power supply. Rectified power supplies are used in radio receivers, amplifier systems, inter-com systems, and in television.

(2) It will effectively stabilize the bias voltage in a cathode-biased audio amplifier stage. Such stabilization is responsible for the amplification of the low audio frequencies, representing the bass tones in an audible signal.

(3) It will remove the chatter of a self-rectifying D-C relay system, such as is employed in electronically-operated photo-electric equipment.

(4) It will enable a split-phase electric motor to start its rotation. Such motors are used in some radio circuits for automatic tuning, involving a set of push-buttons.

These applications for the electrolytic capacitor are possible simply because electrolytics -- like all capacitors -- have the fundamental property of opposing a change of voltage. Besides, the electrolytic can pack a lot of capacity in a small space. It is evident that not only must the job of opposing a change of voltage be done, but also that it must be done by an efficient, compact, and economical device. The electrolytic fits all of these requirements to a remarkable degree.

Section 8. THE ELECTROLYTIC CAPACITOR AS A FILTER

Fig. 4 illustrates the fundamental circuit for a standard half-wave rectified power supply, and is representative of hundreds of thousands of such power supplies used in radio and television receivers today. Notice that this system contains no filtering

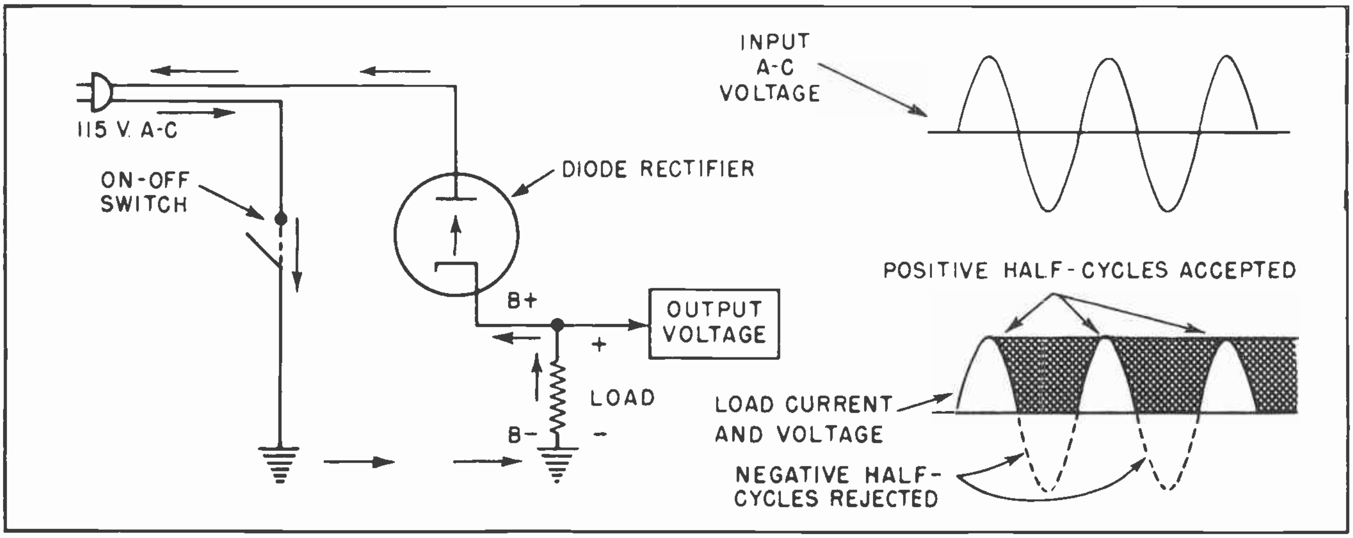

Fig. 4. Half-Wave Rectifier.

circuit, but simply represents the rectifying components involved.

In this illustration, when the plate of the rectifying diode is positive, as it must be on every other half-cycle, current starts flowing at the negative side of the power supply through the on-off switch, into the ground connection, through the receiver chassis to the lower end of the load, up through the load and to the diode cathode and anode, and finally to the positive side of the supply source. This path is indicated by the arrows. The current thus flowing causes a voltage-drop in the load, with the polarity shown.

On the next half cycle, when the diode plate is negative, however, a different condition prevails. Since the diode does not conduct current from plate to cathode, it will block any current from taking this reverse path. The voltage drop across the load now becomes zero, and it will remain at zero so long as the plate is negative with respect to the cathode, which will be until the A-C power source again reverses its polarity.

The results of this rectifying action are evident from the wave-patterns in Fig. 4. While the input voltage from the power source is a smooth-changing *alternating* voltage, the voltage across the load is not only unidirectional, but also is interrupted for the duration of one-half of a cycle during each cycle. We have come to know this type of voltage as *pulsating* D-C. Note the comparatively long interval (shown as cross-hatched) of interrupted voltage across the load.

As is discussed in a previous lesson (The Diode Rectifier), this interrupted, or pulsating form of D-C is seldom suitable for supplying a system of amplifying tubes with their D-C operating voltages, the B-supply. Such interruptions, occurring 60 times each second, will impart to any signal being amplified a 60-cycle hum which may completely mutilate the signal. Looked at from a slightly different point of view, it would be the same as if the amplifying system operated half of the time, with interruptions each 60th of a second.

If we want the amplifying system to operate without interruption all of the time, which is a reasonable requirement, it will be necessary to fill in the gaps between the conducting half-cycles of the rectified output voltage from this rectifier system. This would provide amplifier tubes with a steady D-C potential equivalent in stability to that of a battery, and the signal would be amplified successfully with a negligible trace of hum.

As previously indicated in the lesson on the Diode Rectifier, this stabilizating, or "smoothing" effect is accomplished by a filter system, whose components include the all-important electrolytic capacitor. Fig. 5 is a reproduction of the half-wave rectifier system of Fig. 4, with the addition of the filter circuit, the filtering elements being C-1, the filter choke and C-2.

Here the rectifying action of the circuit is the same as in the previous diagram, with current flowing in the direction indicated by the arrows. The D-C polarity of the

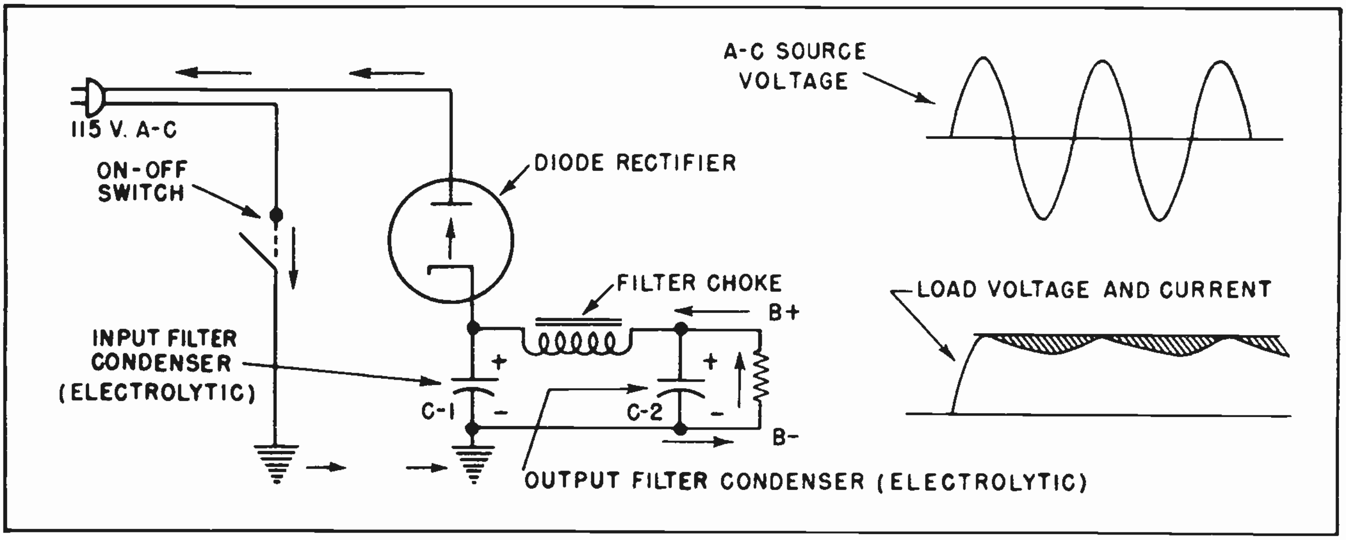

Fig.5. Rectifier with Filter Circuit.

voltage drop across the load is also the same, but, as will soon be evident, this D-C polarity will now be steady, instead of interrupted. Let us study the action of C-2 first.

Section 9. ACTION OF C-2

When current flows through the load, on those half cycles when the diode plate is positive, a voltage drop occurs in the load with the indicated polarity. Note that C-2 is in parallel with the load. Since any two parallel components must always have the same voltage across them, the voltage drop across the load is applied to C-2 as well. If the top of the load is positive, then the top plate of C-2 must also be positive, since they are connected together. The bottom of the load being negative, therefore, makes the lower plate of C-2 negative also, since they are also connected together.

What do "positive" and "negative" mean when applied to a capacitor? If one plate of a capacitor is positive it must be *lacking* in electrons. If the other plate of this capacitor is negative, it must have *too many* electrons. With these conditions in mind, let us now consider the action that must take place during the half-cycle of the power source when the diode plate is driven negative. At this time we know the unidirectional diode will reject the supply voltage, and the current, as well as the voltage drop in the load will tend to drop toward zero.

C-2, which has been charged up on the previous half-cycle, tends to prevent the reduction of load current and voltage during the non-conducting half cycle. If there are too many electrons on its lower plate and too few electrons on its upper plate, and if a discharge path is available, the electrons will move to cancel out this inequality or unbalance. Can C-2 find such a discharge path? You can readily see that such a discharge path is provided by the load. Electrons, in abundance on the lower plate of C-2, will flow *upward* through the load and settle upon the electron-hungry top plate of C-2. Note that they had to move *upward* through the load to get there. This upward motion through the load causes a voltage drop to occur in the load in the same polarity as was caused by diode current through the load on the previous half-cycle.

It is noteworthy that while the supply source is causing the voltage-drop in the load, C-2 is in parallel with the load. However, on the next half-cycle, when the source is effectively inoperative, the charge on C-2 is permitted to act through the load, and on this half-cycle, C-2 is in *series* with the load. In other words, C-2 acts like a battery being *charged* on one half-cycle, and like a battery being *discharged* on the next half-cycle.

The very desirable consequence of C-2 in this circuit, therefore, is to hold the voltage across the load constant, filling in the gaps between conducting half-cycles of the diode rectifier.

In order to accomplish this purpose, C-2 must be made with three requisites in mind. It must have enough capacity to enable it to accept the full voltage developed across the load. It must have the dielectric strength to withstand this voltage without puncturing. And, it must be small enough to conveniently fit into the radio or television receiver of which it becomes a part. The electrolytic capacitor meets these requirements.

For a half-wave rectifier system, C-2 should be at least 20 mfd and should be rated at 150 D-C volts. Because of its location in the filtering circuit, and not due to any peculiarity of the capacitor itself, C-2 is referred to as the *output filter capacitor*.

The *input filter capacitor*, C-1 of Fig. 5, may be an exact electrical and physical duplicate of C-2. Its action, though similar to that of C-2, has an additional feature, presently to be discussed. Let us now examine Fig. 6. As can be seen, this diagram is electrically the same as that of the previous illustration, but the components are laid out in a somewhat different arrangement which makes it a little easier to understand.

Section 10. ACTION OF C-1

While C-2 is performing its job of opposing the *change* of voltage across the load, C-1 is busily at work on a similar task. We may see from the diagram of Fig. 6 that C-1 parallels the remainder of the circuit that includes the filter choke in series with the load, which in turn, is paralleled by C-2.

The cathode of the rectifier is the point of origin for the desired steady D-C potential known as the B-supply. It feeds the

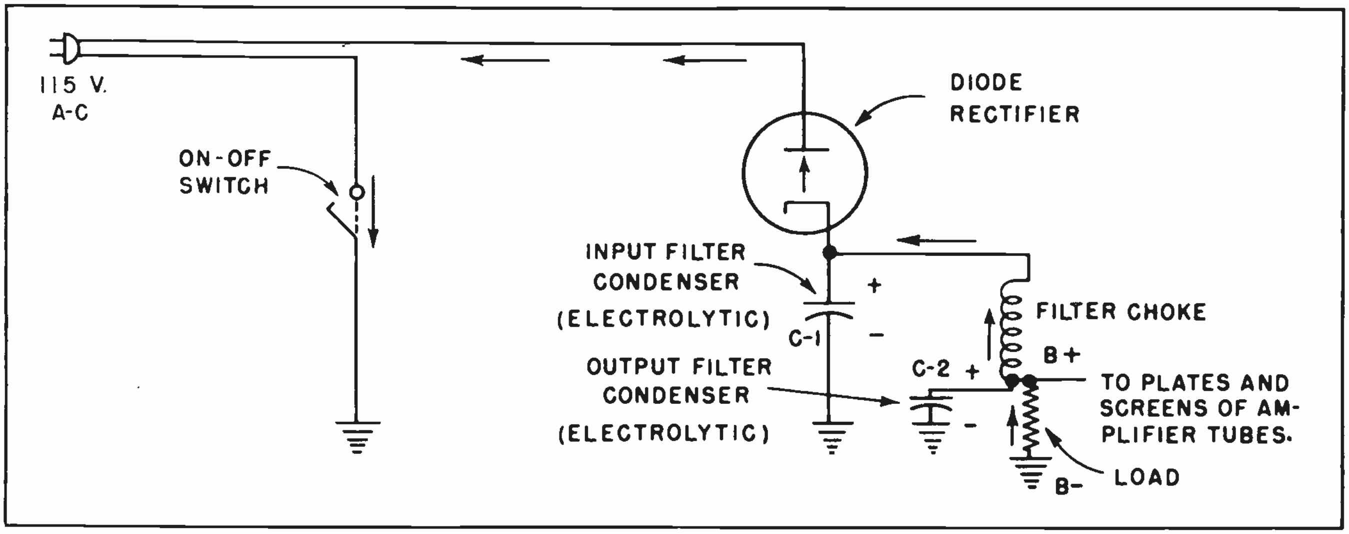

Fig.6.

amplifier tubes with their D-C operating voltages. The cathode, as part of a unidirectional diode tube, will tend to alter its voltage in accordance with the supply source. This places a 60-cycle component upon the cathode, and this hum-generating component, like that in the load itself, must be opposed for successful operation of the receiver in which the filter system is installed.

C-1, like C-2, is an electrolytic capacitor. As such it contains a high capacity within a small space. Being a capacitor gives it the ability to oppose this change of voltage upon the cathode, and being electrolytic enables such opposition to be extremely effective.

Insofar as C-1 is concerned, it will oppose any changes of voltage across any circuit with which it is in parallel. What circuit is in parallel with C-1? As mentioned previously, C-1 is paralleled by the filter choke and the load, which are in series with each other. C-1 will therefore oppose any voltage changes (which tend to occur 60 times per second in accordance with the power source) across the series combination of both the filter choke and the load. The load, being a part of this series circuit, enjoys the additional stabilizing effect of C-1, together with that provided by C-2. Thus the load voltage is further smoothed out, or filtered, by C-1.

Charging the input filter capacitor, C-1, on the conducting half-cycle of the diode is brought about when current from the negative side of the supply line flows through the switch to chassis, up through the load and the filter choke in series, across the diode, and finally to the positive side of the line. Since the input filter capacitor bridges both the load and the choke, any voltage drop across these series components will be applied to the input filter, and the charge is placed upon its plates in the polarity illustrated. The discharge path of this capacitor, on the non-conducting half-cycle of the diode, is from the negatively charged lower plate down to the chassis, through the chassis to the load, *up* through the load and the filter choke, and finally to the electron-hungry positive top plate of C-1. Note that here, as in the case of the output capacitor, in order to make the trip, electrons must move upward through the load. This is the same direction which diode current takes on the conducting half-cycle. The voltage drop across the load, instead of being pulsating, will now have the voltage gaps between the pulses filled in.

Section 11. CURRENT THROUGH THE LOAD

To increase your understanding of the fundamental principle involved in attaining a smooth D-C rectified output by the use of electrolytic capacitors, let us repeat with emphasis a very apt phrase from an earlier lesson on "The Diode Rectifier".

"The load doesn't know nor care whether the electrons which are flowing through it at any particular instant are directly from the power line or are from the discharging capacitor, just so they are all flowing in the same direction." This statement, if the charging and discharging paths of a capacitor are clearly traced, tells the story in a nut-shell.

The input filter capacitor has still another function, in addition to smoothing out the 60-cycle hum component. This function is to build up the D-C voltage to a high value and to keep it high. If the input filter, C-1, is omitted in Fig. 6, the value of the rectified pulsating D-C voltage will be *half* of the average A-C line voltage. This reduced value of voltage will be measurable at the cathode of the diode, with respect to ground. The presence of a high-capacity electrolytic capacitor between the cathode and ground, however, will maintain a voltage across these points at about the *peak* A-C line voltage. Since half of the average A-C line voltage (nominally at 115 volts) is only a value of about 50 D-C volts, it is evident that this voltage would not be suitable for a set of amplifier tubes built to operate at 100 volts. Peak A-C line voltage, on the other hand, will provide a D-C rectified and well-filtered output of well over 135 volts at the rectifier cathode, more than sufficient to be suitable for the amplifier plates and screens. (Remember that the *peak* voltage is 1.414 times the effective voltage.)

Just how this peak value is obtained may be seen by considering the circuit of Fig. 7. This is an equivalent circuit to that of Fig. 6 with this exception (for the sake of simplicity): We have substituted a single resistor to represent the sum of all components in the load.

On the conducting half-cycle of the diode in the figure, current passes through the load and causes a voltage drop across it which, except for the negligible drop in the diode, is equal at any instant to the applied line voltage. What values does the line voltage assume? We may go back to our A-C fundamentals and recall that the peak voltage of A-C is the effective value multiplied by 1.41 or 162.15 volts. At the instant this peak, or maximum is reached, a drop across the load takes place at very nearly this value. Since the load drop is immediately applied across the capacitor, the capacitor must also assume this *peak* voltage. Once obtained, this voltage will remain on the capacitor until it is leaked off either through imperfections in its own construction or through the load. The former possibility is so small as to be of no importance in this connection.

The load, however, is an intentional leakage path for the electrons from the lower plate of this capacitor. If we can make either the load resistance high or the capacitor capacity high, the leakage will be slow. We cannot readily make the load resistance too high since that would alter the load's operating character. Besides the "load" may consist of the tube system, whose internal resistances are unchangeable by ordinary means. The only alternative left is to select a capacitor of a very high capacity. Thanks to electrolytic capacitors, this is possible. These capacitors can pack a lot of capacity into a small space.

It is evident that if the leakage of capacitor electrons is very slow, the capacitor will maintain much of its *peak* charge until the next charging cycle, 1/60 of a second later. We see that in order to attain, and hold, a high D-C charge, the capacitor must be made with the necessary capacity to *keep from discharging* between

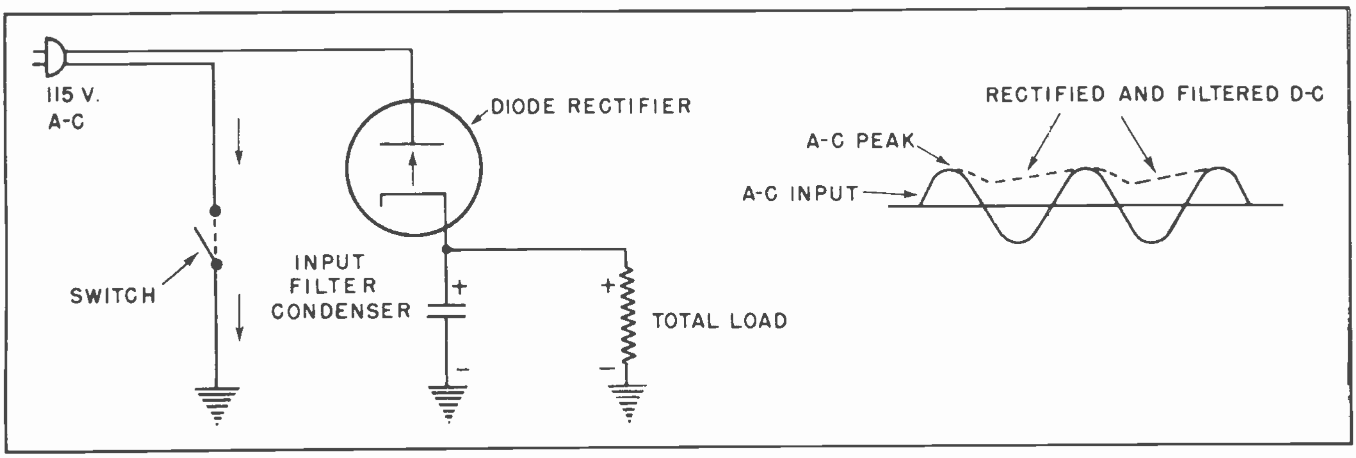

Fig. 7.

conducting cycles of the rectifier. Normally the input filter capacity is rated at around 40 to 50 mfds.

Section 12. THE ELECTROLYTIC AS A CATHODE BY-PASS

High-capacity, and low voltage, electrolytic capacitors are employed to excellent advantage in the cathode circuits of audio amplifiers, a diagram of which is shown in Fig. 8. This is a simplified diagram to illustrate the usefulness of electrolytic capacitors in stabilizing the bias (where cathode bias is used) in an audio amplifier. The diagram represents the two final stages in a radio receiver, which handles audio frequencies only.

Previous lessons on amplifier tubes have explained the meaning of tube bias, and indicated that biasing a stage of an amplifier or a radio receiver is of the utmost importance.

Among the means of obtaining bias in a tube, the cathode resistor and condenser is very common. According to the tube-manufacturer's data, there should be a specific D-C difference of potential between the control grid and the cathode. Now it makes no difference what these two potentials are, so long as the proper *difference* between them is maintained. If the tube manufacturer specifies a bias of negative 8 volts on the grid of the tube with respect to the cathode, we may either make the grid negative 8 volts, or make the cathode positive 8 volts with respect to the grid. This latter method is the simplest and the most economical. It is done in the following manner:

Since tube current must flow from ground to the cathode on its way to the plate of the tube, it is led through a resistor of the proper value to *create a voltage drop* equal to the specified bias of the grid. Reference to Fig. 8 indicates that since this tube current must take an upward path across the cathode resistor, the resulting voltage drop will be as indicated; that is, positive at the cathode with respect to ground. The grid, however, is tied to ground through its grid resistor. Since this grid resistor passes only a minute amount of current, the voltage drop across it is negligible in most cases. This keeps the grid practically at ground potential.

But the cathode is more positive than ground, and therefore more positive also than the grid. This is exactly what the tube manufacturer specified. The actual number of volts by which the cathode is more positive than the grid is easily determined: Choose the ohmic value of the cathode resistor to provide the specified drop when the known tube current is flowing. This is in accordance with Ohm's Law.

The action of the electrolytic by-pass capacitor which parallels the cathode resistor is of great consequence when we are considering the low, or bass, audio notes in a signal. We recall that bias must be a *D-C* potential difference between control grid and cathode. If the by-pass capacitor were absent, the bias would pulsate in unison with tube current, which in turn corresponds to the signal changes. This is not the bias we need. We must do something to keep the bias from pulsating, otherwise the signal strength will be weakened by a process known as *degeneration*.

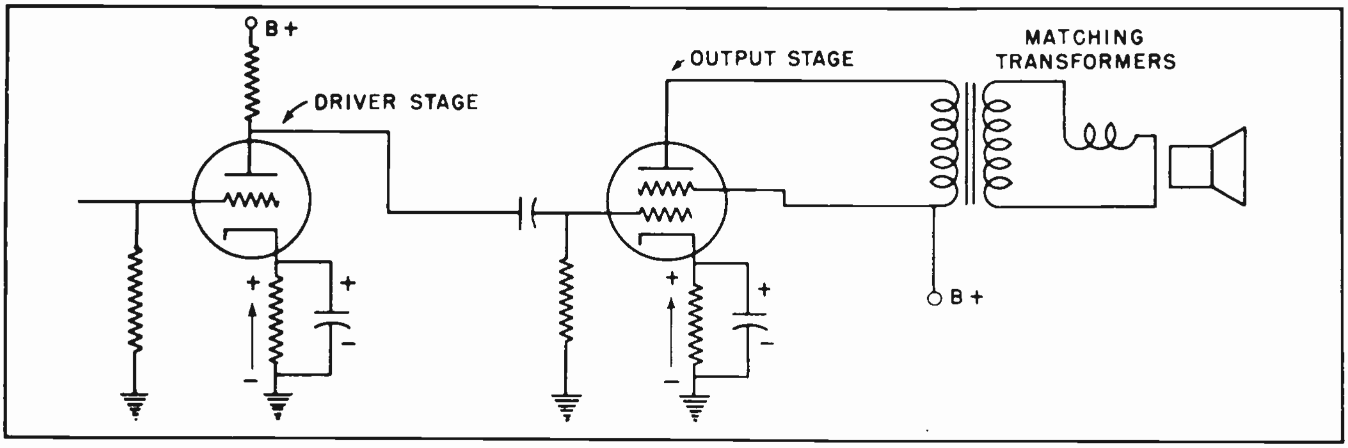

Fig.8. Electrolytic in a Cathode Circuit.

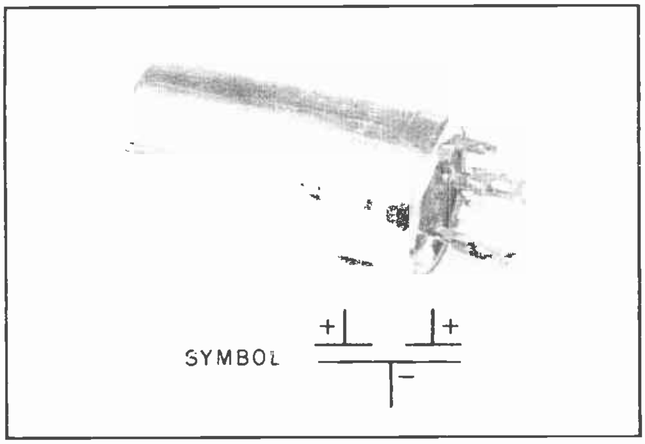

Fig.9. 2-Section Electrolytic.

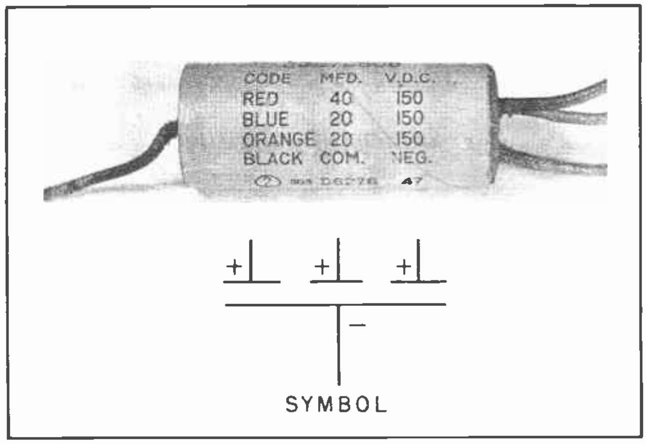

Fig.10. 3-Section Electrolytic.

We know that a rising grid signal voltage causes more tube current to flow. This causes a greater drop in the cathode resistor, and raises the cathode voltage. Likewise, a decreasing grid signal voltage causes less tube current to flow; this causes a decreased drop in the cathode resistor, and lowers the cathode voltage. The result is that the signal voltage on the grid is being cancelled out to a great extent, because every time it changes, the cathode voltage tends to change with it. But the amplification of the stage depends upon a distinct difference of potential (at signal frequency) between the grid and the cathode. If these differences fail to occur to the desired extent, the signal itself is made ineffective.

This is where the electrolytic by-pass capacitor steps into the picture. We see that to avoid the process of degeneration we must do something to oppose the voltage *changes* at the cathode of the stage. The electrolytic capacitor is made to order for the job. If we place it across the resistor, in the correct polarity of course, it will oppose any change of voltage between the cathode and ground provided it contains enough capacity to hold the cathode voltage at a high value between audio pulses.

Audio frequencies may be very low, often below 25 cycles per second. It will obviously take a high capacity capacitor to hold the cathode voltage high between these comparatively slow-changing pulses. If the electrolytic can hold the cathode voltage during 25 cycle audio pulses successfully, it will do so with even greater effectiveness for the entire range of audio frequencies above 25 cycles per second. Generally, in the higher quality receivers, these electrolytic by-passes are of 8 or 10 mfd. In the smaller models, however, much greater depth of tone is achieved by values above 25 mfd. The breakdown voltage of these capacitors need not exceed the tube bias by over ten per cent. Tube bias seldom exceeds 10 or 12 volts, thus the cathode capacitors usually are rated at 25 volts approximately.

Section 13. **MULTIPLE SECTION ELECTROLYTICS**

Since in most of the applications of electrolytic capacitors more than one such unit is employed, manufacturers have provided multiple-section electrolytics. A dual section electrolytic is illustrated in Fig. 9. This would be suitable for use in a radio receiver, each of the two sections being used in the filter system.

Fig. 10 illustrates a triple-section electrolytic unit. Here we have the input and output capacitors, as well as the cathode by-pass capacitor for the output stage -- all in the same package.

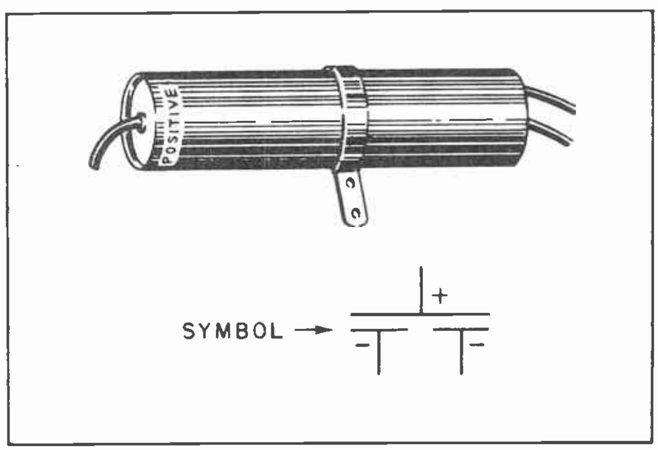

Fig.11. Common Positive Electrolytic.

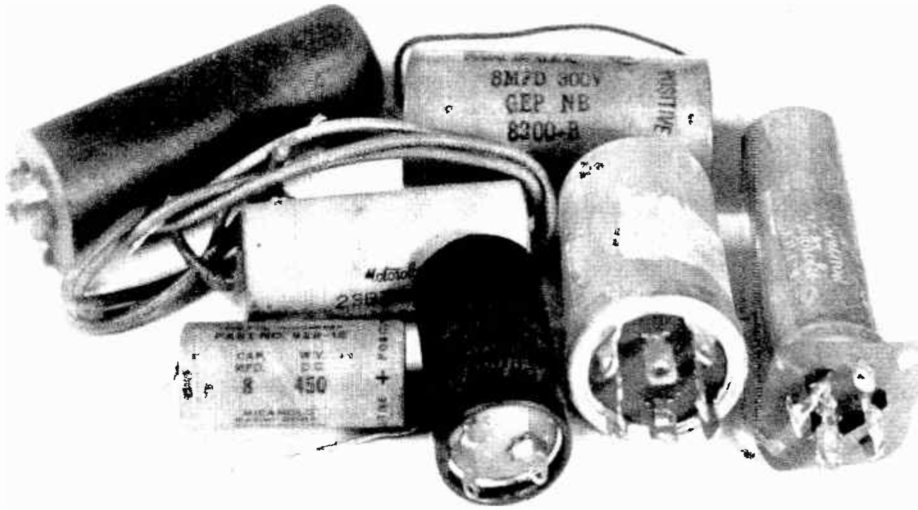

Fig.12. Various Types of Electrolytics.

Fig. 11 illustrates the so-called "common positive" electrolytic capacitor unit. It consists of two separate capacitors with their positive sides tied together. This type is unconventional in most circuits, but it will nevertheless, be found from time to time.

Electrolytics are made in various models and sizes. They may be "wet" or "dry", large or small, single or multiple. They may be square or cylindrical, or they may be metal - or paper - enclosed. Fig. 12 pictures some of the most popular types.

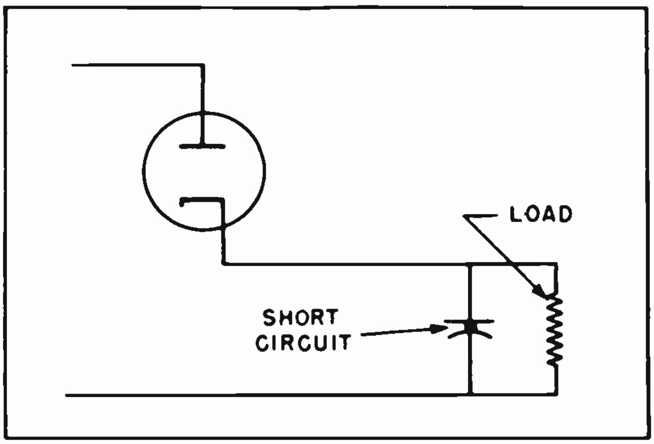

Fig.13.

Section 14. POWER FACTOR IN ELECTROLYTICS

The action of a capacitor in accepting a charge is attributed to the distortion in the molecules of the dielectric. In a dielectric where the electrostatic field is continuously changing, such repeated distortion must result in molecular friction and becomes evident as *heat*. Thus some power is lost in the capacitor due to *dielectric hysteresis*.

Since the dielectric in a capacitor can never be a *perfect* non-conductor, it will pass a minute amount of D-C current when a voltage is applied. This leakage current, too, represents a loss of power from the system.

Both the dielectric loss and the leakage loss account for a small, but noticeable, difference between the power applied to an electrolytic capacitor and that delivered by it; that is, it accounts for a decrease in *efficiency* of the capacitor. The efficiency of any capacitor may be conveniently expressed as its *Power Factor*. It means that if a capacitor has a power factor of 3%, there is a loss within the capacitor of 3% of the applied power.

We must conclude, then, that the lower the power factor, the more efficient the capacitor. If the power factor rises too high, the efficiency becomes low and the capacitor heats up.

(It should be pointed out here that the power factor of the ordinary electrical A-C circuit is mathematical relationship between current and voltage such that the opposite condition is true -- that is , if the power factor is low , the efficiency in the line is also low.)

Power factor of an electrolytic capacitor can be readily measured by the use of an instrument called the *Capacity Analyzer*, which will also measure its capacity. The power factor of an electrolytic capacitor can also be computed from known voltage and current readings throughout the circuit involved.

Section 15. DEFECTIVE ELECTROLYTICS

After Electrolytic Capacitors have been in use for some time, usually several years, they have a tendency to dry out. Sometimes this results in the film on the aluminum becoming even thinner than normal. Sometimes the film disappears.

When the film deteriorates there will frequently be a breakdown under the pressure of the voltage. Instead of the film holding back the electrons they are able to break through. When this happens, the electrolytic will no longer act as a capacitor; instead it will act as a short circuit. (See Fig. 13.)

Usually when this happens the rectifier tube will be affected. A short-circuited

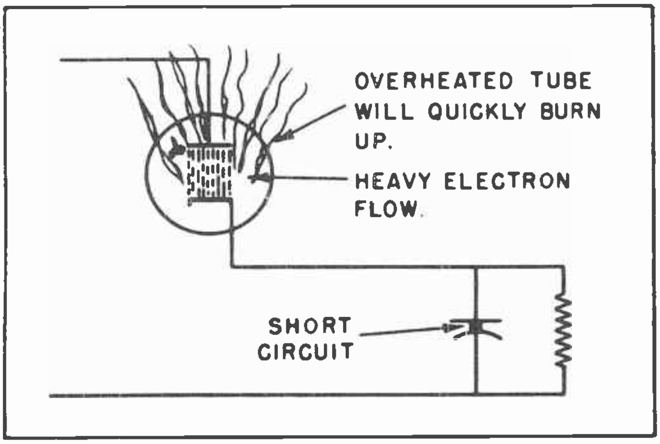

Fig.14.

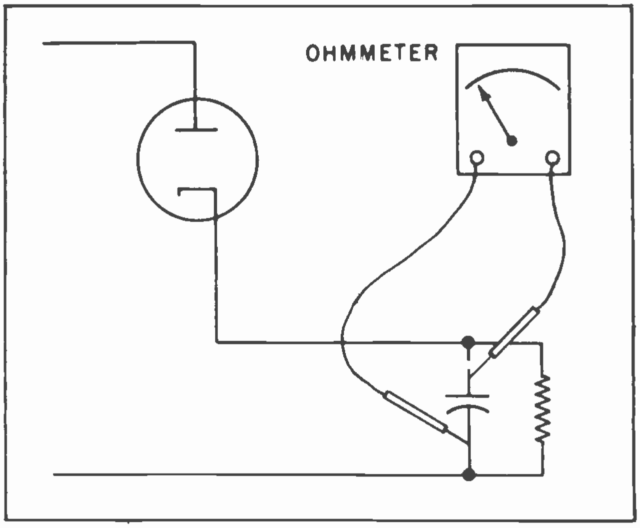

Fig.15. Using Ohmmeter to Check an Electrolytic.

electrolytic capacitor will effectively short circuit the load. Instead of the high resistance of a load there will be only the very low resistance of the short-circuited electrolytic. This will allow a large electron current to flow through the diode rectifier tube.

An unusually heavy current through the tube will overload the anode. The large numbers of electrons will bombard the anode so heavily it will probably become red-hot. A very few minutes of overload will probably overload the tube and burn it out. (See Fig. 14.)

Section 16. TESTING FOR DEFECTIVE ELECTROLYTIC

Whenever an electronic device becomes inoperative and tests show the rectifier tube to be burned out it is always wise to check the electrolytic capacitor before replacing the tube. Should the electrolytic be short circuited, and another tube be inserted, the chances are very good the new tube will also burn out quite quickly -- probably within a few minutes.

The electrolytic can be readily checked by using an ohmmeter. The test prods of the ohmmeter are connected as shown in Fig. 15, with the power turned off. If the ohmmeter shows a high resistance, the capacitor is probably in good condition. But if the resistance is low, that is, only a few ohms, the electrolytic is no good and should be replaced.

In servicing any radio, television or other electronic device the usual procedure is to first check the condition of the vacuum tubes. The second thing is to check the condition of the electrolytic capacitor. These two things account for more trouble than all the other components put together.

NOTES FOR REFERENCE

Electrolytic capacitors pack a lot of capacity within a small space.

They must be polarized properly, and voltage ratings observed.

Their chief use is in rectifier power supplies, where they smooth out the unwanted hum of rectified power.

They are also used extensively in the cathode circuits of audio amplifiers, for the purpose of improving the tone response of a signal.

Capacitance is the ability to oppose a change of voltage.

Capacity is the measure of how many coulombs of electrons a certain capacitor can hold on its plates.

Dielectric strength determines the voltage breakdown point of a capacitor. Its voltage rating should be precisely observed.

D-C working voltage (abbreviated "DCW" on some electrolytic capacitors) is the steady D-C potential which it will withstand for prolonged periods of time.

Peak working voltage (abbreviated "PWV" on some electrolytic capacitors) is the *maximum* voltage the capacitor will withstand, even for an instant. An electrolytic capacitor should be installed only after careful consideration and computation of the peak voltages possible in the circuit involved.

IMPORTANT WARNING: Serious damage to equipment and harm to personnel can be the result of incorrect installation of an electrolytic capacitor. Be careful!

DO NOT USE ON PURE A-C.

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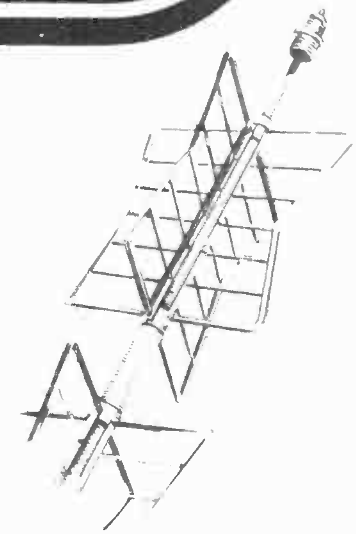

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Contents: Introduction - Voltage in a Capacitor - A Gaseous Discharge Tube - Time Constant - Tapping Off the Generated Voltage - Thyratron Oscillator - The Multivibrator - Action of the Multivibrator - Tube and Socket Identification - Notes for Reference.

Section 1. INTRODUCTION

In our studies of electron tubes and their various applications in radio and television work, we have learned of many unusual things these tubes are capable of doing. We have learned that in one application they can take an almost unbelievably small voltage which has been created by a passing electromagnetic wave and build it up to much greater values. We have learned how another type of electron tube can drive a loudspeaker or operate a relay. Even more astonishing, in a way, is the cathode ray tube which is capable of converting a stream of electrical impulses into a visual picture.

In our study of the cathode ray tube we need knowledge of sawtooth wave forms, and sawtooth oscillators. It is our purpose now to explain to you some of the uses of a sawtooth wave form and, equally important, how such a peculiar wave form is generated.

In most of our previous studies our discussions have revolved around *sine* waves.

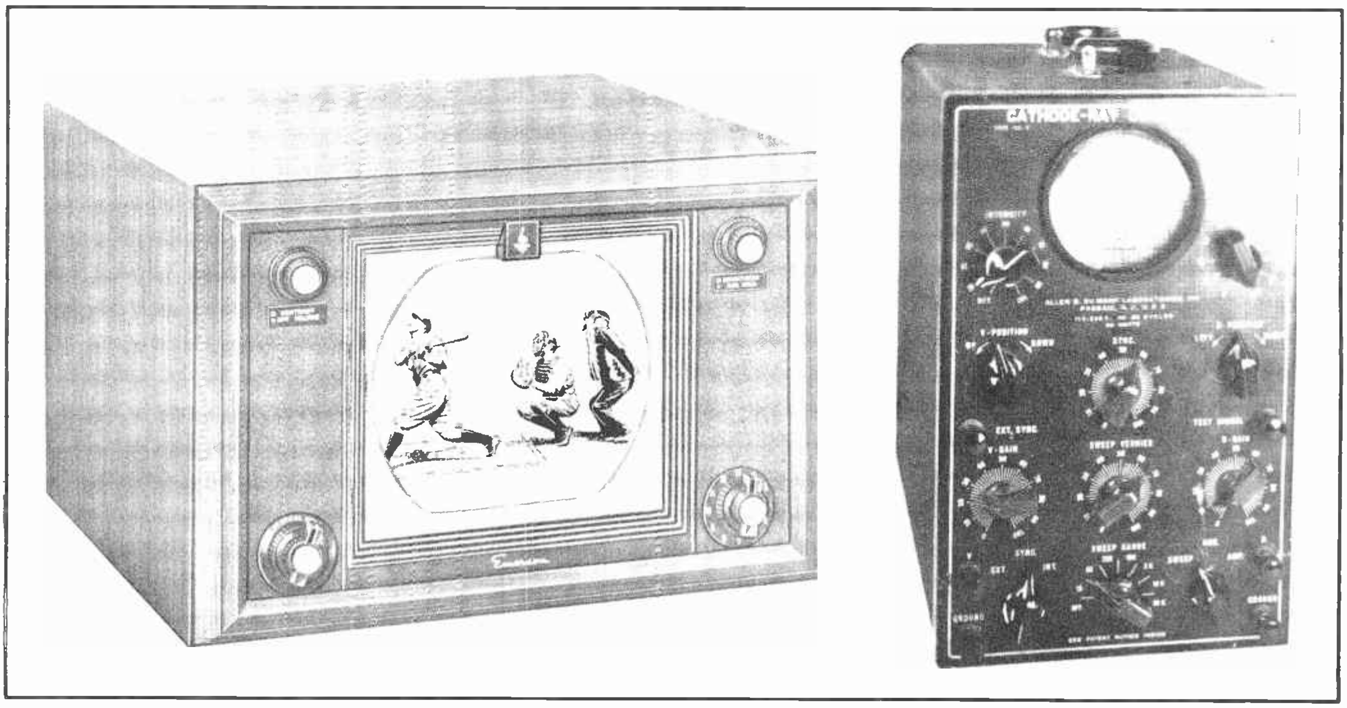

Fig. 1. Sawtooth Oscillators are Used in Television and in Oscilloscopes.

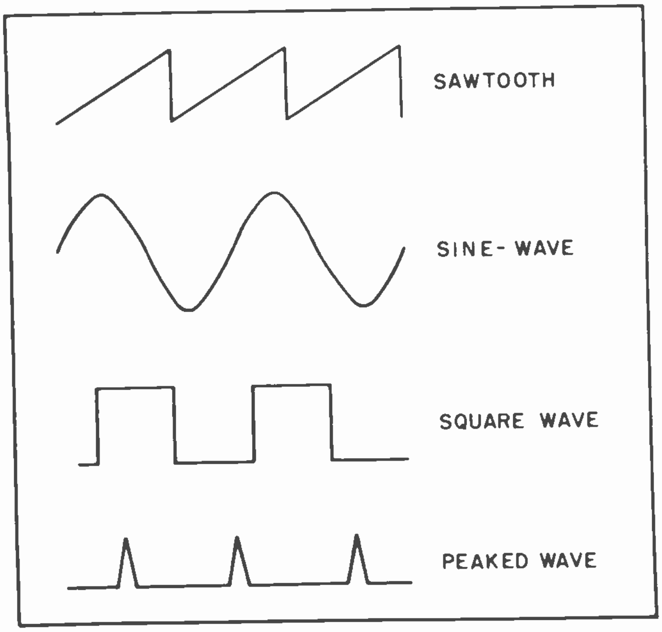

Fig.2. Various Types of Voltage Wave Forms.

The reason for this is that alternating currents and voltages in their normal state assume a wave form which closely follows the curve which is drawn in graphing a trigonometric sine. But there are a number of applications where the natural sine wave is not adequate for our purposes. In those cases it becomes necessary for us to create a special wave form which will meet our needs. (See Fig. 2.)

One or more of these special wave forms is needed in most of the applications of a cathode ray tube where it is used for some specific purpose. Most frequently the special wave form needed in cathode ray tube work is the sawtooth wave form.

The generation of a sawtooth wave form can be brought about in several ways. All of these ways involve the use of some kind of electronic oscillator. In general, the type of oscillator used to generate sawtooth wave forms is called a *relaxation* oscillator. The reason it is so-called is because the act of generating the special wave form involves the charging of a capacitor at a relatively slow rate, then causing the voltage to suddenly collapse -- or "relax".

There are several types of relaxation oscillators. One is called the multivibrator. The multivibrator is very widely used in television and radar receivers to control the sweep circuits. Another type of relaxation involves the use of some kind of *gaseous* electron tube. Usually these oscillators are simply called sawtooth oscillators. Since the multivibrator can also generate sawtooth wave forms it is hardly accurate to reserve the name "sawtooth oscillator" for those types which employ the gaseous tubes; yet it has become customary to so designate them. It is hardly fitting that we try to change this situation.

The generation of a sawtooth wave form involves the peculiar abilities of several pieces of electrical and electronic equipment. One of the most important items is a capacitor. The exact shape, and frequency, of the generated wave depends very largely upon the capacitor. Yet another important component of a sawtooth oscillator is the resistor which is used in the timing portion of the circuit. By no means the least important is the tube itself. Each of these things will be dealt with in our studies.

Section 2. VOLTAGE IN A CAPACITOR

Before going any further it might be well for us to pause and consider the way voltage builds up in a capacitor. (See Fig. 3.) In a previous lesson we have mentioned the fact that when there is no charge on a capacitor a small voltage will cause a rush of electrons into the capacitor. The rush of electrons tends to charge up the capacitor with an *opposing* voltage which then has a tendency to retard the electrons flow into the capacitor. All this can be said in another way. The inrush of electrons into the capacitor sets up a voltage between the

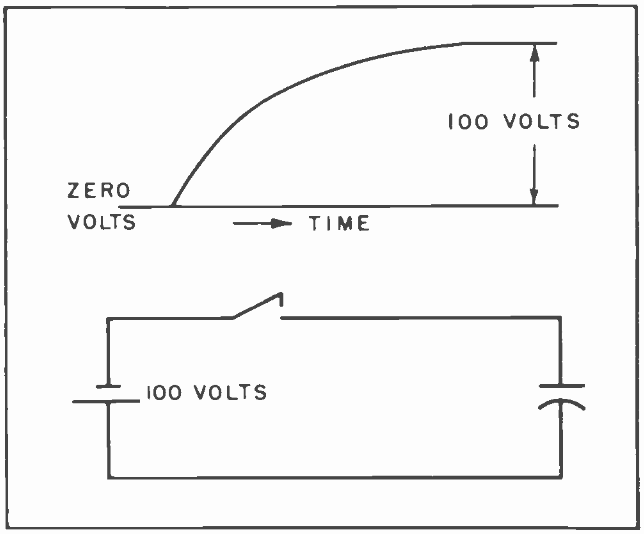

Fig.3. When a Voltage is Applied to a Capacitor it Does Not Charge up to the Peak Value Instantly.

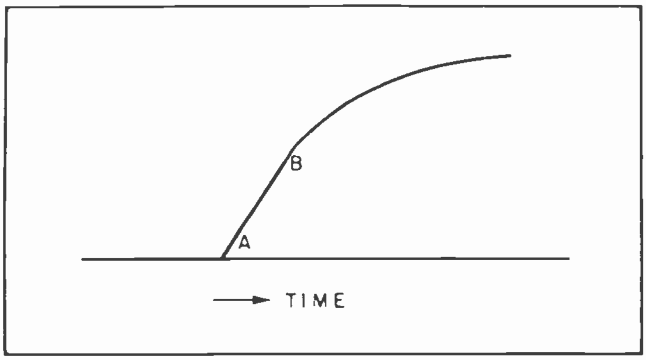

Fig.4. Curve Showing How Voltage Increases in a Capacitor.

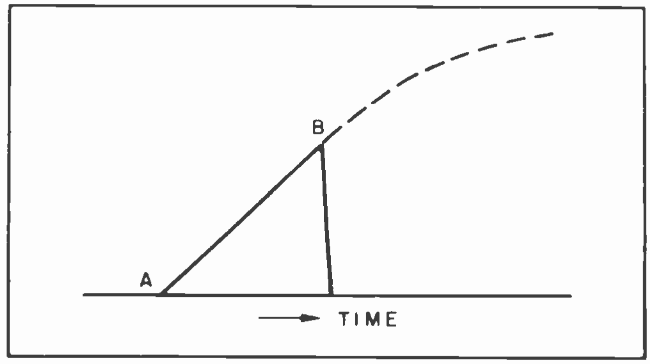

Fig.5. How a Capacitor Can be Discharged Before Becoming Fully Charged.

plates of the capacitor. As the first rush of electrons enter the capacitor the voltage within the capacitor will rise quite sharply. This rise will at first be in almost a straight line, as from *A* to *B* in Fig. 4, then gradually curve until it reaches the maximum value. When the maximum voltage across the capacitor has been reached the voltage curve will be horizontal; that is, in parallel with the base line -- the "zero volts" line of Fig. 3.

In working with sawtooth oscillators we are not particularly concerned with the curved portion of the capacitor voltage graph. But we are very much interested in the *linear* portion, that portion of the curve between *A* and *B* in Fig. 4.

If we had some method of discharging the capacitor at the instant the voltage reached point *B* of the curve in Fig. 4 we would have a voltage graph very much like that of Fig. 5. It will be noted that the capacitor has discharged much more rapidly than it charged up. This is all to the good.

If, after the capacitor has been discharged, it is then allowed to immediately charge up again we will have a graph like that in Fig. 6. The dotted lines show how the voltage *would have risen* had the capacitor not been discharged. After the capacitor has started to charge up a second time it is again discharged at the instant it reaches point *C*.

Section 3. **A GASEOUS DISCHARGE TUBE**

There are several types of tubes which will permit a capacitor to discharge instantly. For the moment we will confine our studies to a neon discharge tube such as the one shown in the diagram of Fig. 7. The little dot shown inside the tube is placed there for the purpose of showing that it is a *gaseous* tube. All electron tubes which contain gas use that dot in their symbols to distinguish them from those tubes which contain a complete vacuum.

It will be noted that the tube in Fig. 7 does not have any filaments. Thus there is no heated cathode in this type tube. For this reason a tube of this kind is frequently referred to as a *cold cathode* tube.

It is not our purpose to go into a lengthy discussion of gaseous tubes at this time. A complete coverage of gaseous electron tubes could fill a big book. A complete knowledge of the operation of gaseous tubes is not necessary to understand how they can be used to generate sawtooth wave forms.

Among other things, a gaseous tube has the ability to withstand a voltage between the two elements within the tube of a considerable number of volts without bringing about a voltage "breakdown". The exact number of volts which can be withstood without a "breakdown" depends upon several things. Among them is the amount of gas within the tube; the kind of gas (whether neon, argon, helium, or some other kind);

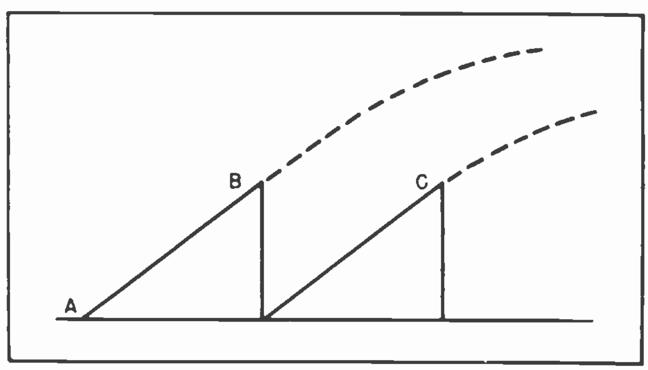

Fig.6.

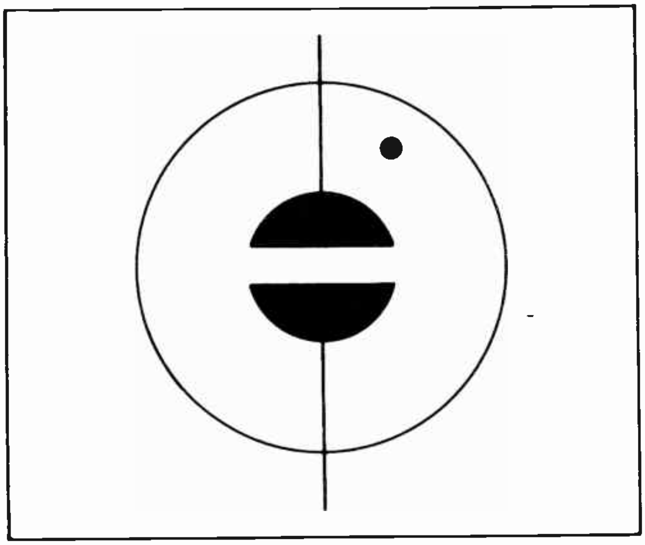

Fig.7. Neon Tube.

and the distance between the elements. These tubes are so constructed that they will "break down" under the strain of a certain number of volts. Some will break down under a strain of 75 volts; some will break down at 90 volts, some at 105 volts and some at other voltages up to about 150 volts. The tubes can be purchased with these specific voltage breakdown values.

Now these tubes have another very peculiar property. When the voltage between the elements within the tube becomes so high that it breaks down the resistance between them, and arcs across the space between them, it causes the gas within the tube to "ionize". Here again it will serve no good purpose to go into a lengthy explanation of *ionization*. Suffice it to say that when a gas (any gas) within a tube ionizes it creates a *good* conducting path for electrons,

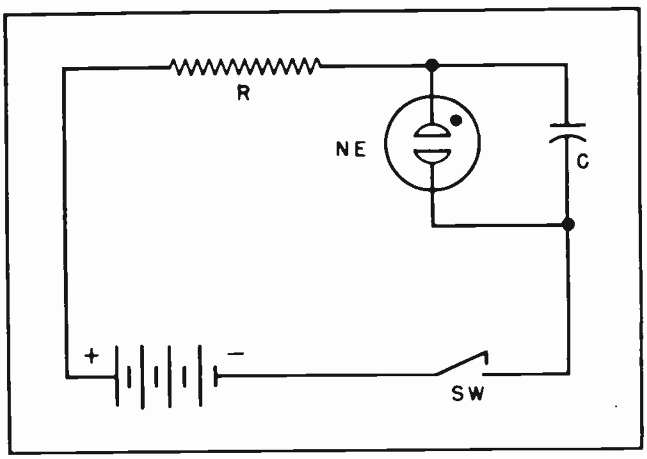

Fig.8. Sawtooth Oscillator Using a Neon Tube.

and the resistance falls instantly to a negligible value.

Now let's see what we have. We have a device which will withstand a voltage as the voltage increases from zero up to some predetermined value. Below this voltage limit there is a very high resistance across the tube. But once the voltage across the tube exceeds a certain critical value the resistance of the tube breaks down and instantly drops to a very small value.

Here we have a very interesting combination. A capacitor which will charge up at an even rate to a certain value. A tube which is an open circuit at those voltages. Finally, when the capacitor reaches a voltage value where its graph is about to start curving the tube breaks down, or "fires", and the capacitor is instantly discharged.

Now our task is to place one of these tubes and a capacitor in a circuit and see

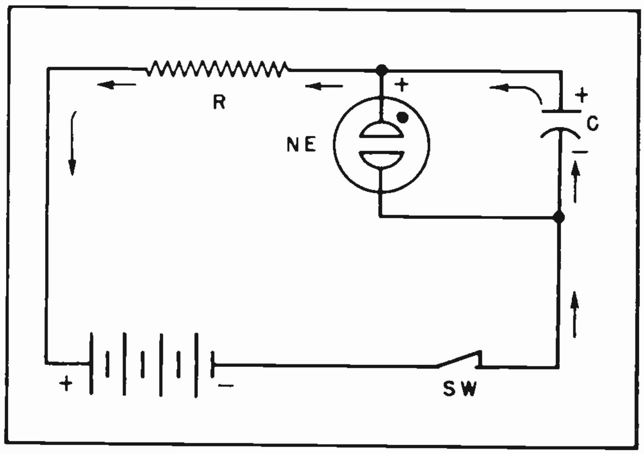

Fig.9.

what takes place. In Fig. 8 we have included the essential elements of such a circuit. We have a battery for a power supply, a resistor, a capacitor, a neon tube and a switch for opening and closing the circuit.

Suppose we now close the switch and see what happens. The battery will cause electrons to flow in the direction of the arrows in Fig. 9. The resistor will retard the flow of electrons which will slow down the job of charging up the capacitor. When the switch is first closed most of the voltage drop will be across the resistor. But as more and more of the electrons, forced from the upper plate of the capacitor, are able to leak across the resistor the

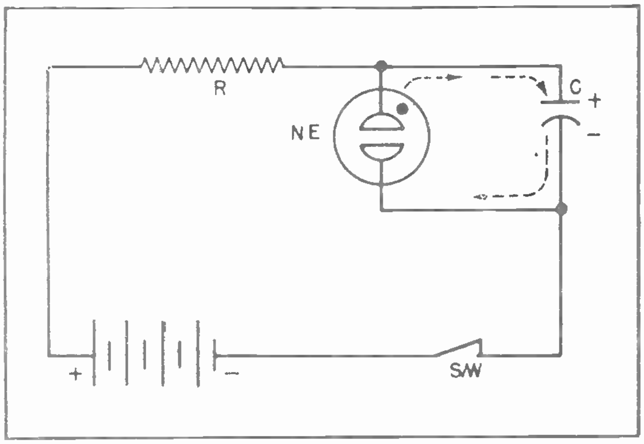

Fig.10. Capacitor Discharging Through Neon Tube.

voltage drop across the resistor will become less. Moreover, as more electrons are able to get away from the upper plate of the capacitor the voltage across the capacitor will increase.

The main point is that as time passes there will be less voltage drop across the resistor and more voltage drop across the capacitor.

Now let's note another thing. The neon tube is connected in parallel with the capacitor. As the voltage across the capacitor increases the voltage across the neon tube will also increase.

When the voltage across the neon tube reaches its critical breakdown value the tube will "fire". When that occurs the tube will act like a short circuit across the capacitor; the capacitor will discharge through the tube as indicated by the dotted arrows of Fig. 10. The voltage across the capacitor will drop to zero -- or almost to zero. Actually the action of the neon tubes is such that when the voltage across them drops to a value of about 12 to 15 volts they will cease conducting. When this occurs they again act like a high resistance.

Since the capacitor has now discharged it means the voltage across the capacitor has dropped to zero, or nearly zero. At this instant the entire voltage of the battery will again be across the resistor. The next action is for the electrons which have now reached the upper plate of the capacitor to start leaking off across the resistor. This they begin doing. Once again the entire action is a repetition of that shown in Fig. 9. The electrons leak off the capacitor across the resistor; the capacitor charges up again. Finally the tube fires and the capacitor discharges again.

Section 4. **TIME CONSTANT**

The length of time it takes the capacitor to charge up is governed by two things: The value of the resistance and the capacity of the capacitor. If the capacitor is large it will take more electrons to charge it up. This means it will take longer for it to charge up. Likewise, the larger the value of the resistor the slower the electrons can leak across it, which also means the longer it will take the capacitor to charge up. This means that the larger we make either the capacitor or the resistor the longer it will take the capacitor to charge up. There is a rule which is quite handy in figuring the time constant of such a resistor-capacitor combination. Since it is seldom necessary, or even desirable to know how long it takes to *completely* charge a capacitor, the rule is used to determine how long it will take to charge a capacitor to 63% of its peak voltage. This is shown in Fig. 11. The rule says that it will take one second to charge a capacitor having 1 MFD of capacity through a resistor of 1 megohm of resistance. Thus, if you have a 1 MFD capacitor and 1 megohm resistor you can charge the capacitor to 63% of its peak value in exactly one second.

With these values to go on you can figure out for yourself any time constant you might want or need. If you wanted to charge the capacitor in 1/2 second you could use a 0.5 megohm resistor with 1 MFD capacitor. Or you could use 0.5 MFD capacity with 1 megohm resistance.

If you wanted a time constant of 1/10th second you could use 100,000 ohms with 1 MFD.

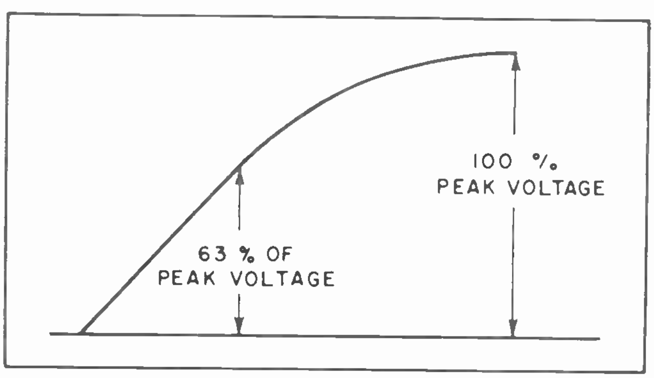

Fig.11. Comparison of Peak Capacitor Voltage with 63% of Peak.

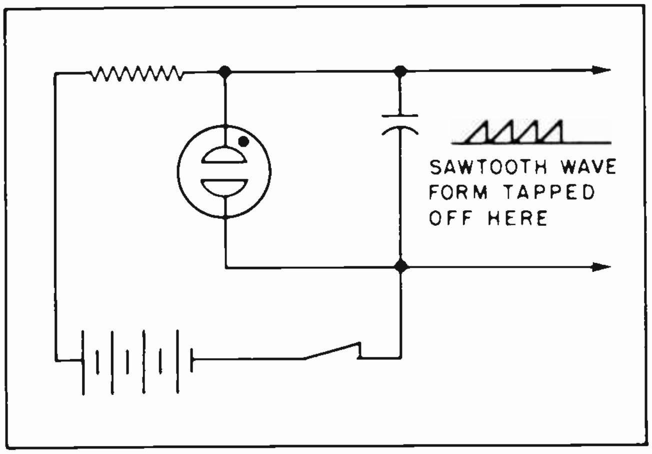

Fig.12.

Or you could use 0.1 MFD with 1 megohm. If you need a time constant of 1/1000th of a second you could use 1000 ohms with 1 MFD. Or you could use .001 MFD with 1 megohm. Or you could use some other combination such as 10,000 ohms with .1 MFD.

Section 5. TAPPING OFF THE GENERATED VOLTAGE

The presence of a constantly changing voltage across the capacitor of the sawtooth oscillator circuit is not going to do us much good so long as the voltage is confined to that one locality. To be of any value we must tap it off and feed it into another circuit. The voltage can be tapped off as shown in the diagram of Fig. 12.

More frequently, however, the sawtooth voltage is tapped off and fed to the grid of a vacuum amplifier tube. Such a circuit is shown in Fig. 13. By handling the sawtooth voltage in this manner it can be built up by the amplifier circuit and then run through a potentiometer so that any amount of the voltage can be applied wherever it might be needed. In this way the *magnitude* of the sawtooth voltage can be kept under constant control.

Section 6. THYRATRON OSCILLATOR

The neon tube we have just been discussing is valuable for many purposes. Nevertheless it has certain limitations. If the only purpose in generating the sawtooth form is to create *one* particular frequency it is entirely satisfactory. But it is often desirable to control the sawtooth generator from an external source. Other times it is desirable to *synchronize* the sawtooth voltage with some external signal. The neon tube is not adaptable for such uses.

Fig. 14 shows the symbol for a gas-filled triode electron tube. In some ways it is similar to a common vacuum triode. In other ways it is considerably different. It is used for entirely different purposes than those for which we use the vacuum tube. The gas filled triode is called a *thyratron*.

In earlier sections of this lesson we have described how the voltage would break down between the elements of a neon tube. We mentioned that each of these tubes had *one* particular voltage at which they would break down.

The thyratron tube does very much the same thing -- with one exception. The presence of the grid makes it possible to control the value of the voltage at which the tube will break down and fire. Without any voltage at all on the grid the tube might break down and fire at about 50 or 60 volts. With one or two negative volts on the grid it might

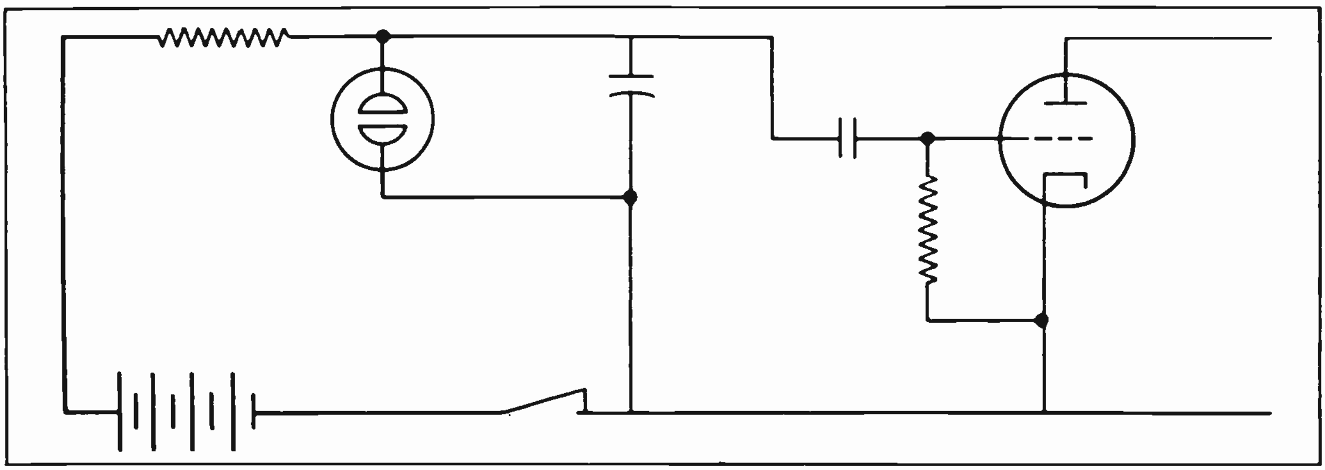

Fig.13. How a Sawtooth Wave Form can be Amplified.

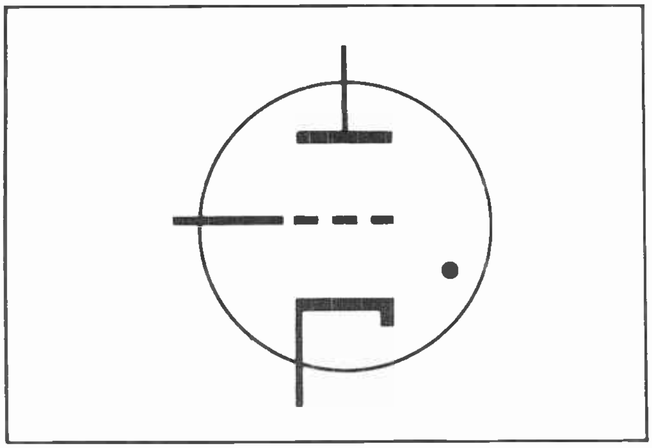

Fig. 14. Thyratron.

take 100 volts to make the tube break down. Putting a little more negative voltage on the grid will make it necessary to increase the voltage still further before the tube will break down.

There is another difference between the neon tube and the thyratron. The neon tube is a cold cathode tube. As such it is extremely limited in the amount of current it can pass -- seldom more than about 30 milliamperes. The thyratron, on the other hand, has a heated cathode. It can pass a large amount of current. It can pass even more current than a large vacuum triode tube.

In this respect it has an advantage over the vacuum tube. But the thyratron has the disadvantage that the grid does not have complete control over the current as is the case with a vacuum tube. In fact the degree of control which the grid in a thyratron is able to exert is very limited. It can keep the current from starting to flow by keeping the grid negative. But once the grid allows *any* current to start flowing the grid loses all control -- and cannot regain control. It cannot regain control until the anode voltage drops to zero, or nearly to zero.

When the anode voltage on a thyratron drops to about 15 volts the tube will cease conducting. This feature is taken advantage of in many circuits. The grid prevents conduction until a certain anode voltage is reached. Then the tube begins conducting. The tube will continue to conduct until the anode voltage drops to about 15 volts.

In Fig. 15 we have drawn a diagram showing a thyratron connected into a circuit. When the switch is first closed the electrons will move in the direction indicated by the arrows. The capacitor will charge up as the polarity marks show. The rate the voltage will build up across the capacitor will depend upon the value of the resistor and that of the capacitor.

As soon as the voltage across the capacitor reaches some predetermined value (the exact value need not concern us at the moment) the tube will break down and fire. The firing of the tube will cause the capacitor to discharge as indicated by the dotted arrows of Fig. 16.

The capacitor will charge up at a relatively slow rate, the exact time be governed by the capacity and the resistance in exactly the same way we explained a little earlier in our lesson. The sawtooth voltage can be tapped off as shown in Fig. 17.

Fig. 18 shows how the output sawtooth wave voltage from a thyratron generator can be

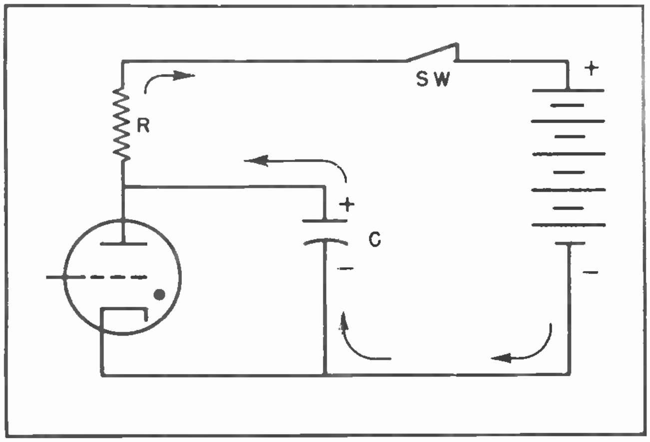

Fig. 15. Charging the Capacitor in a Thyratron Oscillator.

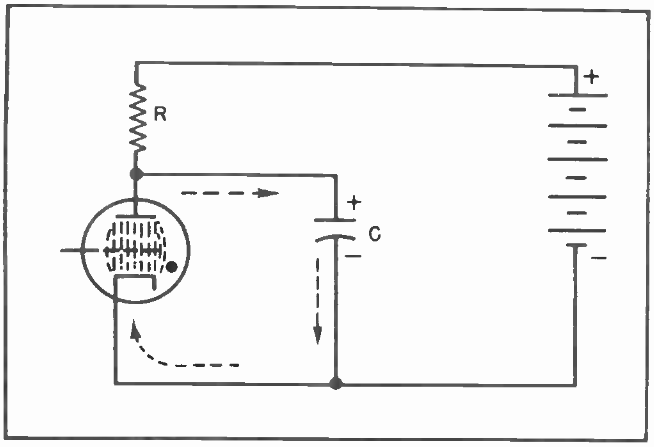

Fig. 16. Thyratron Tube Discharging Capacitor.

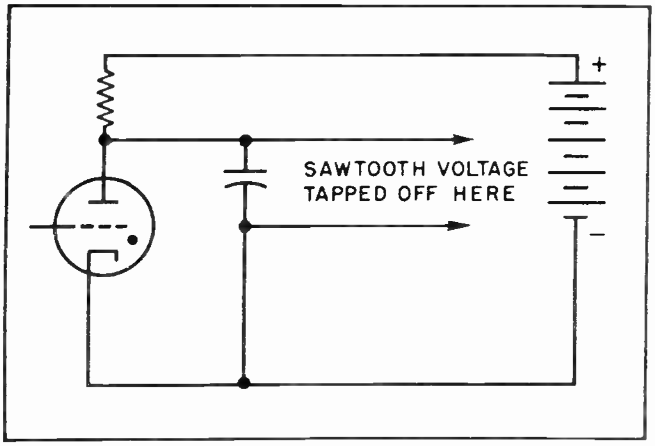

Fig. 17.

locked in with an input voltage and locked into step with some external circuit. The input voltage can be any kind: sine wave, a pulse, or another sawtooth wave voltage. The point is that the presence of the grid in the thyratron makes it possible to synchronize the sawtooth voltage with any other voltage.

This feature is particularly useful in an oscilloscope. The sawtooth voltage might be used to control the sweep of the electron beam in the cathode ray tube. It might be desirable to study some particular alternating voltage or current.

The capacitor and the resistor of the sawtooth oscillator could be adjusted so the oscillator was generating a sawtooth voltage at nearly the same frequency as the one to be studied. Then by locking the voltage to be studied with the grid of the sawtooth oscillator the two voltages would be locked into exact synchronism.

Section 7. **THE MULTIVIBRATOR**

The multivibrator is often considered to be a relaxation oscillator. Whether or not it is a true relaxation oscillator the fact remains that it is capable of generating sawtooth wave forms. Because this is so it is immensely valuable in television work. The sweep circuits in many television receivers are driven and controlled by multivibrator oscillators.

The thyratron sawtooth generator we have just been discussing is a highly useful oscillator for many purposes. The fact that it employs a gaseous type tube makes it unsuitable for higher frequency operation. It takes an appreciable amount of time for the gas within the tube to ionize. Furthermore it takes time for it to de-ionize.

The time it takes the gas to ionize and de-ionize is measured in fractions of a thousandth of a second. Nevertheless that is too long a time for many applications. The sweep generator of a television receiver oscillates at the rate of 15,750 cycles per second. This is a higher frequency than can be attained by many gaseous tubes.

The multivibrator uses vacuum triodes or vacuum tetrodes. It consists of two tubes. Reduced to its simplest form the multivibrator is nothing more than two amplifier tubes, each of which feeds a signal into the grid of the other tube.

Section 8. **ACTION OF THE MULTIVIBRATOR**

Fig. 19 shows the basic essentials of a multivibrator circuit. For the purpose of explaining how this circuit operates let us suppose that something happens to cause the

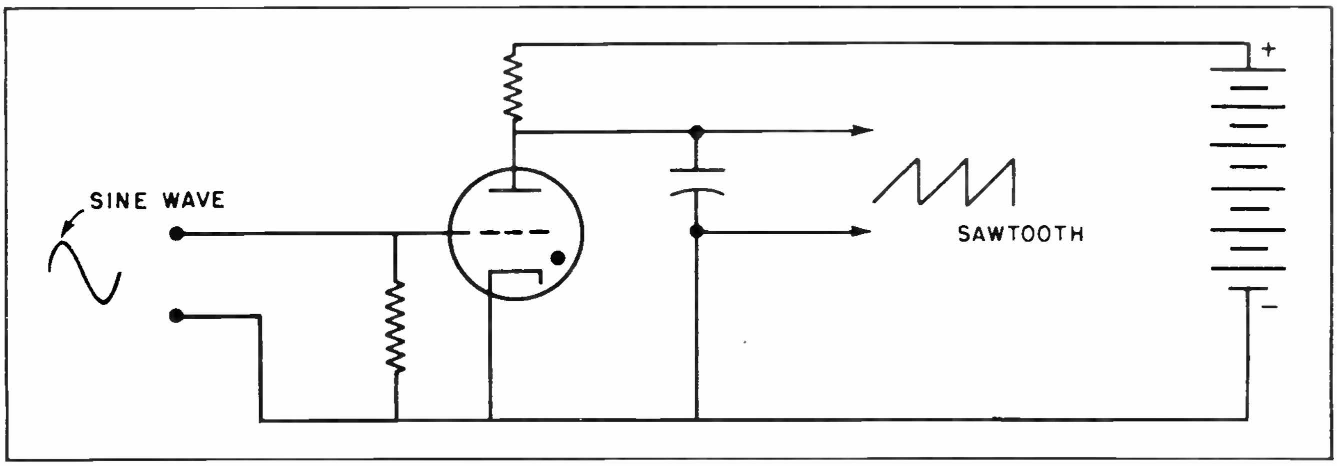

Fig. 18.

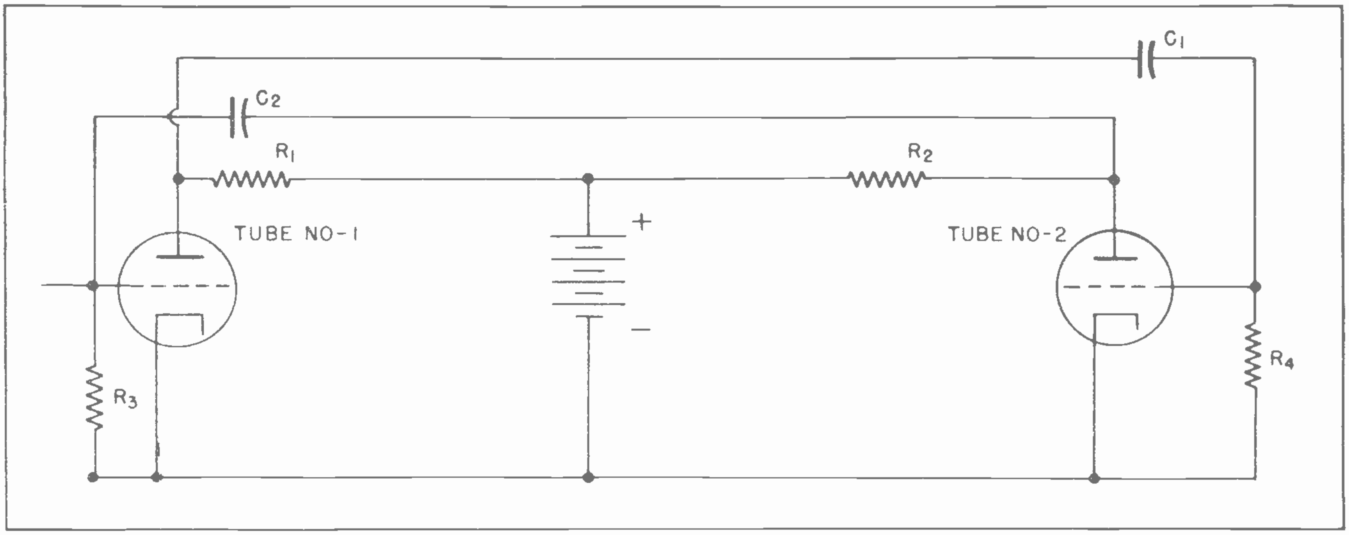

Fig. 19.

grid of tube No. 1 to become slightly more positive. It makes no difference what causes this. As we have mentioned before there are several things which will cause the voltage on a grid to change slightly.

At the present instant we are going to have the grid of tube No. 1 going slightly positive. This change in the grid voltage will allow a little more current to flow in the anode circuit of tube No. 1. The additional current through the anode circuit of tube No. 1 will flow through resistor R_1, creating a voltage drop across that resistor.

The voltage drop across R_1 will be such as to make the left end of the resistor slightly less positive. This is the same as saying the left end of the resistor R_1 will be slightly more negative. This change in voltage will be reflected through capacitor C-1 to the grid of tube No. 2. When the grid of tube No. 2 is made more negative it reduces the current through tube No. 2.

Reducing the current through tube No. 2 will also reduce the current through R_2. That means the right end of resistor R_2 will be slightly more positive. This positive voltage will be reflected through capacitor C_2 to the grid of tube No. 1.

Now let's go back and review this whole action briefly. A slight change in the voltage on the grid of tube No. 1 made it go a little more positive. This slight voltage change was amplified by tube No. 1, and sent to tube No. 2. It was amplified again and instantly brought back to the grid where the action started -- *boosting* the original action.

The grid of tube No. 1 will *really* go positive now -- so positive that the grid of tube No. 1 will attract electrons. During this instant a very heavy anode current will flow from tube No. 1. This action drives the grid of tube No. 2 very negative -- far beyond cut-off.

For an instant now a heavy current will flow through the anode of tube No. 1, but no current from tube No. 2. But this situation is not permanent. As soon as the electrons can leak off the grid of tube No. 2 through grid leak resistor R_4, tube No. 2 will start conducting again. When tube No. 2 starts conducting it will drive the grid of tube No. 1 negative, thus cutting off the current flow through that tube.

This action is repeated over and over.

The frequency is determined by the values of R_3 and C-2 for tube No. 1, and of R_4 and C-1 for tube No. 2. By carefully selecting the values of these resistors and capacitors it is possible to generate any frequency which might be desired. One tube can be caused to drop to zero quite rapidly while the other does so quite slowly. This makes it possible for the multivibrator to generate a sawtooth wave form.

The multivibrator is also used to generate square waves, and other wave forms. All these wave forms are controlled by the proper selection of the circuit components.

Fig. 20 shows how the sawtooth output voltage is tapped off the multivibrator circuit. This voltage can then be fed into

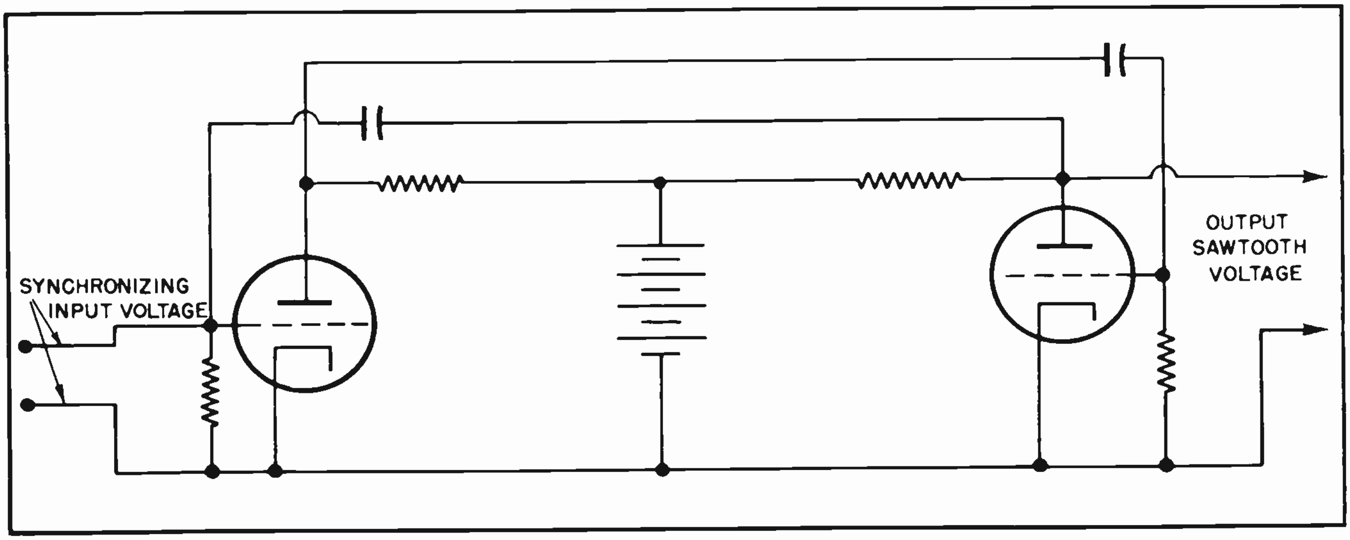

Fig.20.

a vacuum amplifier tube and amplified to whatever value is needed. The multivibrator can be readily synchronized with another circuit by feeding the input signal into the grid of the first tube as indicated at the left of Fig. 20.

The circuits of Figs. 19 and 20 indicate that two tubes are used for this circuit. The tube manufacturers have designed several tubes which are actually two triode tubes within one glass envelope. Such a duo-triode tube is easily able to perform the same functions as two ordinary triodes. Fig. 21 shows the schematic arrangement of such a duo-triode tube. Some of those tubes have two separate cathodes as indicated in Fig. 21. Other tubes use only one cathode for both sections. The 6SC7, the 6SL7 and the 6SN7 are typical twin-triode tubes. The 6SC7 has a single cathode. The other tubes have two cathodes.

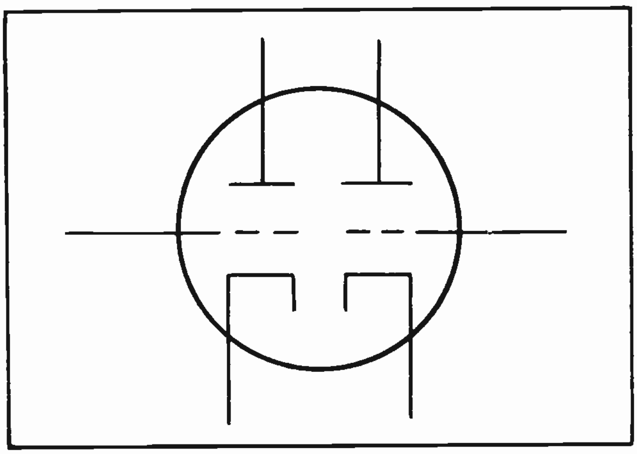

Fig.21. Duo-Triode.

Section 9. **TUBE AND SOCKET IDENTIFICATION**

We have gone into considerable detail about many of our electronic tubes. It is just as well that we take a little time right here and discuss a few of the physical aspects of tubes. This will include the size and shape of the glass or metal envelope, the method of making connections to the tube, and the kinds of tube sockets used.

The development of the vacuum tube from its earliest days down to the present time provides some very interesting details. It is not within the scope of this lesson to go into all of them.

The earliest tubes were relatively large. The glass envelope was formed in very much the same shape as that of the incandescent lamps of those days. As better manufacturing facilities have come into existence it has been possible to reduce the size of the tubes, and improve their operating characteristics. Further than this, as new needs have arisen the manufacturers have designed new tubes to fill those needs.

The earliest vacuum tubes had only four pins at the base. These pins were inserted into tube *sockets*. By means of the tube socket it was possible to anchor the tube to the chassis where it was used, and to make connections to the elements within the tube. Several types of tube sockets are shown in Fig. 22. The largest socket shown is a 4 pin socket.

Four pins were entirely adequate to make connections to all the elements within the

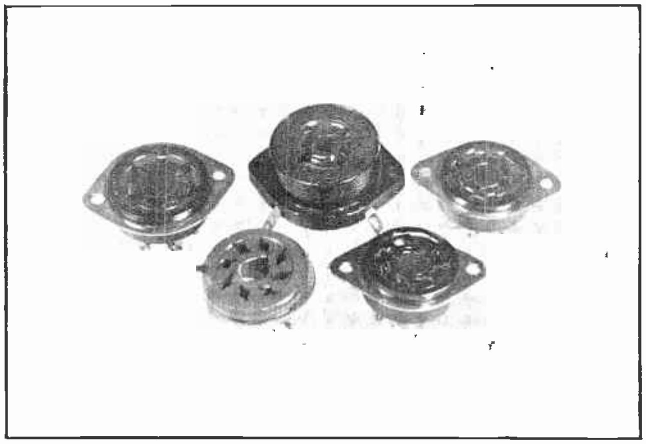

Fig.22. Various Types of Tube Sockets.

early tubes. Two pins were needed for the heater-filament -- one for each end of the filament. A third connection pin was needed for the grid and the fourth one for the anode, or plate.

The use of the tube socket made it unnecessary to make any connections directly to the pins of the tube itself. All the connections were soldered to solder lugs on the bottom of the sockets. Some of the solder lugs can be seen under the sockets in Fig. 22. (See also Fig. 24.) Thus the permanent connections were made to the socket, which was also permanently fastened to the body of the chassis by means of rivets or screws. The top of the socket was designed so the pins of the tube could be inserted into specially located and prepared holes. Inserting the pins of the tube into these holes in the top of the socket made a tight friction fit which held the tube physically in place. More than this, the pins themselves made electrical contact with a metallic part of the solder lug under the socket. Thus any connection to the solder lug under the socket made a perfect electrical connection to the various elements within the tube.

When the manufacturers began adding additional elements to their tubes -- began making tetrodes, pentodes, etc., — it became necessary for them to add more pins to the bottom of the tube bases. When the 4-pin tube became inadequate the manufacturers came up with the 5-pin base. This base was adequate for the tetrodes. In those tubes in which the filament acted as the cathode it was never necessary to provide a special connection for the cathode. But all the indirectly heated cathode tubes required an extra connection. In many cases this problem was solved by bringing out the grid connection to a cap on the top of the glass envelope.

Along about 1930 most radio receiving tubes were built with the glass envelope in the general shape shown in Fig. 23. This method of building the glass envelope prevailed for a number of years.

Near the end of the 1930's a trend developed toward making the physical size of the tube smaller. The bulges in the glass walls of the tube were largely eliminated. The tubes were then shaped very much like a cylinder. Reducing the physical size of the tube made it possible to place the tubes closer together, thus reducing the overall dimensions of the chassis and the finished receiver.

The tube using an envelope shown in Fig. 23 eventually came to include the letter *G* after the tube number. A glass tube of type 1N5 would be designated 1N5G. If the tube used one of the smaller cylindrical envelopes it would be designated 1N5GT. (The GT stood for Glass Tubular.)

Many tubes had identical characteristics regardless of which type envelope was used. When this was true the manufacturers began discontinuing the *G* types of envelopes. Since the smaller tube could be used everywhere the larger one could be used the manufacturers began numbering those particular tubes G/GT. For example a 1N5 tube which could replace either a 1N5G or a 1N5GT would be labeled 1N5G/GT. It was not possible to renumber all *G* type tubes G/GT. Sometimes

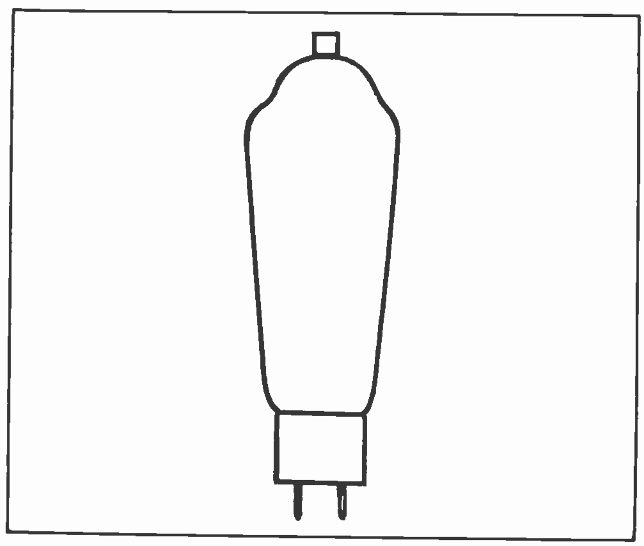

Fig.23. Outline of Glass Tube.

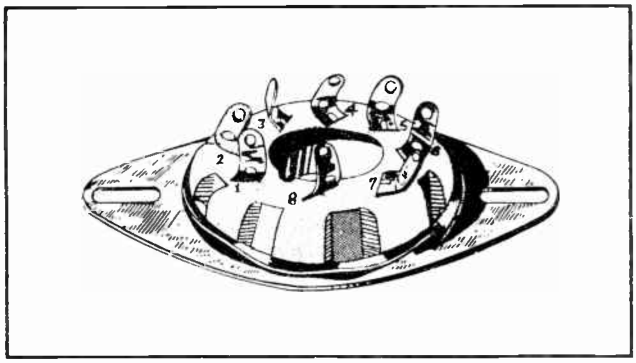

Fig.24. Underside of Octal Socket Showing the Solder Lugs.

the inside physical dimensions of the electrical elements could not be made to fit in the smaller GT envelopes. For this reason there are still some tubes designated as a *G* tube, others designated as a *GT* tube; and still others which can replace *either* of the first two. These last are the ones labeled G GT.

It will be found that metal tubes do not have a suffix letter. This is because no such designation is needed.

As still more elements were added to vacuum tubes, and it became the vogue to include the functions of two or more tubes within one envelope it became evident that additional pins were needed on the tubes. Additional pins called for additional pin holes in the sockets and more solder lugs on the bottom.

For several years there was a temporary standardization on the 6-pin socket. The six pins plus the grid connection on the top made possible seven connections to the inside of the tube.

But even six pins were not enough. For a short time some tubes were built with seven pins. But the 7-pin sockets were not very popular. There were relatively few tubes built which could use the 7-pin socket.

Eventually the entire radio business seemed to settle down and standardize on the 8-pin socket, called the "octal" socket. This was the situation during most of the recent war years, Probably the army and navy requirements had a lot to do with the stabilization and standardization during those years. There are now probably more vacuum tubes in existence which can use the octal socket than can use any other type socket.

But with the growth of television another trend was brought about. A special 9-pin tube came into existence. Television also hastened the development of miniature tubes such as the "acorn" and "peanut" types. These are very small tubes. Being small they can fit into more compact areas. More important -- the smaller size gave them better operational characteristics on the extremely high frequencies encountered in television work.

During and after the war a special type of very small tube was developed which did not use any socket at all. The leads to the tube were brought out through the glass envelope of the tube and soldered directly into the circuit. These tubes were originally designed for use in the proximity fuses. In those applications they were used only one time -- to detonate the shell or bomb -- and thus had no problem of replacement. Some of these tubes have been refined for peacetime use and are now being used in special applications.

Another wartime vacuum tube which was designed for high frequency operation was the "lighthouse" tube. The name came about due to the peculiar shape of the tube. This tube was designed to operate in radar work; there is not much point in going into detailed description of its operation.

Some years ago with the advent of the newer metal tubes the Radio Manufacturer's Association studied this matter of tubes, tube sizes, tube shapes, and above all the system of numbering tubes. Previous to that time there was no systematic arrangement nor agreement among the various manufacturers as to how to number their tubes. Whenever a tube manufacturer brought out a new tube in response to the demand of the radio manufacturers he would place any number on it which might suit his mood at the moment.

As the result of the efforts of the Radio Manufacturer's Association a new method of numbering tubes was brought into existence. The octal socket was adopted as the standard. They decided upon a uniform method of attaching the elements of the tube to the base pins.

It was decided to attach the metal shell of the tube to pin No. 1. In the case of a glass tube the shield within the tube -- if any -- would be attached to the No. 1 pin instead.

Pins No. 2 and 7 were to be used for the filaments. Pin No. 3 was to be used for the anode. The various grids, except the control grid, were connected to pins No. 4, 5 and 6. The control grid was attached to the cap on the top of the tube.

This system worked out very well for quite a while. But eventually there arose a demand for tubes in which the control grid was brought out through the base rather than through the cap on the top. This necessitated the re-arrangement of the connections to the base pins. It was necessary to keep the control grid as far from the filament connections as possible. In the newer tubes one heater connection was moved from pin No. 2 to pin No. 8. This made the filament connections come to two adjacent pins. The control grid connection was made to pin No. 3, and the anode connection moved from pin No. 3 to some other pin.

It is not expected that you will be able to remember all these things. Fortunately there is no reason why you should try to remember them all -- few experienced men try that. Nevertheless, an understanding of the reason behind the many arrangements of the pin connections will remove some of the confusion you might feel when first beginning to work with these tubes. Due to the enormous number of kinds and types of tubes, and the many differing applications to which they are put, it is most difficult to establish any set pattern for all tubes to follow. The result has been that no two tubes are alike. Your best source of information will always be the tube manuals the manufacturers prepare for your guidance. These manuals give you almost every particle of information about every tube you are ever likely to need. This information includes the arrangement of the pin connections; the filament rating in volts and amperes; the grid working voltages; the anode current and voltage limitations, and nearly everything else you might need to know. They even tell you how to use each particular tube, for what purpose each is best suited, and the kind of circuits to arrange for the best operation.

It is not pretended that the tube information contained in this section of this lesson covers all types of tubes. It does not. There is no point in trying to cover every individual characteristic of every tube at this time. Such an attempt would be pointless; furthermore, it would probably be more boring to you than interesting. Especially just at this time.

NOTES FOR REFERENCE

Sawtooth oscillators are used to create the special wave forms needed for the sweep circuits of oscilloscopes and television receivers.

Capacitors are charged by adding electrons to one plate or removing them from the other.

The neon tube is a cold cathode tube.

The thyratron is a grid-controlled gaseous triode.

The thyratron is used to generate sawtooth wave form voltages.

The multivibrator can generate higher frequencies than gaseous tubes.

Tube sockets are used to fasten the tubes to the chassis, and to make the electrical connections to the elements inside the tubes.

All the electrical connections are soldered directly to the lugs of the tube socket rather than to the tube itself.

The holes on the octal socket are numbered on the bottom side of the socket. The No. 1 hole is directly to the left of the positioning spline. They then number around the socket in a clockwise direction.

The 6SC7 is a twin-triode. It is most often used in phase inverter circuits. It can also be used as a multivibrator.

The 6SL7 and the 6SN7 are also twin-triode tubes. They are especially adaptable to multivibrator circuits because each section of the tube has its own cathode.

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RADIO TELEVISION

CATHODE RAY TUBES

Contents: Introduction - The Cathode Ray Tube - Deflection - Frequency of Deflection - Vertical Sweep - Field and Frame - Blanking and Synchronizing Circuits - Vertical "Sync." - Raster and "Aspect Ratio" - Electromagnetic and Electrostatic Deflection - Retrace and Flyback - Notes for Reference.

Section 1. INTRODUCTION

Learning the principles of television sometimes seems a long and somewhat tiresome series of studies of many apparently unrelated subjects. It is unfortunate that this must be true when one first enters upon the study of this most intensely interesting subject. However, before one can hope to understand just how a television receiver operates there are many things about the innumerable circuits within the receiver which must first be thoroughly understood and mastered.

Most persons who have seen a television receiver, and many others who have not, understand the picture which they see is actually a lighted screen composed of fluorescent materials on the inside of a huge evacuated tube. Many are even aware that the picture is actually a series of still pictures which are being changed many times each second.

But few persons, other than trained technical men, realize the picture is being painted on the fluorescent screen inside the tube by a tiny beam of electrons. Nor do they know that the beam of electrons is being moved back and forth across the screen many thousands of times each second, nor that it is also being moved up and down across the screen many times each second. And if they learned about this unbelievable behavior of a tiny dot at the end of a beam of electrons they are completely at a loss to know how the beam could be moved around so fast, so surely and with such precision.

It is to prepare you to understand these things that we must first teach you many other things which may at times seem utterly irrelevant. How, for example, could you understand the action of a stream of electrons

Fig. 1. The Picture Tube in a Television Receiver is One Type of Cathode Ray Tube. (Courtesy Emerson Radio and Television.)

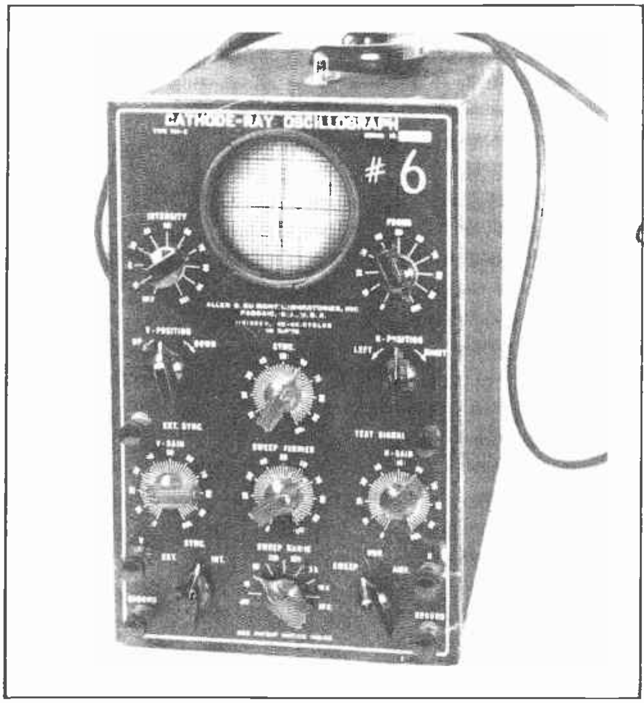

Fig.2. Oscilloscopes also Use Cathode Ray Tubes.

within a vacuum tube unless we had already taught you the functioning of a vacuum tube cathode, an anode and a control grid? How could you visualize the electrostatic or electromagnetic fields which act upon the stream of electrons within a television picture tube unless we had prepared you by already explaining the peculiar actions of such fields? Most important of all, how could you accept the fact that it is possible to move such a stream of electrons back and forth across the face of the fluorescent screen some 15,750 times each second unless we had already hinted at the possibilities inherent in vacuum tube oscillators?

Even the things we have already covered are by no means sufficient to enable you to completely understand the functioning of a television picture tube. However, you have progressed far enough that we can explain in a general way some of the actions which take place inside the tube. These actions will be dealt with individually in much more detail as you progress with your studies. It is our purpose now to show you just how some of the many things you have been learning are so important to the proper functioning of the most important part of a television receiver -- the picture tube. But always remember there are many more things yet to learn before you can properly call yourself a television technician.

Section 2. **THE CATHODE RAY TUBE**

The television picture tube is merely one adaptation of a general type of electronic vacuum tube which goes by the name *cathode ray tube*. There are several general types of cathode ray tubes, and each is used for a different purpose. Other than its use in television receivers the place the cathode ray tube is used most widely is in the oscilloscope. The oscilloscope was designed for the purpose of studying voltage and current wave forms under actual operating conditions. By its use an engineer or technician can watch the pattern of a voltage wave in any circuit, or any electrical machine, or in any kind of electrical or electronic device. The voltage wave can be studied as the conditions which affect it are changed in any way which might suit the observer's wishes.

As an example of this a television technician might have reason to believe the voltage output of a vacuum tube amplifier did not have exactly the same shape as the signal at the input. By use of the oscilloscope the technician could study the input signal and study its characteristics; then he could study the output from the amplifier and compare it with the input. By means of the visual picture on the screen of the cathode ray tube in the oscilloscope he would be able to *see* the two wave forms. He would *know* if there was any distortion present or not. There would be no guesswork.

The oscilloscope is a very important instrument to the radioman and television

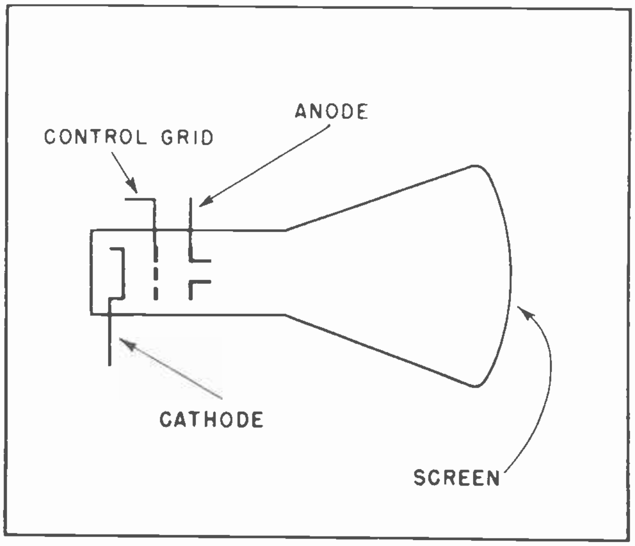

Fig.3. Principal Elements in a Cathode Ray Tube.

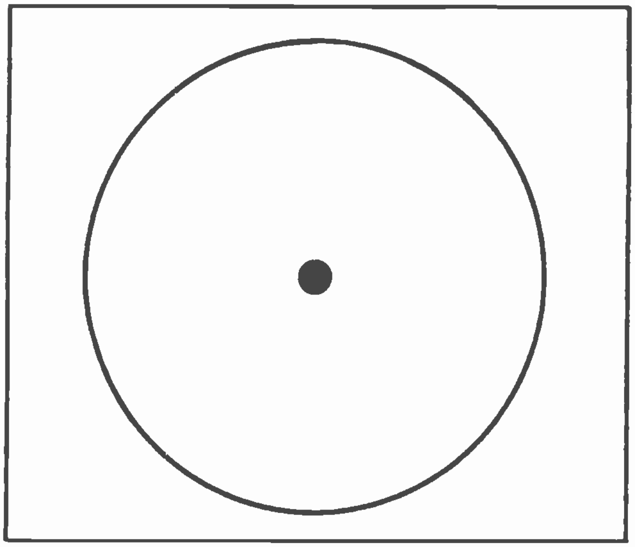

Fig.4. If the Electron Beam is Motionless all the Electrons Will Strike the Screen at the Same Spot.

technician. It is so important we will devote more than one whole lesson to its operation and use. The point is that the principal element within the oscilloscope is the cathode ray tube. This cathode ray tube belongs to the same general family of tubes which includes the picture tube of the television receiver.

In its essentials the cathode ray tube consists of a cathode which emits electrons just as does any other type of vacuum tube, a control grid which controls the passage of electrons from the cathode in much the same manner as other vacuum tubes, and an anode or two. The anode, or anodes, in a cathode ray tube perform somewhat different functions than do the anodes in other tubes we have already studied.

Yet it is not particularly difficult to understand what they do. Actually they serve much the same function in a cathode ray tube as does the screen grid in all the many amplifier tubes we have studied to date. They set up an electrostatic field between the grid and the anode, or the cathode and anode, which has the effect of imparting a high velocity to the electrons after they emerge through the passageway in the control grid.

The electrons attain such high velocity they go right on past the anodes. In fact they keep right on going until they strike the fluorescent screen on the front of the tube. When they strike the screen they cause it to "fluoresce", or light up.

Section 3. **DEFLECTION**

Of course there is somewhat more to the cathode ray tube than that. Special electrostatic or electromagnetic fields must be provided which will cause the electrons to bunch together into a stream instead of following their natural inclination to scatter. Other electrostatic or electromagnetic fields must also be provided which will cause the stream of electrons to move back and forth across the screen. After all, we do not want the stream of electrons to continue striking the screen in the same spot all the time. If they did we would see nothing but a single dot in the center of the fluorescent screen. (See Fig. 4.)

By applying the proper electrostatic or electromagnetic fields to the stream of electrons we can cause them to move from side to side across the face of the fluorescent screen. (See Fig. 5.) The purpose of applying these fields to the stream of electrons is to *deflect* the stream from their destination straight ahead and deflect them to one side or the other.

Sometimes the deflection is caused by placing a pair of metal plates inside the neck of the tube, one on each side of the stream of electrons. If a positive voltage is placed upon one of the plates and a negative voltage on the other the stream of electrons will be deflected somewhat from their original direction straight ahead and turned slightly in the direction of the positive plate. They will not be deflected

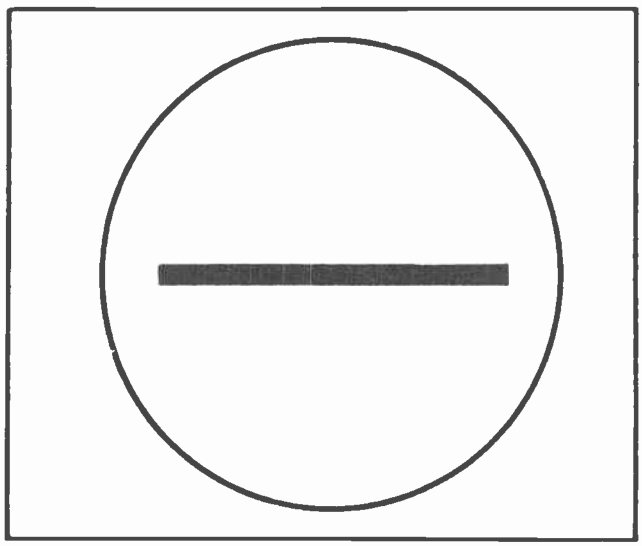

Fig.5. Horizontal Deflection Creates a Straight Line Across the Face of the Screen.

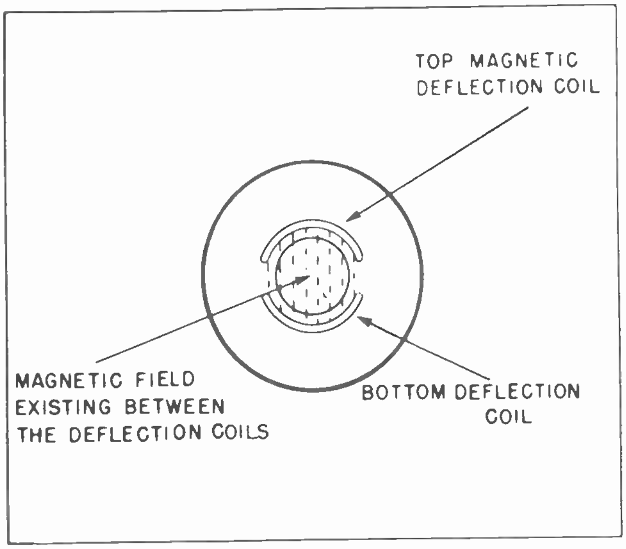

Fig. 6. The Coil Above the Neck of the Tube and the One Below Create an Electro-Magnetic Field Between Them.

enough for the stream to actually reach the positive deflection plate, but the stream will be *bent*. When the deflection is accomplished by means of a pair of plates inside the tube we say the tube employs *electrostatic deflection*. In other cases there will be a pair of coils placed above and below the neck of the tube. When a current is allowed to flow through these coils an electromagnetic field will be set up between the two coils. We already know that when an electron, or a stream of electrons, tries to pass through a magnetic field there is a tendency for them to be deflected in a direction at right angles to the lines of the magnetic flux. In the case of the coils above and below the neck of the cathode ray tube we will have an electromagnetic field between the coils with the lines of magnetic flux being straight up and down. Fig. 6 is a view looking right through the screen of the tube so we can see the placement of the magnetic coils and the lines of force between them. When the stream of electrons tries to pass through the lines of force on their way to the screen they will be deflected either to the right or to the left, depending upon whether the north pole is at the top or the bottom. If the current through the coils is alternating the stream of electrons will be moved back and forth across the face of the screen in the same manner as is shown in Fig. 5.

The action of the stream of electrons on the face of the fluorescent screen can be compared somewhat roughly with a stream of water from a garden hose. In Fig. 7 we see a man holding the nozzle of a garden hose. He is directing the stream against the end of a barn, moving it back and forth horizontally. The water leaves a mark across the end of the barn in the same manner the

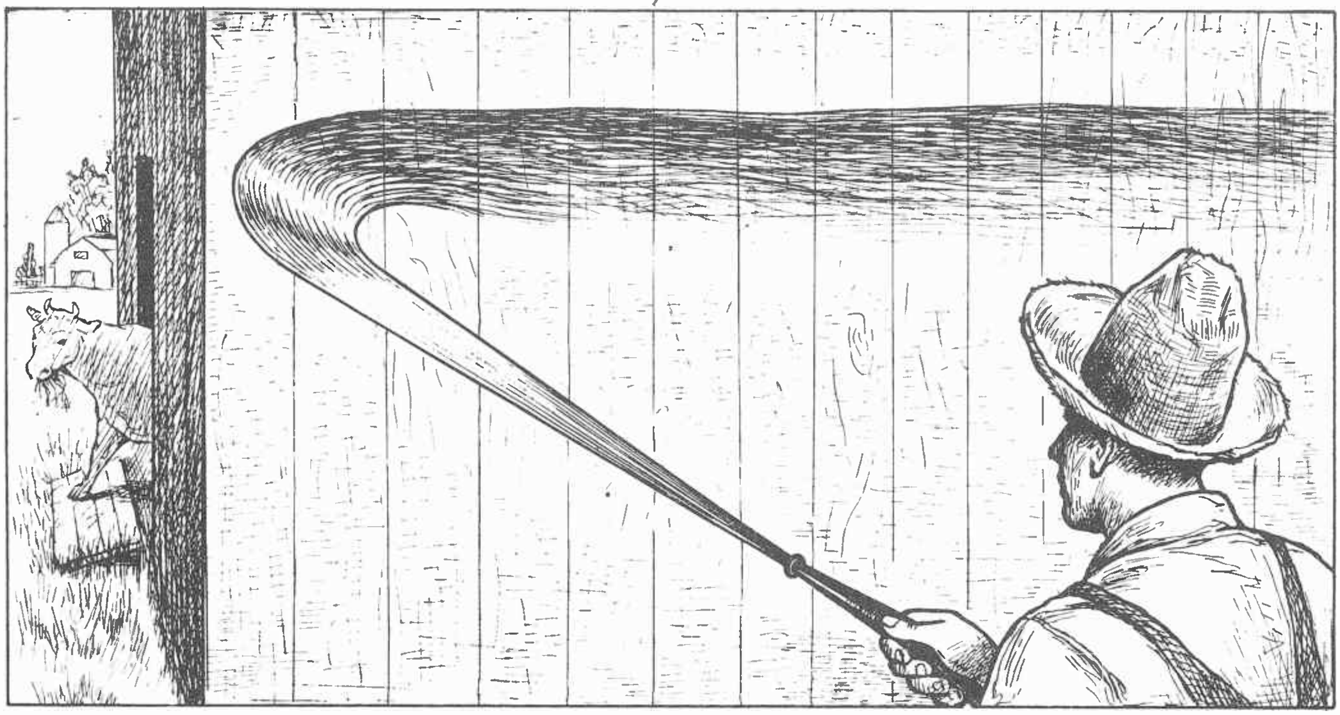

Fig. 7. Moving the Hoze Nozzle Creates a "Trace" of Water Horizontally Across the End of the Barn.

stream of electrons leaves a mark across the front of the fluorescent screen in the cathode ray tube. After passage of enough time the water mark will evaporate from the barn. Likewise, time will erase the fluorescent trace from the screen. The water may take many minutes to evaporate. The fluorescent trace will disappear in a fraction of a second -- unless renewed.

Section 4. FREQUENCY OF DEFLECTION

The stream of electrons, or "beam" as it is more commonly called, can move back and forth across the face of the screen as frequently as is desired. When the cathode ray tube is used in an oscilloscope it is a common practice to place a 60-cycle voltage on the horizontal "sweep" so as to move the beam back and forth 60 times each second. However, most oscilloscopes are so constructed that voltages having other frequencies can also be applied to the horizontal "sweeps".

In the case of the television picture tube, however, the beam moves across the face of the picture tube from the left to the right 15,750 times each second. The beam does not follow the same path back and forth as in Fig. 5, however. Instead it starts in the upper left hand corner of the face of the picture tube as in Fig. 8 at point *A*. From there it sweeps across the screen to point *B*. The beam must move across the screen at a definite rate of speed. To be exact, it must move across the screen from the left side to the other in 53.0 microseconds. (A microsecond is one-millionth of a second.)

But the beam goes across the screen in the opposite direction, that is from the right to the left, much faster. In order to keep in perfect step with the signal from the television broadcast station it must retrace its path from the right to the left in not less than 10.16 microseconds, and must not take longer than 11.4 microseconds.

If these values of time seem somewhat fantastic to you at this time just forget them. Before you go much further in your studies you will learn how you can split time up into unbelievably small fractions, and then work with it with perfect confidence. It is not our purpose to baffle you with figures at this time, but merely make you acquainted with them. We will explain all these actions in much greater detail after you have progressed a little more. But since we are describing the action

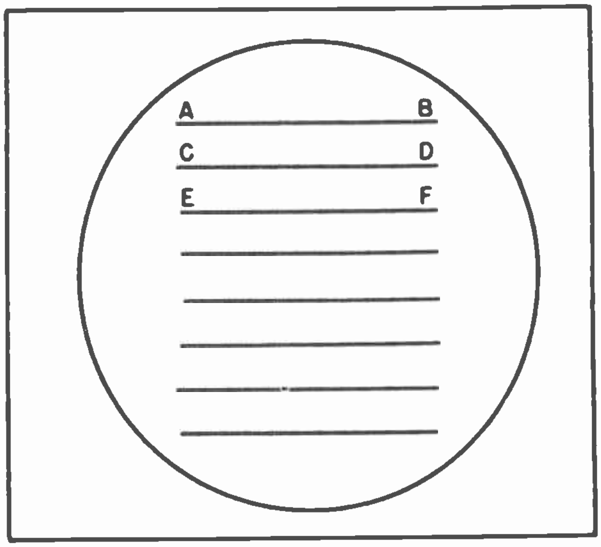

Fig.8. The Electron Beam Traces One Line After Another Across the Face of the Screen, Each Line Just Below the Preceding One.

in the operation of a picture tube we might just as well work in a few of the technical details.

When the beam gets back to the left side of the screen at point *C* it starts back again toward the right side at *D*. The beam continues moving back and forth across the front of the screen until it works itself clear down to the bottom of the screen.

In Fig. 8 we have shown only a few lines across the face of the screen. Actually there are 525 lines. This is the standard set up for television broadcasting by the Federal Communications Commission. It is adhered to by all television broadcast stations and by all television receivers.

It should not be thought, however, that the beam crosses the screen 525 actual times during its one trip down from the top to the bottom. As a matter of fact it crosses the screen only half that many times. Instead of crossing the screen first at line 1, second at line 2, and third at line 3, it only crosses at every other line.

The beam makes its first trip across the screen from *A* to *B* as in Figs. 8 and 9. This would be the same as line 1. Its next trip across the screen would be from *C* to *D* as in Figs. 8 and 9. This would be line 3. Then from *E* to *F* which is the same as line 5. After going all the way to the bottom of the screen in this manner, crossing at every other line, the beam will return to the top

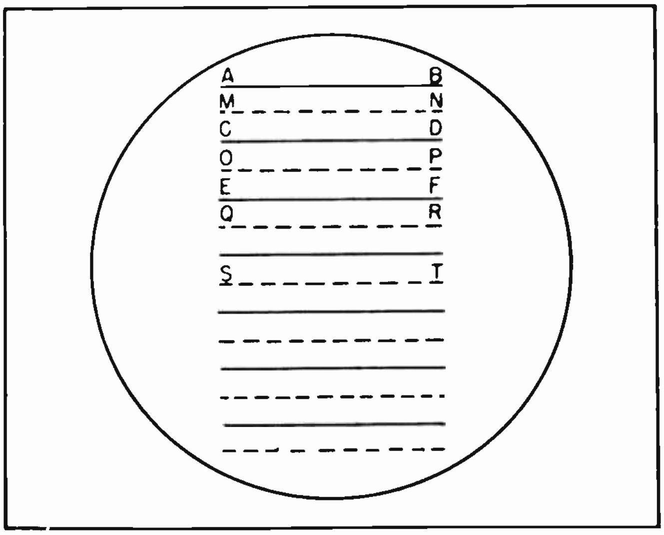

Fig.9. After Making a Complete Trip From the Top of Tube to Bottom the Beam Returns and Begins Filling in the Spaces Between the Original Lines.

of the screen. Now it will start across the screen again. But instead of starting at point *A* again it will start halfway between *A* and *C*, at what is designated as point *M* in Fig. 9. This is equivalent to line 2 on the face of the screen. The next time it goes across it will start at point *O* and go across to *P*, making line 4.

In other words the first time the beam goes from the top of the screen to the bottom it will "scan" every other line, scanning all the odd numbered lines until it reaches the bottom of the screen. Then the beam will return to the top and start scanning all the even numbered lines. This is called "interlaced" scanning. Interlaced scanning is the standard procedure at this time. All television transmitters use interlaced scanning, thus it is necessary for all television receivers to also use the same type of scanning in order for the picture to be intelligible.

You may ask just how it is possible to cause the beam of electrons to sweep back and forth across the face of the screen at the speeds we have just described. As a matter of fact the sweeping beam is moved under the influence of an alternating current or alternating voltage. If electrostatic deflection is used an alternating voltage will be applied to the deflection plates, a voltage which has a frequency of 15,750 cycles per second. If electromagnetic deflection is used an alternating current will be applied to the deflecting coils.

These frequencies will be generated by an oscillator similar to those we have already studied -- but not quite the same.

Those oscillators we have previously studied all generate a sine wave voltage. A sine wave voltage is traced in Fig. 10. But a little reflection is enough to tell us that we do not want an alternating current or alternating voltage which is a perfect sine wave. A sine wave would move the beam from the right side of the screen to the left side at the same rate it moves from the left to the right. This we do not want. We want the beam to move from the left to the right at a relatively slow rate, but to move from the right to the left at a much higher speed. Rather obviously this calls for some other type voltage wave than a sine wave.

As a matter of fact we use a special type oscillator which generates a voltage wave having a very special form. (See Fig. 11.) The voltage builds up from zero to peak in 53.0 microseconds, then returns from peak to zero in approximately 10.5 microseconds. This kind of voltage wave is called a "sawtooth" wave form. It is created by what is called a "sawtooth" oscillator. There are several types of sawtooth oscillators. They are dealt with in detail in another lesson before going into all the intimate technicalities of the picture tube.

Section 5. **VERTICAL SWEEP**

In Fig. 5 we showed the kind of trace the electron beam would make on the face of the screen when horizontal deflection was placed on the beam. There we saw that the beam merely made a straight line across the middle of the screen. Then we went on to Fig. 8 and started making a group of lines across the face of the screen. Perhaps you wondered: How come? What caused the beam to move up and down at the proper times?

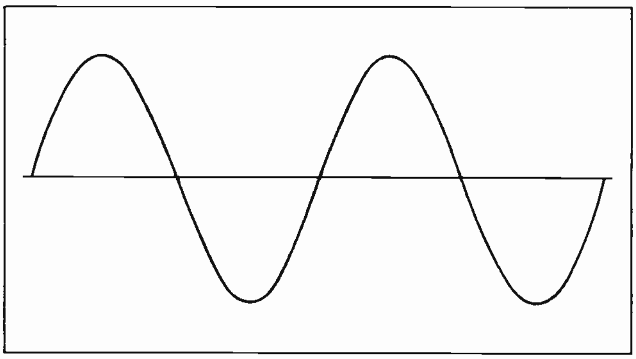

Fig.10. A Sine Wave.

When we were describing the scanning we thought it wiser to postpone a description of the vertical sweep until now. It is, of course, reasonably obvious that if the beam is to move from the top of the screen to the bottom, then back to the top again at the proper times this action must be brought about by some predetermined influence.

Just as the beam is moved from side to side by the action of electrostatic or electromagnetic deflection so can it also be moved from top to bottom, or from the bottom to the top of the screen. But what about the frequency of deflection? Will the oscillator which supplies the voltage or current necessary for vertical deflection have the same frequency as that used for horizontal deflection?

A moment's reflection will tell us it will not have. As the beam moves from the top of the screen to the bottom it will move from the left side to the right side one-half of 525 times, or 262.5 times. Or to put it another way, the beam will scan half the lines while it moves from the top of the screen to the bottom, then go back and scan the other half on the second trip down. This means that during two trips from the top of the screen to the bottom it will scan 525 horizontal lines.

What actually happens is that the beam will move from the top of the screen to the bottom 60 times each second. It will move from the left side to the right 15,750 times each second. Thus the horizontal oscillator must have a frequency of 15,750 cycles while the vertical oscillator need have a frequency of only 60 cycles.

But the wave form of the vertical oscillator must also have a sawtooth wave form just as does that of the horizontal oscillator. The beam is moved slowly from the top to the bottom as it moves rapidly from left to right and back. But once it reaches the bottom there must be no delay in getting back to the top to start all over again.

Section 6. **FIELD AND FRAME**

One trip of the beam from the top to the bottom is called a *field*. During this time the beam has scanned 262.5 horizontal lines.

After the beam has completed *two* complete trips from the top of the screen to the bottom it has scanned 525 lines. A complete scanning of all the lines on a television picture tube screen is called a *frame*. This name probably comes from the moving pictures where each still picture on a reel of film is called a *frame*.

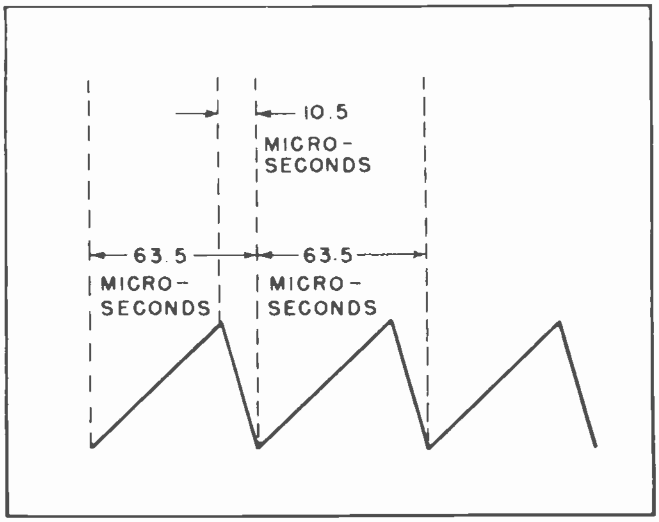

Fig.11. The Sawtooth Wave Form of a Horizontal Sweep Oscillator.

Since the vertical oscillator sweep moves from the top to the bottom of the screen 60 times each second it will have completed 60 *fields* each second. Since there are two fields to each frame the beam will scan *30 frames each second.*

30 frames on the television tube each second compares with that of moving pictures where it is the customary practice to show from 20 to 30 frames each second. Some kinds of moving picture films have standardized on 24 frames each second. Others have standardized on a speed slightly slower while others are slightly higher. The point is that the 30 frames each second of the television picture tube compares very favorably with the best in moving pictures.

The more frames are shown each second the less chance there is for undesirable flicker. Due to the action of interlaced scanning virtually all trace of flicker is removed from the screen of the tube. Half a frame is thrown on the screen each 60th of a second. Due to the persistence of the fluorescence on the screen a good part of that picture will remain while the other part of the picture is being traced. By the combined action of the persistence of the screen and the persistence of vision of the human eye there is virtually no possibility of the average eye detecting any flicker.

Section 7. **BLANKING AND SYNCHRONIZING CIRCUITS**

While it is highly desirable for the electron beam, which is constantly varying in strength due to the action of the control grid, to create a picture on the face of the tube while the beam is moving from the left to the right it is not desirable for the beam to create a trace as it moves from the right to the left. For this reason the television transmitter sends out what is called a "blanking" pulse as the beam reaches the end of each line it scans.

This blanking pulse places a highly negative voltage on the grid of the picture tube, momentarily shutting off the passage of all electrons into the electron beam. This blanking pulse lasts the duration of the beam's movement from the right to the left, or about 10.5 to 11.4 microseconds. Shortly after the blanking pulse shuts off the electron beam an even stronger pulse is sent out by the transmitter. This last pulse is called the "synchronizing" pulse, or more commonly the "sync" pulse. Its purpose is to trip the sawtooth oscillator at exactly the proper instant to cause the beam to move back to the left side of the screen. The sync pulse has a very short duration, being not less than 5.08 microseconds nor more than 5.68 microseconds.

There is a sync pulse at the end of each horizontal movement of the beam. This keeps the beam in the picture tube of the television receiver in exact step with the scanning beam in the camera tube at the transmitter. And, of course, there is the slightly longer blanking pulse which keeps the beam shut off during the time it is retracing back across the screen.

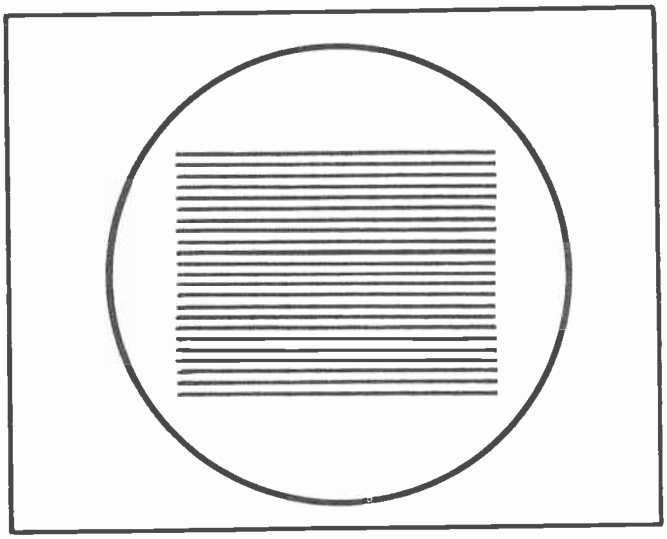

Fig.12. Raster.

Section 8. **VERTICAL "SYNC"**

The vertical oscillator is also synchronized with that of the vertical oscillator at the transmitter. But instead of one single pulse to trigger the vertical sweep when it reaches the bottom of the screen, there are a series of pulses. Actually there are six very short "equalizing" pulses transmitted very close together, much closer than the sync pulses for the horizontal oscillator. These six "Equalizing" pulses are followed by six "Vertical sync" pulses each 27.3 microseconds apart. These "vertical sync" pulses trigger the vertical oscillator causing the beam to retrace from the bottom of the screen to the top.

The vertical oscillator is much slower acting than the horizontal oscillator. It takes the beam much longer to move from the bottom of the screen to the top than it does to move from the right to the left on that retrace. The beam is also blanked out during the time it takes to retrace from the bottom of the screen to the top. The vertical blanking will last from about 833 to 1330 microseconds for each field, and from about 1666 to 2640 microseconds for the retrace after each frame. While this time seems long when measured in microseconds it should be remembered that 1000 microseconds are only one-thousandth of a second. The human eye cannot detect one-thousandth of a second.

We are not yet prepared to go into the technical details of the sawtooth oscillators which control the deflecting fields. But we soon will be. Neither are we prepared to go into the intricate details of the synchronizing circuits. The method by which the synchronizing circuits are able to lock the picture on the face of the television receiver picture tube into perfect step with that of the camera at the transmitter is something truly fascinating to study.

Section 9. **RASTER AND "ASPECT RATIO"**

Fig. 12 shows the face of a round television picture tube. Across the face of the tube are a number of horizontal lines. These represent the horizontal lines which are traced by the electron beam on the screen of the tube. Usually the portion of the tube which is filled by the tracings of the beam will be somewhat wider than it is high. The ratio is about 4 to 3. That is, if the traced portion is about 4 inches wide across the face of the tube it should be about 3 inches high from the bottom to the top. Likewise if the traced portion on which the picture appears is 8 inches across it should be 6 inches high.

This ratio of the width of the traced portion of the screen to the heighth is called the "aspect ratio". In order to keep the pictures on the screen proportional to the transmitted picture this aspect ratio should be maintained.

Should the traced portion on the tube be as high as it is wide all the objects in the pictures would seem to be higher, and more slender, than they actually are. Thus their appearance would be distorted. On the other hand should the width of the traced portion become considerably larger than the vertical portion all the objects in the picture would appear to be wide and squatty. This again would present a distorted picture. For these reasons the "aspect ratio" should be maintained exactly right -- 4 to 3.

A study of Fig. 12 will reveal that by no means all the screen is used to present the picture. There are spaces at the top, the bottom and both sides which are not used to show the picture. Only the portion on which the traces of the electron beam appear will have anything to do with the picture.

That portion of the tube on which the traces of the electron beam appear is called the *raster* of the picture. For many purposes the raster is much more important than the total area of the screen. In a rectangular tube the raster conforms very closely to the shape of the screen on the tube.

Section 10. **ELECTROMAGNETIC AND ELECTROSTATIC DEFLECTION**

Electrostatic deflection of the electron beam within a cathode ray tube is used almost exclusively in oscilloscopes. Electrostatic deflection has several advantages for this use. In oscilloscope work the grid is not usually modulated. For this reason the strength of the electron beam is virtually stable for any setting of the various controls. There is little tendency for the plates to distort the beam or to spread it out. More than this, electrostatic deflection makes it unnecessary to have cumbersome coils on the outside of the tubes.

The cathode ray tubes themselves have relatively small screen diameters, *3-inch, 5-inch and 7-inch screens* being the most popular and the most widely used. Electrostatic deflection requires that the tubes be somewhat longer than when electromagnetic deflection is used, but when the screen of the tube does not exceed 7 inches, -- and it is often smaller, -- the length does not become troublesome.

But in television the trend seems to be toward ever larger tubes. At one time the 7-inch tube seemed to predominate the market. But except for portable receivers the 7-inch tube seems to have fallen into disfavor.

Most 7-inch television receiver tubes use electrostatic deflection. Some 10-inch tubes also use electrostatic deflection. But most 10-inch tubes, and all of the larger sizes, use electromagnetic deflection. The use of electromagnetic deflection makes it possible to use much shorter tubes. And since the tube is by far the most bulky thing about a television receiver, anything that will keep it shorter is to be welcomed. Furthermore it is possible to operate a picture tube with much lower voltage on the anodes when electromagnetic deflection is used than when electrostatic deflection is used. Electrostatic deflection has some tendency to spread out the electrons in the beam, and make the picture slightly fuzzy unless the anode voltage is quite high. Where the tube is small this is not a

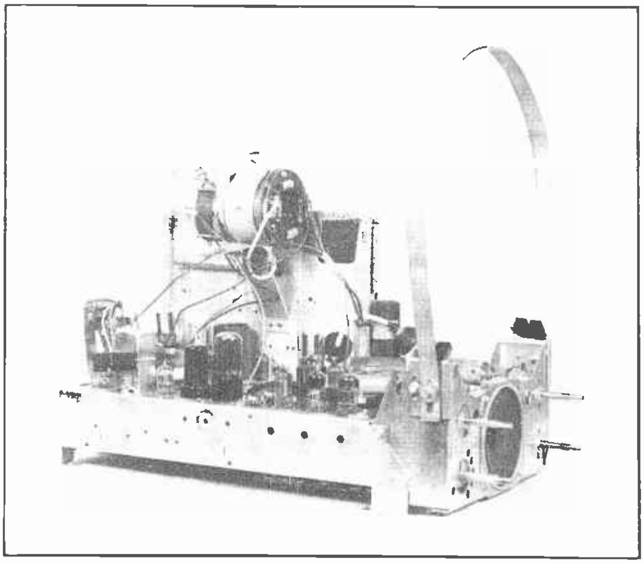

Fig. 13. Television Chassis Showing the Electromagnetic Deflection Coils. (Courtesy General Electric)

serious matter, but it would be quite a problem if such deflection were used on 12 1/2-inch, 16-inch, 19-inch or larger tubes.

The voltage which is required on the anode of a television picture tube runs up into the thousands of volts. If a definite saving can be made by using magnetic deflection it is to the advantage of the designer to do so.

The coils which form the magnetic deflection yoke are sometimes rather bulky. But they are usually combined with the support for the neck of the tube as in Fig. 13. When they are made in this form the charge of "bulkiness" is of little importance.

Section 11. **RETRACE AND FLYBACK**

There are two names in common use to describe the return movement of the beam from the right side of the screen to the left side. Sometimes the movement is called the *retrace*. This is the name applied to the return movement in a television picture tube. This comes from the fact that the beam *traces* a pattern from the left to right; it is only natural the *return* movement should be called the *retrace*.

When the cathode ray tube is used in an oscilloscope, however, it is the practice to refer to the return movement of the beam as the "flyback". The term "flyback" has been in existence longer, and is quite an appropriate description of the action. But with the increase in importance and prevalence of television there is some indication that in time the term "retrace" may be used in both oscilloscope and television work.

We have already described how the beam is blanked out during the retrace on a television tube. It is only reasonable to assume a similar action takes place in a cathode ray tube used in oscilloscope work.

However, such is not generally the case. The strength of the beam is not usually so great in an oscilloscope tube as in a television picture tube. Neither is the velocity of the beam so great. In fact the beam is usually so adjusted that it just makes a good readable fluorescent line during the trace period. Since the flyback period is only about one-sixth as long as the trace period the effect of the beam on the screen is greatly diminished during flyback. The result is there is a negligible effect on the screen during flyback; normally not enough to register. For this reason it is not generally considered necessary to blank out the beam in an oscilloscope tube during flyback.

Fig. 14. Checking Television Circuits with an Oscilloscope. (Courtesy Emerson Radio and Television.)

An oscilloscope is an almost indispensable instrument when servicing and repairing television equipment. It is not hard to learn how to use the instrument, and when its use has once been mastered the technician no longer needs to guess what is happening in the television circuits under investigation. Fig. 14 shows a young lady technician in a television factory using an oscilloscope to check the circuits on the underside of a television chassis.

NOTES FOR REFERENCE

Sawtooth oscillators provide the alternating frequency for the sweep circuits of television receivers.

The cathode ray tube is used in oscilloscopes and television receivers.

The horizontal sweep frequency of a television receiver is 15,750 cycles per second.

The vertical sweep frequency of a television receiver is 60 cycles.

Electrostatic deflection is generally used in oscilloscopes.

Electromagnetic deflection is used in all the larger television receivers, although some of the smaller tubes use electrostatic deflection.

The aspect ratio refers to the size of the picture on the screen of a tube. The aspect ratio is always 4 to 3, being wider than high.

Raster refers to the portion of the face of a tube actually used for the picture.

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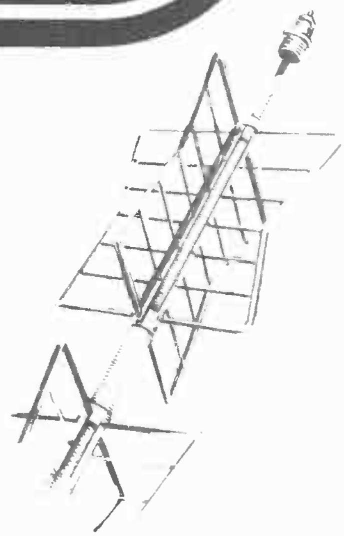

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RADIO TELEVISION

RESONANT CIRCUITS

Contents: Introduction - Mechanical Resonance - Resonant Frequency of Pendulums - Electrical Resonant Circuits - Effect of Frequency on Inductance - Effect of Frequency on Capacitance - More About Capacitive and Inductive Reactance - Effect of Capacitance and Inductance in the Same Circuit - Resonance - How to Find the Resonant Frequency by Calculation - The Resonance Curve - The Circuit "Q" - The Parallel Resonant Circuit - Variable Tuned Circuit - Notes for Reference.

Section 1. INTRODUCTION

Way back at the beginning of our studies we mentioned the matter of "resonance" in connection with radio and television transmission and reception. The matter came up again in our studies of oscillators. In this lesson we will delve a little deeper into this subject and learn just how important it is in making possible the wonders of television.

By way of introduction it should be stressed that there are many types of resonance. The laws of Physics presents us with many examples. There is hydraulic resonance, of which the waves and the tides on the oceans are the best examples. Then there is mechanical resonance. Mechanical resonance is used in many ways, probably the most important being its use in keeping watches, clocks and other time pieces operating with high degrees of accuracy. And

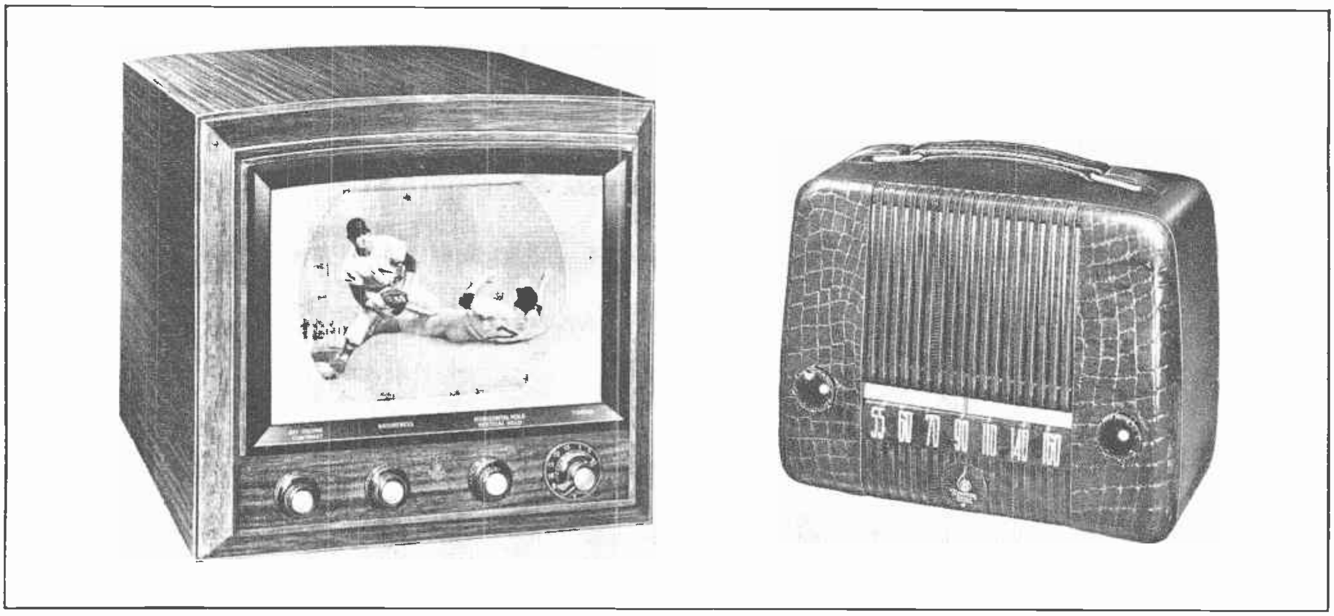


Fig.1. Without "Electrical Resonance" neither Radio nor Television would be Possible.

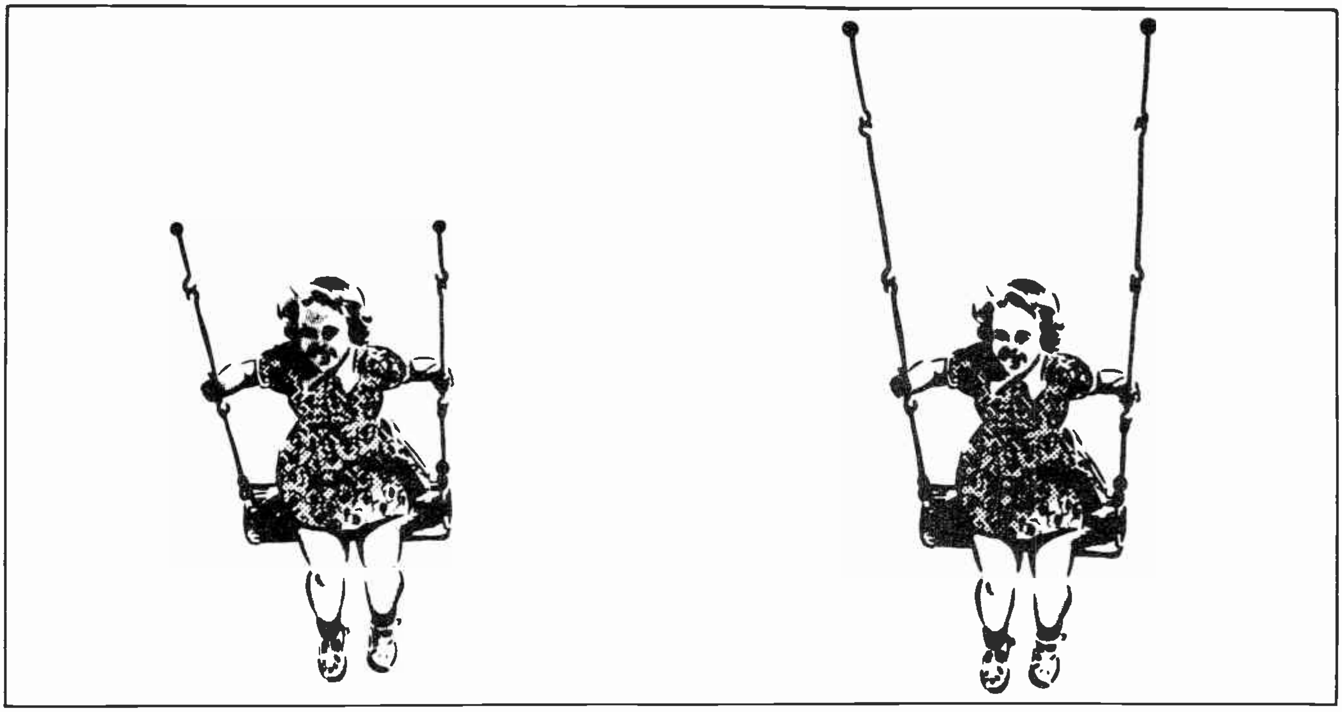


Fig. 2.

of course, there is electrical resonance. It is with this last that we are most concerned at this time.

Section 2. MECHANICAL RESONANCE

Probably the example of mechanical resonance with which we are most familiar is that of a child's swing. We have all swung on such swings when we were children. We have all been aware of the fact that we would swing back and forth much faster on some swings than we did on others. In the public parks and other places where the swing ropes were quite long, the *frequency* of the swing movement was much slower than on the smaller backyard swings where the swing ropes were much shorter.

It is probable that in our childhood most of us gave little thought to the reason behind these facts. But as we grew older we became more and more aware of the fact that the longer the ropes on the swing, the slower would be the frequency of the swing.

It makes little difference how far back and forth the child moves along the arc of the swing. That is, how high it goes, the frequency will always remain the same for any given swing. If the swing ropes are rather short, the child can swing back and forth at a fairly rapid frequency. If the child swings back and forth so the swing does not go very high in either direction, the *frequency* of each swing will be just the same as though the child was going high and fast.

To be a little more exact, if it takes 2 seconds for the swing to move from the peak of one swing to the peak of the next when the swing is moving slowly -- and not going very high -- it will take the same period of 2 seconds for the child to move from the peak of one swing to the peak of the next when it is moving fast and high. Thus, it makes no difference how high the child is swinging, the frequency of its swing is the same at all times, provided the lengths of the swing ropes are not changed.

The truth of this is emphasized by observing the movement of a swing which is started by sending it swinging as high as possible, then allowing it to "die down". When it is swinging high the swing will be moving quite fast at most times, but it will pass any given point only at certain times each minute. As the swing "dies down" it will move much slower, but it will continue to pass any given point at the same *rate* -- the same number of times per minute -- as when it was swinging high. Even when the distance through which it moves back and forth has been reduced to only a matter of inches, it will still continue to swing at the same *rate*, or *frequency*, as when it was swinging high.

As a matter of fact, the rate, or frequency at which a swing moves back and forth is determined by the length of the ropes. If the ropes are short, the rate, or frequency will be high. If the ropes are long, the frequency will be much slower.

An important fact about resonance can be explained by means of the child's swing. The swing can be started by giving a slight push. If additional pushes are given at exactly the right instants, the swing will attain considerable sweep with little effort on the pusher's part.

The important thing is that the pushes must have exactly the same *frequency* as the back-and-forth movement of the swing. If an attempt is made to give the pushes a little more rapidly than the movement of the swing, the result will be a diminishing sweep of the swing. It will not move so far back and forth. It may even stop -- or virtually stop.

In other words, if the pushes are given in exact step with the resonant frequency of the swing, they will keep it swinging high with little effort. But if the pushes are out of step with the resonant frequency of the swing, they will hinder its movement rather than aid it, regardless of how strong the pushes are.

Section 3. RESONANT FREQUENCY OF PENDULUMS

The pendulums on the old fashioned grandfather clocks and the more modern cuckoo clocks provide us with another example of mechanical resonance. On the tall grandfather clocks the pendulums are quite long and swing back and forth quite slowly. On the cuckoo clocks the pendulums are quite short and move back and forth quite rapidly. But in each case the *rate* of movement, the *frequency*, remains constant. By using the movement of the pendulum to control the escapement wheel inside the clock it is possible to keep the hands moving around the face of the dial at a steady, constant speed.

The frequency of the pendulum movement is not affected by the tension on the main spring of the clock. When the tension is great, such as it would be just after the main spring had been wound up, the pendulum will move a little farther each way -- it will swing a little higher. When the tension on the main spring becomes somewhat less, the pendulum will not move quite so far in either direction. But regardless of whether the spring is tightly wound or almost run down, or whether the pendulum makes long swings in either direction or merely enough to trip the escapement wheel, its *frequency* of swing continues at exactly the same rate at all times.

It is this constant frequency which makes the pendulum so useful in the control of

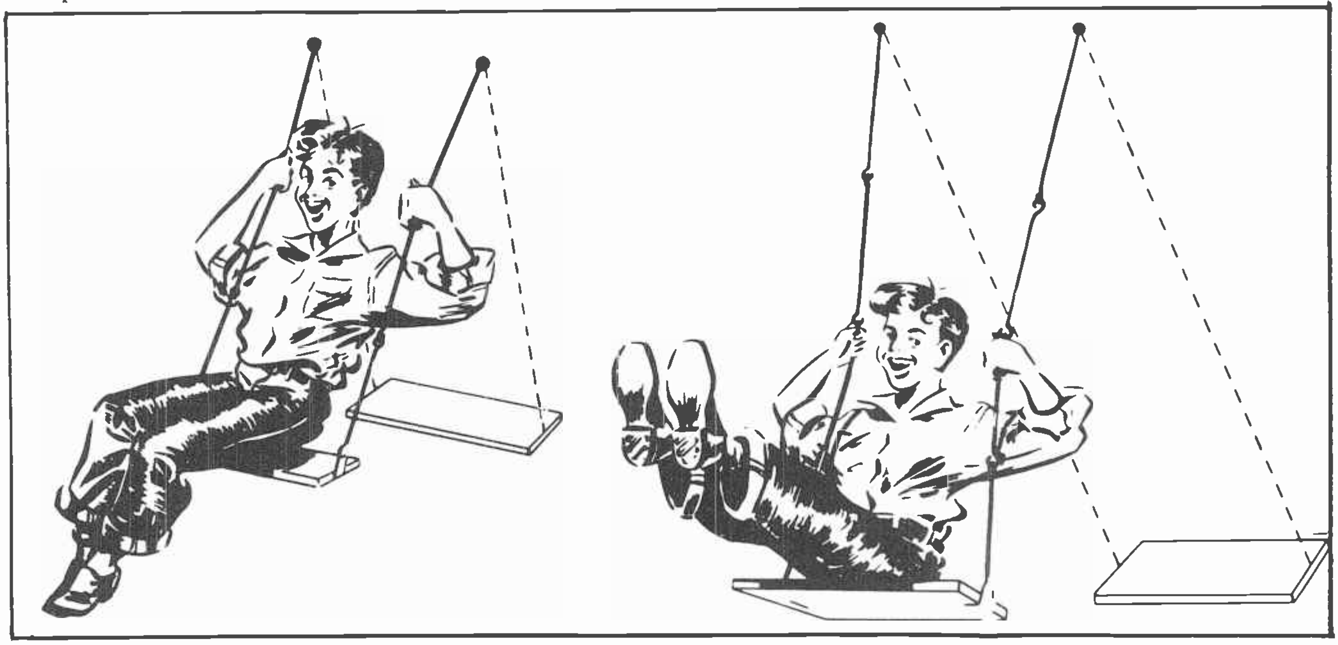


Fig.3. The "Frequency" of the Swing Movement is the Same Regardless of Whether the Swing is Moving Fast or Slow.

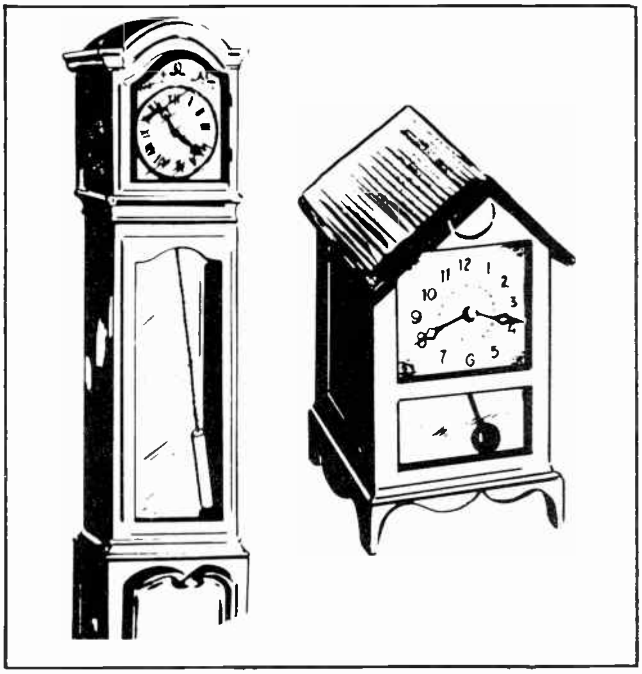


Fig.4. The Frequency of the Pendulum's Swing Depends Upon Its Length.

clocks. The weight on the end of the pendulum is usually adjustable so it can be moved up or down slightly. Should the clock have a tendency to run a little slow, the pendulum can be moved upwards so that its "swing" will be slightly less. This will increase its frequency, and cause the clock to speed up to its proper rate. On the other hand, should the clock have a tendency to run a little fast, it can be slowed down by lengthening the pendulum.

The rate at which the pendulum swings back and forth is called its "resonant frequency". Each pendulum has one resonant frequency -- and only one. There is a different resonant frequency for each different set of conditions. But under any one set of conditions there will be only one resonant frequency.

Section 4. ELECTRICAL RESONANT CIRCUITS

The movement of children's swings and the pendulums on clocks are things which can be seen. For that reason they are reasonably easy to understand. In radio and television circuits we also have resonant conditions. But it is not easy to see what goes on inside such circuits. Sometimes they are not easy to understand. Very often we have to take the word of someone as to exactly what is happening, and thus not be able to see for ourselves the action which is taking

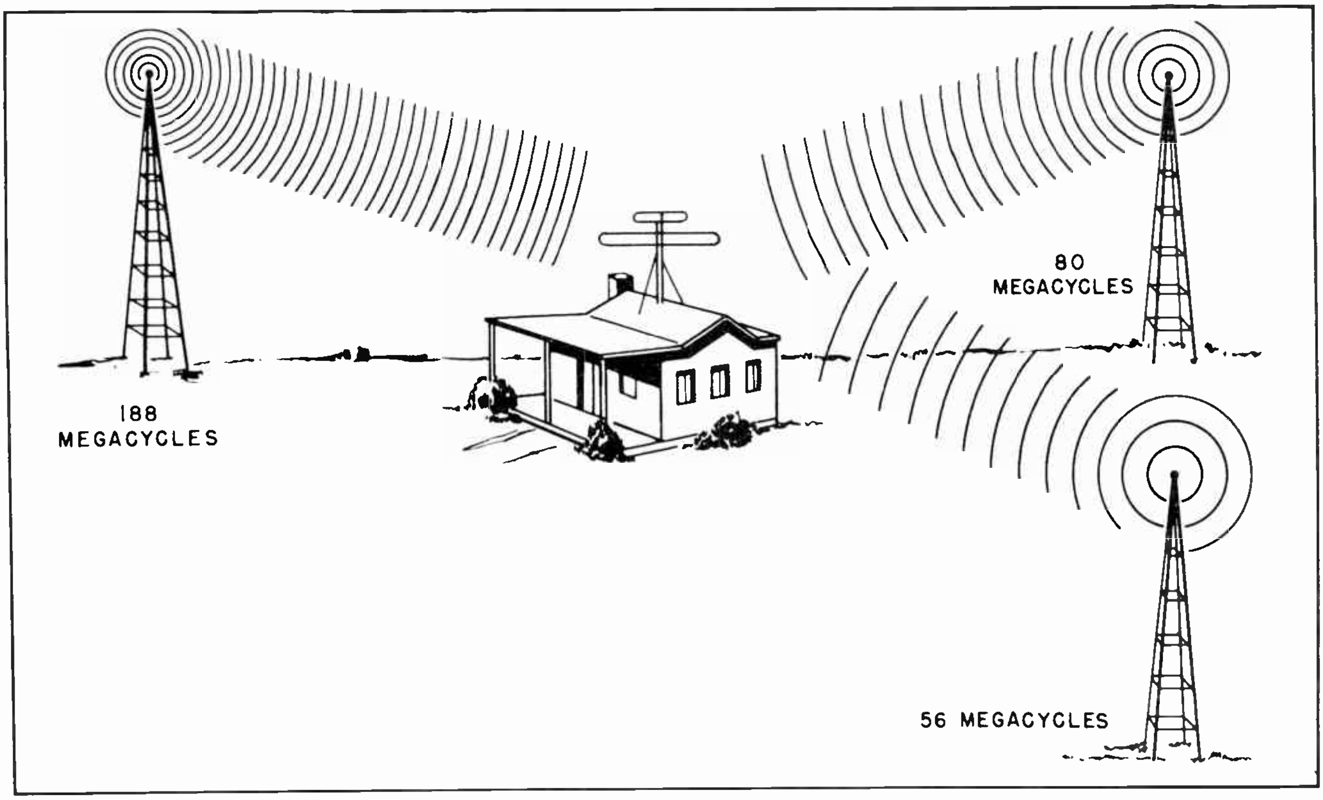


Fig.5. Only a Resonant Circuit can Distinguish Between the Frequencies of the Signals Broadcast by the Many Transmitters.

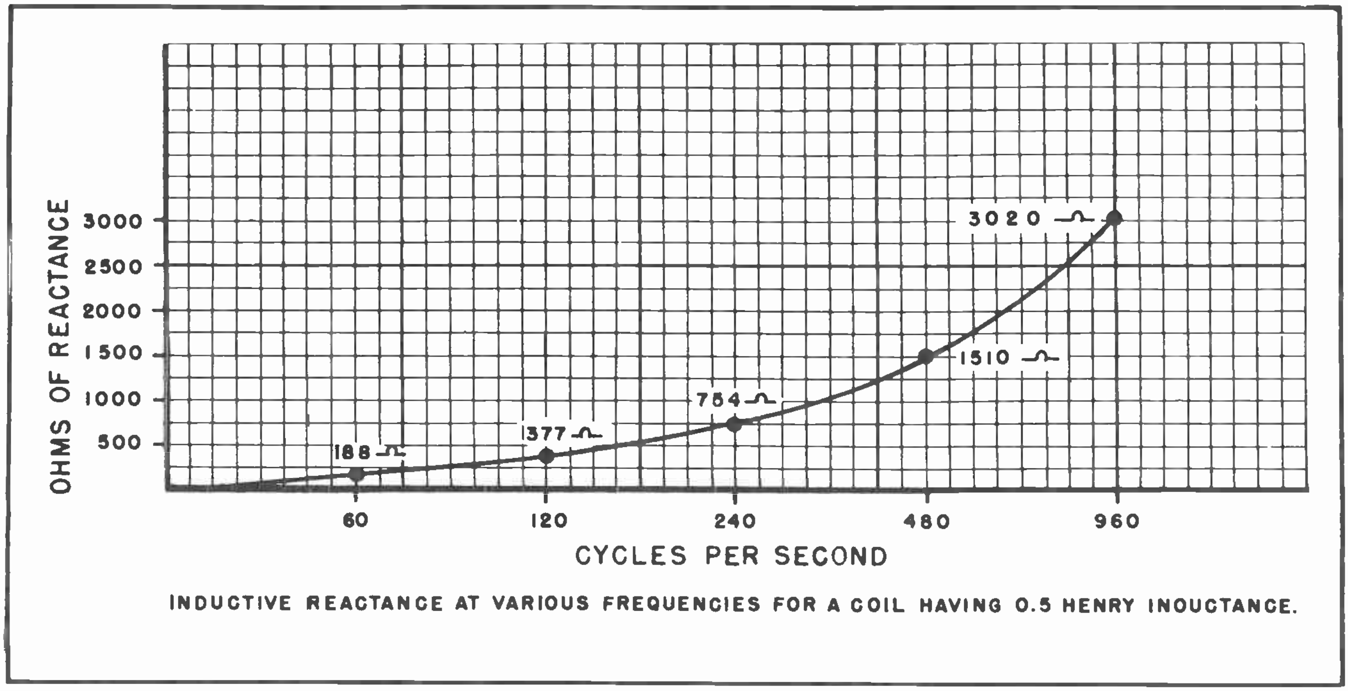


Fig.6.

place. But sooner or later, all men who work with radio or television circuits will deliberately set up resonant circuits for himself, and thus prove the truth of the actual existence of such circuits.

In our study of oscillators we received a brief introduction to the use of resonant circuits in electrical work. But the importance of resonant circuits goes far beyond their use with oscillators. Probably their most important use in radio and television work is in trapping the almost imperceptible signals which have been spread out through space from the transmitters, and bringing them into the receiver. Resonant circuits are used many other places in radio and television work, but in most of the other places they are not the *only* circuits which could be used. But when it comes to trapping the faint signal which exists in space, and distinguishing between the *one* particular signal which is wanted and all the others which are also out there, we have nothing which can compare to the resonant circuit, nor which we could substitute for it. (See Fig. 5.)

In picking some one particular signal from the air we create a resonant circuit which is resonant to the frequency of that one signal, but will not respond to any other frequency. In creating a resonant circuit we must choose a capacitor and an inductance which will *resonate* at the proper signal and thus form the resonant circuit. The problem now is to learn how to determine the proper values of inductance and capacitance.

Section 5. EFFECT OF FREQUENCY ON INDUCTANCE

In our previous studies of inductance we learned that as the frequency of the alternating current or voltage increased, there would be more opposition created within the inductance to the flow of the current through it. This matter of increasing opposition as frequency increases is readily demonstrated by the formula for inductive reactance:

$$X_L = 2\pi f L.$$

According to the formula we find that the reactance of an inductance will increase when either the inductance is increased or the frequency is increased. For any given inductance, that is, a coil which has some known amount of inductance, the opposition -- or reactance -- will progressively become greater as the frequency of the current applied to it becomes greater.

Fig. 6 is a graph showing how the reactance of an inductance of 0.5 henry changes as the frequency increases from zero cycles per second to 960 cycles per second. The horizontal movement of the graph represents the change in the frequency. The vertical rise of the chart shows the increasing amount of reactance in ohms. By extending the graph we can show the reactance for any possible frequency.

It will be noted that as the frequency increases from zero cycles per second -- at which time there is zero reactance -- to 60 cycles per second, the reactance will increase from zero ohms to approximately 188 ohms. Increasing the frequency to 120 cycles per second increases the reactance some more. From the graph we find the reactance has increased to approximately 377 ohms.

Each of these values of reactance can be calculated by using the formula for inductive reactance. The reactance in ohms will be equal to 6.28 x f x 0.5. At 60 cycles we merely substituted 60 for *f*. At 120 cycles we substituted that number -- 120 -- for *f*. The reactance in ohms is the same as the values shown on the graph.

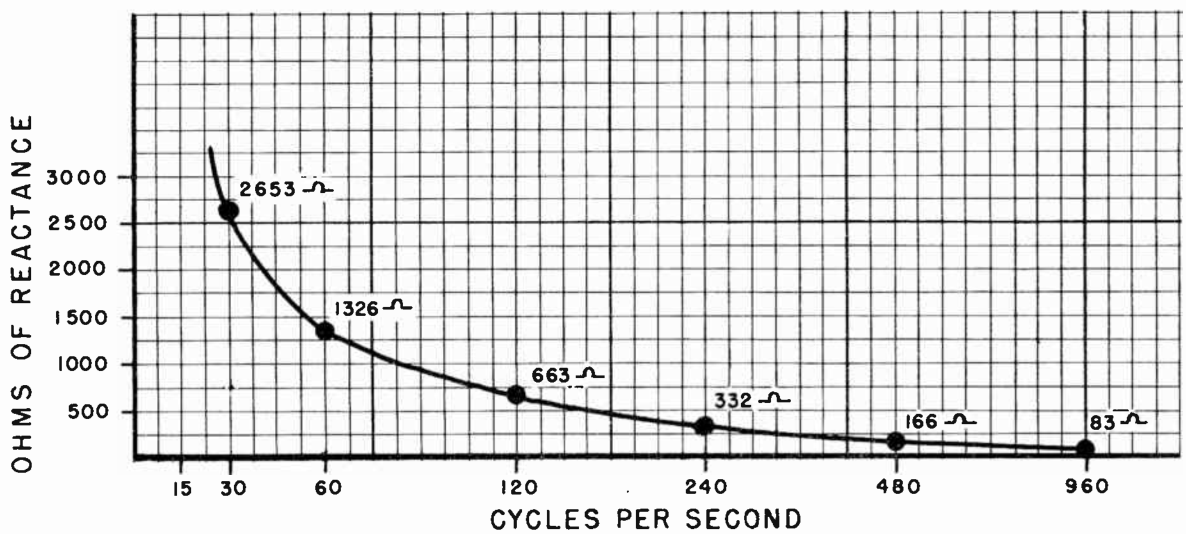
The reactance in ohms was calculated for each of the frequencies: 60, 120, 240, 480 and 960 cycles. The reactance could have been calculated for any of the intervening frequencies. But by drawing a curve between each of the values we calculated we were able to set up a graph which showed us within very close limits what the reactance would be for any particular frequency.

The reactance at 240 cycles was found to be approximately 754 ohms, at 480 cycles it was approximately 1510 ohms and at 960 cycles it was approximately 3020 ohms. Note that in the case of the inductance the curve of the graph will rise as the frequency is increased.

Section 6. EFFECT OF FREQUENCY ON CAPACITANCE

In the case of capacitance we have another situation. You will recall from your study of capacitors and capacitance that the opposition, or reactance, of a capacitor to the passage of alternating current *decreased* as the frequency of the alternations increased. Such a situation is exactly opposite to that caused by inductance.

In Fig. 7 we have set up a graph which shows the changing reactance of a 2 mfd capacitor as the frequency is changed from a little more than 20 to 960 cycles. Of necessity, we must begin our calculation with a frequency somewhat greater than zero. The reactance at zero would be *infinite;* that is, it would be incalculably great. Even a frequency as low as 15 cycles per second causes a reactance so great as to run



CAPACITIVE REACTANCE AT VARIOUS FREQUENCIES FOR A CAPACITOR HAVING 2 MFDS OF CAPACITANCE.

Fig. 7.

off the top of the graph. As a result we begin the graph at the top of the paper, and make our first calculations with 30 cycles per second.

You will recall from your study of capacitors that the reactance presented by any capacitor can be calculated by using the formula:

$$X_C = \frac{1}{2\pi fC}$$

The formula tells us that the smaller the capacitance, or the lower the frequency, the greater will be the reactance. If we have a given value of capacitance, say 2 mfds., we will obtain a variety of reactance by merely changing the frequency.

Fig. 7 is the graph of the reactance of such a capacitor. There we have a capacitance of 2 mfds. Since the formula is designed for use with *farads*, and our capacitor is rated in *microfarads*, we can set up the formula in this manner:

$$X_C = \frac{1}{6.28 \times f \times .000002}$$

Our elementary arithmetic and algebra books tell us we can multiply the top and the bottom of a fraction by the same number and will not change its value. In order to get rid of some of the decimal fractions in the equation suppose we multiply both the top and the bottom by 1,000,000. We will then be working with whole numbers instead of decimals. In multiplying through by 1,000,000 we will change the appearance to look like this:

$$X_C = \frac{1{,}000{,}000}{6.28 \times f \times 2}$$

And although we have changed the appearance, we have in no way changed the overall value of the fraction any more than we would have changed it by multiplying by 2 or by 4 or by 10, or any other number. You will recall that it is a common practice to simplify fractions by multiplying both the numerator and the denominator by some number. This is frequently the practice when it is necessary to add fractions or to subtract them.

Now to get back to our figuring. By substituting the figure 15 in the formula for the frequency we change the formula to this:

$$X_C = \frac{1{,}000{,}000}{6.28 \times 15 \times 2}$$

If you work out the formula to find the reactance you will find it comes to approximately 5307 ohms. This amount of reactance is greater than can be shown on our graph.

But suppose we try finding the reactance the capacitor will present to alternating current when the frequency is raised to 30 cycles per second. By working it out in the same manner as we did for 15 cycles we will find the reactance amounts to approximately 2653 ohms. We have marked 2653 ohms on the graph with a dot directly above the 30 cycle location, and to the right of the point which would represent 2653 ohms on the vertical side of the graph.

When we apply the formula to 60 cycles we find the reactance will amount to 1326 ohms. Again we have marked this location on the graph by means of a dot. Then we find, in succession, that 120 cycles results in approximately 663 ohms, 240 cycles results in approximately 332 ohms, 480 cycles results in approximately 166 ohms, and finally, 960 cycles results in approximately 83 ohms of reactance. (Slide rule values)

After all these points have been located on the graph we have drawn a smooth curve which connects all the dots together. By means of the curve it is then possible to determine the amount of reactance which would result from any frequency.

The main point to remember, however, is that increasing the frequency causes the reactance of a capacitor to decrease.

Section 7. MORE ABOUT CAPACITIVE AND INDUCTIVE REACTANCE

We learned in a previous lesson that when current starts to flow through a coil it causes magnetic waves to spread out into space surrounding the coil. And in spreading out the magnetic lines of force cut the turns of wire in the coil, inducing a voltage in the coil. This induced voltage tries to hold back the inflowing current.

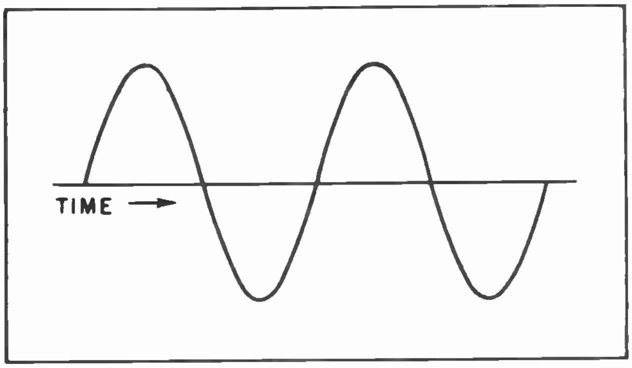


Fig.8. A Sine Wave of Voltage.

The net result is that for a moment after the voltage is applied to a coil the induced voltage tends to oppose the applied voltage and hold back the current. For these reasons the current through a coil always tends to *lag* somewhat behind the applied voltage. If the current is regularly alternating, the peaks of the current will always be just a little behind the peaks of the voltage. In Fig. 8 we have shown the sine wave of an alternating voltage as it might be applied to a coil.

Now study Fig. 9 for a few moments. Note how the curve representing voltage rises from the zero line to maximum, then back through zero to maximum in the other direction. This is the same as happened in Fig. 8. But note also, the current wave is not in step with the voltage. It does not reach its maximum value in the positive direction until after the voltage has reached its maximum value and declined again.

The situation shown by the graph of Fig. 9 is typical of voltage and current relationships when alternating current flows through a coil. The effect of the coil is first to hold back the flow of the current while the magnetic lines of force build up. Then after the applied voltage passes its peak and starts to decline, the magnetic lines of force collapse into the coil inducing a new voltage which forces the current along. But this always occurs after the voltage has passed its peak and starts declining. The main point to remember is this: *Alternating current through a coil always lags behind the applied voltage which causes it to flow.*

Now let's see what the situation is in the case of a capacitor. We learned in an earlier lesson that even a very small voltage was enough to start current flowing into a capacitor. We learned further that as soon as the current started flowing into the capacitor it would build up an opposing voltage in the dielectric of the capacitor. For this reason a tiny voltage could cause a very large current to flow during the fractionally small instant in which the flow started. But to keep a current flowing into the capacitor required an increasingly

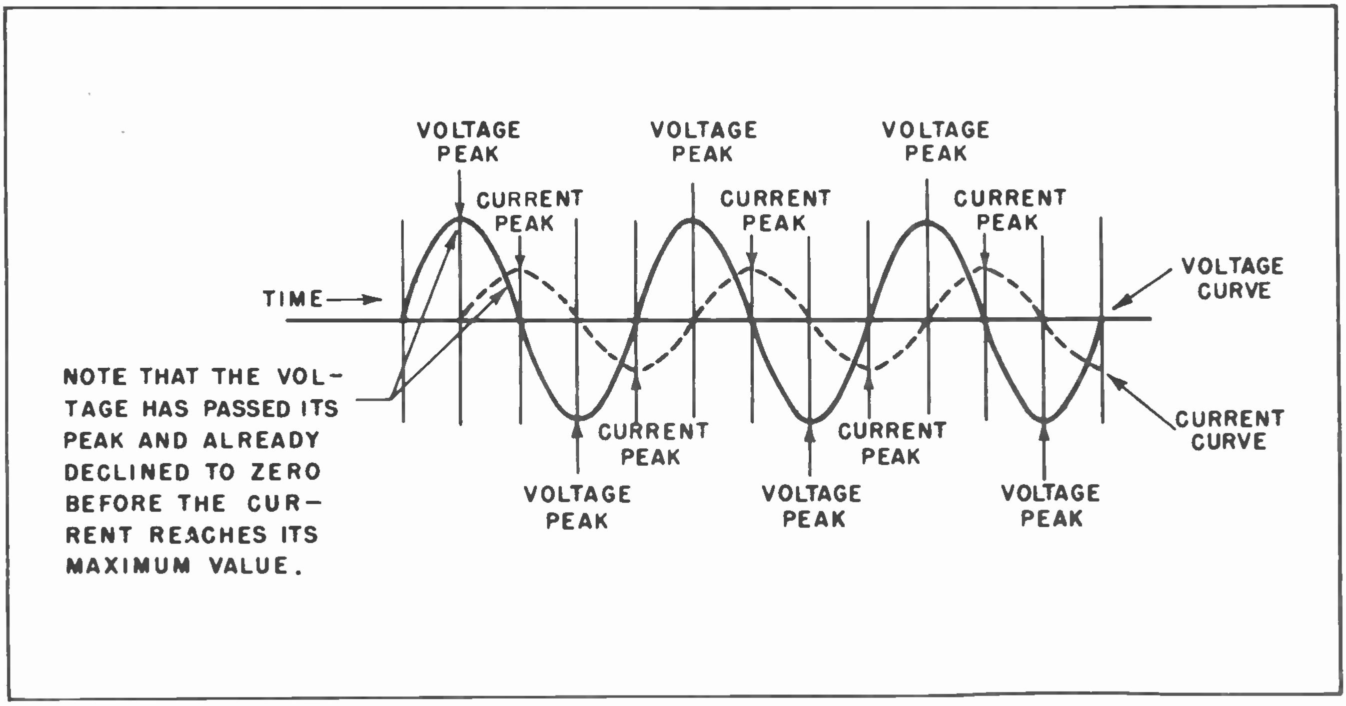


Fig.9. The Voltage Leads the Current Through an Inductance.

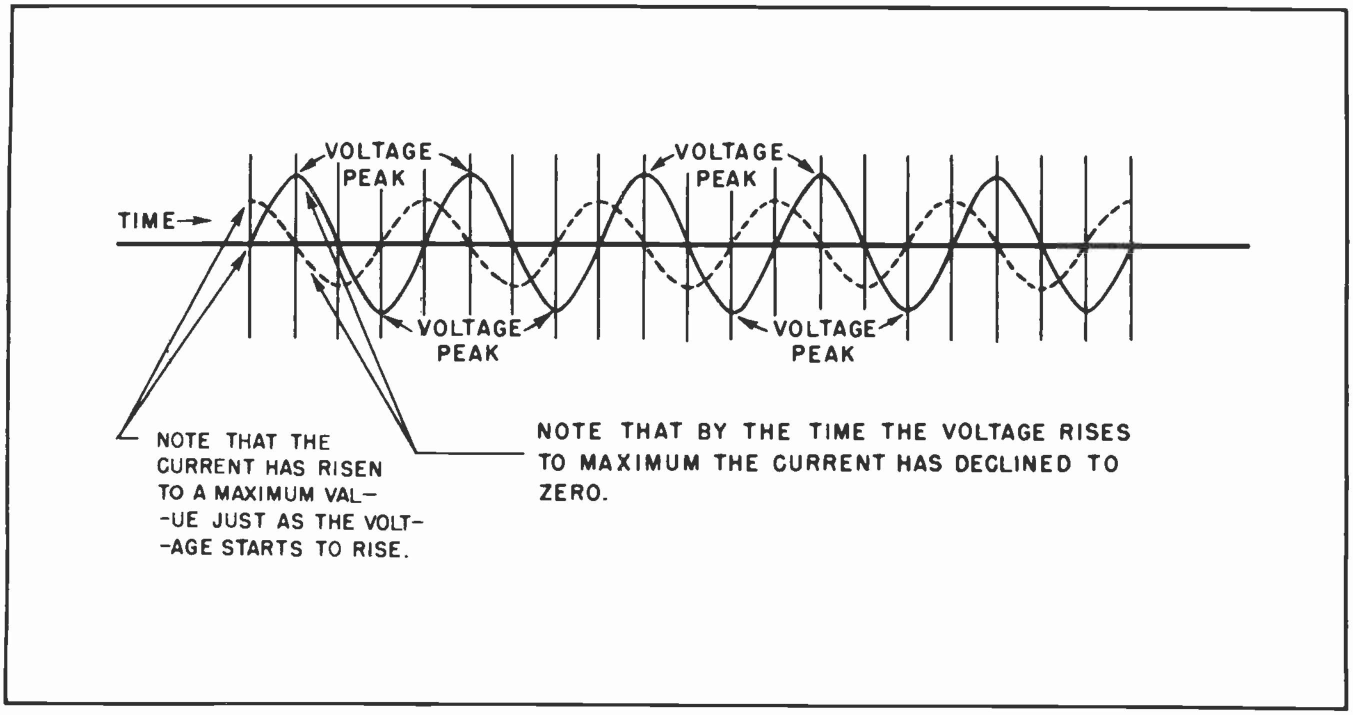


Fig. 10. The Current Leads the Voltage through a Capacitor.

greater voltage. For these reasons the flow of current into a capacitor is greatest just at the instant the voltage starts pushing it in. The current becomes progressively smaller as the voltage builds up until at the instant the applied voltage reaches its maximum value we find the reactive voltage just as great as the applied voltage -- which means that at that instant no more current can flow into the capacitor.

From a practical standpoint we find we have a situation where the current flow into the capacitor is maximum at the instant when the voltage is actually the smallest, while the current flow is the smallest when the voltage reaches the maximum. But note particularly: *The maximum current flow precedes the maximum applied voltage.*

Now we have a situation where the current, for all practical purposes, *leads* the voltage.

Fig. 10 is a graph showing how the current always precedes the voltage in a circuit which contains capacitance. If the circuit is wholly capacitive -- that is, no resistance nor inductance -- the current will lead the voltage by a full 90°. We often say the current leads by 90 electrical degrees.

When the circuit contains only inductance, -- that is, no resistance nor capacitance -- the current will lag a full 90 electrical degrees behind the voltage.

Now it is virtually impossible to create an inductance which does not contain at least a small amount of resistance, and usually a small amount of capacitance. For this reason it is seldom we can create a circuit where the current will lag the voltage by exactly 90°. But by using the highest grade of wire, and carefully designing the coil so as to eliminate as much inter-winding distributed capacity as possible, we can approach 90° very closely, and can in many cases exceed 89 degrees.

The *inter-winding distributed capacity* comes about by reason of the very nature of the materials from which we build the coil. Remember, a capacitor is any two electrical conductors separated by a dielectric. Note that in Fig. 11 the adjacent turns of the coil are composed of metal wire insulated from each other by means of some type of dielectric. The capacity which exists between adjacent turns of the coil is quite small but is nevertheless a genuine reality. At low frequencies the distributed capacity is usually so small it can be completely neglected. But at the higher frequencies it becomes important and must be taken into consideration. This is somewhat similar to the situation we found inside triode vacuum tubes. There we found the

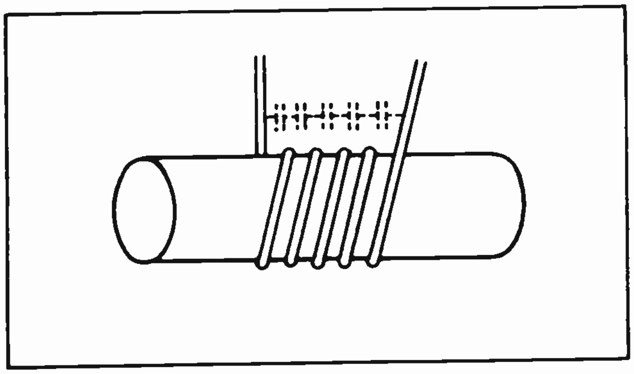


Fig.11. There Exists a Small Amount of Electrical Capacity Between the Turns of Wire on a Coil.

very small interelectrode capacitance which existed between the grid and the other elements was of little importance at low frequencies but became important at high frequencies.

For somewhat similar reasons it is almost impossible to create a capacitor so perfect that the current will lead by a full 90°. The leads to the capacitor consists of some type of metal, and all metals have some amount of resistance even though it may be quite small. Further than this, no dielectric is absolutely perfect. Even the best will have a small amount of loss. Any loss in a capacitor tends to prevent the current from leading by the full theoretical 90°. But, as in the case of the inductance, we can come very close. Many capacitors are so nearly perfect they will cause the current to lead by as much as 89°. For most practical purposes, this is more than sufficient.

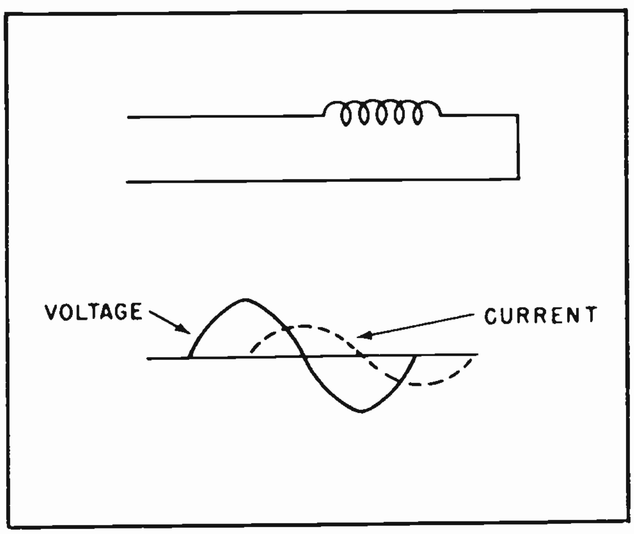


Fig.12.

Section 8. EFFECT OF CAPACITANCE AND INDUCTANCE IN THE SAME CIRCUIT

In Fig. 12 we have a coil in a circuit. From the graph at the bottom of the illustration we find the current lagging behind the voltage. We do not know how much current is flowing in the circuit. The exact amount will depend upon several things: The voltage, the resistance, and the reactance of the coil. To avoid complicating our calculations we will just assume for the moment there is no resistance in the circuit; the entire opposition to the flow of current will then come from the reactance of the coil.

Suppose, for the sake of convenience, we apply 100 volts of 1000-cycle alternating current to the circuit. Suppose further, that the inductance is such that the coil presents exactly 50 ohms of reactance to

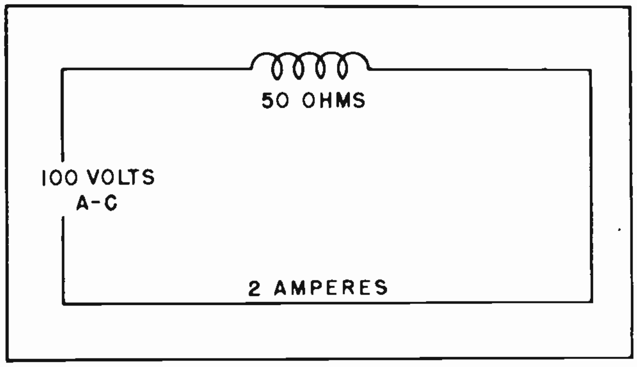


Fig.13.

the flow of current. In this case there will be 2 amperes of current flowing in the circuit. All this is simple enough, and is nothing we do not know already. (See Fig. 13.)

But suppose we now place a capacitor in the circuit as in Fig. 14. What is going to be the effect of the capacitor? How is it going to affect the flow of current?

We already have 50 ohms of reactance due to the action of the inductance. Suppose that at the frequency of 1000 cycles which is being applied to the circuit the capacitor has a reactance of 10 ohms. Now how do we determine the total opposition to the current? How can we learn how much current will flow with both the inductance and the capacitance in the circuit?

The natural assumption is that we would merely add the reactance of the capacitor

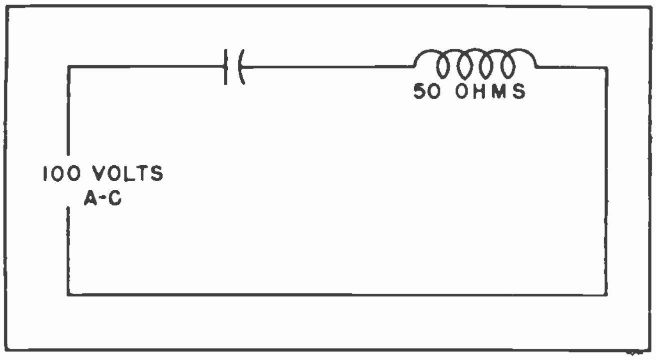


Fig. 14.

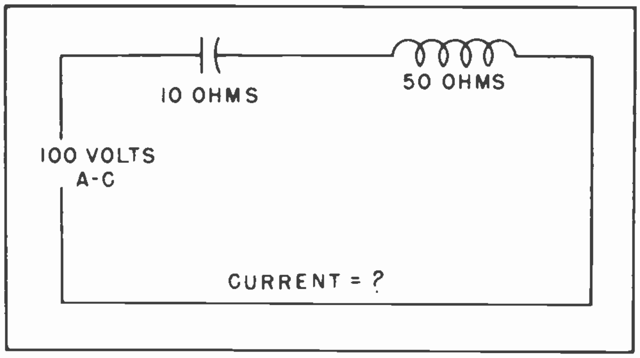


Fig. 15.

to the reactance of the inductance and thus obtain the total reactance. This is what we do in the case of two resistors in series.

But strangely enough, such would be completely wrong. Remember that the current through an inductance lags behind the voltage, and the current through a capacitor actually leads the voltage. By placing a capacitor in series with the inductance we actually reduce the opposition rather than increase it. To illustrate this, suppose we have a beginning pulse of alternating voltage as in Fig. 16. The voltage starts to charge up the capacitor. At this instant a very large current will flow into the capacitor on one side and, of course, out the other side. The maximum amount of this current is going to precede the maximum pressure of the voltage.

Now what happens on the other side of the capacitor? Why the current which flows out the other side of the capacitor is going to start flowing into the coil, and thus start building up a magnetic field around the coil. By the time the maximum voltage pressure comes along, the magnetic field around the coil is going to be partially built up. Instead of an entire voltage having to be used to get the current going through the coil, the action of the capacitor has actually gotten the current started through the coil before the voltage comes along, thus relieving the voltage of part of its work.

If all this seems just a bit confusing, do not feel discouraged. No student ever faced the problem of learning this peculiar action of electrical circuits without at first suffering an acute attack of confusion. But the feeling soon passes and a feeling of elation at learning about such an apparently incomprehensible action soon displaces the feeling of confusion.

But let us get back to the thing we were studying. The ultimate result of the action of the capacitor when placed in series with the inductance is to reduce the total reactance of the circuit. With the capacitor in series with the inductance, more current can flow than when the inductance is in the circuit by itself.

Whenever a capacitor is placed in series with an inductor, the total reactance is obtained by subtracting the reactance of the lesser amount from the reactance of the greater one. In this case the reactance of the capacitor is smaller than the reactance of the inductor. We subtract the 10 ohms of capacitive reactance from the 50 ohms of inductive reactance and come up with a total opposition of 40 ohms. (See Fig. 17.) Since there are now only 40 ohms of opposition to the flow of current, there will be 2-1/2 amperes of current through the circuit instead of only 2 amperes when the inductor was in the circuit by itself.

We have carried our reasoning another step further in Fig. 18. There we find a capacitor which has a reactance of 25 ohms in series with an inductor of 50 ohms. What is our total reactance going to be in that case, and how much current will flow?

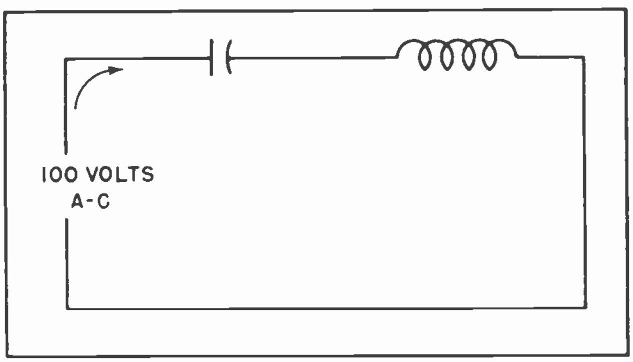


Fig. 16.

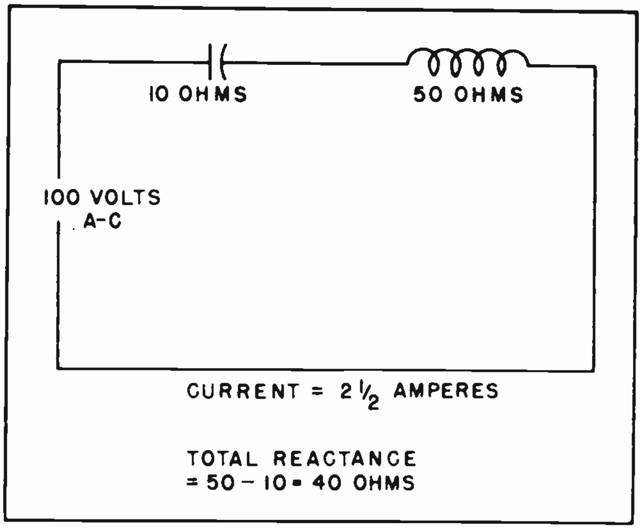


Fig.17.

The same reasoning which we applied before will apply in this case. We subtract the reactance of the capacitor from the reactance of the inductor, and that will give us the total reactance. Subtracting 25 ohms from 50 ohms leaves us 25 ohms of reactance. And 100 volts will force 4 amperes of current through 25 ohms of reactance.

This all sounds very good. But, you might ask, suppose the capacitive reactance was raised to 45 ohms, or even 49 ohms. What would happen then?

The same reasoning still holds true. If the capacitor had 45 ohms of reactance we would subtract that from the 50 ohms of inductive reactance and find we had a total reactance of only 5 ohms. With only 5 ohms of reactance in the circuit the voltage would force 20 amperes of current through the circuit -- provided there was no resistance. (Actually, of course, there is always some resistance present.)

In the case of the capacitor which had a reactance of 49 ohms, we would subtract the 49 ohms from the 50 ohms and find that we had only 1 ohm of reactance in the circuit. If the 1 ohm of reactance was the only opposition in the circuit, the voltage would force 100 amperes of current through the circuit.

If the resistance is kept quite low, a very large current could flow through the circuit. But when the current reaches values of this magnitude even a very small resistance becomes important. If there is only 0.5 ampere flowing in a circuit, a resistance of 0.5 ohms will cause a voltage drop of only 0.25 volts. But when the current increases to 100 amperes that same 0.5 ohm will cause a voltage drop of 50 volts.

You might reasonably point out somewhat triumphantly that we have done all right so far, but what of the situation where the capacitive reactance exactly balances the inductive reactance? What happens there?

Now we are coming to the most important point of all. It is that very situation where the inductive reactance and the capacitive reactance do balance each other out which we have been leading up to. It is the whole point of this lesson. It is, in fact, probably the most important secret of radio and television.

Section 9. RESONANCE

When the inductive reactance and the capacitive reactance are exactly balanced we have the condition known as *resonance*. Tremendous amounts of current can flow through the circuit, provided the resistance is kept low. Further than this a very tiny voltage, of the proper frequency, when applied to the circuit can cause unbelievably large currents to flow, provided the resistance is kept low.

Note we mentioned "proper frequency". Proper frequency is vitally necessary. This is because for a given capacitor of a certain value and for an inductor of some certain value, there is only *one* frequency at which the reactance of both will be equal. At any frequency below the resonant

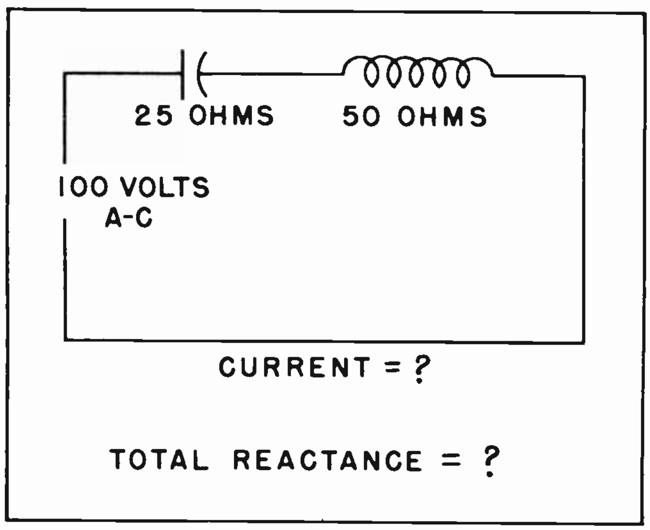


Fig.18.

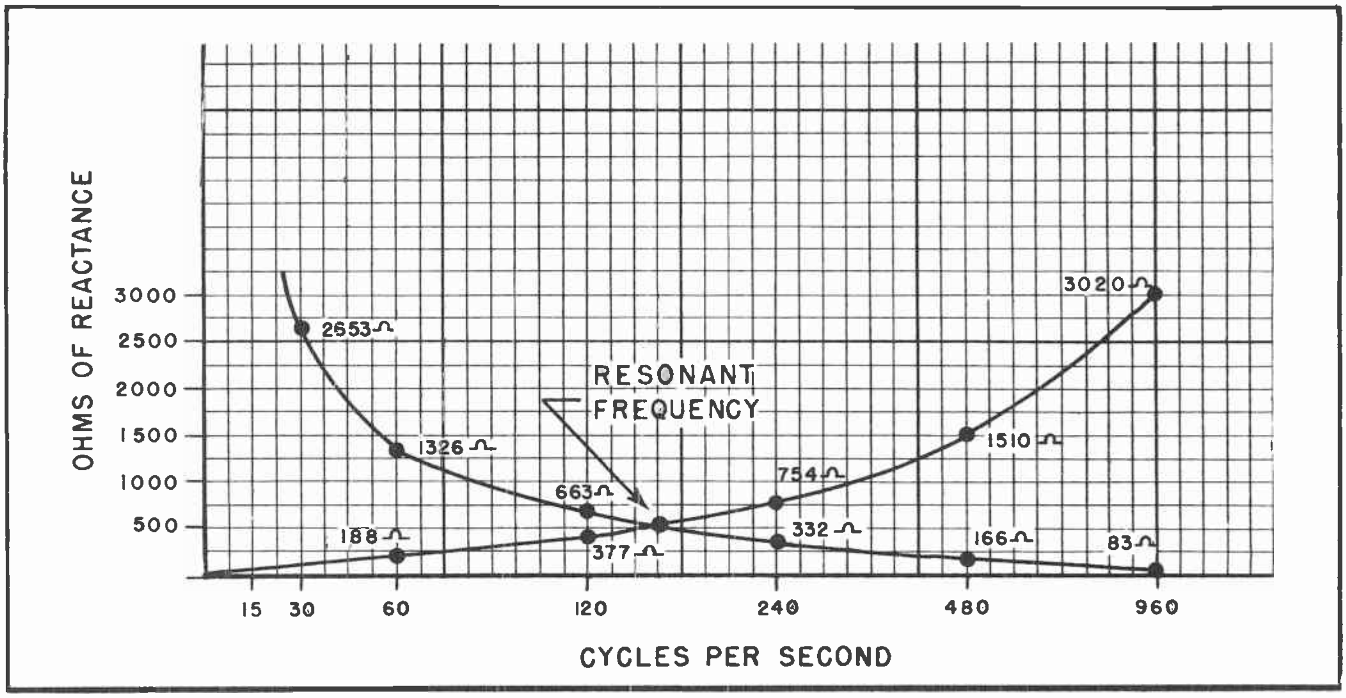


Fig.19. Finding the Resonant Frequency for a Given Inductance and a Given Capacitor by Means of a Graph.

frequency the reactance of the capacitor will be greater than it is at resonance. Likewise, the reactance of the inductor will be lower. For this reason, at any frequency below the resonant frequency, the reactances of the two principle components will be unequal. On the other hand, if the frequency is higher than the resonant frequency, the inductive reactance will become greater, while the capacitive reactance will become less. They will no longer be equal. The circuit will no longer be resonant.

In Fig. 19 we have redrawn the graphs from Fig. 6 and Fig. 7. We have drawn the upward curving graph of the inductive reactance just as it was drawn in Fig. 6. Then we drew the downward curving graph of the capacitive reactance just as it was drawn in Fig. 7. You will note that the two curves cross each other at approximately 160 cycles. Actually it is just under 160 cycles, between 159 cycles and 160 cycles, but closer to 160 cycles. When we have an inductance of 0.5 henry as in Fig. 6, and a capacitance of 2 microfarads, as in Fig. 7, and they are both in the same circuit, that circuit will resonate at approximately 160 cycles.

Had the CAPACITANCE of the capacitor been somewhat less, the capacitive reactance curve in Fig. 19 would have been located above the one we drew. In this case the resonant frequency would have been somewhat higher. Had the INDUCTIVE REACTANCE been slightly less, that curve would then have been a little lower on the graph. There again, the circuit would have resonated at a higher frequency. In one case the capacitance is less; the other, the inductive reactance is less.

From this it follows that the smaller the inductive reactance, or the smaller the capacitance, the higher will be the resonant frequency. By reducing the values of both the capacitance and the inductive reactance, it is possible to raise the resonant frequency to whatever suits our fancy. Note very carefully that it is the capacitance we reduce in order to increase the frequency -- not the capacitive reactance.

We also can reduce the resonant frequency by increasing the capacitance, or increasing the inductive reactance, or by increasing both. For any combination of values of inductance and capacitance there is *one* and only one, resonant frequency.

Section 10. **HOW TO FIND THE RESONANT FREQUENCY BY CALCULATION**

It is frequently necessary, or convenient to determine the resonant frequency of a given coil and capacitor without going to the trouble of constructing a graph. It is very easy to calculate the resonant frequency when the inductance of the coil and the capacity of the capacitor are known.

From our discussions so far it is easy to remember that a resonant condition exists whenever the capacitive reactance equals the inductive reactance. From this we can set up an equation:

$$X_L = X_C$$

We already know that inductive reactance (X_L) is equal to $2\pi fL$. We also know that capacitive reactance (X_C) is equal to $\frac{1}{2\pi fC}$.

So we can go a step further and say that:

$$2\pi fL = \frac{1}{2\pi fC}$$

If you are familiar with the rules of algebra you can probably take it on from this point without any trouble and quickly determine the value of *f*. But in case you are a little rusty on algebraic manipulations we will work out the equation for you. By going through it step by step this way you will be able to understand it a little better than if we gave it to you without an explanation.

Our first step is to get all the *f's* on the same side of the equals sign. To do this we will take the *f* from the right side of the equals mark and move it to the left side. Under the rules of algebra we can do it like this:

$$2\pi fLf = \frac{1}{2\pi C}$$

Now the next step is to get the $2\pi L$ from the left side of the equals sign to the right side. By the rules of algebra we can do it like this:

$$f \times f = \frac{1}{2\pi L \times 2\pi C}$$

We can combine the terms on each side of the equals sign so that the equation now looks like this:

$$f^2 = \frac{1}{4\pi^2 LC}$$

We will take one more step and we will be through. All we do this time is extract the square root of each side of the equation:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

This formula for finding *f* is considered a basic formula in radio and television work. There will be many times when you will find it invaluable. When you know the value of the inductance, merely insert that in the formula in place of the *L*. Then when you know the value of the capacity you insert that in the formula in place of the *C*. From there on out it is merely simple arithmetic.

To see exactly how the formula works, suppose we calculate the resonant frequency of the capacitor and inductor whose reactances have been graphed in Fig. 19. There we had an inductor which had 0.5 henry inductance. The capacitor had 2 microfarads of capacitance. We take our fundamental formula:

$$f = \frac{1}{6.28\sqrt{LC}}$$

and insert the values of *L* and *C*. The formula will then look like this:

$$f = \frac{1}{6.28 \times \sqrt{.5 \times .000002}}$$

It should be remembered the formula deals with *farads* and *henries*, not with fractions of those units. Since our capacitor is rated in *microfarads*, we must change the microfarads into farads. 2 microfarads is the equivalent of .000002 farads.

The next best step is to multiply the values under the radical sign, that is, multiply .5 by .000002. This will give us .000001. So we will insert this in the formula and it will change to look like this:

$$f = \frac{1}{6.28 \times \sqrt{.000001}}$$

The best step to take next is to find the square root of .000001 and thus get rid of the radical entirely. We can find the square root by the use of tables, by using the slide rule, or by calculation. Actually, in this case, the value is such we can probably work it out in our heads. The square root of .000001 is .001. Now we can insert that in our formula and change it to look like this:

$$f = \frac{1}{6.28 \times .001}$$

The most logical step now is to multiply 6.28 by .001. This will give us .00628. By inserting this into our formula we find it looks like this:

$$f = \frac{1}{.00628}$$

All that remains is to divide .00628 into 1. By doing so we come up with the answer. By actually dividing it out we find the answer is slightly over 159, but for round numbers, 160 is close enough. In other words, we find that:

$$f = 160$$

The same procedure can be followed for any combination of inductance or capacities you will ever encounter. You will find that with a little practice you will not have to take all the steps we took in explaining the problem. If you know algebra, or know how to operate a slide rule, you will find the solution falling into your hands with almost no trouble whatsoever. But even if you do not know algebra or have a slide rule, the solution is simple.

Section 11. THE RESONANCE CURVE

Suppose we take the circuit in Fig. 20, which is similar to that of Fig. 14, except that we are using the values in the graph of Fig. 19. We have placed 100 volts across the circuit and then seen just how much current flows at various frequencies. We will lump all the resistance of the circuit at 1 ohm. We will take the first current reading at 30 cycles.

We know from our previous studies that at 30 cycles the capacitor will have so much reactance that virtually no current will flow. The capacitor will have 2653 ohms reactance at 30 cycles. The inductor will have a small amount of reactance to subtract from the capacitive reactance, but not much by comparison. There will be a total reactance of a little more than 2500 ohms, plus the 1 ohm of resistance. Thus the current which will flow at 30 cycles is only a very small part of an ampere. If we place a dot on the graph to represent the current, it will have to be practically on the zero current line.

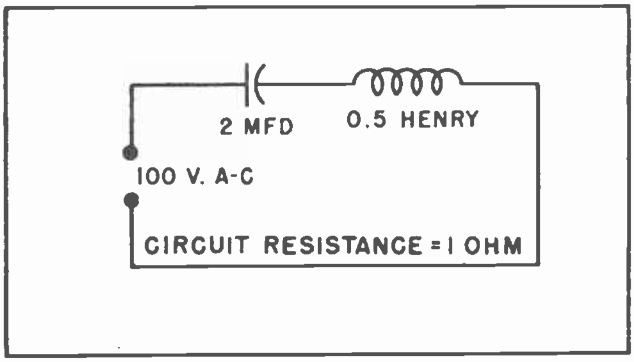


Fig. 20.

At 60 cycles the reactance of the capacitor is still high, 1326 ohms. The inductive reactance will bring that down to about 1138 ohms, but that is still so high, very little current will be able to flow. But we will place another dot on our graph to represent the current at 60 cycles. Here again the dot must be virtually on the zero current line since there will be less than 1/10 of an ampere flowing in the circuit.

At 120 cycles the capacitive reactance has dropped to 663 ohms while the inductive reactance has increased to 377 ohms. The difference here is 286 ohms, still enough to keep the current below 1 ampere. So we will place a dot on the graph to represent the current at 120 cycles.

Let us next measure the current at 145 cycles. Here we find the inductive reactance is approximately 455 ohms and the capacitive reactance is approximately 560 ohms. This is a difference of only 105 ohms. With 105 ohms of reactance in the circuit, the current can rise to about 1 ampere. We will place a dot on the graph to show the value of the current.

Next let us measure the current at 155 cycles. We find the inductive reactance has increased to 486 ohms, and the capacitive reactance has reduced to approximately 514 ohms, a difference of approximately 28 ohms. With only 28 ohms of reactance in the circuit we find the current will rise to approximately 4 amperes. We have marked the graph to indicate the 4 amperes of current at 155 cycles.

Now let's look at 158 cycles. We will find the inductive reactance up to approximately

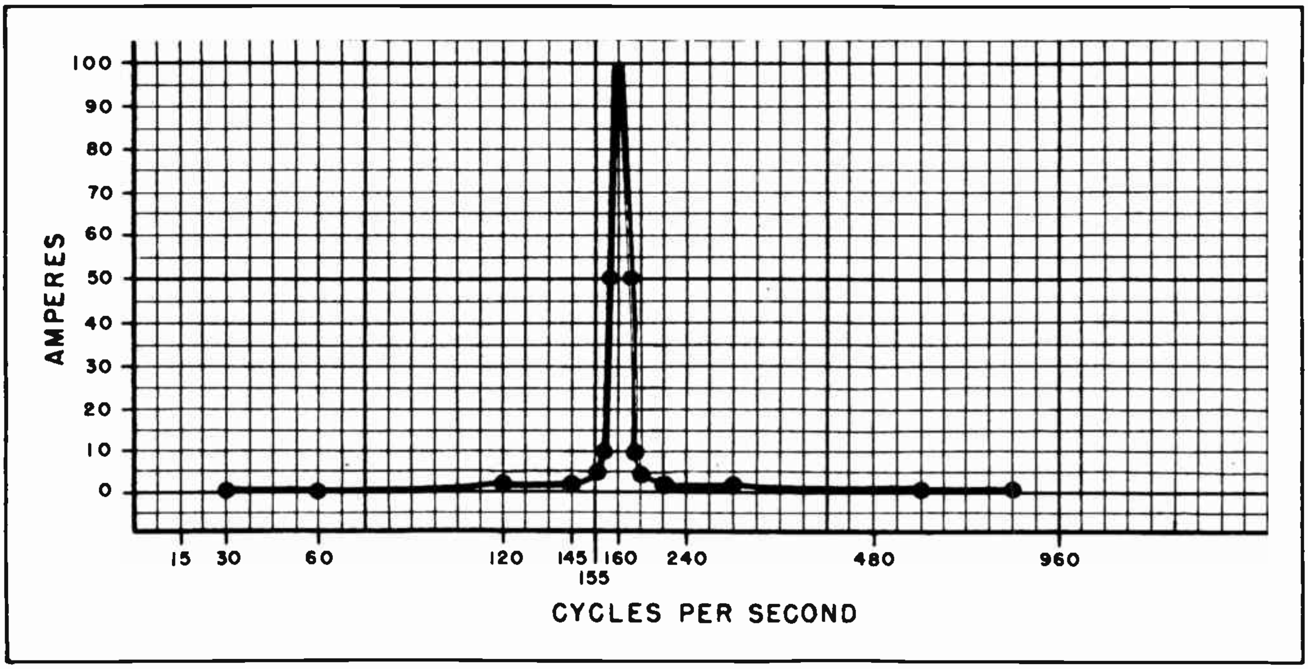


Fig.21. Curve Showing the Current in a Tuned Circuit at the Resonant Frequency.

497 ohms and the capacitive reactance down to approximately 505 ohms. This is a difference of 8 ohms. With only 8 ohms of reactance in the circuit and 1 ohm of resistance we find the current has increased to over 10 amperes. A dot has been placed on the graph to represent the 10 amperes of current.

At 159 cycles the inductive reactance has increased to 499 ohms and the capacitive reactance is down to approximately 501 ohms. This allows approximately 50 amperes of current to flow as indicated by the dot on the graph.

At 160 cycles the circuit will be resonant. There will be no opposition to the flow of current except the one ohm of resistance. Thus there will be 100 amperes of current flowing at 160 cycles.

If the frequency is increased further, the current will immediately start dropping off. The inductive reactance and the capacitive reactance will no longer be the same. The current will drop off as indicated by the curving line on the graph.

The graph shows very clearly the effect on the current in a resonant circuit as the frequency is varied from below the resonant frequency, through the resonant frequency, and on above the resonant frequency. The current remains quite small until the resonant frequency approaches. Then the current gradually increases. As the frequency closely approaches resonance, the current rises quite sharply until right on the resonant frequency it is very high. At that one frequency the flow of current is limited only by the actual resistance of the circuit.

The lower the resistance in the circuit the sharper will be the rise of the current. When the resistance is as low as we have indicated in the foregoing example, the rise of the current is exceedingly sharp. Under actual operating conditions it frequently is not possible to obtain a resistance as low as 1 ohm when the inductance and capacitance are as high as the figures used in the problem. The effect of higher resistance in a resonant circuit is to lower the peak of the curve and widen out the base somewhat. The curve shown in Fig. 22 is a little closer to the curve of an actual circuit than is the one in Fig. 21.

Occasionally it is desirable to deliberately broaden the base of the curve, or to reduce the height. That can be done by increasing the resistance. Actually, a resistance is not always inserted in the circuit. What is done is to use smaller wire in the inductance. This has the effect of reducing the height of the current curve. It should be mentioned that in some television circuits, particularly in the video I-F circuits, the tuned circuit is deliberately loaded with resistance in order to make the circuit respond to a wider band of frequencies. Much more will be said about video I-F circuits when we reach that subject.

Section 12. THE CIRCUIT "Q"

The higher the peak of the curve the higher will be the "Q" of the circuit. The "Q" of a circuit is a figure of merit. It defines the ratio of the reactance of the circuit to the resistance. If the reactance is quite high with respect to the resistance, it is understandable that the curve will go higher, just as we have explained. And as it goes

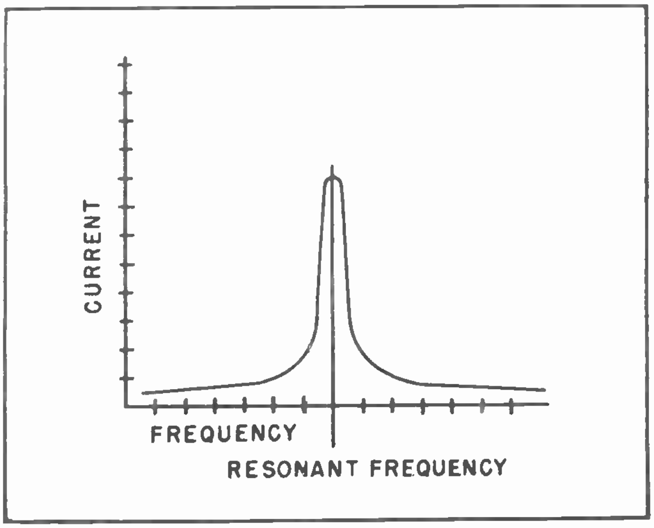


Fig.22. The Broader Curve at Resonance When there is a Larger Proportion of Resistance. This is the Curve of a Circuit with a Lower "Q" than Fig. 21.

higher the "Q" goes up. Normally the "Q" of a circuit should be as high as is practical, and is expressed by means of an equation:

$$Q = \frac{X}{R}$$

Much more will be said of the "Q" of a tuned resonant circuit after we have advanced considerably further in our studies.

The resonant circuit we have been discussing is called a *series resonant circuit*. This is because the capacitor and the inductor are in series with each other and with the source. It should be remembered that the prime characteristic of a series resonant circuit is that the opposition,

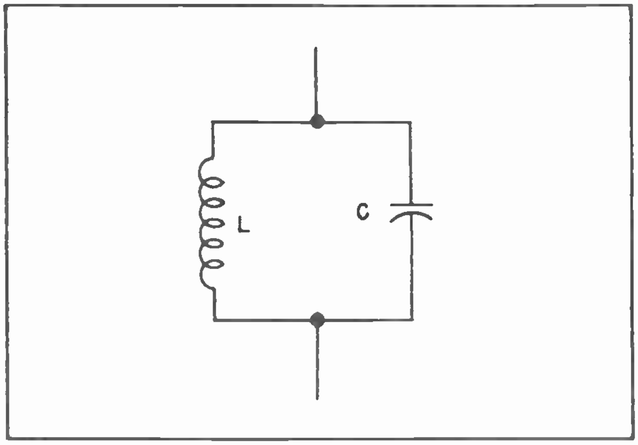


Fig.23. Parallel Resonant Circuit.

or *impedance* becomes very small at the resonant frequency. *The impedance is minimum at resonance, the current is at maximum.*

Section 13. THE PARALLEL RESONANT CIRCUIT

A resonant circuit can be either series or parallel. Both are widely used in radio and television work. But in some ways the parallel resonant circuit is even more useful and important than the series resonant circuit. Fig. 23 illustrates the essentials of a parallel resonant circuit. You will recall we encountered this circuit in our studies of the oscillator. We will discuss it slightly further at this point, and continue our study of it in subsequent lessons.

Suppose a small electrical voltage was placed on the circuit as shown in Fig. 24. When the voltage reached the junction at point *A* it would tend to send part of the current toward the inductor and part of it toward the capacitor. If the alternating voltage was at any frequency except the

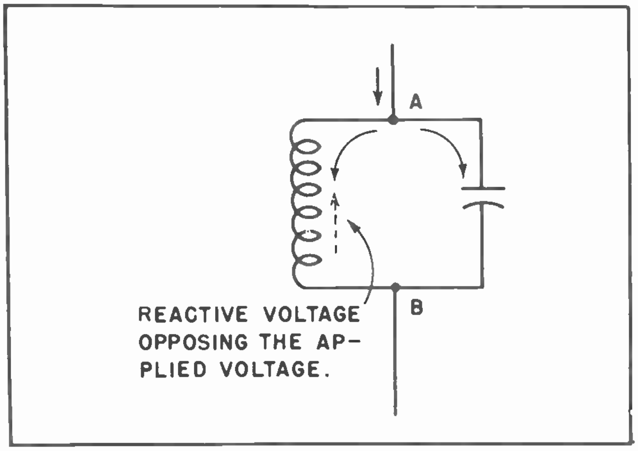


Fig.24.

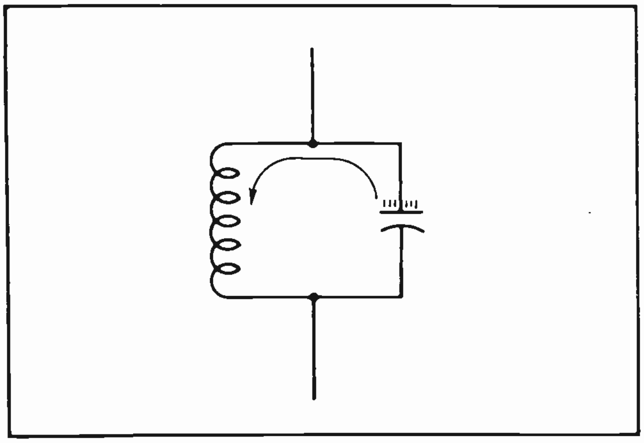


Fig.25.

resonant frequency, part of the current would pass through the inductor and part would pass through the capacitor. There would merely be two paths for the current to follow, and neither would seriously interfere with the other.

But suppose the frequency was such that it would cause the circuit to "resonate". That is, suppose it was of such a frequency that the reactances of the inductor and the capacitor were equal.

If an alternating current at the resonant frequency of the circuit tries to get through the circuit, it will encounter an entirely different situation from that which meets a non-resonant frequency. The current will divide just as before. The part trying to go through the coil will set up magnetic lines of force around the coil, and will meet momentary opposition. That pulse of current will be delayed.

But the portion of the current which moved into the capacitor meets little opposition at first, and the current flows in quite freely. But opposition to the influx of current into the capacitor builds up quite rapidly. At the same instant the current through the coil side overcomes its opposition and starts getting through; the voltage built up on the capacitor will cause it to discharge. The current from the capacitor will also flow through the coil at the same time the original pulse from the outside succeeds in getting through. (See Fig. 25.)

But as soon as the current begins to decrease in the coil, the magnetic lines of force begin collapsing and these induce a voltage in the coil which sends the current into the other side of the capacitor. The capacitor is thus charged up from the other side.

If the frequency which is being applied from the outside is exactly the same as the resonant frequency of the circuit, the outside current will have been reversed just as the coil in the resonant circuit is collapsing. The outside voltage and the induced voltage from the collapsing magnetic field will combine to charge up the capacitor as in Fig. 27. Then at the instant the capacitor discharges and builds up another field around the coil, the external voltage will have reversed again, thus tending to charge up the other side of the capacitor.

This condition continues indefinitely. Each time the external current and voltage reverses, it finds the voltage and current inside the resonant circuit just right to oppose its passage. For this reason a current and voltage at the resonant frequency of the circuit finds great difficulty in

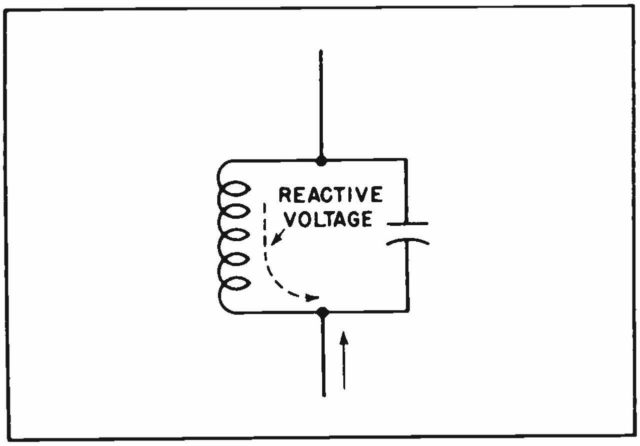


Fig.26.

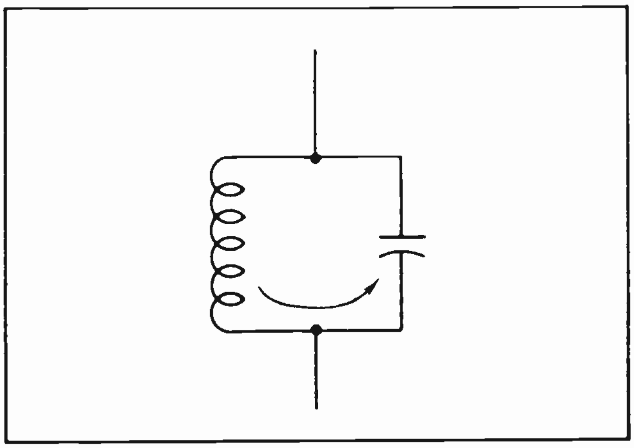


Fig.27.

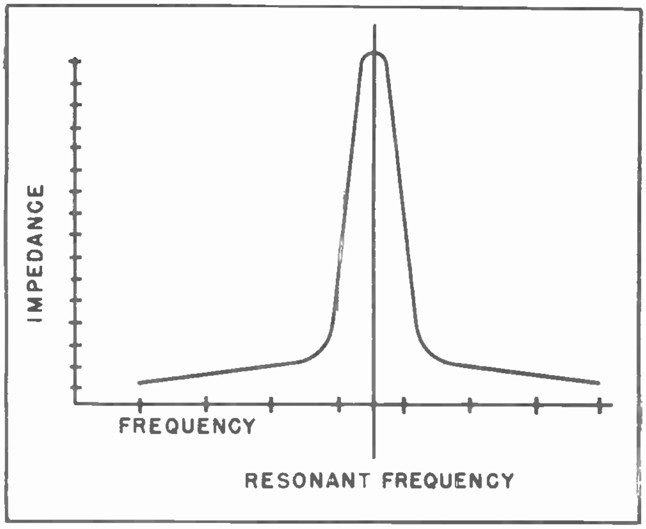


Fig.28. Impedance Curve for Parallel Resonant Circuit.

passing through a parallel resonant circuit. And, for this reason, a parallel resonant circuit offers maximum opposition (impedance) at the resonant frequency.

A curve can be drawn to show the *impedance* of a parallel resonant circuit. The impedance curve for a parallel resonant circuit is almost identical to the current curve for a series resonant circuit. (See Fig. 28.)

At all frequencies removed from that of resonance, the parallel circuit will offer very little opposition to the passage of alternating current. But at the point of resonance, virtually no current can pass through the circuit.

It is not hard to figure out uses for circuits such as those of parallel and series resonance. If we have a flock of existing frequencies in a circuit and want to pass only one of them, we can accomplish that result by using the series resonant circuit. On the other hand, if we want to pass all of them but one, we can accomplish that by a parallel resonant circuit. An example of the latter use is the resonant circuit used to pass all the frequencies in the antenna circuit of a radio or television receiver except the one it is desired to receive.

An alternating current or voltage need not be applied at the side of a parallel resonant circuit. Suppose such an alternating current were to be applied by means of another coil as in Fig. 29. A very small impulse, provided the frequency was exactly right, could set up quite large currents and voltages within the resonant circuit itself. The "tickling" signal could be very small, but if its frequency was exactly right, the currents and voltages within the tuned resonant circuit itself could reach considerable magnitudes.

Now we will see just how this is useful to us in radio and television work. We already know the air is constantly filled with a large number of radio and television signals. Each of these signals is operating on a different frequency. These frequencies in the air are in the form of electromagnetic waves which are spreading out in space in all directions from the transmitter. As these electromagnetic waves cut across any conductor they will induce voltages within the conductor in the same manner any other magnetic wave will induce a voltage in any other conductor.

If a conductor in the form of an antenna is raised into space, the electromagnetic waves will cut across the conducting material of the antenna and induce a voltage in it. If a connection is made to such an antenna as in Fig. 30, the voltage can be led into a radio or television receiver and used to set up voltage impulses in the tuned resonant circuit of the receiver.

When a signal consisting of electromagnetic waves strikes the antenna at a frequency which is exactly the same as the resonant frequency of the tuned resonant circuit in the receiver, there will be strong alternating currents and voltages caused to circulate within the tuned circuit. If one end of the tuned circuit is then connected to the grid of a vacuum tube, the voltages can be amplified and passed along to another circuit.

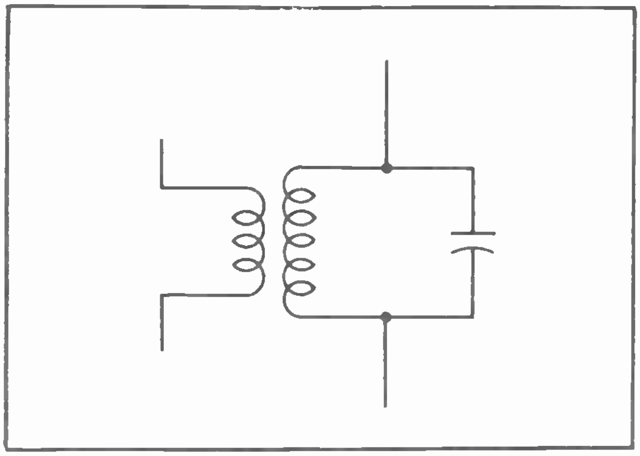


Fig.29.

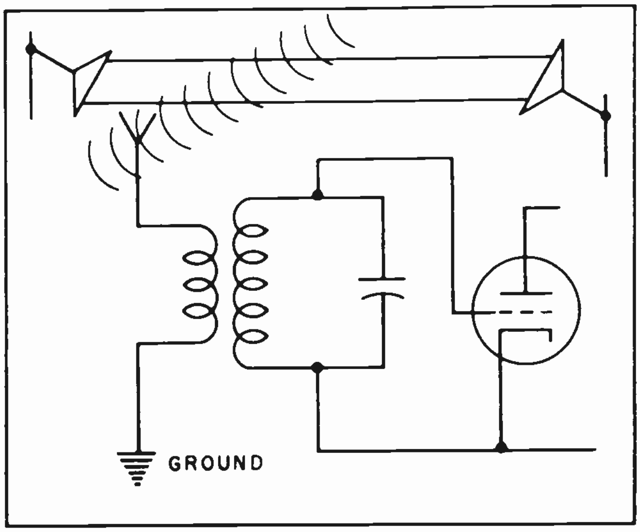


Fig.30. A Parallel Resonant Circuit in a Radio or Television Receiver.

Right there is the whole secret of how radio and television signals are picked up out of the air. The electromagnetic waves passing through space induce tiny voltages in an antenna. These tiny alternating voltages, possibly only a few hundred microvolts in strength, or even less, are used to excite a tuned resonant circuit. The voltage inside the tuned resonant circuit is then amplified by means of vacuum tubes.

Section 14. VARIABLE TUNED CIRCUIT

In all our discussions we have intimated that the inductor was of some one fixed value of inductance, and the capacitor was of some one fixed value of capacitance. And indeed, such is often the case.

But there is no reason why either the capacitor or the inductor needs to be one fixed value. Either, or both, can be variable. If either the capacitor or the inductor is variable it will then be possible to change the resonant frequency of the tuned resonant circuit at will.

In most radio receivers it is a standard practice to use a variable capacitor in the first stage of the receiver. The tuned resonant circuit can then be changed so as to resonate with whatever signal frequency it is desired to pick up out of the air.

As an example of this, it is a common practice to use a coil which will resonate with the smallest amount of capacity the capacitor can be changed to. In most cases this is about 1600 kilocycles, the top of the broadcast band. Then the capacity of the capacitor can be increased. As the capacity is increased, the resonant frequency of the circuit is lowered. As more and more capacity is added to the capacitor, the resonant frequency becomes lower and lower until it reaches the bottom of the broadcast band at 550 kilocycles. Thus by varying the capacity of the variable capacitor it is possible to tune the resonant circuit to the frequency of any broadcast station between 550 kilocycles and 1600 kilocycles which might be on the air.

If it is desired to pick up stations operating at a higher frequency than those in the broadcast band, such as police calls, aircraft, ships, automobiles, and so forth, the original inductor coil is switched out by means of a "band switch" and another coil which has less inductance is switched into the resonant circuit. When the capacitor is at minimum value, the resonant frequency will be much higher with the second inductor coil than with the first. Many radios have two or three different bands, each of which can be switched in or out at the will of the operator. Communications receivers, such as those used by amateurs and commercial radio operators, frequently have as many as six different bands.

Much the same procedure is followed in switching a television receiver from one channel to another. The receiver is switched from one channel to another by means of a band switch which changes the inductance in the resonant circuit of the first stage of the receiver. Then the tuning of the receiver is sharpened by adjusting the "fine tuning" which is simply an adjustable capacitor.

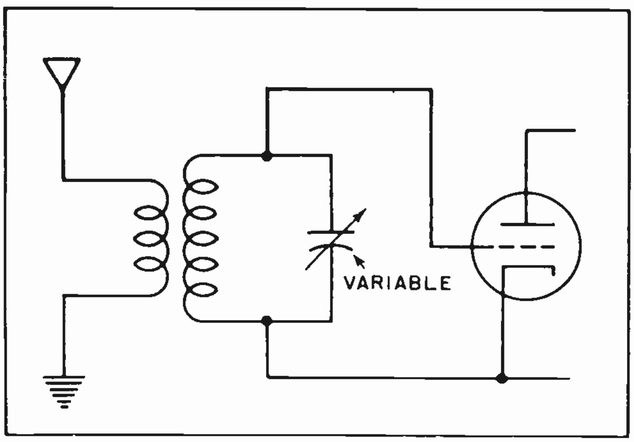


Fig.31. Changing the Resonant Frequency by Means of a Variable Capacitor.

You may find trouble in understanding and remembering everything which has been mentioned in this lesson. We cannot stress too strongly the importance of learning and remembering everything contained here. However, we recognize the difficulty of fully understanding such technical information as is set forth here. For that reason we will again discuss from several angles most of the information we have given you in this lesson. We would like to repeat again, even at the risk of becoming monotonous, that the material contained in this lesson is literally the key to all radio and television work. The things we have mentioned here are the very things which make radio and television possible. Without them there would be no such things as radio and television.

NOTES FOR REFERENCE

Electrical resonance is a condition where the reactances of the capacitor and the inductor are exactly equal for some particular frequency.

For every value of capacity and inductance there is one resonant frequency.

The formula for finding the resonant frequency is:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The "Q" of a circuit is a figure of merit. The higher the "Q" the better the circuit. The formula for "Q" is:

$$Q = \frac{X}{R}$$

The "Q" of a circuit is the ratio of the reactance to the resistance.

A series resonant circuit has a *mimimum* of impedance at the resonant frequency.

A parallel resonant circuit has a *maximum* of impedance at the resonant frequency.

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RADIO TELEVISION

IMPEDANCE

Contents: Introduction - Nature of Impedance - Pythagorean Theorem - Combining Resistance and Reactance into Impedance - Why We can Use Pythagoras' Theorem to Find Impedance - Combination of Resistance and Capacitive Reactance - Combining Capacitive Reactance, Inductive Reactance and Resistance - Impedance Matching - Ohm's Law for A-C - Power Transfer Through Impedance Match - Impedance Matching by Transformer Action - Low Pass Filters - High Pass Filters - Band Pass Filters - Notes for Reference.

Section 1. INTRODUCTION

In the course of our studies we have mentioned the word *impedance* quite a few times. Each time we did so we said we would discuss the nature of impedance in considerably greater detail in a later lesson. It is not desirable that we postpone the study of impedance any longer.

The way some writers and teachers present impedance, it is a most intricate and difficult subject to understand. Such a thing need not be. By getting down to earth in the explanation of impedance, it can be made a most interesting subject. It is well that it can be made interesting since you will be working with impedance during every one of your working days so long as you make television your business.

We have previously mentioned that the impedance of a vacuum tube anode circuit must be *matched* in some way with the impedance of the voice coil circuit in a loudspeaker. The anode circuit of the vacuum tube has a *high-impedance* while the voice coil circuit is a *low-impedance* one. We did say at that time that it was the conventional practice to use a transformer in order to effect the match, but did not go into any detail to explain why such a match was deemed essential.

The television technician runs into another important instance of impedance matching when installing a television receiver. One of the most important items in correct installation is matching the impedance of the roof-top antenna to the input impedance of the receiver. This is extremely important in the so-called "fringe" areas where the transmitted signal is somewhat weaker than it is nearer the television transmitter.

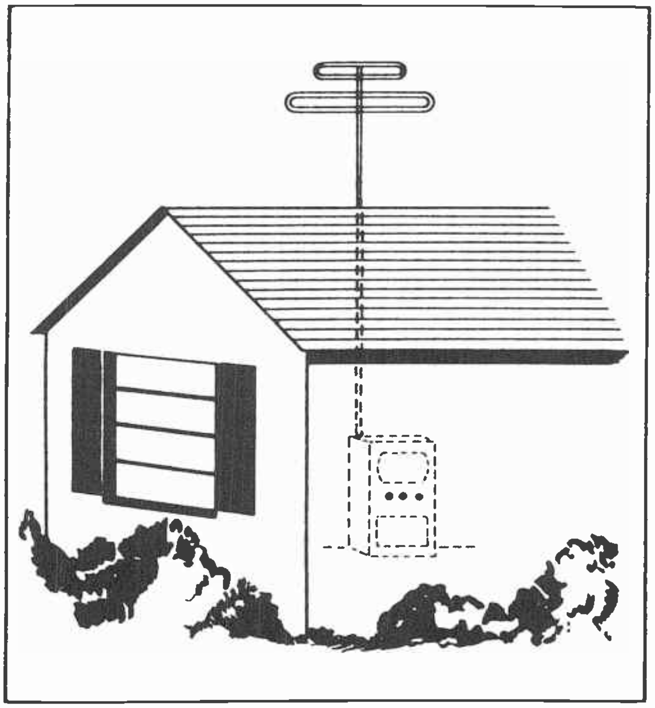


Fig.1. The Impedance of the Antenna Must be Matched to the Input of the Receiver for Good Reception.

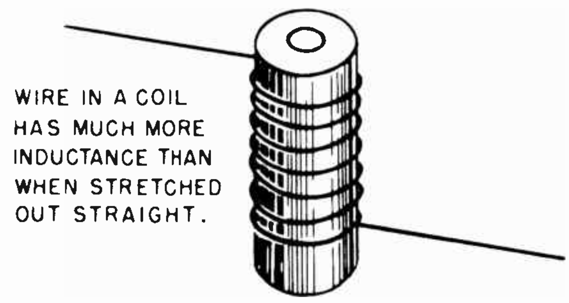


Fig. 2.

Section 2. **NATURE OF IMPEDANCE**

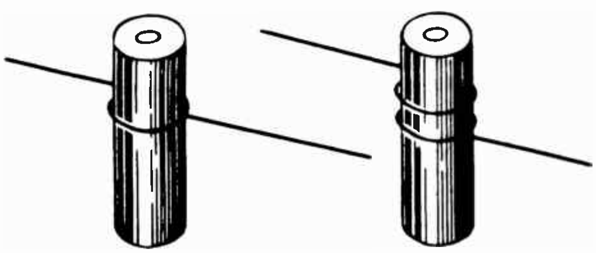
Before we can begin working with impedance in an intelligent manner, it is necessary that we first understand the basic nature of it. In this respect impedance is defined as being the total opposition offered to the flow of current in an electrical circuit. Since reactance -- either inductive or capacitive -- is not generally considered to be an obstruction to the flow of direct current, it follows that we encounter reactance only when working with alternating current. This means that resistance is the only factor which limits the flow of direct current. Since this is true, the total opposition to the flow of direct current is resistance. In this respect it would be possible to say that impedance is to be found in both direct current circuits and in alternating current circuits, even though resistance is the only opposition in the case of direct current.

However, since resistance *is* the only opposition to the flow of direct current, the term is seldom used in connection with it. Technically, the term impedance can be applied to direct current; in practice however, we rarely use the term in direct current work.

In the case of alternating currents, however, we find an entirely different situation. We find the current opposed by the ohmic resistance of the conductor, just as in the case of direct current, *plus* the reactance of coils and capacitor.

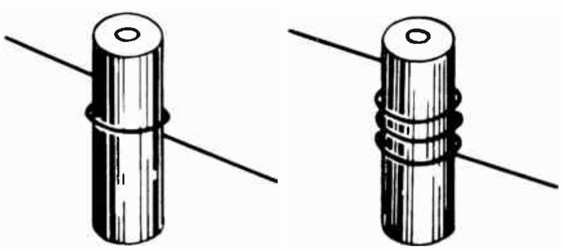
In the case of a coil we will have a form wound with a considerable amount of wire. The fact that the form is wound with many turns of the wire causes the lines of magnetic force from each turn to cut across all the other turns, thus causing any given length of wire to have much more inductance when wound in the form of a coil than when stretched out straight.

It is somewhat surprising at first to realize just how rapidly the inductance increases when wire is wound in the form of a coil. Roughly speaking, it increases as the *square of the number of turns.* By this we mean that if one turn of wire has a certain amount of inductance, two turns will have four times as much inductance, three turns will have nine times as much inductance, and ten turns will have 100 times as much inductance as one turn. There are some practical limits to this rule, since some of the lines of force from one turn may not cut all the other turns when the coil becomes too large. But within limits this rule is reasonably accurate. It should be noted that the rule mentioned is not as accurate as an engineer would need, but since you are not likely to be designing inductance coils for a long time, the general rule is accurate enough for the time being.



TWO TURNS OF WIRE HAS FOUR TIMES THE INDUCTANCE OF ONE TURN.

Fig. 3.



3 TURNS OF WIRE HAS NINE TIMES THE INDUCTANCE OF ONE TURN.

Fig. 4.

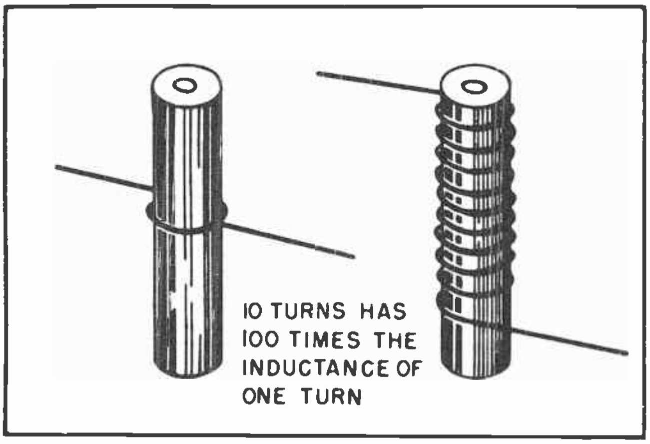


Fig.5.

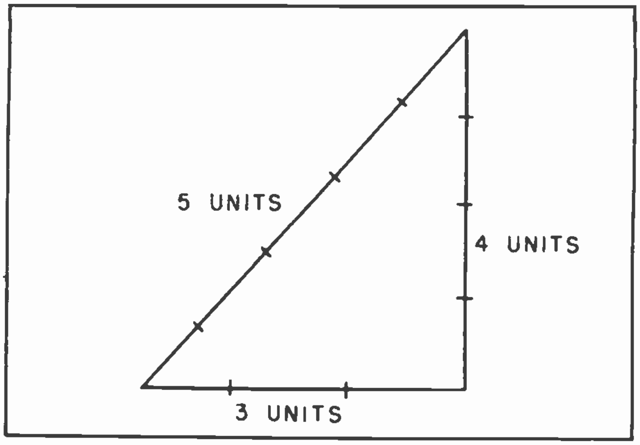


Fig.6. A Right Angle Triangle.

All the inductive reactance in the coil will have the effect of restraining or opposing, the flow of alternating current. But note also that the coil is composed of wire, and that all wire has resistance. The resistance of the wire will also tend to oppose the flow of alternating current.

Now for the sake of convenience, let us assume that a certain coil will present 5 ohms of resistance and 12 ohms of reactance to the flow of alternating current. The total opposition of both the resistance and reactance is called the *impedance*. One of our first problems is to determine just how many ohms of impedance will oppose the flow of alternating current when the resistance amounts to 5 ohms and the reactance amounts to 12 ohms.

The first impulse is to say that since both represents opposition to the flow of current, the best thing would be to merely add them together and that should give us the total impedance. Unfortunately, the solution is not quite so easy -- though it can be easily learned.

Section 3. PYTHAGOREAN THEOREM

It so happens that reactance and resistance in an electrical circuit can be combined by following an old mathematical formula first proven by a Greek mathematician named Pythagoras about five hundred years before the birth of Christ. The mathematical formula has come to be known as the *Pythagorean Proposition*, or, more commonly, as the *Pythagorean Theorem*.

Even so, the theorem was not original with Pythagoras. He merely proved what had been generally accepted for many years before his time. In fact, there is evidence that the Ancient Egyptians and the Chinese had made use of the formula as much as 1500 years before Pythagoras was able to prove that it actually was a basic mathematical rule. The Egyptians used it for many centuries in laying out their land, but they were unable to work out the mathematical proposition to an exact degree where it would fit every existing situation.

Essentially what Pythagoras did was to prove the unchangeable relationship of the three sides of a right triangle, such as shown in Fig. 6. He proved that when the length of any two of the sides was known it was always possible to determine the length of the third.

Pythagoras proved that if you added the square of the base of the triangle to the square of the altitude, as in Fig. 7, it would give you the square of the hypote-

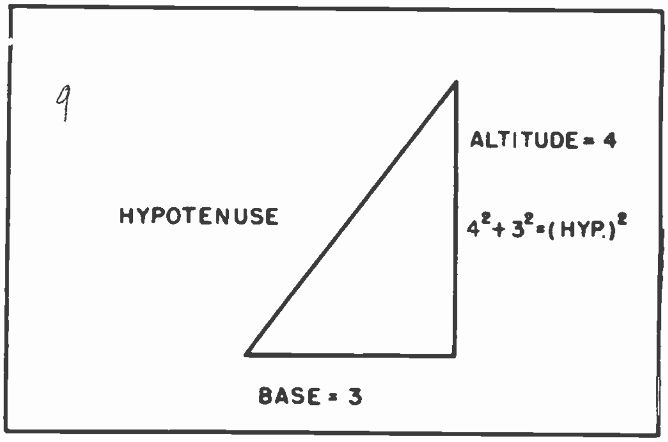


Fig. 7. The Square of the Hypotenuse is Equal to the Sum of the Squares of the Other Two Sides.

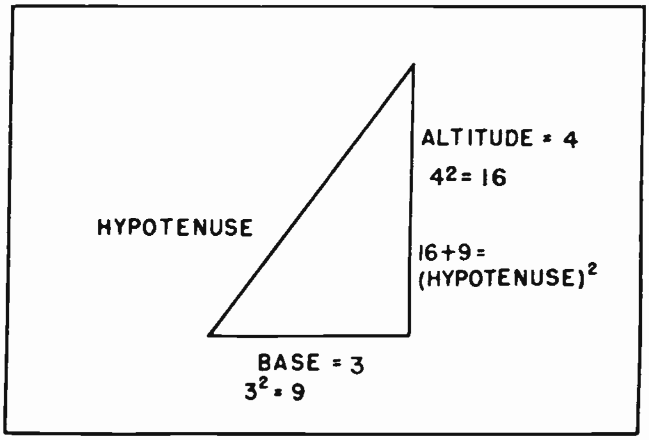


Fig. 8.

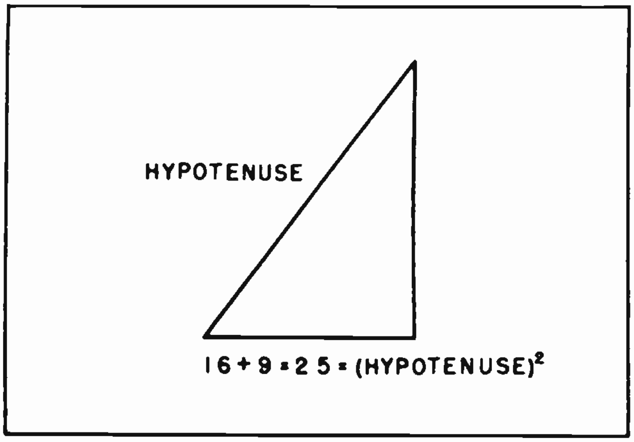


Fig. 9.

nuse, as in Fig. 8. The square of the hypotenuse is found to be 25, as in Fig. 9.

Since we are wanting to find the hypotenuse itself rather than the square of the hypotenuse, the next step is to find the square root of 25 as in Fig. 10. Here we take the square root of 25 and find that it is 5, and this 5 is the hypotenuse of a triangle where the base is 3 and the altitude is 4.

The mathematical rule, as laid down by Pythagoras says: *The square of the hypotenuse is equal to the sum of the squares of the other two sides.* It should be noted in passing that this rule applies only to a *right angle triangle.* A right angle triangle is one which has one angle of 90 degrees.

The main point we are trying to make is that this ancient mathematical rule makes it possible for us to combine the resistance and the reactance in an alternating current circuit into the total impedance such a circuit would offer to the flow of current. It is fortunate that we can find such a rule all ready for our use. Otherwise it would have been necessary to have worked out a rule to fit our needs. It is probable that you are already familiar with Pythagoras' Theorem from your regular school work. If so, all this will be nothing new to you; you can consider it in the nature of a review. You will be finding many uses for Pythagoras' Theorem in your work with Television.

Section 4. COMBINING RESISTANCE AND REACTANCE INTO IMPEDANCE

In solving impedance problems it is customary to substitute the amount of resistance for the base of the triangle, as in Fig. 11, and the reactance for the altitude. Then the impedance is the same as the hypotenuse. When the resistance is known and the reactance is known, all that is necessary is to square each of those values and add them together. When the square root is taken of that sum we will have found the total impedance.

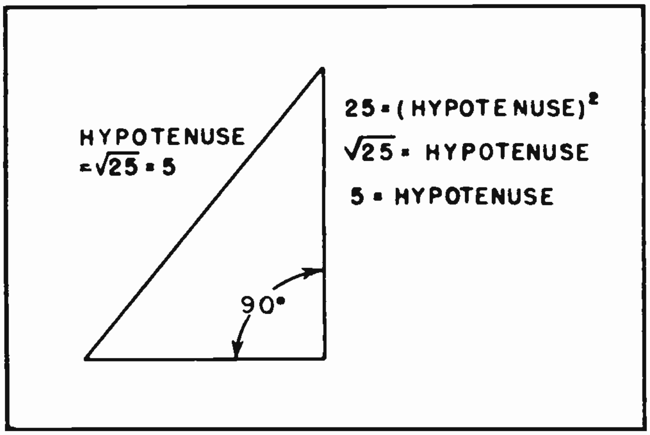


Fig. 10.

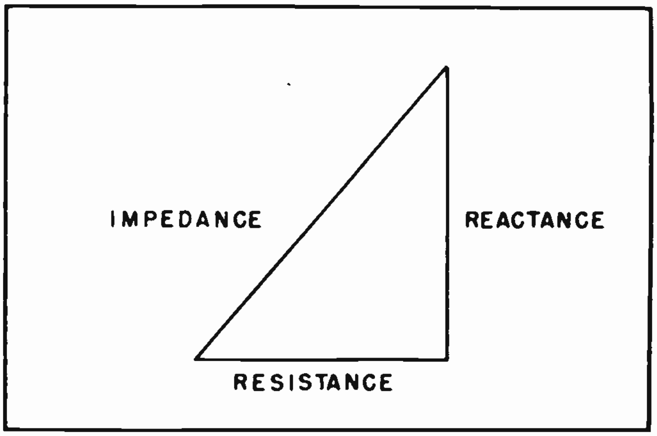


Fig. 11. The Impedance Triangle.

Now to get back to our original problem. We had 5 ohms of resistance and 12 ohms of reactance. We wanted to find the total impedance such a circuit would offer to the flow of alternating current.

Our first step should be to set up the impedance triangle as in Fig. 12. We place the 5 ohms of resistance along the base of the triangle. Next we put the 12 ohms of reactance in the place of the altitude of the triangle. Then we proceed to work out the problem.

We find that the square of 5 is equal to 25. Then we find that the square of 12 is equal to 144. Adding 25 to 144, as in Fig. 13, gives us 169. Now the figure 169 is the square of the impedance. Actually the thing we want to find is the impedance itself, not the square of it. But once

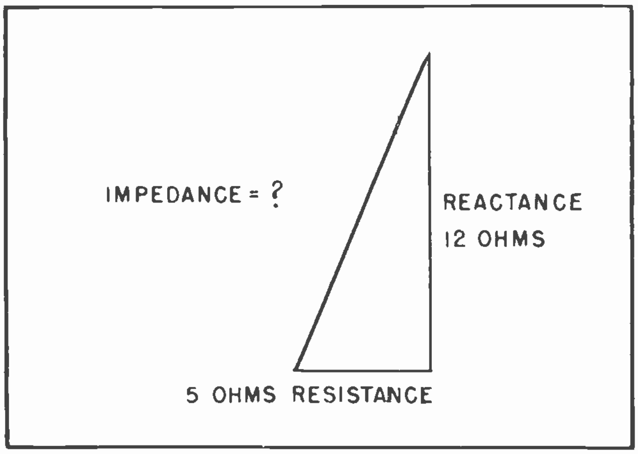


Fig.12.

we have the square of the impedance it is a simple matter to find the impedance; all we have to do is take the *square root* of 169, as in Fig. 14, which we find is 13.

Thus, when there are 5 ohms of resistance and 12 ohms of reactance in a circuit there will be a total opposition, or impedance, of 13 ohms to the flow of the current.

From our studies it is easy to see that every coil of wire contains both resistance and reactance. For all practical purposes the resistance and the reactance of the coil are in series with each other, and each contributes to the opposition presented to the flow of current. When this is true, the resistance and the reactance can be combined into one unit -- impedance -- the value of which can be obtained by using Pythagoras' Theorem. Fig. 15 shows how the

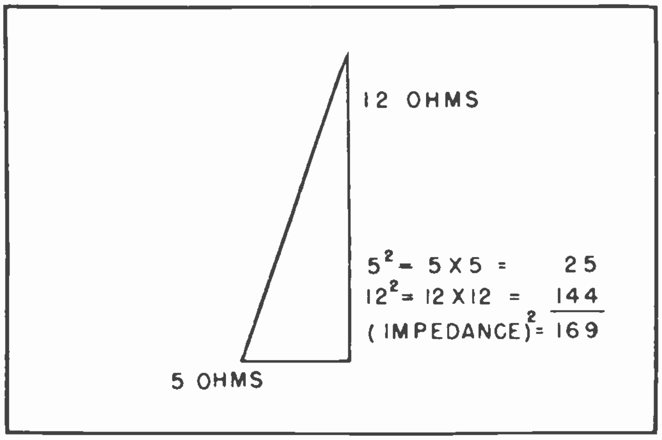


Fig.13.

resistance and reactance of a coil are often shown as two separate oppositions when diagramming a circuit.

Since other electrical units have some letter, or symbol, assigned to represent them, it should not be surprising to learn that a letter has been assigned to represent impedance. Electrical men agreed among themselves long ago that the letter *Z* would be used to represent impedance. It is so used by radio and television men. In fact, it is probable that radio and television men now have need to work with impedance far more than most electrical men.

It is also reasonable to expect that a formula for finding impedance had been worked out for us. Such, indeed, is the case. It is quite simple, and merely puts into a handy form the things we have been explaining. The basic formula for impedance where the reactance and the resistance are in series is:

$$Z^2 = R^2 + X^2$$

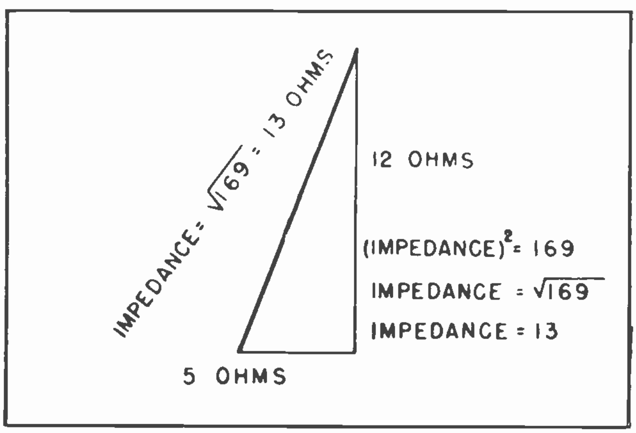


Fig.14.

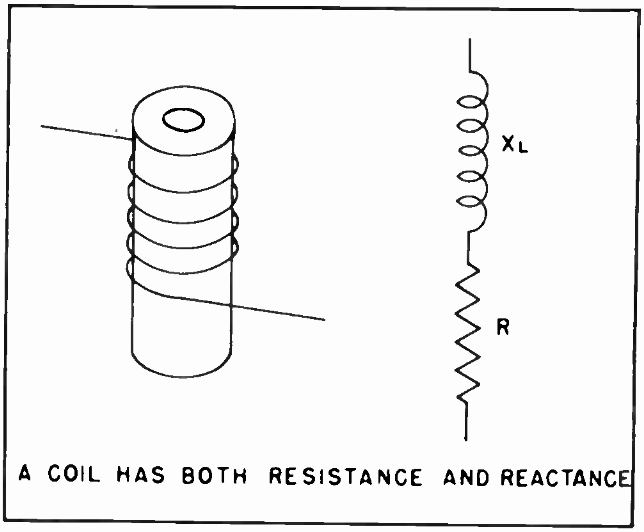


Fig.15.

But since we usually want to find the impedance rather than the square of the impedance, the formula will be found written in this manner most frequently:

$$Z = \sqrt{R^2 + X^2}$$

All this does is put into the form of a formula what we have already learned about impedance; that is, that impedance is equal to the *square root of the sum of the squares of reactance and resistance*. This formula should be jotted down in your little notebook where you can find it whenever you need it. You will soon be using it so frequently, however, that you probably will not have to refer to your notebook for long.

Section 5. **WHY WE CAN USE PYTHAGORAS' THEOREM TO FIND IMPEDANCE**

It is only natural that you should be curious as to why we are able to apply a mathematical formula as old as the Pythagorean Theorem to something as new as electricity, radio and television. The answer is found in the fact that when alternating current is applied to a resistance, the current through the resistance will always be exactly proportional at all times to the voltage across it, while the action of inductive reactance is to cause the current to lag somewhat behind the voltage.

In Fig. 16 we find the current through the resistance rises at the same time the voltage rises across it. The current through the resistance is exactly proportional to the value of the voltage, and can be determined by use of simple Ohm's Law. For example, when the voltage rises to 20 volts we find that the 20 volts will cause a current of 2 amperes to flow through the resistance. Then as the voltage rises to 40 volts, 60 volts, and so forth, we find the current rising to 4 amperes, 6 amperes and so forth -- exactly in step.

But the situation is different in the case of the current through an inductance. The current does not rise to its maximum value until after the maximum voltage peak has passed. There is a *time displacement* involved. The maximum opposition of the resistance occurs at the time the voltage is maximum. the maximum opposition of the inductance comes later.

From a strictly technical standpoint there is another way to look at the matter, but it involves considerable mathematics for full understanding. It is not necessary that we go into it in that way just as this time. Essentially, it is this: The action of the inductance is to hold the current behind the voltage; the peak of the current coming after the peak of the voltage. The impelling voltage of the collapsing magnetic field around the coil is somewhat less than the applied voltage, but is strong enough to force some of the current through

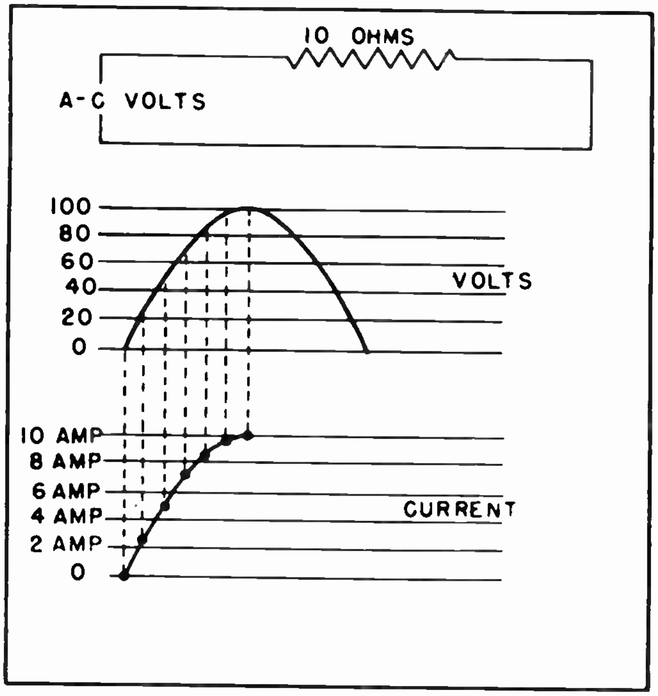


Fig.16. The Current Rises in Step with the Voltage in Accordance with Ohm's Law.

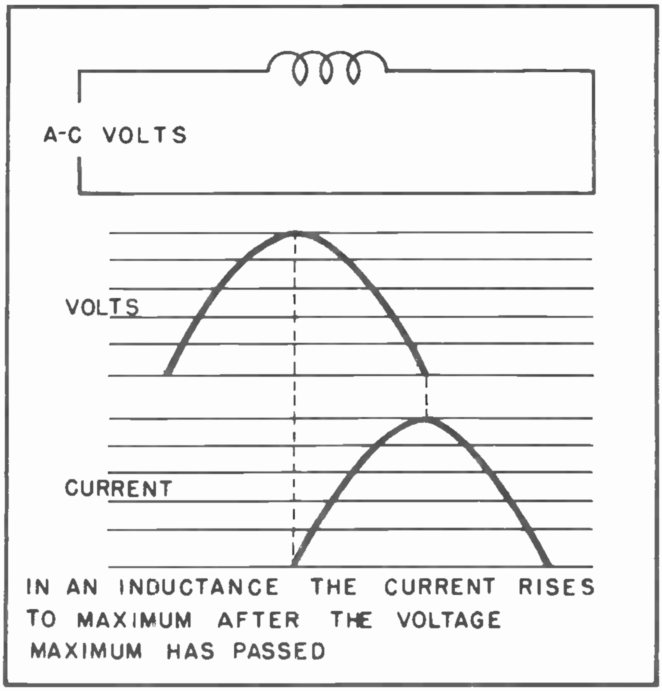


Fig.17.

the resistance. The combined action of the inductive reactance and the resistance is to restrict the current. Both oppositions together are stronger than either separately, but is not so strong as the sum of the two.

It can be said from long practical experience it has been proven that the two oppositions act at right angles to each other. One way of showing this is to locate the resistance on the horizontal plane of a graph, as in Fig. 18, and the reactance on a vertical plane. By using ordinary graph paper the impedance problem can be worked out without using much arithmetic.

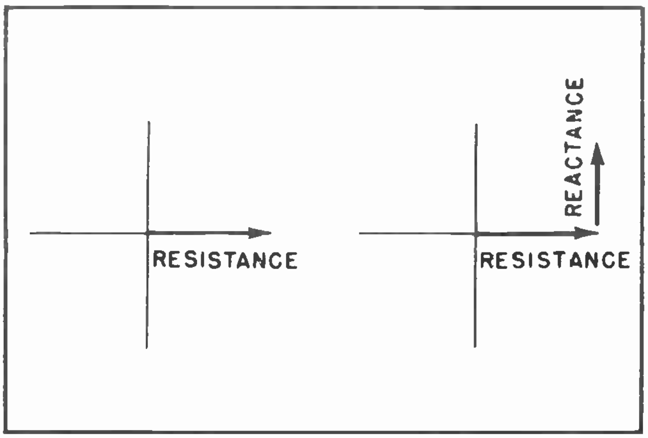


Fig.18.

An example of how this can be done is shown in Fig. 19. Here we have an X-X' and a Y-Y' axes drawn on the graph paper. Now suppose we want to find the total impedance of 6 ohms of resistance and 8 ohms of reactance. We can draw a line to the right from the zero-zero point of the graph for a distance of 6 lines, then vertically for a distance of 8 lines. The next step is to draw a line from the upper point of the vertical line back to the starting point, such as the dashed line in Fig. 20. If the dashed line is measured it will be found to be exactly as long as the distance between 10 of the lines. Notice the similarity of the action here to that in Figs. 13 and 14. For your own satisfaction it will be to your advantage to solve the problem

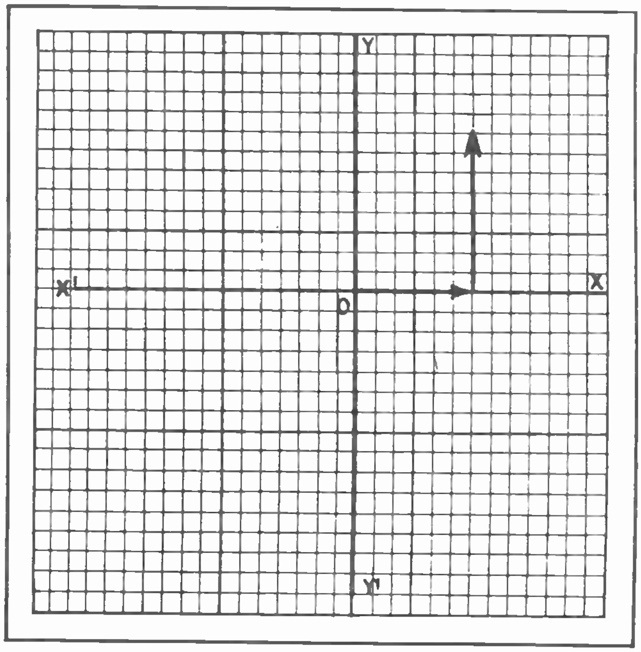


Fig.19.

of 6 ohms resistance and 8 ohms reactance by using the Pythagorean Theorem. See if you do not arrive at the same answer of 10 ohms of impedance.

Section 6. COMBINATION OF RESISTANCE AND CAPACITIVE REACTANCE

There are many instances where a capacitor will be in series with a resistance in the problems you will face in your everyday television work. When you find such a situation you will be able to find the solution very much the same as in combining inductive reactance and resistance. The total impedance can be found by taking the square root of the sum of the squares of

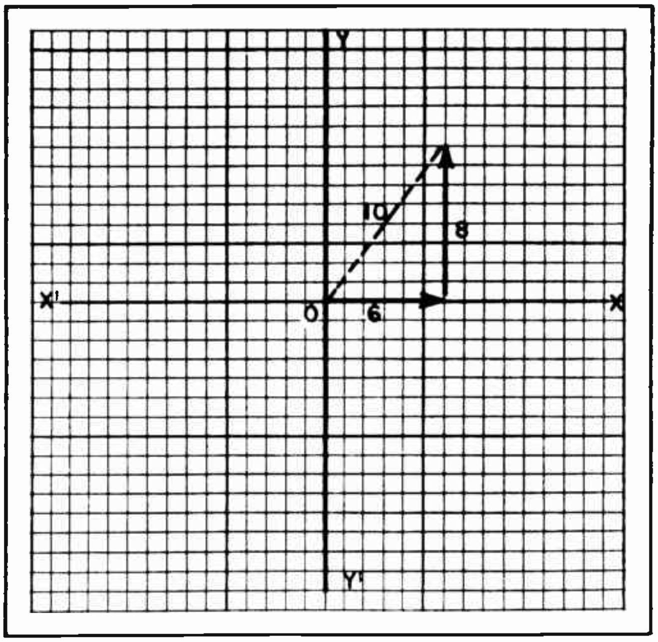


Fig. 20.

the capacitive reactance and the resistance. Thus it can be seen that it makes no difference whether the reactance is inductive or capacitive, it combines with the resistance in the same manner. (See Fig. 21.)

In graphing the capacitive reactance, there will be a slight difference. Instead of the reactance going upward in a vertical direction, it will go down. As an example of this, suppose we have a capacitor which has a reactance of 12 ohms and it has a resistance of 9 ohms in series with it.

We will graph the 9 ohms of resistance by running a line beginning at the zero-zero point of the graph, and going to a point 9 lines to the right, as in Fig. 22. From there we go downward 12 lines to represent

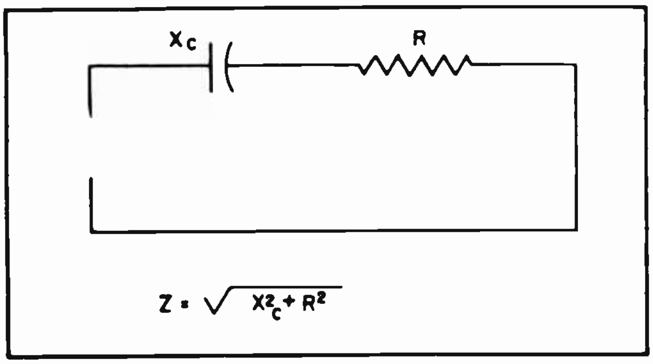


Fig. 21.

the capacitive reactance. By then drawing a third line, as shown by the dashed line in Fig. 22, we have the hypotenuse of a right angle triangle, or in this case, the impedance of the circuit. If the dashed line is measured out it will be found to be exactly 15 units long, meaning the circuit would have 15 ohms of impedance.

Here again, it will be to your advantage to work out this problem by the use of Pythagoras' Theorem. See if you do not come out with an answer of 15 ohms.

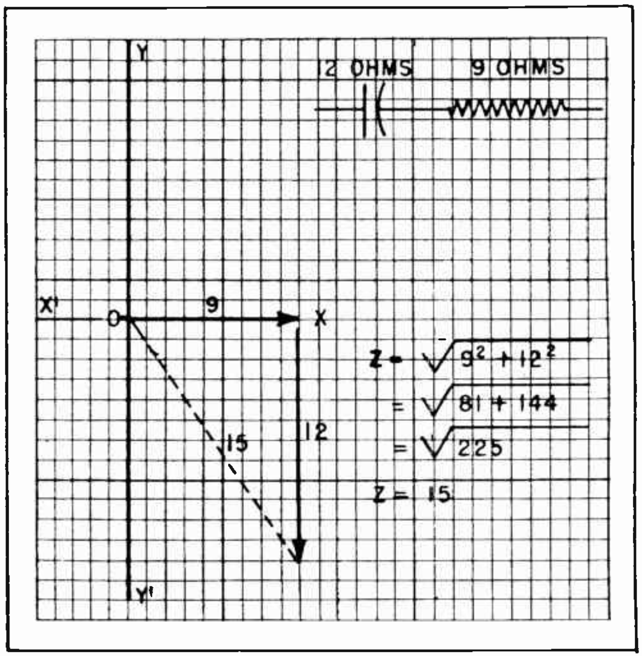
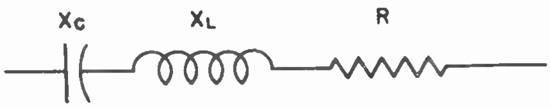


Fig. 22.

Section 7. COMBINING CAPACITIVE REACTANCE, AND INDUCTIVE REACTANCE AND RESISTANCE

In radio and television circuits we are continually confronted with circuits which contain all three kinds of opposition to the flow of alternating current. This is particularly true as the frequency increases. At the higher frequencies even a very small amount of inductance can give the circuit considerable reactance. By the same token, capacities which can be completely ignored at the lower frequencies must be taken into consideration at the higher frequencies. At the frequencies which are encountered in television work, we frequently find that two ordinary pieces of wire, even though separated from each other, will have enough inductance and capacitance to seriously interfere with the proper operation of the



$$X = X_L - X_C \quad \text{OR} \quad X = X_C - X_L$$

$$Z = \sqrt{R^2 + X^2} \qquad Z = \sqrt{R^2 + (X_L - X_C)^2}$$

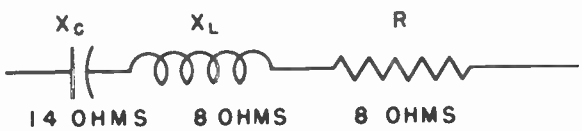
Fig. 23.

receiver. This same situation is also found in the "transmission lines" which bring the signal from the outdoor antenna to the receiver inside the house.

In tackling the problem of capacitive reactance in series with resistance and inductive reactance we have a situation somewhat like that shown in the diagram of Fig. 23. At first glance this appears somewhat complicated. But a little thought and study tells us the problem is by no means as awkward and complicated as it appears at first glance.

Impedance indicates a combination of reactance and resistance. The kind of reactance is immaterial. Either may be negligible, but a combination is applied.

Remember also, that the *total reactance* in any series circuit is equal to the difference between the inductive reactance and the capacitive reactance. Suppose the reactances are as shown in Fig. 24: 14 ohms capacitive and 8 ohms inductive. Our first move is to combine them to find the *total reactance*. In this case the total reactance would be the difference between 14 ohms and 8 ohms, or a total reactance of 6 ohms.



$$X = X_C - X_L$$

$$X = 14 - 8 \qquad X = 6 \text{ OHMS}$$

Fig. 24.

$$Z = \sqrt{6^2 + 8^2}$$

$$Z = \sqrt{36 + 64}$$

$$Z = \sqrt{100}$$

$$Z = 10$$

Fig. 25.

Now we can go right ahead with the solution of our problem. The reactance is 6 ohms, the resistance is 8 ohms. The problem is solved as in Fig. 25, and we come up with the answer of 10 ohms of impedance.

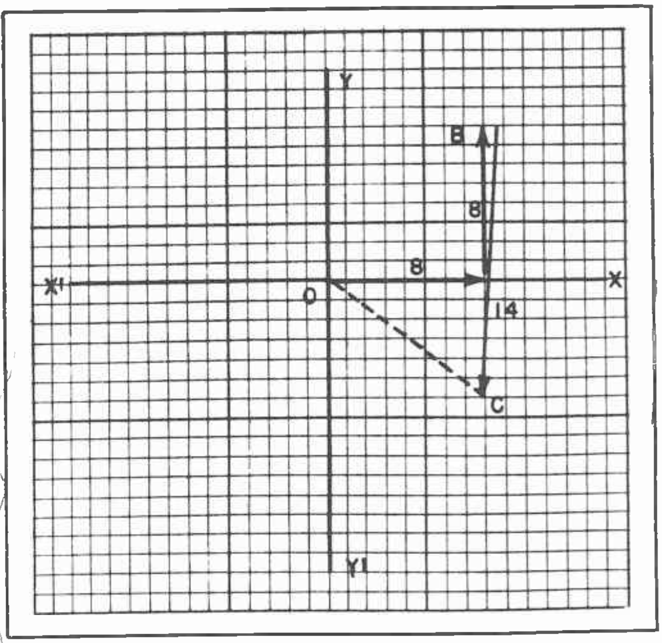


Fig. 26.

Graphing such a problem shows even more clearly what happens. In Fig. 26 we start at the zero-zero point marked *0* and move to the right 8 spaces to represent the resistance. Then we move upward 8 spaces to represent the inductive reactance. This puts us at point *B*. Then we move downward 14 spaces to represent the action of the capacitive reactance. This takes us to point *C*. Now all that remains to do is draw the dashed line between point *C* and the starting point. If this line is measured it will be found to equal exactly 10 spaces, thus showing that the total impedance amounts to 10 ohms. Note that in this case the

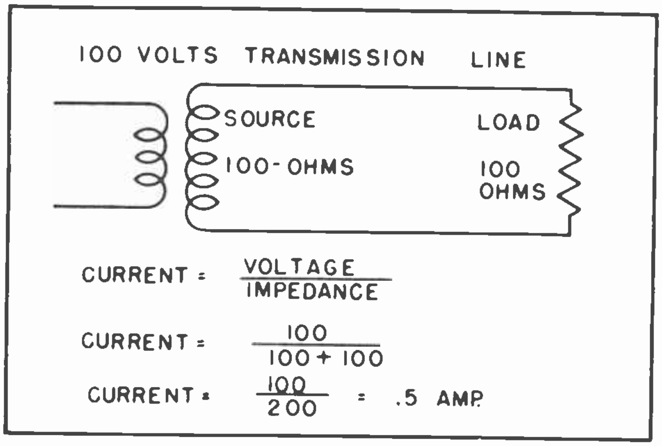


Fig.27. A Transmission Line in which the Impedances are Matched.

total impedance of the two reactances and the resistance is somewhat less than that of the capacitive reactance alone. Had we not already explained this peculiarity to you in a previous lesson you might find it hard to understand. But, as you already know, this is the condition which leads to resonance when the two reactances are exactly equal.

Section 8. IMPEDANCE MATCHING

In all your work you will be faced with the problem of matching the impedance of one circuit with the impedance of anoth•r. There are so many places where you will encounter this problem it is difficult to point out any one and say that it is more prominent than any other. But we have mentioned the one of matching the output of a vacuum tube to the voice coil of a loudspeaker several times, so will proceed now to use it as an example.

Actually the problem of matching impedances can be boiled down to that of transferring power from one point to another. It has been found that the maximum amount of power can be transferred from one point to another when the impedance of the load equals the impedance of the source. To understand this we will work out some practical problems, using the things you already know, and thus show why the impedance must be matched if we expect to transfer the maximum amount of power from one point to another.

Section 9. OHM'S LAW FOR A-C

Before going any further it might be well to mention that Ohm's Law for alternating current is slightly different from that for direct current. The Ohm's Law for D-C, you will recall, says the current is equal to the voltage divided by the resistance:

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

In using Ohm's Law for A-C, the value of the impedance in the circuit is used instead of the resistance. The law then says the current is equal to the voltage divided by the impedance:

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

Impedance is substituted for the resistance in the other forms of the Ohm's Law when it is used with alternating current. Thus, E = IR becomes E = IZ, and the third form,

$$R = \frac{E}{I} \text{ becomes } Z = \frac{E}{I}$$

Section 10. POWER TRANSFER THROUGH IMPEDANCE MATCH

There are many places where we want to transfer power from one place to another in a radio or television receiver. The antenna picks up the extremely small signals from the air. These signals must be transferred from the antenna to the input to the receiver. If the signal is to have any effect on the receiver it is imperative that as much as possible of the original must be transferred to the receiver. This calls for proper impedance matching.

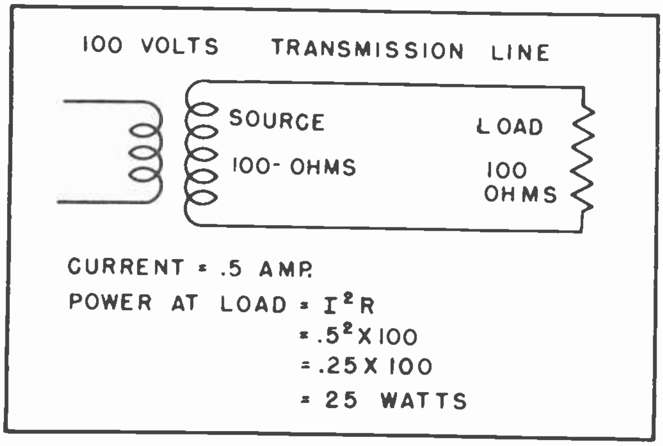


Fig.28.

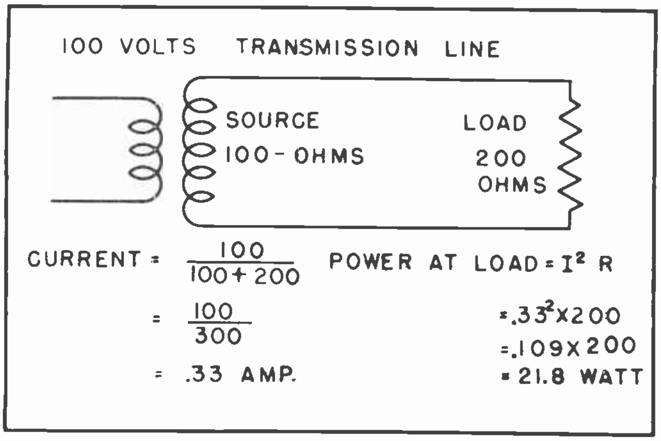


Fig. 29.

The circuit shown in Fig. 27 is not one such as that found in antenna circuits. Possibly it does not actually exist anywhere, but it has values which are readily understandable, and will serve as a good example to explain the problem of impedance matching.

Here we have the secondary of a transformer, which represents the source of the transmission line. There are 100 ohms of impedance in the secondary of the transformer. The secondary feeds power into a transmission line which terminates in a load of 100 ohms resistance. In this particular case the impedance of the load matches the impedance of the source.

Before we can determine how much power is transferred from the source to the load by means of this circuit we must first find how much current is flowing in the circuit. To find the amount of current we must find the total impedance in the circuit and then divide that into the voltage of the source. Since there are 100 ohms in the source and 100 ohms in the load, we have a total impedance of 200 ohms. (For the purpose of demonstration we will disregard the resistance of the line.)

By dividing this 200 ohms of impedance into the 100 volts of the source we find we have 0.5 amperes of current flowing in the circuit. All this is shown by Fig. 27.

The next step is to find the amount of power which is transferred to the load by means of the circuit. We already know the current amounts to 0.5 amperes. The load resistance is 100 ohms. We can always find the power by squaring the current (I^2) and multiplying by the resistance (R). $P = I^2R$.

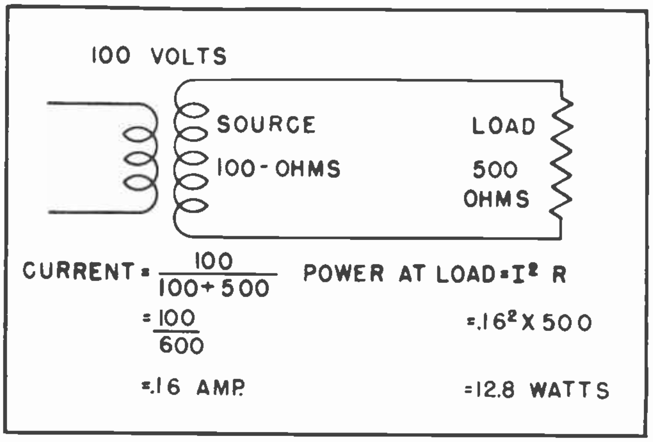


Fig. 30.

We do that in Fig. 28 and find we have transferred 25 watts of power to the load.

Now let's see what we can do by increasing the resistance of the load. In Fig. 29 we have increased the resistance of the load from 100 ohms to 200 ohms. But instead of increasing the amount of power delivered to the load, we find it has actually decreased from the 25 watts in Fig. 28 to 21.8 watts in Fig. 29.

Just to show that this is not a freak of figuring, we will increase the load resistance to 500 ohms as in Fig. 30. But here we find that the power transferred to the load has decreased some more. It has actually dropped to about half the power we had in Fig. 28. With 500 ohms resistance in the load we are able to transfer only 12.8 watts to the load.

It might be thought -- and very naturally so -- that more power could be transferred by reducing the resistance of the load

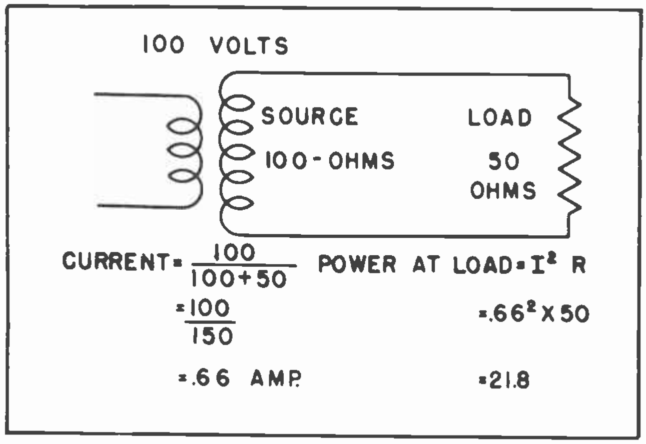


Fig. 31.

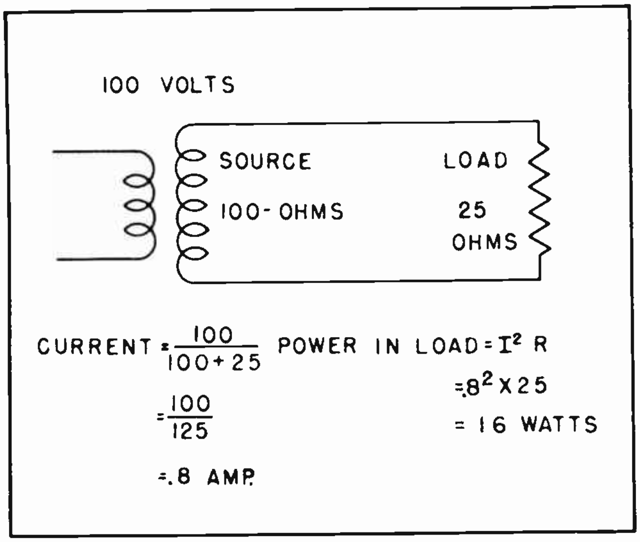


Fig. 32.

instead of raising it. In Fig. 31 we have reduced the load resistance from 100 ohms to 50 ohms. This makes a total impedance in the circuit of 150 ohms and allows .66 amperes of current to flow. 0.66 amperes of current flowing through a resistance of 50 ohms in the load results in the transfer of 21.8 watts. This is less power than was transferred when the load resistance was 100 ohms.

To carry out experimenting just another step further we will reduce the load resistance just a little more, making it 25 ohms instead of 100 ohms or 50 ohms. When we do this we increase the current to 0.8 amperes. But we find that 0.8 amperes of current through the 25 ohms of resistance gives only 16 watts of power.

You can carry this series of experiments to any length you care to, but you will find that the maximum amount of power which can be transferred from the source of any circuit to any load will be attained only when the impedance of the source exactly equals that of the load. By increasing the load impedance above that of the source, or reducing it below that of the source, always results in a transfer of less power than when the impedances are exactly balanced.

There is another angle to this matter of impedance matching which we have not touched upon yet, and which we will not go into in detail at this time. That is the matter of distortion. Not only will less power be transferred when the impedances do not match, but distortion will be introduced into the signal.

It is hoped that you are beginning to obtain some understanding of the importance of impedance matching. Even though you feel you do not thoroughly understand it at this point, do not become discouraged. Impedance matching is an important thing in radio and television work and we do not propose to give it all to you at one time; to do so, might possibly confuse you. The most important point to understand right now is that the impedances of a source and a load should match; at this time, the reasons *why* they should match are less important.

Section 11. IMPEDANCE MATCHING BY TRANSFORMER ACTION

A transformer is an ideal device by which the impedance of one circuit can be matched to the impedance of another. As mentioned before, a perfect example of a high-impedance circuit which must be coupled to a low-impedance one is that of coupling a vacuum power tube to the voice coil of a loudspeaker. (See Fig. 33.) The plate resistance of the tube is quite high as compared with that of the voice coil. In the case of the 7A5 tube, a beam power tube, the plate resistance is given as 2500 ohms. Most voice coils have an impedance which does not exceed about 10 ohms. An ideal problem, and a common one, would be to determine the kind of transformer which would be needed to couple the plate of a 7A5 tube to the voice coil of a loudspeaker.

Before we can solve such a problem we must first learn a little more about transformers and especially about something we call *coupled impedance*. You will recall that the primary and the secondary circuits of a transformer are separate circuits which

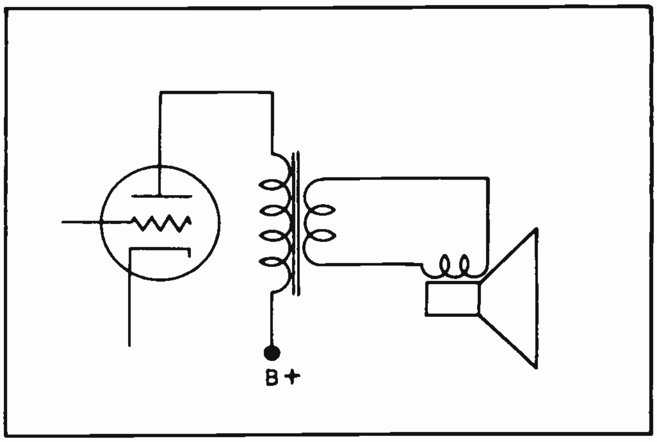


Fig. 33. Matching the Impedance of a Vacuum Tube to a Loudspeaker.

are magnetically coupled together. The primary has a certain impedance of its own, and the secondary has its own impedance. The impedance of the primary is usually designated as Z_p and that of the secondary as Z_s. The impedance of the primary, when there is no load applied to the secondary, consists of the resistance and the inductance of the primary winding. (See Fig. 34.)

When there is no load on the secondary, the effect is as though the secondary did not exist. At that time the impedance of the primary is like an inductance and a resistance in series. (See the insert in Fig. 34.)

But when there is a load on the secondary we have a somewhat different situation. The impedance of the secondary winding consists of the resistance and inductance of the secondary winding itself *plus* the impedance of any load which might be connected to the circuit.

When a load is connected to the secondary circuit, current will begin to flow in the entire circuit. The exact amount of current will depend upon the voltage and the impedance of the circuit; it can be disregarded for the moment. Nevertheless, the secondary voltage is dependent upon the magnetic linkage between the primary and the secondary, the degree of coupling between the two windings, and several other factors. The important thing, however, is that placing a load on the secondary acts very much like adding an impedance in series with the primary. This added impedance is generally referred to as *coupled impedance.*

It is not necessary to go into all the ramifications of what happens in a transformer when a high impedance circuit is coupled to a low impedance one. The whole action can be explained clearly enough by the formula for the coupling:

$$\frac{(\text{Turns of Primary})^2}{(\text{Turns of Secondary})^2} = \frac{\text{Impedance of Primary}}{\text{Impedance of Secondary}}$$

What this means is that the ratio of the turns on the primary and the secondary windings are directly responsible for the coupled impedances. This is nothing unusual, and is probably exactly what you expected. The thing that probably is new is that the impedances do not change in direct proportion to the changes in the turns ratio.

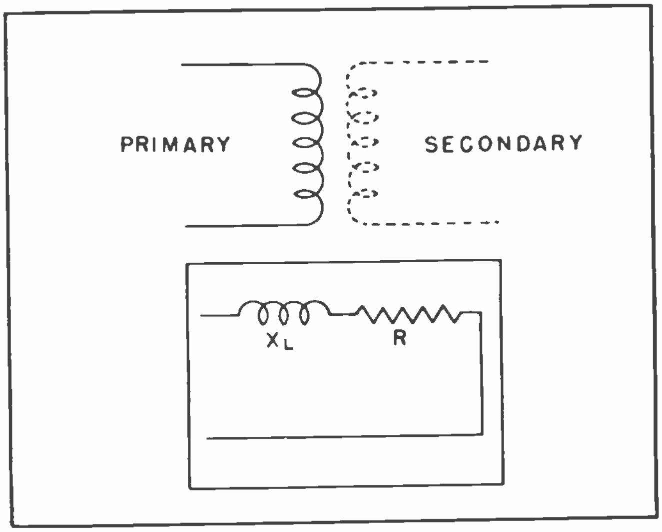


Fig.34. With No Load on the Secondary the Impedance of the Primary Will Act Like a Resistance in Series with an Inductance.

Instead, the impedance goes up as the square of the turns ratio.

As an example of this, suppose the primary has 100 turns and the secondary has 1000 turns. In the formula this would look like this:

$$\frac{(100)^2}{(1000)^2} = \frac{\text{Impedance of Primary}}{\text{Impedance of Secondary}}$$

If we happen to know the impedance of the primary is, say, 500 ohms, we can change the problem to look like this:

$$\frac{(100)^2}{(1000)^2} = \frac{500}{\text{Impedance of Secondary}}$$

Since we are actually more interested in the *ratio* of the number of turns than we are in the number of turns themselves, it is easier to simplify the problem like this:

$$\frac{(1)^2}{(10)^2} = \frac{500}{\text{Impedance of Secondary}}$$

This is equal to:

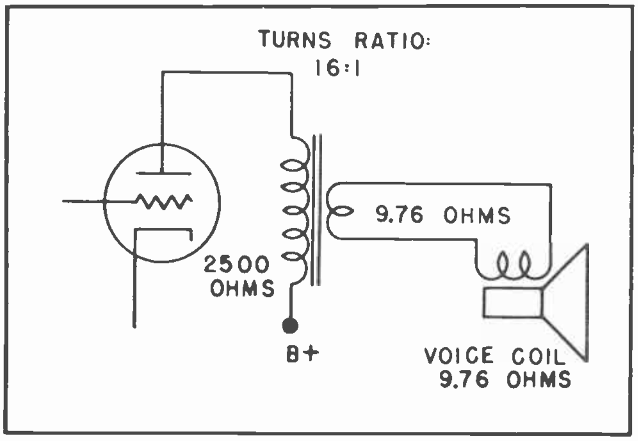


Fig.35. A Transformer with 2500 Ohms Impedance in the Primary will Match a Secondary Impedance of 9.76 Ohwn when the Turns Ratio are 16:1.

$$\frac{1}{100} = \frac{500}{\text{Impedance of Secondary}}$$

What this now tells us is that the impedance of the secondary is to 500 as 100 is to 1. In other words, the impedance of the secondary is 100 times as great as 500, or is 50,000 ohms. Thus if there are 10 times as many turns on the secondary as there are on the primary, there will be 100 times as much impedance in the secondary as there is in the primary.

Of course the situation could be just reversed. If the primary had more turns than the secondary, the impedance situation would be just reversed. The main point to remember, however, is that the ratio of the impedance of the primary and the secondary is as the square of the ratio of the turns of the two windings.

Now to get back to our problem of matching the plate resistance of the 7A5 tube, amounting to 2500 ohms, to the voice coil of a loudspeaker which has an impedance of a little less than 10 ohms, say 9.76 ohms. Our problem is to find the *turns ratio* necessary for the transformer to match the high impedance circuit to the low impedance one.

The impedance of the primary circuit is 2500 ohms. The impedance of the secondary circuit is 9.76 ohms.

$$\frac{(N_p)^2}{(N_s)^2} = \frac{2500}{9.76}$$

This is the same as saying:

$$\frac{N_p}{N_s} = \sqrt{\frac{2500}{9.76}} = \sqrt{256} = 16$$

The circuit of Fig. 33 now is changed so the values of Fig. 35 will fit that particular situation. This means that any transformer which has a 16:1 turns ratio and has 2500 ohms impedance in the primary will serve to match the impedance of the output of the tube to the input of the loudspeaker.

This is an ever-recurring problem. It is constantly being encountered by the radio man and the television man. It must never be forgotten that every television receiver has a lot of radio in it. It has a sound section very similar to that of any ordinary radio receiver. In addition to the sound channel there is the video channel to consider. Both are important, and necessary to the proper operation of the television receiver.

Section 12. LOW PASS FILTERS

There are a number of circumstances where it is desirable to pass some of the lower frequencies past a certain point in a circuit but hold down the passage of higher frequencies. This can be accomplished in either of two ways. An inductance can be placed in series with one side of the line as in Fig. 36, or a capacitor can be placed between the lines as in Fig. 37. The inductor will not present much opposition to the passage of the *low frequencies*, but will present increasing opposition to the passage of the *higher frequencies*. On the other hand, the capacitor will not allow the lower frequencies to pass from one side of the line to the other, but will pass the higher ones.

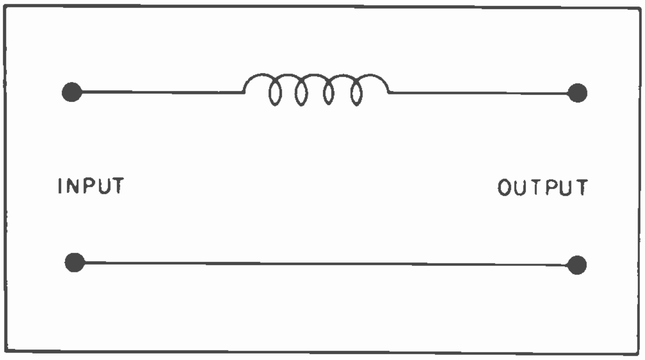


Fig.36.

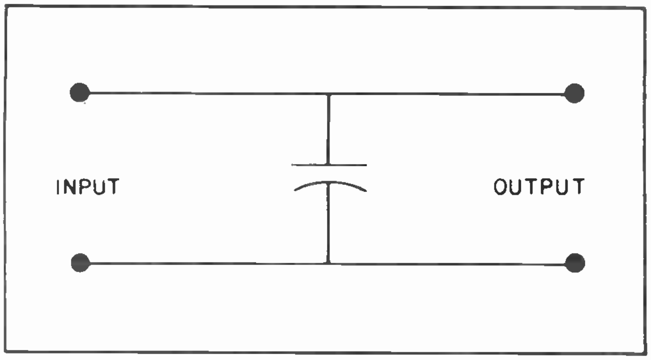


Fig.37.

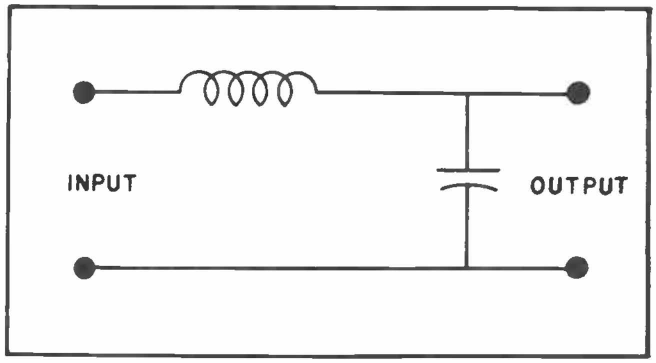


Fig.38

Both of these methods are useful, but both have one fault. They do not produce any sharp point of difference between the frequencies they will pass and those they will not pass.

If they are used together as in Fig. 38, they will have a much sharper line of demarcation between the frequencies which are passed and the ones which are rejected. Fig. 39 shows several circuits which allow the passage of low frequencies but rejects the passage of the higher frequencies.

Section 13. HIGH PASS FILTERS

There are other occasions when it is desirable to pass the higher frequencies but reject the lower ones. When this is the situation, it is better to use a simple capacitor in series with one side of the line, as in Fig. 40, or an inductor between the lines as in Fig. 41.

Other combinations which allow the passage of the higher frequencies but reject the lower ones are shown in Fig. 42.

Section 14. BAND PASS FILTERS

Probably the type of circuits used as much as any other in radio and television work are those which pass only one *band* of frequencies, but reject all others. These circuits are especially useful where it is desired to separate one band of frequencies from another band, and send each group into different channels.

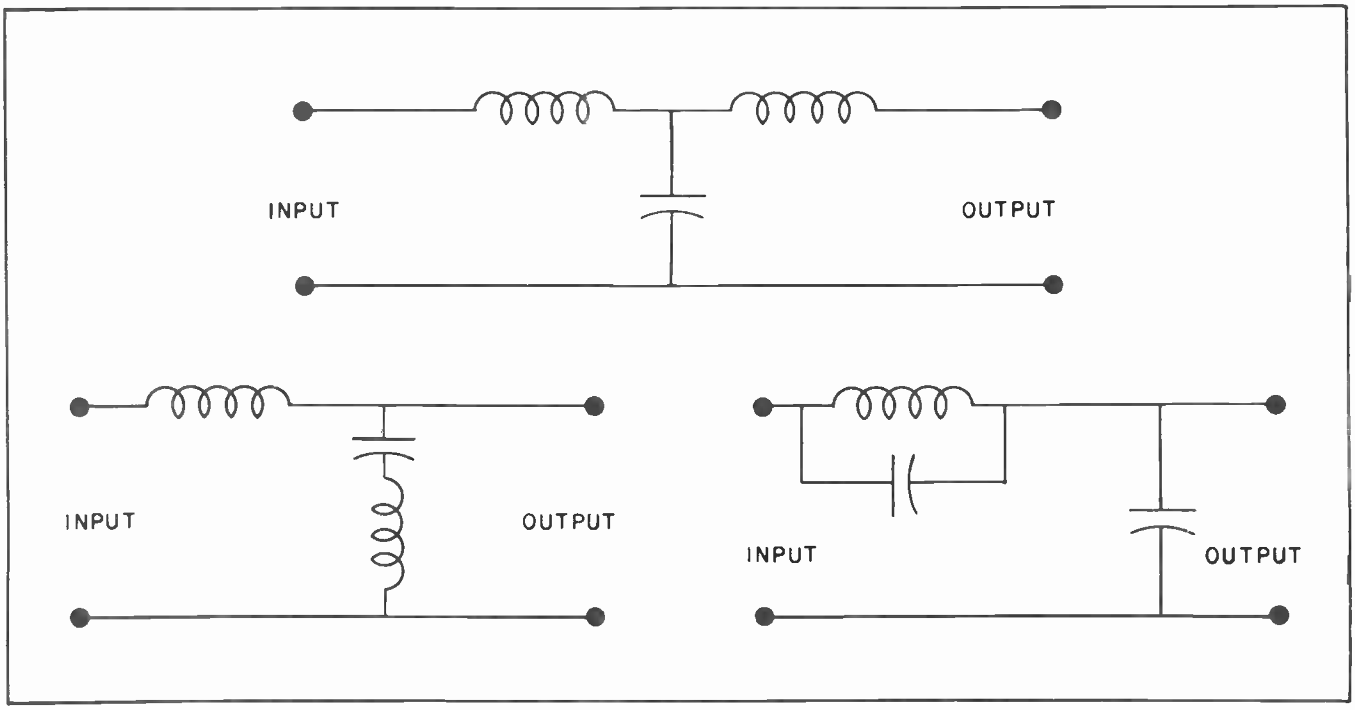


Fig.39. Several Low Pass Filters in Common Use.

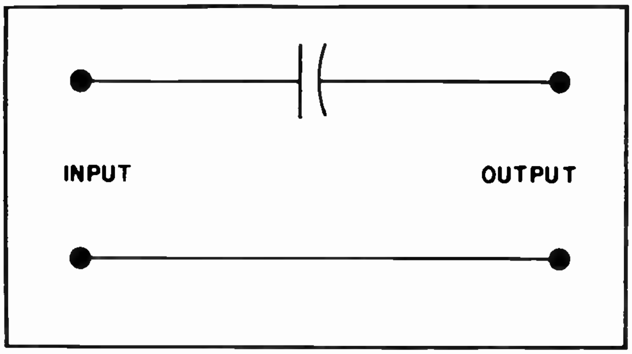


Fig. 40.

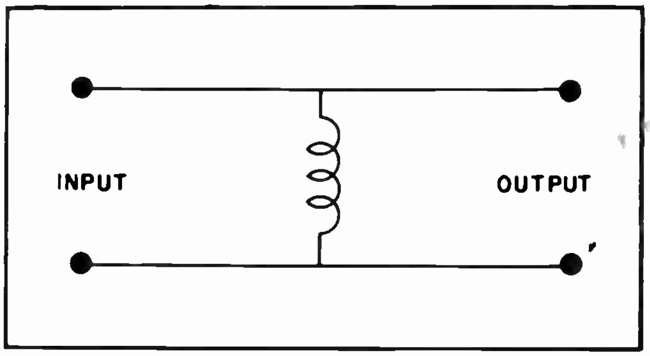


Fig. 41.

A good example of the need for such circuits is where the video frequencies are separated from the sound frequencies in a television receiver. The sound and the video are brought into the receiver on frequencies only a little different from each other. All of them are amplified in the first few stages of the receiver. Then they are separated, the sound going one direction and the video going the other. It is necessary to use circuits which will pass only the particular band which is desired.

Fig. 43 shows one of the simplest types of band pass circuits. It is merely a resonant circuit in series with the line. Such a series resonant circuit will present a low impedance to the passage of the resonant frequency but a high impedance to all other frequencies.

Fig. 44 shows how a parallel resonant circuit can be used as a band pass. All frequencies above the band will readily pass through the capacitor in the resonant circuit. All those below the resonant frequency will readily pass through the inductor. But those right at the resonant frequency of the circuit cannot pass from one side of the line to the other, and must of necessity, pass on into the output to wherever it is desired that they go.

Very frequently the two types of resonant circuits are combined as in Fig. 45. Here the band of frequencies which will be passed can be made quite sharp. Those right at

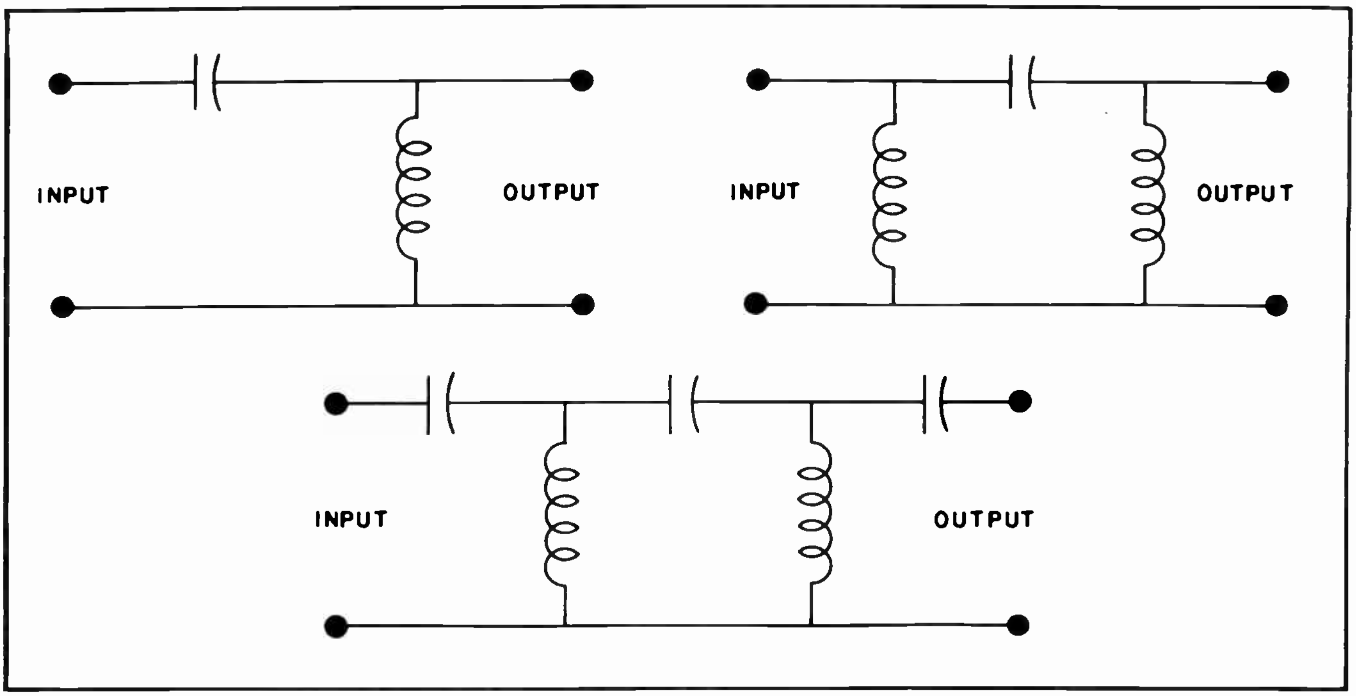


Fig. 42.

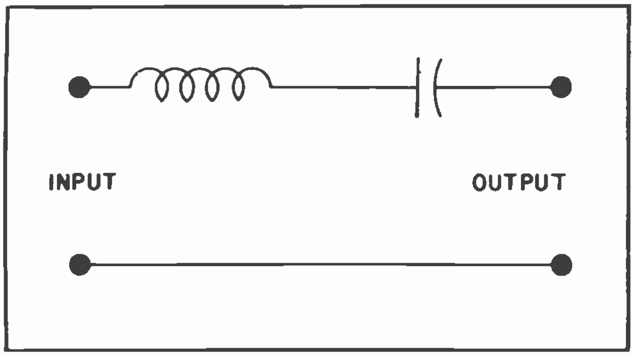


Fig.43. A Series Band-Pass Filter.

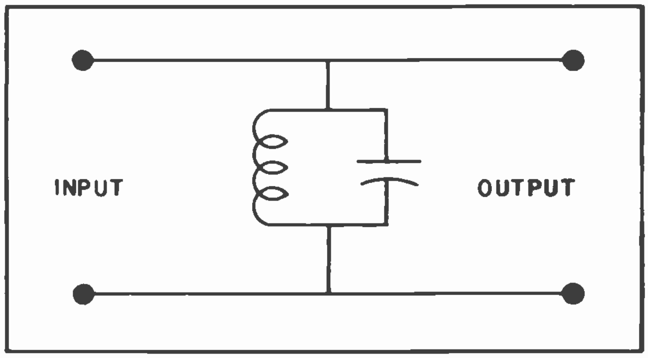


Fig.44. A Parallel Band-Pass Filter.

the resonant frequency will pass very readily through the series resonant circuit to the output of the band pass circuit. But all others will be rejected by the series resonant circuit. The parallel resonant circuit is tuned to the same frequency. It will pass all frequencies except the ones at the band which it is desired to pass. At that frequency the impedance of the parallel resonant circuit will be quite high and will reject that band of frequencies.

This lesson on impedance will introduce you to that most important subject. It is not pretended that this is a complete coverage of the subject. Much more about it will be discussed from time to time. But what you have learned from this lesson should carry you along during the next few lessons very nicely. Sometime later we will take up the subject of impedance in parallel circuits. But it is not thought necessary to burden you with that right at this time.

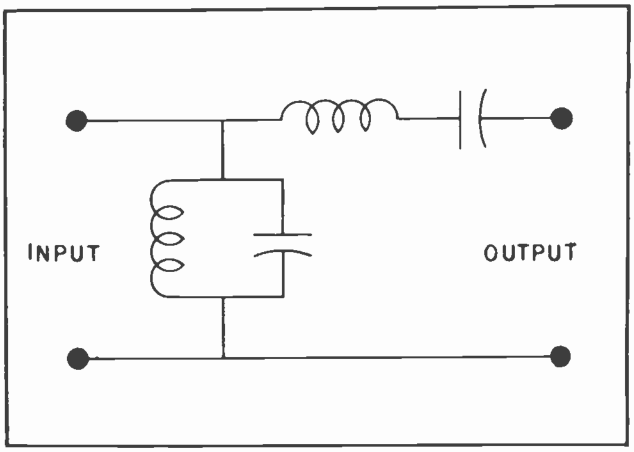


Fig.45. A Band-Pass Filter Using Both Series and Parallel Resonant Circuits.

NOTES FOR REFERENCE

Impedance is a combination of reactance and resistance.

Pythagoras' Theorem is highly useful in solving impedance problems.

Pythagoras' proved that the square of the hypotenuse of a right triangle was always equal to the sum of the squares of the other two sides.

The basic formula for impedance is $Z = \sqrt{R^2 + X^2}$

Maximum power is transferred from the source to the load when the impedance of the source matches that of the load.

It is always important that the impedance of the load shall match the impedance of the source.

The formula for the coupled impedance in a transformer is:

$$\frac{N_p^2}{N_s^2} = \frac{Z_p}{Z_s}$$

(over)

Ohm's Law for A-C is $E = IZ$.

Relatively speaking, a high impedance circuit will have a high ratio of voltage to the current.

In a low impedance circuit the ratio of the voltage will be rather low with respect to the current.

A transformer is an ideal method by which a high impedance circuit can be coupled to a low impedance circuit.

NOTES

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3125
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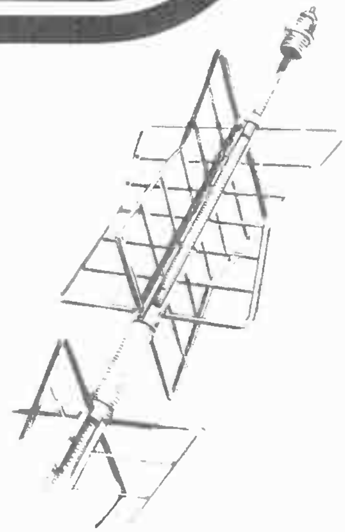

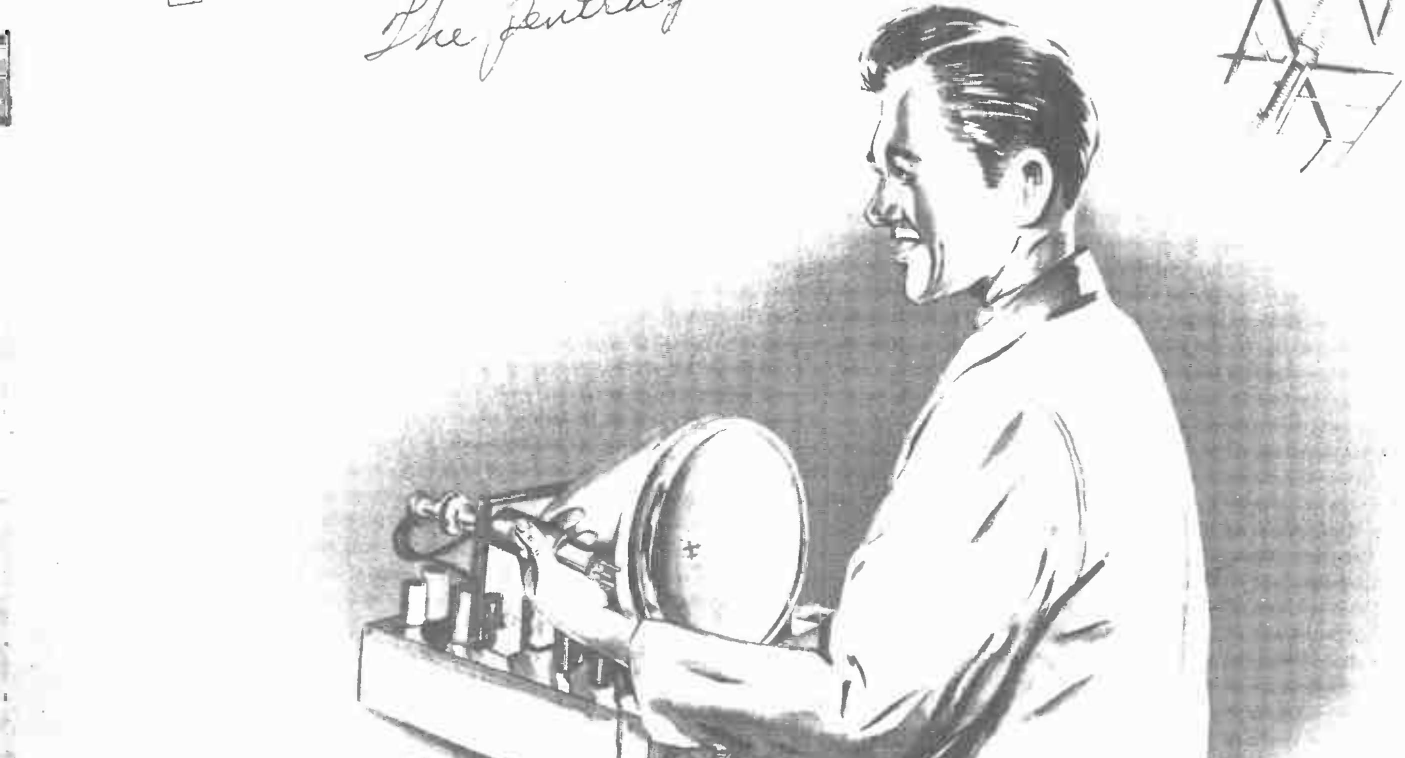

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RADIO TELEVISION

THE PENTAGRID CONVERTER

Contents: Introduction - Radiating Oscillator - Grounding - Carrier Wave - Modulation - Biasing Points - Systems for Amplifying Radio Signals - Mixer Circuits - The 6A8 Tube - Triode Heptode Converter - Notes for Reference.

Section 1. INTRODUCTION

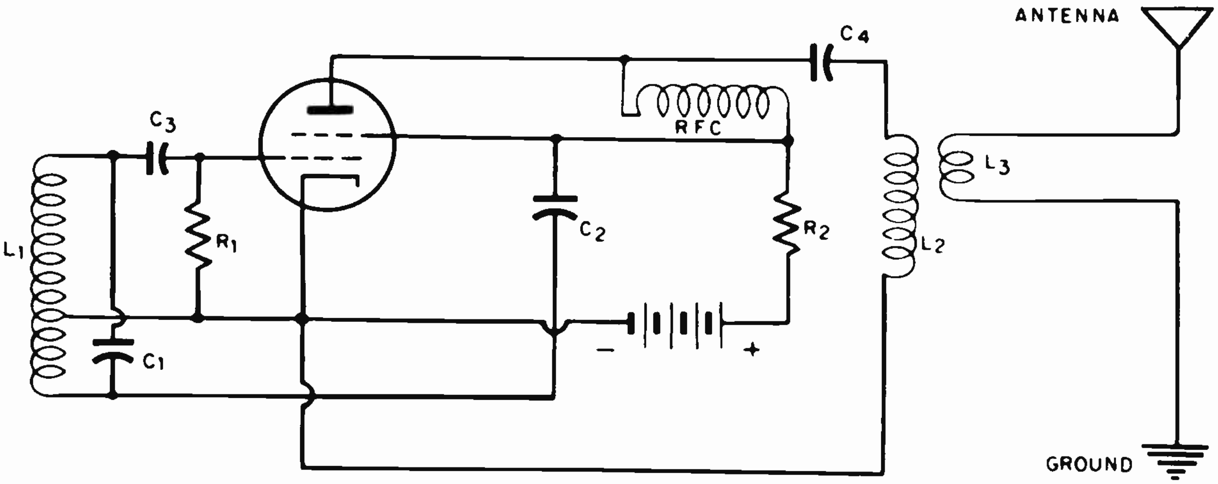
As you progress with your studies, many new and wonderful things are unfolded to you and explained. By the very nature of radio and television work it is first necessary to study individual parts which go to make up a radio or television receiver, and to study many peculiar electrical phenomena, before we can hope to understand how all these things are put together and made to work in harmony. We have covered enough of these things by this time so that we are almost ready to start the study of a functioning receiver.

The main purpose of a receiver, whether radio or television, is to pick up the many electromagnetic signals which exist in space, select one particular frequency from all the others, amplify the chosen one and reject all others, and finally change it into a form which is perceptible to the human senses. To do all these things requires the proper functioning of many parts, each doing some job which it is best qualified to do.

In the case of a radio, the chosen signal which is radiating out through space is changed into electrical impulses which operate a loudspeaker, and in so doing reproduces a sound which was first produced in the transmitter studio. It changes the radiated signal into sound which is audible to the human ears.

The television receiver has a dual function. It changes the radiated signal into sound which is audible to the human ears in very much the same manner the ordinary radio does it. In addition, it also changes another part of the radiated signal into electrical impulses which act upon a special vacuum tube which we usually refer to as the "picture tube" in such a manner that a scene in the studio is reproduced at the receiver in a form visible to the human eyes. Thus it can be seen that a television receiver incorporates all the elements of an ordinary radio receiver, plus some specialized circuits of its own. It would seem fit and proper that a study of television would

Fig.1. A Combination Radio-Phonograph-Television Receiver Uses One or More Pentagrid Converter Tubes. (Courtesy of Emerson Radio Corporation.)



C1 TUNING CAPACITOR
C2 RF BY-PASS CAPACITOR
C3 GRID-COUPLING CAPACITOR
C4 LOAD COUPLING CAPACITOR
L1 TUNING INDUCTANCE
L2 PRIMARY OF ANTENNA COUPLING TRANSFORMER
L3 SECONDARY
R1 GRID LEAK RESISTOR
R2 SCREEN DROPPING RESISTOR
RFC RADIO FREQUENCY CHOKE TO KEEP HIGH FREQUENCY FROM POWER SUPPLY.

Fig.2. An Oscillator for Generating and Radiating a Continuous Wave.

first include thorough instructions concerning the functioning and operation of a radio receiver.

Section 2. RADIATING OSCILLATOR

Modulation is a term you are going to meet very frequently in your studies from this point onward. It refers to the action of impressing audible or visual frequencies upon the "carrier frequency" of a transmitter and, in our case, their separation within the receiver.

Very early in our studies we mentioned that the ordinary frequencies which were perceptible to the human senses could not be radiated. We also said that in order to radiate any signal it was necessary to create alternating currents and voltages which are quite high. To produce these frequencies we use an ordinary oscillator. (See Fig.2.) Such an oscillator will create alternating voltages and currents and, if properly designed, will generate such voltages and currents at high frequency. You will note from a careful study of the diagram that the oscillator is an E.C.O., that is, an electron coupled oscillator. It could, of course, have been almost any type oscillator, just so the tuning circuit caused the output frequencies to be high enough for radiation.

The cathode, the control grid and the screen grid act as the active tube elements in the oscillatory circuit. But the high frequency alternating voltages and currents also appear in the anode circuit of the tube. The radio frequency choke connects the anode of the tube with the battery power supply. The inductance of the choke is such as to prevent the passage of any radio frequencies through it, thus keeping such frequencies out of the power supply. Direct current, however, will readily pass through the choke.

Note coupling capacitor C4. It will allow the passage of alternating voltages and currents, thus permitting the high frequencies to reach the primary of the antenna coupling transformer L2. Through transformer action, a high frequency voltage is induced in the secondary of the transformer. The secondary feeds the voltages and currents to the antenna.

Section 3. GROUNDING

It would be well to note the symbol for "ground". (Figs. 2 and 3.) This symbol was originally used to denote any connection which was actually made to the earth. Most modern electrical power systems have at least one connection which is physically made to the earth, either by driving a metal pipe into the ground or by connecting to a water pipe. Radio transmitters usually have an elaborate underground system consisting of underground wires fanning out in all directions from the antenna itself. Such connections are all noted on schematic diagrams by use of the symbol in Fig. 3.

But the symbol also has another use. In radio and television work it is the general practice to mount all the component parts on a metal "chassis". Since the chassis is of metal it is also a conductor of electricity. Being such, it is possible to use the metal of the chassis as a return path for many of the circuits in the radio or television receiver. Wherever a connection is made to the metal of the chassis it is the customary practice to use the "ground" symbol to denote such action. Actually, the symbol, through usage, has come to mean a "common connection" rather than a "ground connection". Almost every diagram you will encounter from this time on in your studies, and afterward in your everyday work, will make use of this "ground" symbol.

Section 4. CARRIER WAVE

The oscillator in Fig. 2 would produce what is called a *continuous wave*. That is, it will produce an alternating current and voltage which has one definite fixed frequency. This frequency will not change unless the value of either the tuning capacitor or the tuning inductance is changed. This frequency will be quite high, probably not less than 50,000 cycles per second; in fact it will probably be in excess of 500,000 cycles per second.

The main point is that it will be a continuous succession of high frequency sine waves, each having the same *amplitude*, and each following the one ahead at the same speed. For example, if the oscillator is operating at 500,000 cycles per second a new cycle will start each 1/500,000th of a second. It will have the same maximum voltage as each of the cycles which precede it, and each of those which follow will also have the same maximum voltage. In other words, each cycle is like all the others.

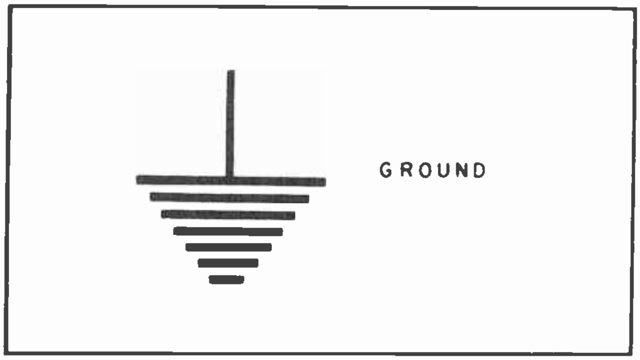


Fig.3. Grounding Symbol.

Such a succession of sine waves could be diagrammed as in Fig. 4. Of course, it is difficult to diagram a succession of such cycles, especially when there are so many of them each second. Even a period of time as short as 1/100th of a second would have 5,000 complete cycles. But the succession of sine waves in Fig. 4 will serve our purpose to show something of their nature.

So long as the power for the oscillator is stable, such as that of a battery, the maximum size, or height, of the sine waves will not change. If one cycle has a certain maximum voltage swing from the positive peak to the negative peak, all the other cycles will have the same voltage swing. Then in graphing such a continuous succession of waves as we have in Fig. 4, we would draw each cycle as all of the others.

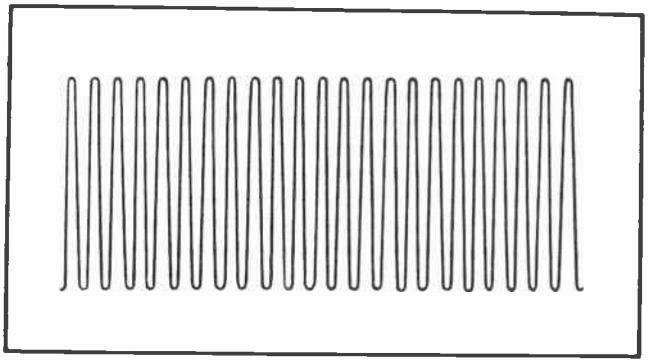


Fig.4. A Series of Continuous Sine Waves.

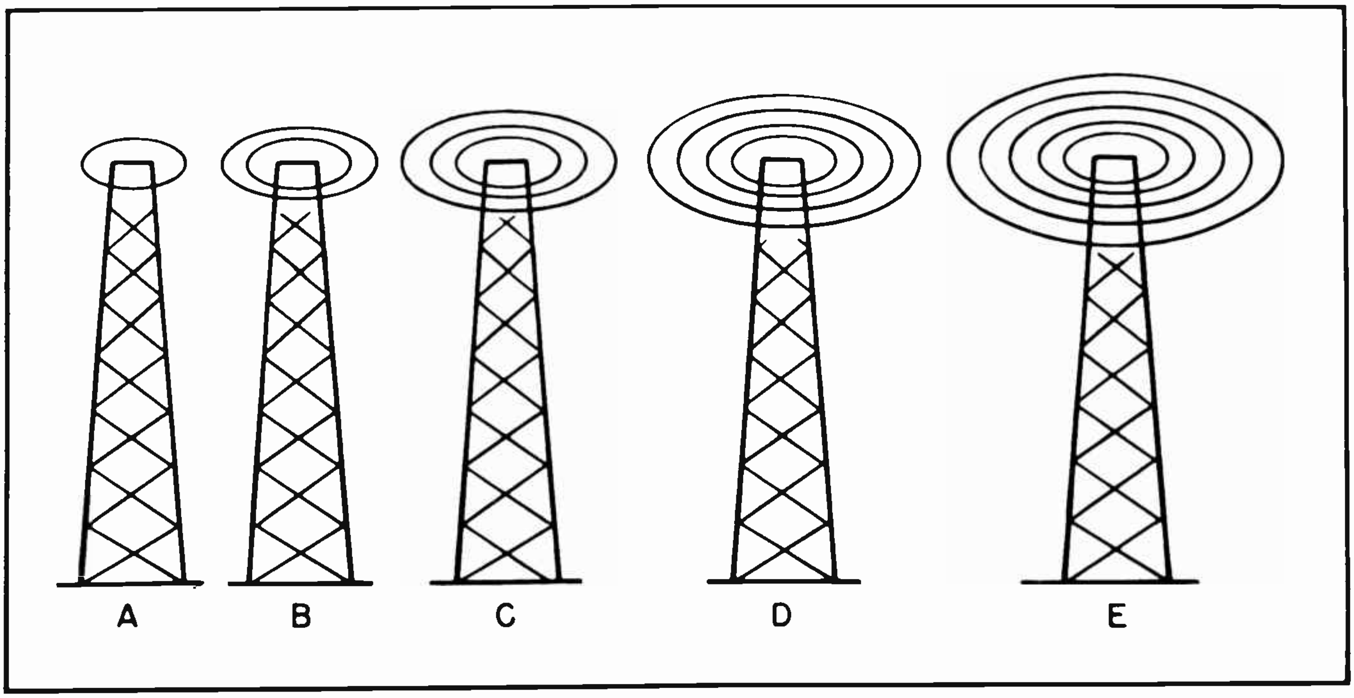


Fig.5. How Energy is Radiated Out into Space at High Frequencies.

Such an alternating current as is represented by Fig. 4 will have alternating magnetic fields building up and collapsing around it just as is the case of alternating currents at lower frequencies. You will recall that when dealing with the lower frequencies we learned that when current flowed into a circuit a magnetic field would build up around the circuit. Then when the current ceased to flow the field would collapse into the circuit.

The same thing is true -- within limitations -- at the higher frequencies. You will recall that it takes a definite period of time for the magnetic field to build up. Further than this, it also takes a definite period of time for the field to collapse. This action is so fast at low frequencies that the building up and collapsing can take place in step with the changing currents.

But as the frequencies increase, a point is reached where the field builds up in one direction, changes and starts to build up in the other direction before the first field can completely collapse. As the frequency is raised still higher we find a field built up in one direction, then before that field can reverse and collapse a second field is built up, pushing the first a little further out into space. Then before either of these can collapse, a third field starts building up, pushing the first two still further out into space. This continues indefinitely. The high frequency currents keep building up a succession of magnetic fields, each of which begins to build up before the preceding one can completely collapse. The result is that the first magnetic field is shoved further and further away from the circuit, the first is followed by the second, the second by the third, and so forth indefinitely. When this happens we say the circuit is "radiating" into space. The magnetic fields which are "radiated" are a form of energy. And when these magnetic fields cut across any metal conductor they set up induced voltages within those conductors.

An idea of how successive impulses of extremely high frequency electrical current through a conductor causes a succession of magnetic impulses to radiate out through space is indicated by Fig. 5. The first pulse creates a magnetic wave as at *A*. Before that field can collapse a second is built up as at *B*, pushing the first farther away. Others follow as at *C*, *D* and *E*.

It should be noted that only high frequency alternating currents will "radiate" any appreciable amount of magnetic energy into space. Such a succession of electromagnetic waves are commonly called a "carrier wave". Since the frequencies which can be radiated into space are much higher than those which are perceptible to the human senses, it becomes evident that ordinary sound frequencies cannot be radiated by themselves. But it is possible to superimpose ordinary sound frequencies upon a much higher frequency and use the higher frequency to "carry" the lower audible frequencies. This is where the name "carrier frequency", or "carrier wave", comes from.

Section 5. **MODULATION**

There are several ways by which the carrier wave can be used to carry the much lower frequency from the transmitter to the receiver. The oldest method is to change the *amplitude*, or strength, of the carrier wave to correspond with the changing voltage of a "modulating" audible alternating current or voltage.

In Fig. 6 we have redrawn Fig. 2. Essentially it is the same circuit, but in Fig. 6 we have made wider use of the "ground" symbol, thus simplifying the circuit somewhat. It also permits rearranging the circuit on the paper in such a manner that we can add other elements in later diagrams. Note also that we have designated the frequency at the antenna transformer as being 500,000 cycles. We have chosen this frequency arbitrarily because it is easy to work with and is one which will radiate easily.

It might be well worth mentioning at this time that the word "radio" is intimately connected with "Radiation". The early term for what we now call "radio" was "wireless", and it is still so called in England and some other countries even unto this time. But because the engineers were primarily concerned with ways of radiating more and more energy out into space, the term "radio" gradually crept into use in this country so that now it is used to refer to any type of such radiated energy whether it is used to transmit voice, pictures, facsimile, or some of the other things.

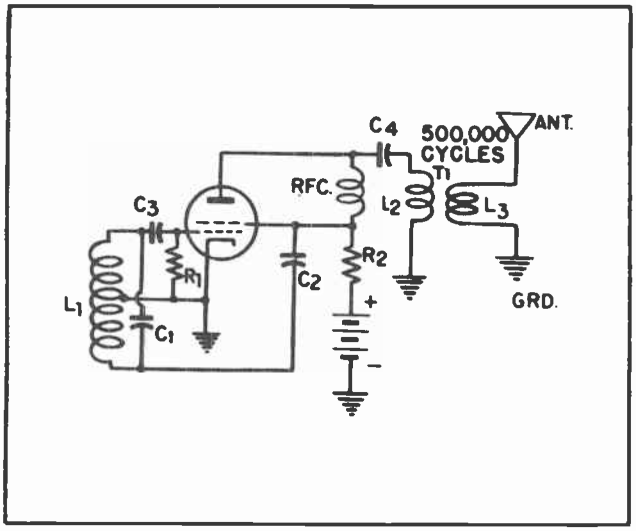


Fig.6.

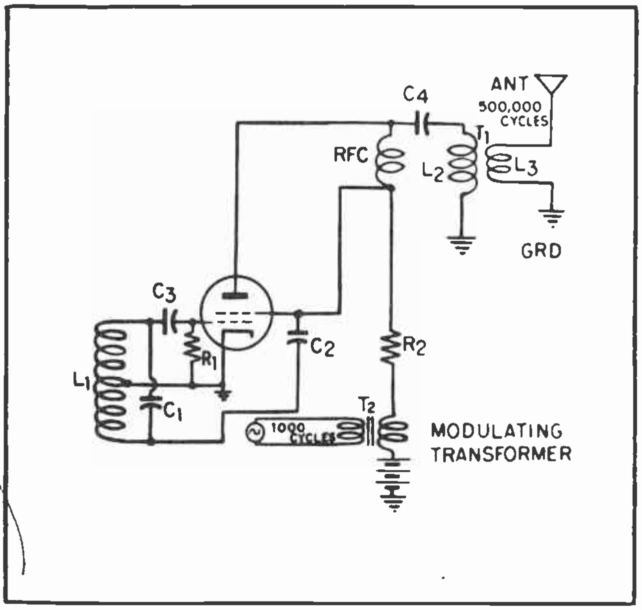


Fig.7. How a Modulating Transformer is Connected to the Anode Power Supply of an Oscillator.

In Fig. 6 we continue to have a steady source of power for the anode of the oscillator. Thus this oscillator will feed a continuous wave of energy cycles to the antenna at the rate of 500,000 cycles each second. Each cycle will have the same shape and size as those before and behind, just as in Fig. 4.

But suppose we arrange to periodically change the voltage on the anode of the oscillator tube. This could be done in several ways but probably the easiest and most common is to place the secondary of a transformer in series with the battery power supply, as in Fig. 7. Note that transformer *T2* has an iron core. An iron core transformer will easily pass audio frequencies but will not pass radio frequencies. If an audible frequency of, say 1000 cycles, is applied to the primary of the transformer, a 1000-cycle frequency voltage will be applied in series with the battery power supply. Now we have a varying power supply voltage so far as the anode of the oscillator tube is concerned.

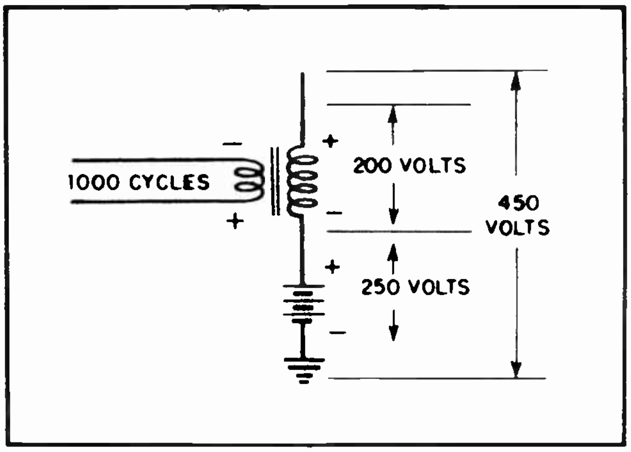


Fig.8. How the Modulating Voltage Adds to the Power Supply Voltage on the Positive Cycles.

To understand exactly how the superimposed 1000-cycle frequency from the transformer affects the supply voltage to the oscillator tube you should study Fig. 8 for a few moments. For the sake of convenience, we will assume the battery is supplying 250 volts. The voltage from the battery will be constant, steady. The voltage from the secondary of the transformer, which is in series with the battery, will be alternately positive and then negative.

If the current in the primary is such as to induce 200 volts across the secondary of the transformer, we will have the situation as shown in Fig. 8 during those instants when the upper end of the transformer secondary is positive with reference to the lower end. At that instant the voltage of the transformer will add to the voltage of the battery, resulting in a voltage of 450 volts on the anode of the tube.

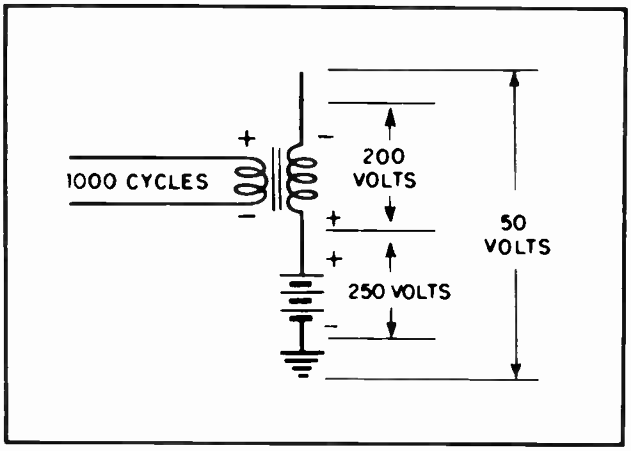


Fig.9. How the Modulating Voltage Reduces the supply Voltage on the Negative Cycles.

At the next instant, however, when the voltage reverses across the secondary of the transformer we will have the situation shown in Fig. 9. At this instant the voltage of the transformer will oppose the voltage of the battery. Now there will be only 50 volts applied to the anode of the tube instead of the 250 volts normally applied, and the 450 volts applied when the transformer voltage *aids* the battery supply voltage.

These changing voltages on the anode of the tube are not going to affect the frequency of oscillation. The frequency is controlled by the tuned circuit in the grid circuit of the tube. But the varying anode voltages are going to have some affect on the strength of the signal which is fed into the antenna transformer *T1* of Fig. 7.

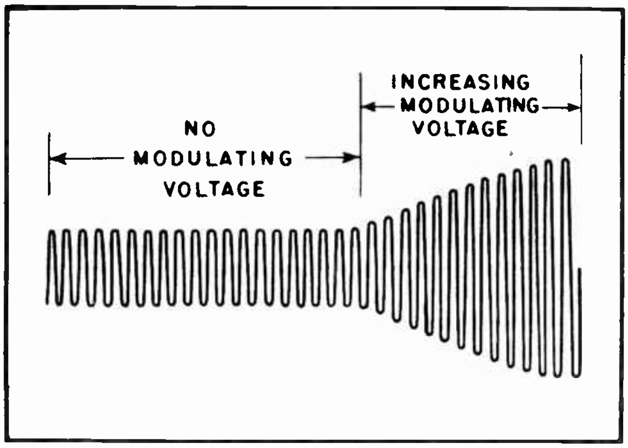


Fig.10. How the Amplitude of the Waves Increase when the Anode voltage is Increased. There is no Change in the Frequency.

When there is no voltage on the modulating transformer *T2* of Fig. 7, there will be a continuous wave of radiated energy as indicated by Fig. 4. But when the anode voltage is increased by the action of the transformer as in Fig. 8, the magnitude of the waves will increase in response to the increased anode voltage as in Fig. 10. The voltage from the transformer will not rise instantaneously. For this reason the magnitude of the radiated waves will not rise sharply. Rather they will rise gradually in response to the increased voltage as in Fig. 10. It should be remembered that the radio frequencies are going through their cycles once each 1/500,000th of a second. But the voltage in the modulating transformer is going through a cycle only once each 1/1000th of a second, or just 1/500th as fast.

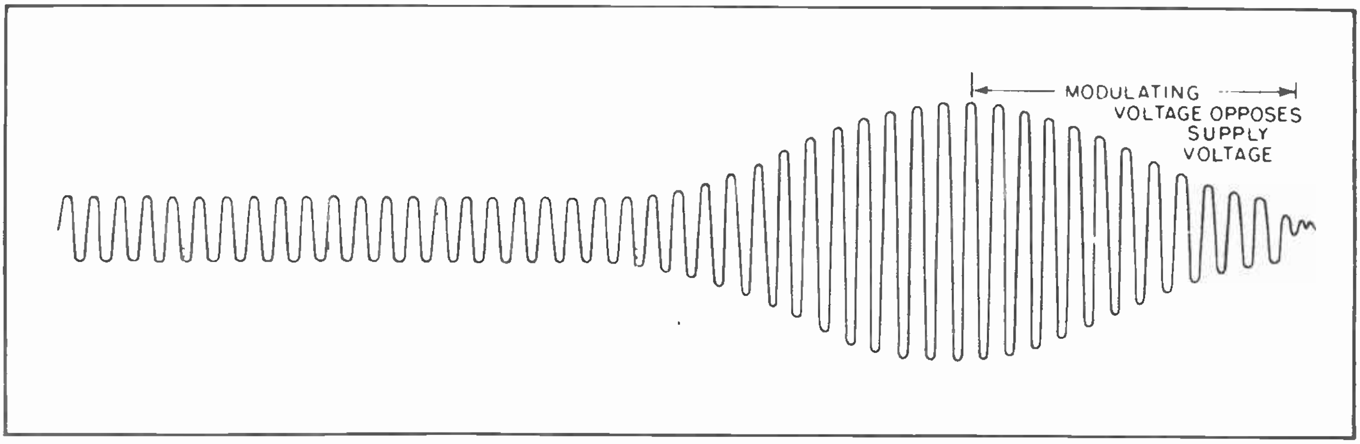


Fig. 11. The Modulating Voltage can Reduce the Amplitude as Well as Increase it.

Further than this, as soon as the transformer secondary voltage reaches a peak it will turn around and start in the other direction until its voltage is completely reversed. At this latter instant there will be only 50 volts on the anode of the tube and the magnitude of the radiated waves will have been reduced almost to nothing. In fact, for an instant there will be virtually no power being radiated. (See Fig. 11.) The action of superimposing the negative voltage from the modulating transformer on the anode of the oscillator tube is to reduce the power output of the tube almost to the vanishing point, and reducing the radiated power from the antenna almost to zero.

Then as the modulating transformer starts through another cycle it will gradually reduce its negative voltage and eventually increase the positive voltage on the anode of the tube to 450 volts again. When this occurs, the magnitude of the radiating waves will again increase until full power is being again radiated as indicated by Fig. 12.

Note very carefully that we now have two types of frequencies being radiated out through space. The main carrier frequency is being radiated at a frequency of 500,000 cycles per second. The carrier waves themselves are being *modulated* at the rate of 1000 cycles per second. The carrier wave is the medium of transmitting signals through space. The *intelligence* is being carried as a superimposed modulation of the carrier wave through the medium of varying the *strength*, or amplitude, of the carrier wave.

To put this in other words, the carrier wave's *magnitude of strength* is being changed in accordance with the frequency of the words or music it is desired to broadcast through space. In order to pick up such a signal and decipher it we must have a receiver to select the desired

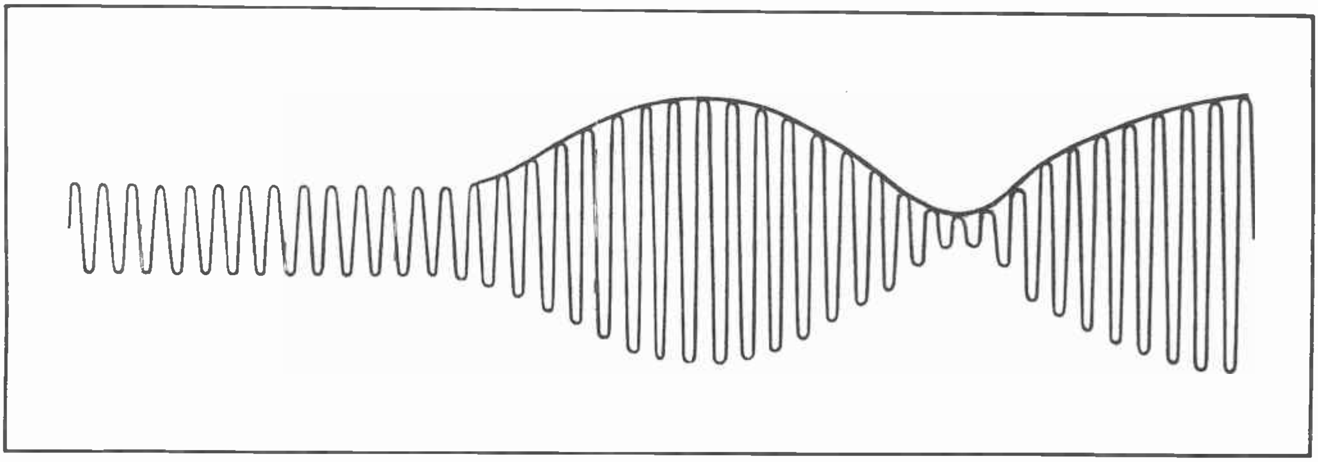


Fig. 12. Note how the Amplitude of the Carrier Changes through the Action of a Sine Wave of Much Lower Frequency than that of the Carrier.

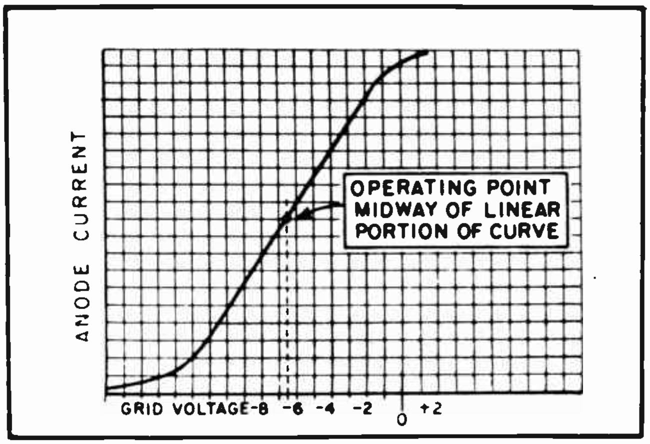


Fig.13. Biasing for Class "A" Operation.

frequency from all the others on the air, change the *varying strength* of the carrier into intelligible electrical impulses, and discard the no longer needed carrier frequency. Modern radio and television receivers do all these things.

Section 6. BIASING POINTS

The method of superimposing a modulating voltage on a carrier wave which has just been described is called *plate modulation.* It is widely used in transmitter work, probably the most widely used method of all.

The signal can also be modulated by impressing the modulating voltage on one of the grids inside the tube. When this is done, the tube should be biased to operate on the linear portion of the characteristic curve as shown in Fig. 13. When the tube is so biased, the lower frequency will appear in the plate circuit superimposed upon the higher frequency. In other words, there will be only two frequencies appear

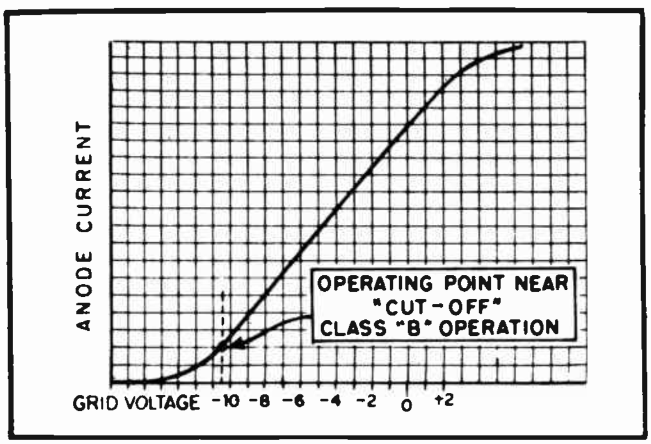


Fig.14. Biasing for Class "B" Operation.

in the plate circuit of the tube -- those which were impressed on the two grids of the tube.

Should the tube be so biased that it will operate along the *non-linear* portion of the characteristic curve, an entirely different situation will be brought about. Fig. 14 shows the operating point for a tube biased with a little more than 10 negative volts. When a tube is so biased that it operates at, or near cut-off, it is said to be biased for class "B" operation. This contrasts with the operation of a tube biased midway along its characteristic curve as in Fig. 13. The tube in Fig. 13 is biased for class "A" operation.

When two different frequencies are imposed on two different control grids of a vacuum tube, as in Fig. 15, and the tube is biased

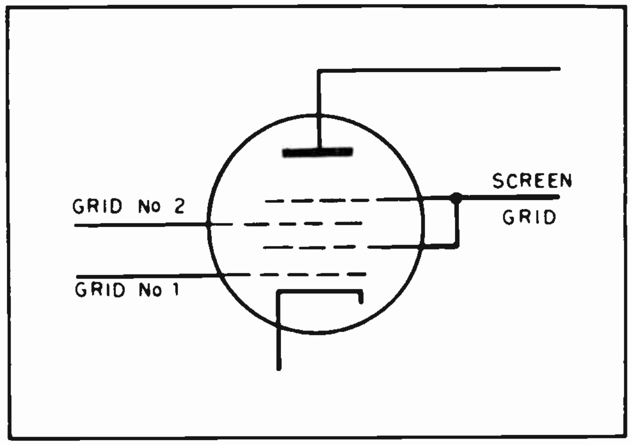


Fig. 15.

near cut-off or in the non-linear portion of the characteristic curve, there will be *four* different frequencies appear in the anode circuit of the tube. There will be the frequency impressed on grid No. 1. There will be the frequency impressed on grid No. 2. There will be a third frequency which will be equal to the *sum* of the first two frequencies. And there will be a fourth frequency which is equal to the *difference* between the first two frequencies.

This can be understood a little better by referring to Fig. 16. There we find a frequency of 1,000,000 cycles impressed on one control grid of the tube. We also find another frequency of 460,000 cycles impressed on the other grid of the tube. In the anode circuit we find *four* frequencies. As would be expected, we have the original 1,000,000 cycle frequency and the 460,000

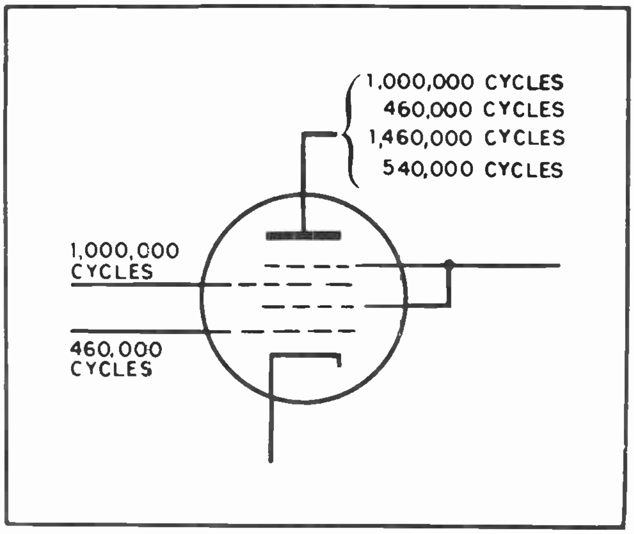


Fig.16.

cycle frequency. In addition to these two we have two others. The first is the sum of the first two frequencies, 1,460,000 cycles; the second is the *difference* between the first two, 540,000 cycles.

A special tube has been designed to take advantage of this peculiar performance, and to put the phenomenon to work for us. It is called the *pentagrid converter*.

Section 7. **SYSTEMS FOR AMPLIFYING RADIO SIGNALS**

We have already mentioned that two different systems are used to amplify the radio frequency signals which are picked up from space until they are strong enough for us to separate the audio portions from the carrier wave portions. (See Fig. 17.) One is called the *TRF*, of which more will be said later. In a receiver using the TRF principle the original radio frequency is amplified over and over until it is quite strong. Then the two main components of the signal are separated from each other.

The TRF system has several drawbacks. It takes more stages of amplification to amplify a high-frequency radio signal than it does to amplify a lower frequency. Further than this, it means that a large size ganged variable capacitor having many section must be used so that all the stages of amplification can be tuned to the same radio frequency. The result is that TRF receivers are usually bulky, expensive, and none too selective.

The other system, called the superheterodyne system, changes the original radio frequency to some lower frequency by mixing it in a *converter* or *mixer* tube with a third frequency. The superheterodyne is so arranged that the lower frequency to which the incoming signal is changed is always some *fixed* frequency. For example, many receivers are so designed that all incoming radio signals are changed in the converter, or mixer, tube to 465,000 cycles. It makes no difference what frequency the incoming signal might be, the receiver changes the signal to 465,000 cycles for amplification purposes.

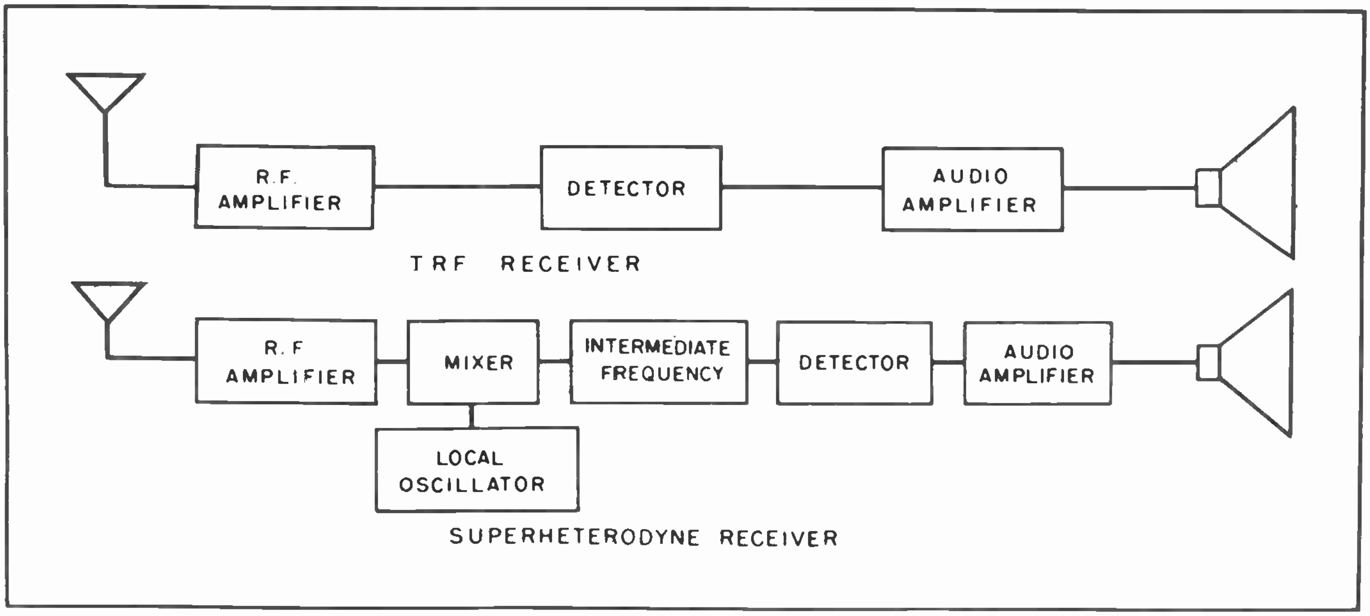


Fig.17. Signal Channels in Two Types of Receivers.

Another receiver might change all the incoming signals to 455,000 cycles. In this case every frequency which is received is changed to 455,000 cycles for amplification.

Some of the older radio receivers changed all the incoming signals to 175,000 cycles for amplification. A frequency of 175,000 cycles has certain definite advantages, but also some disadvantages. Few, if any, modern receivers use 175,000 cycles as a fixed frequency.

Many television receivers change the incoming signals to 21,250,000 cycles for amplifications. Others to 25,750,000 cycles. Still others to some other similar frequency. It might be argued that this is a very high frequency to be used as a fixed frequency, especially when the purpose of the fixed frequency is to obtain a *lower* frequency than the one picked up from the air. But remember that the carrier frequencies of television signals are quite high. Some range up into the hundreds of millions of cycles per second. When this is considered, it can be seen that 21,750,000 cycles is much lower than the carrier frequency. Furthermore, it is a fixed frequency and being such, it is possible to build special high-gain transformers to connect the various states of amplification.

Section 8. **MIXER CIRCUITS**

Some mixer tubes require a separate tube for use as an oscillator. Typical of this type is the 6L7. The 6L7 tube is widely used as a mixer tube in communication receivers, and in other receivers where excellent performance is more important than the additional expense of the extra tube. Many receivers which operate in the higher frequencies also use the 6L7 since it operates very well at frequencies much higher than those of the broadcast band.

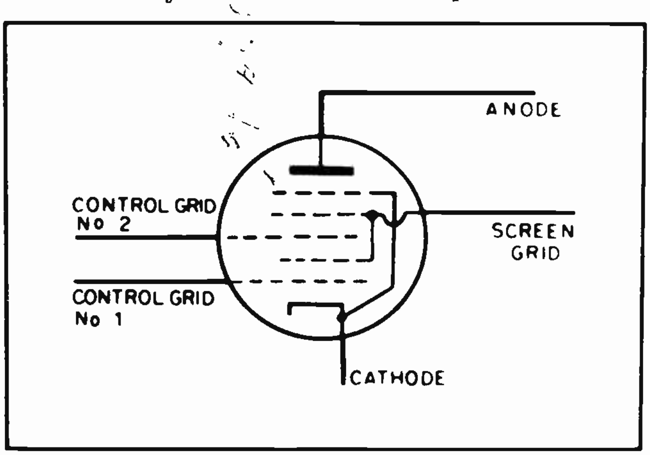


Fig. 18. Tube Elements in a 6L7 Mixer Tube.

The arrangement of the elements within the 6L7 are diagrammed in Fig. 18. Note that there are five grids. It is from this fact that the pentagrid converter obtains its name. *Pentagrid* means five grids.

The suppressor grid is connected inside the tube to the cathode. Control grid No. 1 is connected to a metal cap on the top of the tube. The two parts of the screen grid are connected together inside the tube. All connections to the internal elements except the first control grid and the suppressor grid are brought out to terminal prongs on the bottom of the tube.

Fig. 19 shows the type of circuit which would be used with a type 6L7 mixer tube. The oscillator tube is entirely separate. A type 6C5 triode tube is very frequently used as an oscillator tube with the 6L7.

The incoming radio frequency signal is fed into the 6L7 on control grid No. 1. This is the grid which is brought out to the cap on the top. The input to this grid is a tuned circuit, the variable capacitor of which is mechanically coupled with the variable capacitor for the oscillator circuit. This means the capacitance of both capacitors are changed together -- at the same time.

The oscillator frequency from the local oscillator is fed into the 6L7 on control grid No. 2. By studying Fig. 19 very carefully it can be seen that the stream of electrons from the cathode of the 6L7 tube to the anode will be controlled by the action of both grids.

It is extremely difficult, without going deeply into mathematics, to explain exactly the action which takes place within the tube. The important thing is that as a result of the two grids, and due to the fact the 6L7 is biased near cut-off and thus operating on the non-linear portion of the characteristic curve, the anode circuit of the tube will contain *four* frequencies.

Fig. 19 does not show any particular frequencies on any of the grids, nor in the anode circuit. But Fig. 20 shows the essential parts of Fig. 19, with the various frequencies shown at the more important locations.

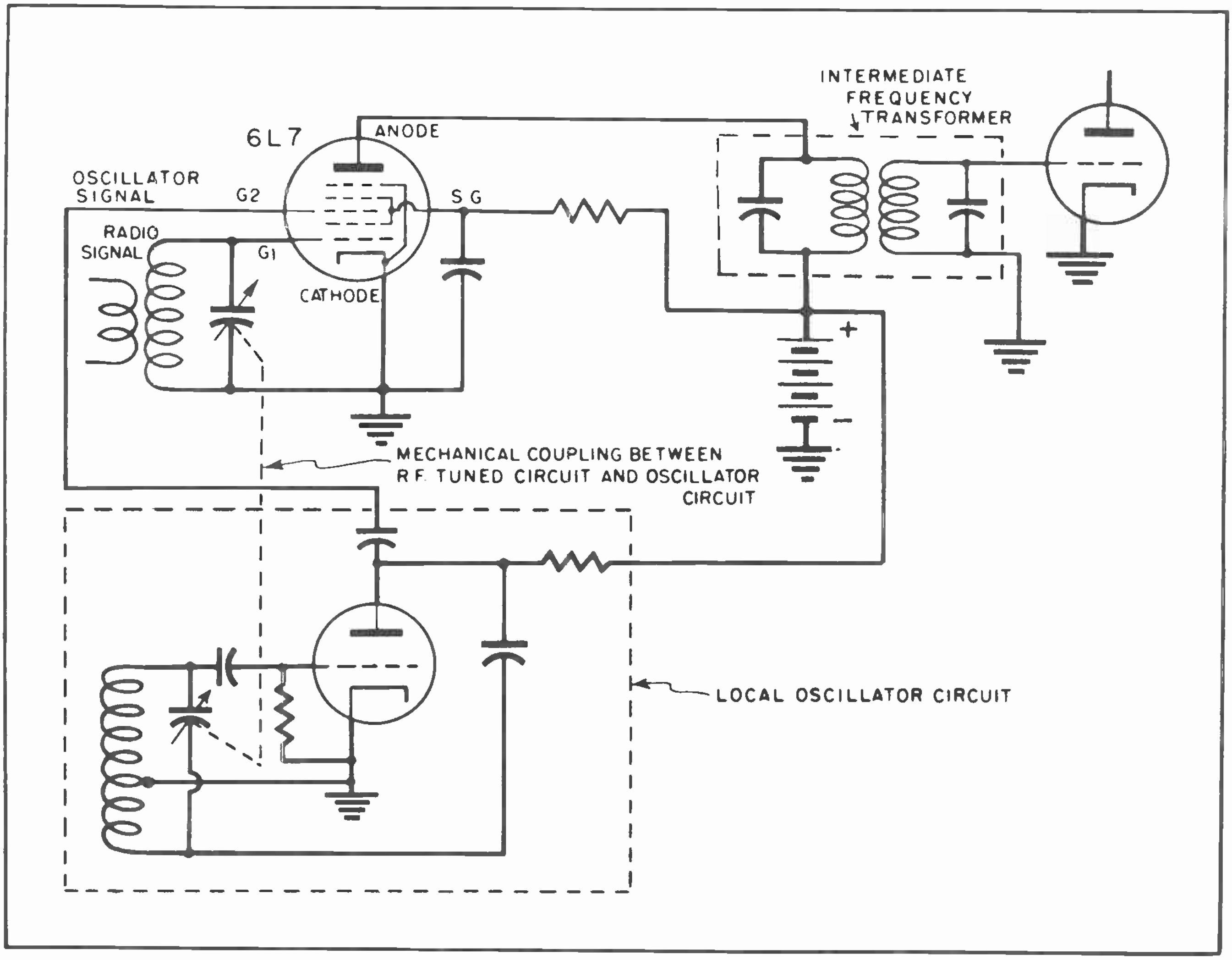


Fig.19. Mixer Circuit Using a 6L7 Tube.

The oscillator circuit of Fig. 19 has not been shown in Fig. 20. But the lead from the oscillator is shown leading to control grid No. 2. The incoming radio signal is 1160 kilocycles, which is equivalent to 1,160,000 cycles. These two frequencies mix together in the 6L7 tube with the result that four different frequencies appear in the anode circuit of the 6L7.

These frequencies are the 1160 k.c. frequency which was picked up by the antenna, the 1625 k.c. frequency generated by the local oscillator circuit, and two others. The other two frequencies are the *sum* frequency, 2786 kilocycles, and the *difference* frequency, 465 k.c. All these frequencies are fed into the double tuned transformer which is indicated by the dotted square.

The double tuned transformer is an intermediate frequency transformer which is permanently tuned to one fixed frequency. In this case it is tuned to 465 k.c. When the 465 k.c. frequency is fed into the transformer, the primary circuit of the transformer will resonate and the 465 signal will be passed on into the secondary circuit. The secondary circuit is also tuned and it, too, will resonate. The result is that the 465 k.c. signal will pass to the grid of the next tube greatly amplified.

The 1160 k.c. frequency will have virtually no effect on the primary of the transformer. Neither will the 1625 k.c. frequency nor the 2785 k.c. frequency.

It might be said that so far all is well and good. It is understandable that a 1160 k.c. signal can be changed into 465 k.c. and thus amplified, but suppose the incoming signal had been 1240 k.c., or 720 k.c. or some other frequency. What then?

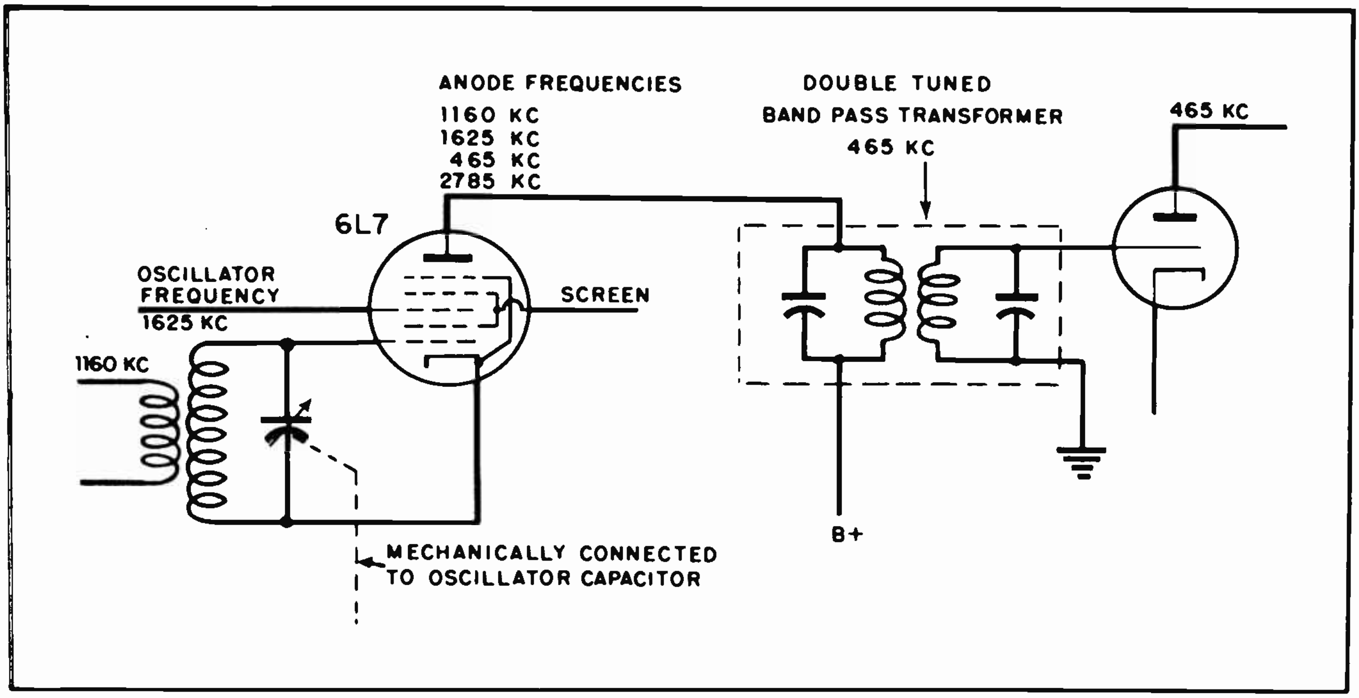


Fig.20. Frequencies at Various Points in a 6L7 Mixer Circuit.

Such a question would be very sensible. Let us take the example of the 1240 k.c. frequency first. In order to tune the tuned circuit in the No. 1 control grid circuit to 1240 k.c. we must change the capacitance of the capacitor in that tuned circuit. To tune to the higher frequency it means we must reduce the capacitance of the capacitor. This is done by varying the capacity just enough for the circuit to resonate at 1240 k.c.

But in changing the capacity of the capacitor in the tuned circuit of control grid No. 1 we have also changed the capacity of the capacitor in the tuned circuit of the oscillator. Figs. 19 and 20 show how these two variable capacitors are mechanically coupled together. When the capacity of one is changed, the capacity of the other is also changed.

Since we reduced the capacity of the tuning capacitor in the tuned circuit of grid No. 1, it is reasonable that we also reduced the capacity of the capacitor in the tuned circuit of the oscillator. If we do this we are going to increase the frequency of the oscillator at the same time we increase the frequency of the main tuned circuit.

If we raise the frequency of the main tuned circuit from 1160 k.c. to 1240 k.c. we will increase the frequency of the oscillator circuit from 1625 k.c. to 1705 k.c. This being the case, let's see just what effect it will have on our mixer circuit.

Our incoming radio frequency is now 1240 k.c. Our main tuned circuit is tuned to this frequency. Our oscillator frequency will be 1705 k.c. Both these frequencies will appear in the anode circuit of the tube. The sum frequency will also appear in the anode circuit. The sum frequency is 2945 k.c. Most important of all, the difference frequency will also appear. While all the other frequencies in the anode circuit in Fig. 21 are different from the corresponding frequencies in Fig. 20, the difference frequency is the same -- 465 k.c. And this 465 k.c. will resonate in the double tuned transformer just as in Fig. 20.

We have seen now how an incoming frequency of 1160 k.c. can be changed into 465 k.c. in Fig. 20, and how this 465 k.c. will resonate in a special transformer designed to amplify that one particular frequency. We have also seen how an incoming frequency of 1240 k.c. will also be changed into 465 k.c. to resonate in the special transformer. These two incoming frequencies are fairly close together. Let's see what will happen at the much lower frequency of 720 k.c.

In order to tune the main circuit of the mixer tube to 720 k.c. we must add considerable capacity to the circuit. This is done by turning the variable capacitor until the circuit resonates at 720 k.c. And in turning the variable capacitor we also added capacity to the oscillator circuit, thus reducing the frequency of that circuit.

When the main circuit resonates at 720 cycles the oscillator circuit will resonate at 1185 k.c. Again we will have four frequencies in the anode circuit of the 6L7 tube. We will have the 720 k.c. incoming frequency, the 1185 oscillator frequency, the sum of these two, 1905 k.c., and the difference frequency. And again we find the difference between 1185 k.c. and 720 k.c. will be 465 k.c. And, just as before, this 465 k.c. is just right for amplification in the tuned circuits of the intermediate frequency transformer.

As a matter of fact, it makes no difference what the incoming signal might be. When the main tuned circuit is adjusted to resonate at that frequency the oscillator frequency will be changed so that it is always exactly 465 k.c.'s higher than the incoming frequency. This means that the difference between the incoming signal and the oscillator frequency is always 465 k.c., which further means that whatever the incoming signal might be, after it passes through the mixer tube it will be 465 k.c.

As was mentioned before, all intermediate frequencies are not 465 k.c. Some are 455 k.c., some are 175 k.c., and in the television circuits some are 21.25 megacycles. But they are all so designed that the incoming signal will be changed to the frequency of the intermediate frequency transformer by the action of the mixer tube.

Section 9. THE 6A8 TUBE

While the 6L7 tube is an important, and highly useful one, it is by no means the only mixer tube. Although the 6L7 is frequently chosen for use in receivers which must operate at the higher frequencies, it has the drawback of needing an extra tube to act as an oscillator. This means extra cost.

Other pentagrid converter tubes have been designed to perform the dual function of mixing signals and providing their own oscillator frequency. Such a tube is the 6A8.

Fig. 22 shows the essential elements of the 6A8 type tube. At first glance it does not appear greatly different from the 6L7. However there are several differences. It will be noted that the grid nearest the

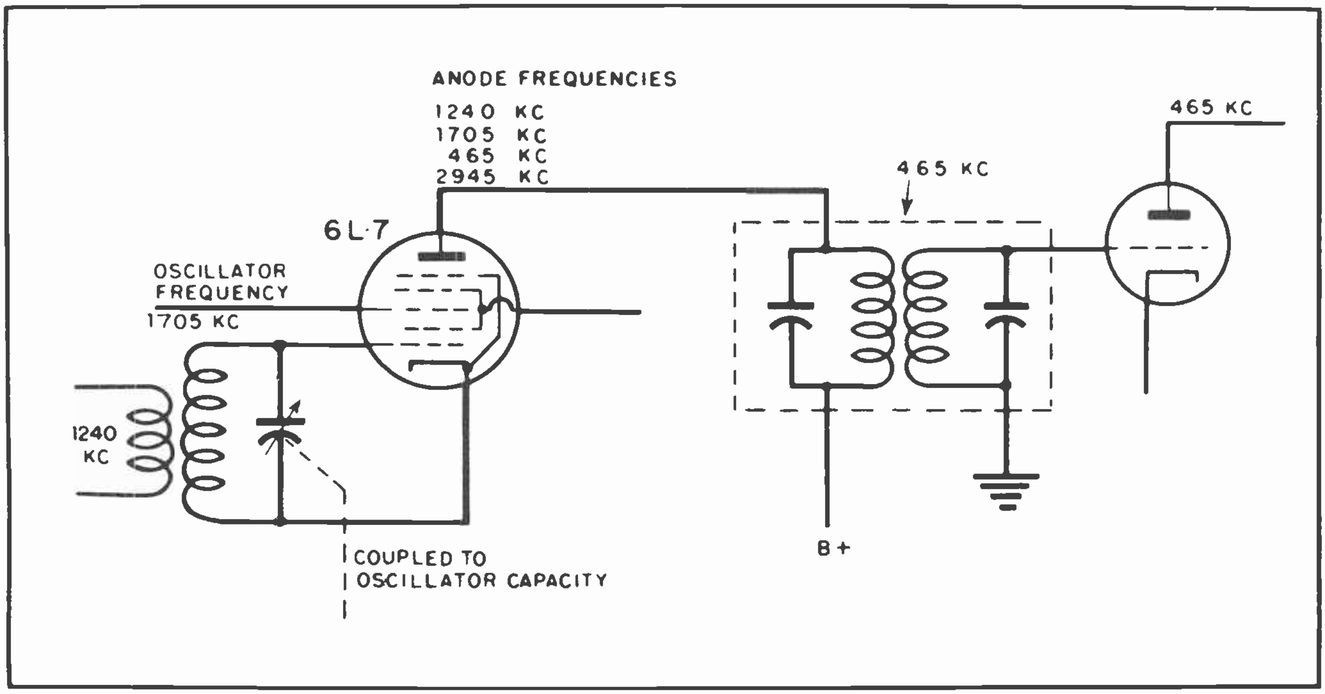


Fig.21.

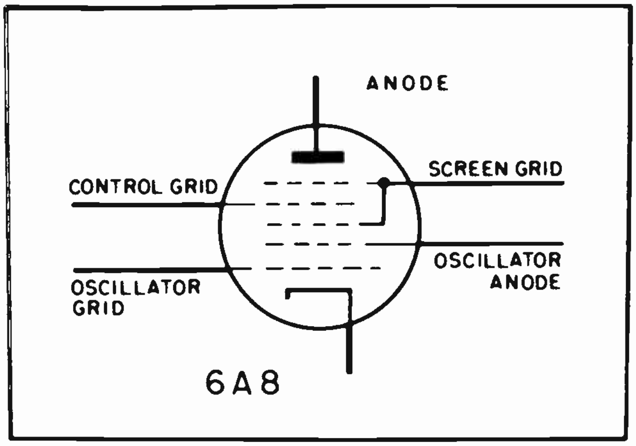


Fig.22. Tube Elements in a 6A8 Converter Tube.

cathode in the 6A8 is the oscillator grid, whereas in the 6L7 that was the main control grid. The second grid in the 6A8 serves as the anode for the oscillator circuit. Note that these three elements, the cathode, the first grid and the second grid act as the elements for the oscillatory circuit. Note also, that anything these elements do to the electron stream will also affect the action of the other tube elements, and affect the current in the anode circuit.

The next element after the oscillator anode is part of the screen grid. You will note by examining Fig. 22 quite carefully that the screen grid is divided into two parts, one on each side of the control grid. The control grid is the fourth grid in the electron stream instead of the first as in the 6L7. Then comes the other half of the screen grid, and finally the main anode.

Since the 6A8 contains its own oscillator elements it does not need a separate tube to act as an oscillator. The operation of the oscillator circuit elements modulates the electron stream just as effectively as would a separate outside tube and tube circuit.

A common method of coupling a type 6A8 tube into a mixer circuit is shown in Fig. 23. The variable capacitor in the oscillator circuit is coupled mechanically to the main tuning capacitor in the same manner as in the circuit which used the 6L7.

The 6A8, and its variations, will be found in more types of radio receivers than probably any other tube. At ordinary broadcast frequencies it has good properties, and is reasonably stable in operation. It is not a good tube to use at the higher frequencies. This is largely because of its relatively low transconductance. At the higher frequencies it will sometimes stop oscillating, or will have a tendency to drift. But for frequencies up to 6 or 8 megacycles it is satisfactory. At frequencies higher than

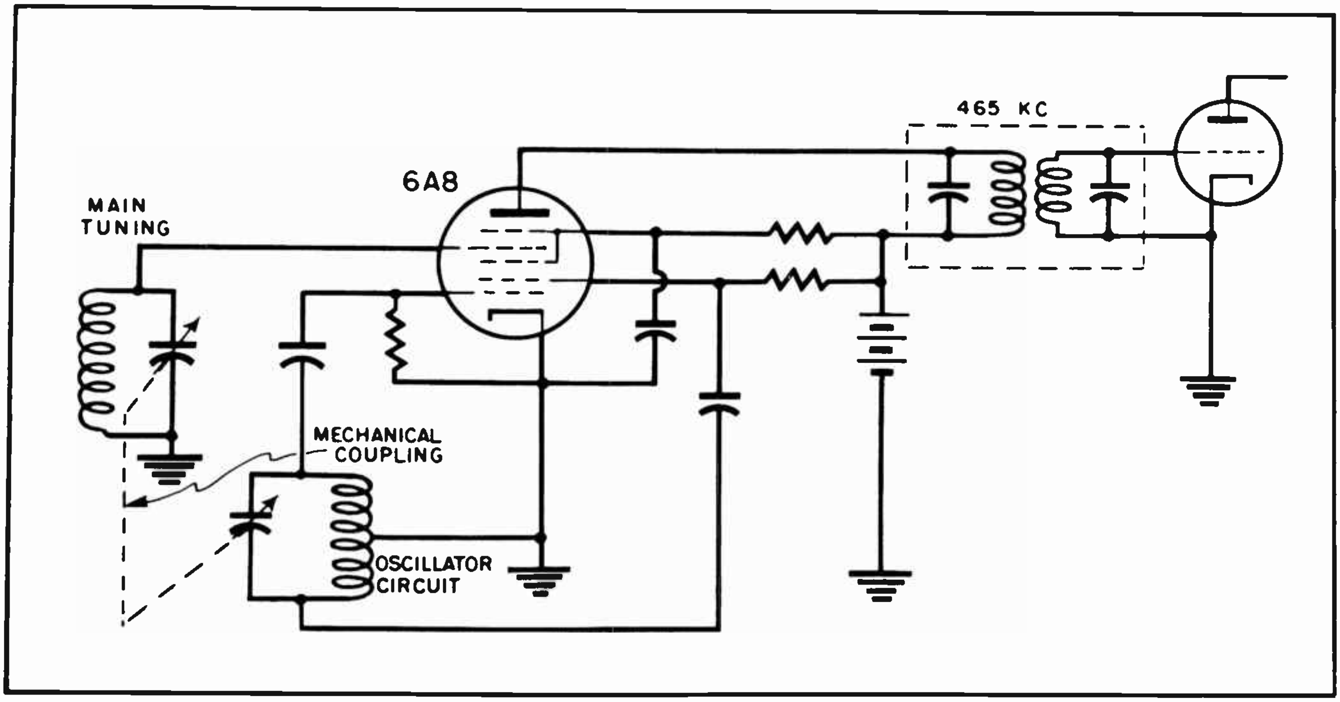


Fig.23. Mixer Circuit Using a 6A8 Tube.

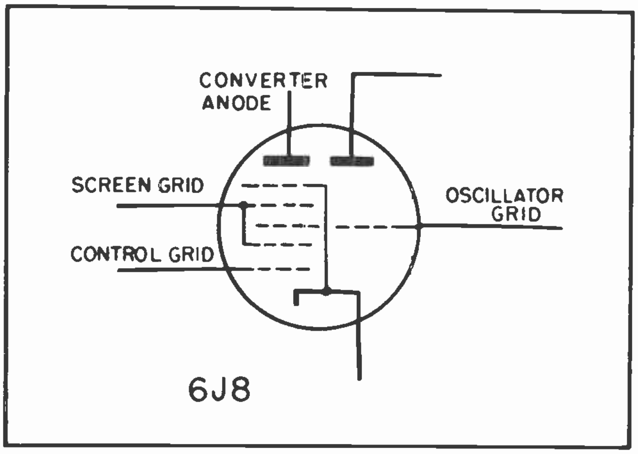


Fig.24. Tube Elements in a Triode-Heptode Mixer Tube.

those, it is usually better practice to use a tube like the 6L7.

Other tubes of the 6A8 type include the 1A6, 1A7, 1C6, 1C7, 1D7, 2A7, 6A7, 6D8, 7B8 and 12A8. A modified tube which has shown excellent operating characteristics at higher frequencies is the 6AC7. Some radio men claim the 6AC7 is one of the finest mixer tubes ever designed. All agree it has very fine properties.

Section 10. **TRIODE HEPTODE CONVERTER**

A special type of converter tube which has a separate oscillator within the glass envelope of the tube, but largely separated from the main converter elements is known as a *triode-heptode converter.* The essentials of such a tube, the type 6J8, is shown in Fig. 24.

In the triode-heptode tube the oscillator anode is entirely separate from the other elements of the tube. It is not placed in the main electron stream at all. The oscillator grid, however, is common to both the oscillator electron stream circuit and the main converter electron stream within the tube. This arrangement avoids the necessity of providing an additional connection in order to inject the oscillator frequency into the mixing section of the tube.

Fig. 25 gives a little better idea of the physical arrangement of the various elements within the triode-heptode tube. It will be noted that the oscillator anode surrounds the cathode in much the same way as the main anode, but each is separate. The oscillator grid extends the full length of the cathode, thus acting to control the stream of electrons between the cathode and the main anode as well as the stream between the cathode and the oscillator anode. The main control grid, however, is placed only between the cathode and the main anode. To avoid confusion, the other elements of the tube are not included in the illustration in Fig. 25.

A typical circuit using a 6J8 pentagrid converter is shown in Fig. 26. Note there is no need for a special external connection between the oscillator circuit and the main electron stream inside the tube. This is accomplished inside the tube by the extended oscillator grid.

The triode-heptode converter tube combines the better features of the 6A8 and the 6L7. It does not need an extra oscillator tube as does the 6L7. It is much more stable at the higher frequencies than is the 6A8. It does have the disadvantage that it has so many elements inside the tube that the tube is not quite so dependable as the other types.

In fact, the one great drawback to all pentagrid converter tubes is that so many elements are crowded together into such a small space that any movement on the part of any of the elements is most likely to short out one of the other elements. When trouble develops in a receiver, the best

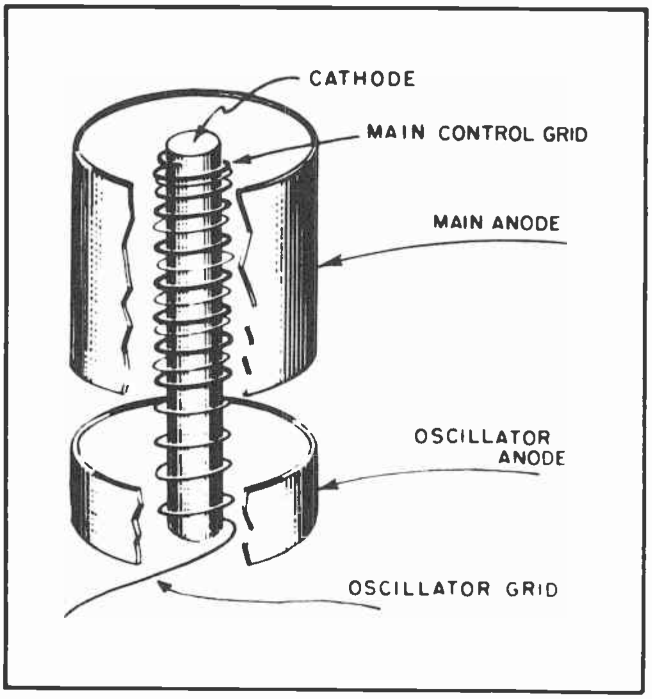


Fig.25. Physical Arrangement of Some Elements in a Triode-Heptode.

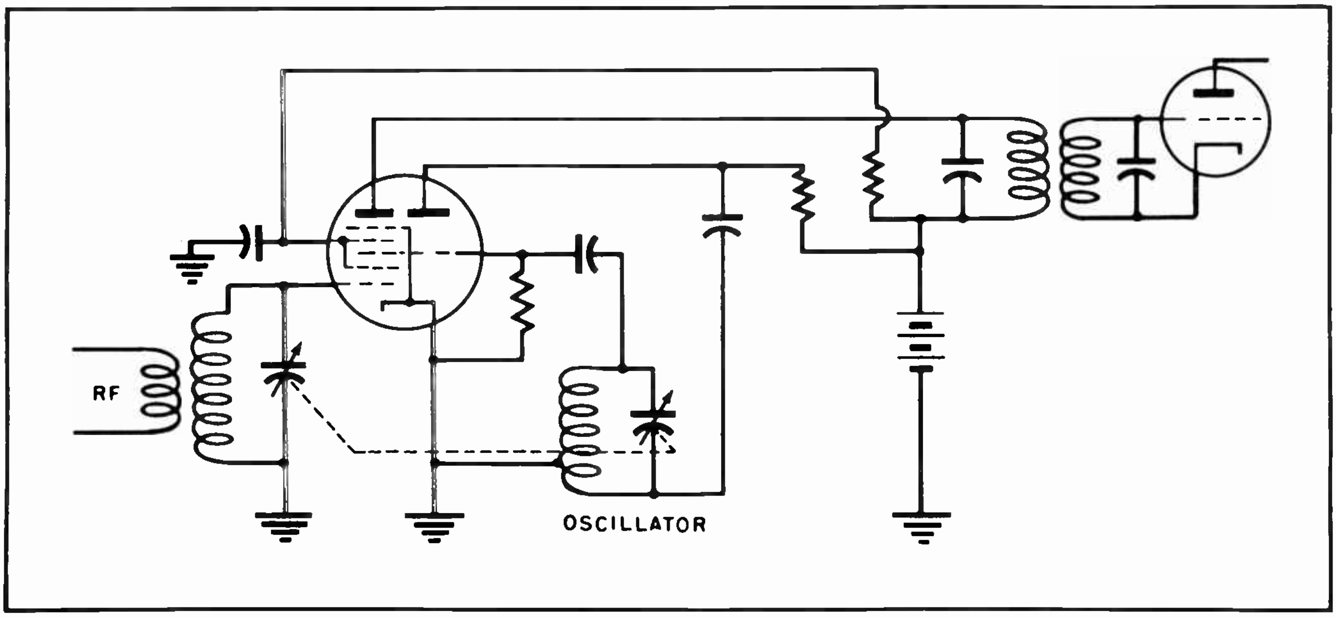


Fig.26. Mixer Circuit Using a Triode-Heptode.

place to look first is the converter tube. The wise service man will test the converter tube the first thing. In more than half the cases the trouble will be found in that tube.

Any kind of tube which combines two signals and then brings four out at the anode is called a *mixer* tube. When the tube combines the oscillator inside its own glass envelope it is called a *converter* tube. Most converter tubes require five grids. For this reason they are called *pentagrid converters*.

Much more will be mentioned in later lessons concerning the methods for shooting trouble in the converter stage of a receiver. The converter stage of television receivers is quite similar to that of a radio receiver. One difference is that the television receiver operates at a higher frequency, and in most cases uses a separate tube as an oscillator. Nearly all the tubes used in the converter stage of television receivers are miniature type tubes.

Another difference frequently found in television converter stages is that the anode will often feed two I-F channels rather than one as in a radio receiver. The reason for this is that the video frequencies are usually separated from the sound channel

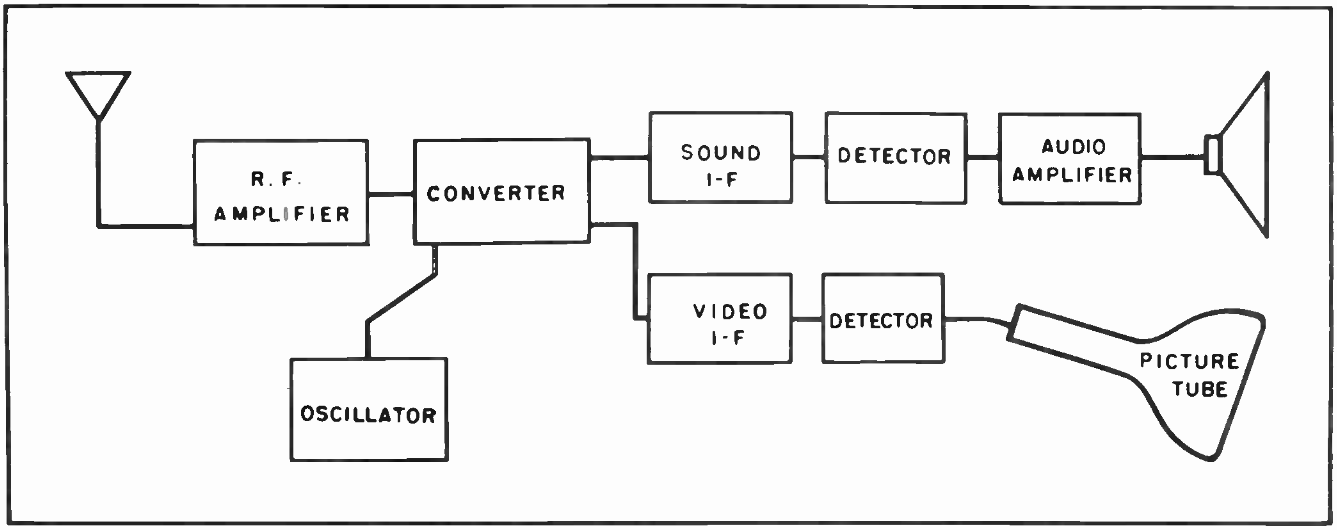


Fig.27.

at the converter stage. (See Fig. 27.) After leaving the converter stage, the audio-modulated portion of the I-F signal goes through one channel of I-F transformers, and finally through the detector and on to the loudspeaker. On the other hand the video-modulated portion of the I-F signal goes into another channel of I-F transformers, then is later detected and finally fed to the grid of the picture tube.

NOTES FOR REFERENCE

Modulation is a system of superimposing one frequency upon another so that one is carried by the other.

Mixing is a system of combining two frequencies in such a manner that four frequencies will be present in the output of the tube.

Mixing is always done by operating a tube near cut-off, on the non-linear portion of its characteristic curve.

A carrier wave is a high frequency signal which is capable of being radiated out into space.

A pentagrid converter is a special tube designed for mixing two frequencies so a third can be obtained at the output of the tube.

NOTES

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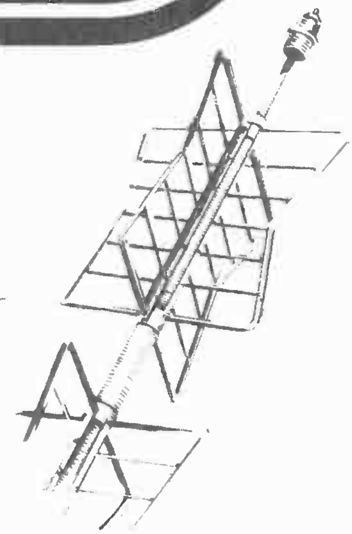

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HARMONICS

Contents: Introduction - Harmonics of Sound - Harmonics in Electrical Work - More About the Frequency Doubler - Class "C" Biasing - The Tri-Tet Oscillator - Image Frequency - Trouble from Harmonics - Other Troubles from Harmonics - Notes for Reference.

Section 1. INTRODUCTION

Since, in radio and television, we are dealing constantly with *frequencies* we have a situation very similar to one we find in music. In music we have notes, harmonics of the notes, overtones and other similar things. These are all directly related to vibrating frequencies. In the case of music the frequencies deal with disturbances of the air set up by vibrations from the musical instrument.

In the case of a piano we have an arrangement of tightened strings of various lengths, and varying degrees of tautness. When properly tuned the piano can create a note with a frequency so low the string will vibrate at a rate slightly over 26 times each second. At the other end of the scale the piano can produce another note with a frequency so high the string will vibrate at a rate of 4096 times each second. In between these two extremes are a large number of other notes, each vibrating at a frequency different from each of the other notes.

Everyone who has ever tried to play the piano, or who has listened to someone else try to play, knows that it is possible to hit two keys on the piano and produce a "discord". A *discord* is a sound which tends to jangle the nerves; they do not seem to "fit" together - they are not in harmony.

Yet everyone also knows that two or more other notes can be struck at the same time and the resulting sound will be very pleasant to the ear. To sound right the notes which are played together must "harmonize" with each other.

Section 2 HARMONICS OF SOUND

To understand a little better why some notes harmonize and others do not, let us study one situation as it actually exists. Every part of the piano keyboard revolves around its relationship to the key called "middle C". *Middle C* is the note *C* which is located nearest the center of the piano keyboard. On the written scale it is the most centrally located note of all.

When the key for note *middle C* is struck on the piano a little hammer will strike a taut string deep within the piano. The striking of the string will cause the string to vibrate. The vibrating string will set up vibrations in the air.

Fig.1. Each Key on a Piano Keyboard Causes a Vibration at a Different Frequency.

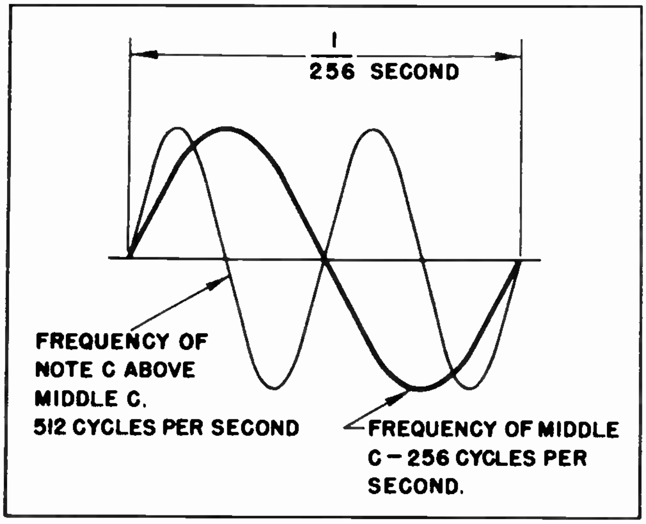

Fig. 2. Frequency of Middle C.

In the case of *middle C* the string will vibrate 256 times a second. This means that the note *middle C* has a frequency of 256 cycles per second.

All the notes to the left of *middle C* on the piano will vibrate at lower frequencies than 256 cycles; all the notes to the right will vibrate at higher frequencies.

By moving eight keys to the right of *middle C* we come to another note which is also called *C*. Sometimes this is called *the C above middle C*. Sometimes it is called other names. The most important thing to remember, however, is that this is another *C* note. (See Fig. 2.)

Since we have said that all keys, or notes, to the right of *middle C* vibrate at a higher frequency it might seem at first thought that we are inconsistent in our statements that *C* has a frequency of 256 cycles per second, yet another note of a higher frequency also is called *C*. Yet such a thing is actually true. The second *C* note has a frequency exactly twice that of *middle C*. The second note has a frequency of 512 cycles per second. As we will see a little later these two notes will harmonize together.

We might go another step further. We could call 256 cycles the *fundamental frequency of middle C*. It is called the fundamental frequency because it is the main or principle frequency of *middle C*. In the same manner we could call the frequency of the *C* above *middle C* -- 512 cycles -- the *second harmonic* of middle *C*.

You will recall from our lesson on pentagrid converters that we could mix two radio frequencies together in a converter tube and come out with the two original frequencies plus two additional frequencies. The additional frequencies amounted to the sum of the original frequencies and the difference between them. Much the same thing is true in music.

We have already mentioned that the frequency of middle *C* is 256 cycles per second. We can now say that the second note above middle *C* is the note *E*. It has a frequency of 320 cycles per second. Now let's see what happens when these two notes are struck together.

First we have the two fundamental frequencies, 256 cycles and 320 cycles. More than this we have the addition frequency (256 plus 320) which is 576 cycles. Now it so happens that 576 cycles is the exact frequency of the note *D* above the *C* above middle *C*. Further than this, the frequency of *E* -- 320 cycles -- is the tenth harmonic of low *C* which has a frequency of 32 cycles.

Also we have the difference frequency (320 minus 256). This is 64 cycles. And it so happens that 64 cycles is the frequency of the *C* above low *C*. As a matter of fact this could be carried on to even greater extent. It merely goes to show that when two notes having a related frequency is struck it sets up in the air a vast number of frequencies all of which are *harmonically* related to each other.

On the other hand when two notes are struck which are not harmonically related

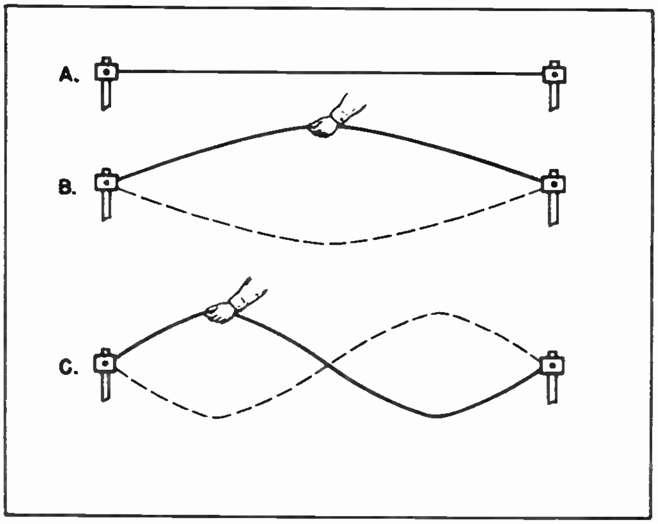

Fig. 3. How Overtones are Created.

we set up in the air a discordant jangle of frequencies which do nothing but grate on our sensory nerves of sound.

This explanation can be carried another step further. If a string is stretched between two posts as in *A* of Fig. 3 so that it will vibrate at 256 cycles per second it will give off the sound which is characteristic of note middle *C*. If the string is then plucked at the center, as at *B* of Fig. 3, the string will vibrate properly and will create the sound of middle *C*. This will be a pure note.

But if the string is plucked at a point between the center and one end as at *C* of Fig. 3 it will have a double vibration as shown in that illustration. It will continue to have its fundamental vibration frequency, but in addition will vibrate in two parts and thus set up a *harmonic* frequency as well as the fundamental frequency. In music these harmonic frequencies are usually called *overtones*. Some musical instruments are given characteristic tones by accentuating the overtones. This accentuation, or strengthening, is brought about by building hollow cavities in the instrument which will resonate with those overtones which it is desired to build up, or accentuate.

In other instruments we find their characteristic tones created by reducing or suppressing certain of the overtones. It should be noted in particular: The frequency of an overtone is always some multiple of the fundamental pitch frequency. This is a particularly important point to remember when thinking about harmonic relationships in the electrical circuits we will soon be studying. *A harmonic is always some multiple of the fundamental.*

As an example of this, 14 and 21 would be harmonics of 7, but neither 13 nor 15 nor 20 nor 22 would be. Likewise, 9 and 15 and 21 are multiples, or harmonics, of 3, but 10 and 14 and 17 are not.

Section 3. HARMONICS IN ELECTRICAL WORK

In radio and television work a good understanding of harmonics is vitally necessary. On one hand we put harmonics to work for us and find them extremely useful. On the other hand they can cause us much trouble if not properly controlled.

One of the most useful services harmonics perform for us is to produce frequencies higher than can be easily generated by many oscillators. We have casually mentioned "crystal controlled oscillators". We have not yet gone into the details of their operation. Such crystal oscillators are indispensable for keeping frequencies exactly stable.

As an example of this the Federal Communications Commission assigns definite frequencies on which certain services can operate. In many cases they assign one specific frequency for the operation of one specific transmitter. Under their regulations that transmitter must remain exactly on that frequency -- it must not be permitted to "drift" onto some other nearby frequency.

To maintain rigid control over such frequency engineers install a small piece of crystal which has certain peculiar properties which, in turn, enable it to control the frequency of operation. Such crystals are highly reliable, and very stable. However, they cannot operate at frequencies which exceed a few megacycles. When it is necessary to control frequencies above 5 to 7 megacycles it is necessary to use what are called "frequency doublers". It is here that we put our knowledge of harmonics to work.

Suppose we are assigned a frequency of 31 megacycles by the FCC. We will be required to keep our transmitter operating exactly on that frequency. To obtain a high degree of stability in our oscillator it will probably be desirable that the oscillator be controlled by a quartz crystal. But a quartz

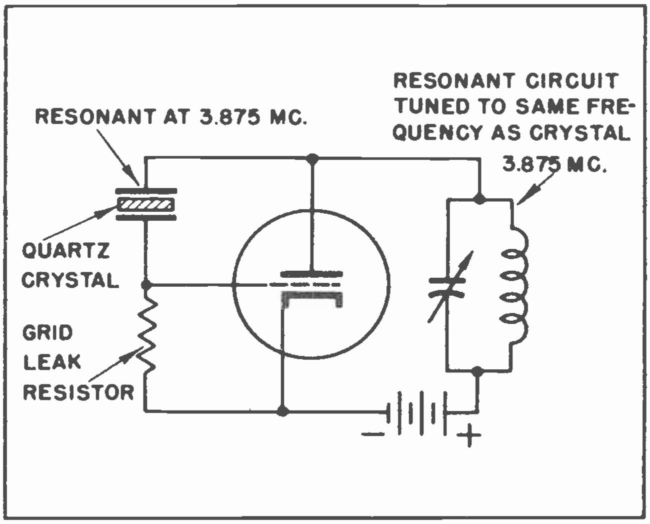

Fig.4. Crystal Controlled Oscillator.

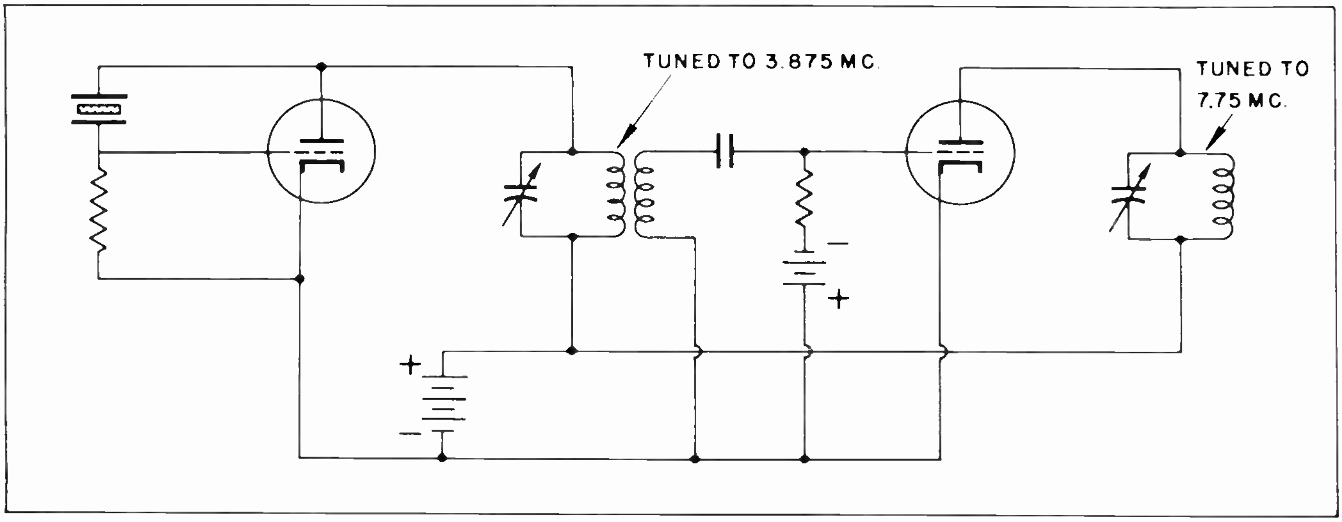

Fig.5. Frequency Doubler

crystal cannot operate at a frequency as high as 31 megacycles. So we build what is called a frequency doubler.

Since a crystal cannot operate at 31 megacycles we will choose a lower frequency, then double the output of the oscillator. One-half of 31 megacycles is 15.5 megacycles. Even this frequency is too high. So we will choose a crystal which has been designed to operate at some frequency still lower.

Suppose we select a crystal which has been so prepared that it will resonate at 3,875,000 cycles per second. This is equivalent to 3875 kilocycles or 3.875 megacycles. We will install it in an oscillator circuit as in Fig. 4.

The oscillator circuit is then coupled into another amplifier circuit which has a resonant circuit as a load for the anode. The resonant circuit of this second amplifier is tuned to a frequency just *twice* as high as that of the oscillator. In this case the resonant circuit of the amplifier would be tuned to 7,750,000 cycles, which is equivalent to 7.75 megacycles, this being double the frequency of the oscillator. The arrangement is shown in Fig. 5.

You have probably noticed the symbol we use for the capacitor in the tuned circuits of Figs. 4 and 5. You may have noticed them before in some of the other schematics in some of the previous lessons. A symbol drawn in this manner means that the capacitor is variable. An air-tuned variable gang capacitor would be a good example. The regular symbol for such a capacitor is shown in Fig. 6.

There is another type of capacitor which is moderately variable. It is called a *trimmer* capacitor. Normally it has very little capacity, possible only 5 to 20 mmfds. Notice that this value is given in *micro-microfarads*. The purpose of a trimmer capacitor is to adjust, or trim, the lumped capacities in a circuit, and bring the cir-

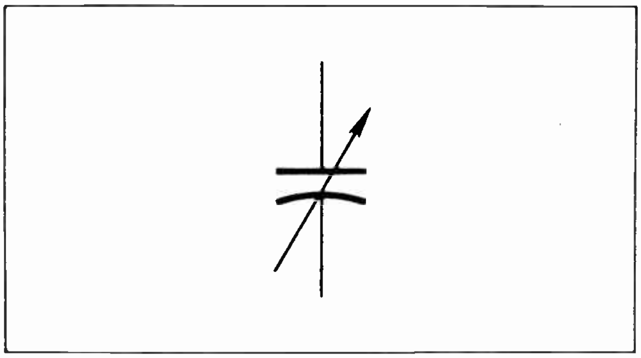

Fig.6. Symbol for Variable Capacitor.

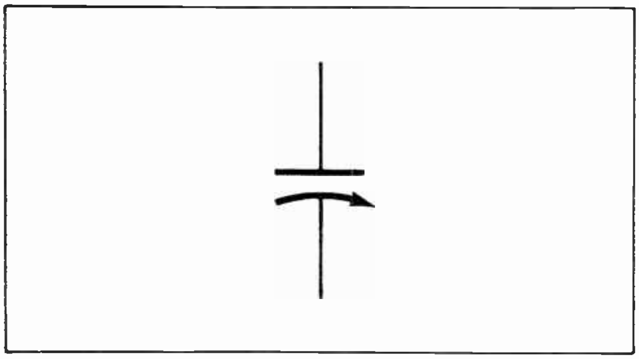

Fig.7. Symbol for Trimmer Capacitor.

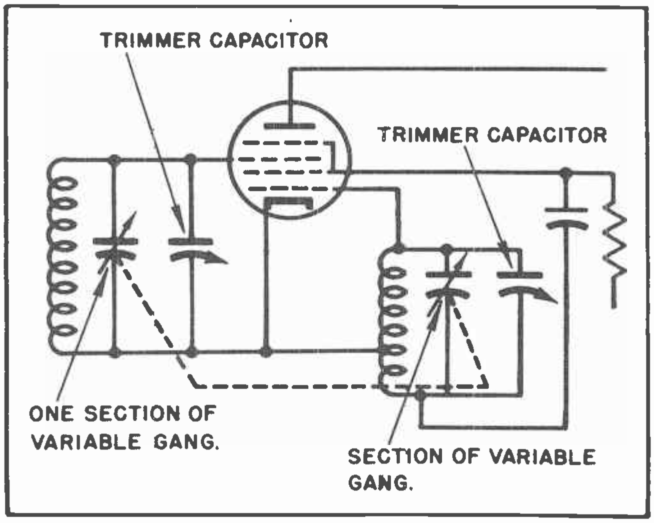

Fig. 8. How Trimmers Fit in a Circuit.

cuit into proper electrical balance. Sometimes the trimmer capacitor is shown by a symbol exactly like that in Fig. 6. More often, however, it is designated by a symbol like that in Fig. 7. The reason it is shown in this manner is to distinguish between it and the regular variable capacitor in a circuit.

The schematic diagram of Fig. 8 shows how the trimmer capacitor is used to balance out a circuit. The main variable capacitor of the input circuit leading to the grid of the tube in Fig. 8 is mechanically coupled to the variable capacitor in the oscillator circuit. These variable gang capacitors are carefully built under rigid inspection. Their capacity is carefully controlled and will always be found to be very close to the value given by the manufacturer. Nevertheless, by their very nature, sometimes the value is off by a few micromicrofarads. Further than this, there is a small amount of *distributed* capacity in the circuits which must be balanced.

Now suppose the main variable capacitor in the input circuit has 4 or 5 mmfds too much capacity. The first thought is that the capacity could be reduced by adjusting the capacitor itself by turning the rotor. But a moment's reflection will bring out the thought that such action will also change the amount of capacity in the main variable capacitor in the oscillator circuit. This is not desirable.

The customary practice, therefore, is to parallel each section of the variable gang by a small variable "trimmer" capacitor as shown in Fig. 8. Then if the capacity in the input is too great the trimmer is adjusted slightly to reduce the capacity. This can be done without affecting the oscillator circuit since the trimmer capacitor in the main input circuit is in no way connected to the trimmer in the oscillator circuit.

On the other hand if there is too little capacity in the main input circuit the trimmer can be adjusted to add a little capacity. Normally it is necessary to add or remove only a very small amount of capacity, seldom more than 4 or 5 mmfds.

The same thing applies to the capacitor in the oscillator circuit of Fig. 8. In fact, it often applies even more strongly to the oscillator circuit than to the input circuit. If the capacity in the oscillator circuit is too great for some particular setting of the main variable gang capacitor the capacity can be reduced by adjusting the trimmer capacitor, And if there is not enough capacity a small amount can be added by means of the trimmer.

Very often there is still another capacitor added to the oscillator circuit of a superheterodyne mixer as shown in Fig. 9. This is usually a variable capacitor, but sometimes is fixed. It is called the *padder* capacitor. It is not our purpose to go into discussion of the padder capacitor at this time. That will be taken up when we are studying the design and troubles of mixer and converter stages of superheterodyne receivers. Nevertheless, it is just as well to get acquainted with the term.

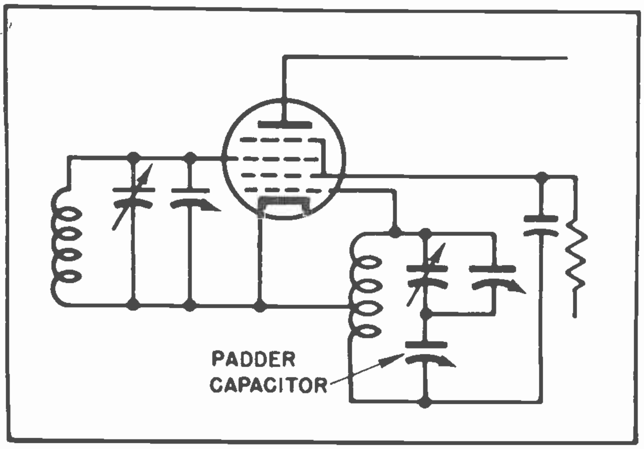

Fig. 9. How a Padder Capacitor Fits in a Circuit.

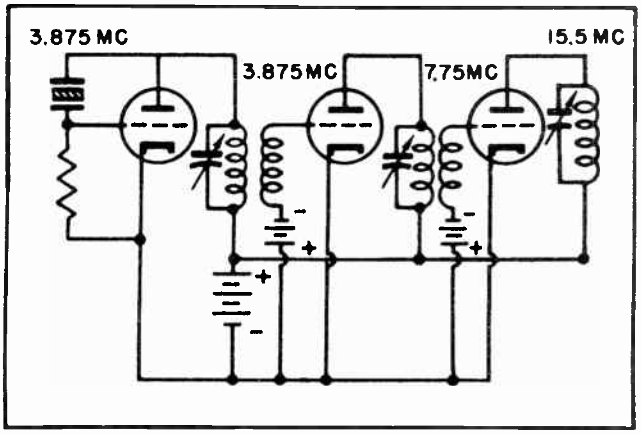

Fig.10. Several Frequency Doublers in Cascade.

Section 4. MORE ABOUT THE FREQUENCY DOUBLER

We have digressed from our discussion of the frequency doubler of Fig. 5. In Fig. 5 we had increased the frequency of the crystal from 3.875 MC to 7.75 MC. This is double the frequency of the crystal, but still is not high enough for the transmitter we want to control.

So we will add another doubler stage. This will be as in Fig. 10. Here we find the frequency increased to 15.5 MC.

Since 15.5 MC is still not enough to control the transmitter we will add another doubler stage. This will be as in Fig. 11. The output of the final amplifier stage could be fed directly to the antenna if it were so desired.

Section 5. CLASS "C" BIASING

The thought will probably have occurred to you to wonder just what there is so special in the circuit diagrams of Figs. 5, 10 and 11 that they are capable of doubling the input frequency in each stage of amplification. The circuit diagrams, unfortunately, do not tell the entire story. The frequency doubling is brought about by the method of biasing the grids and the tuning of the output circuits.

Note the biasing battery in the grid circuit of each of the amplifier stages. This bias voltage is high enough to bias the grid far beyond "cut-off". At this time it might be worth mentioning something which has been discussed before; that is, there are three general classes of biasing when using a tube as an amplifier. Class "A" bias calls for a negative voltage on the grid of such value that the tube will operate near the middle of the linear portion of its characteristic curve. We have gone into this class of operation in considerable detail in a previous lesson.

The second type of biasing is called Class "B". We have mentioned it briefly, but have not gone into it in detail. We will have occasion to study Class "B" in considerable detail later. Class "B" is sometimes sub-divided into Class AB_1 and AB_2.

Class "C" is the third main class of operation. This is the type of biasing used at the output of many transmitters, on the grid of many oscillators, and on the grid of frequency doublers. When operating Class "C"

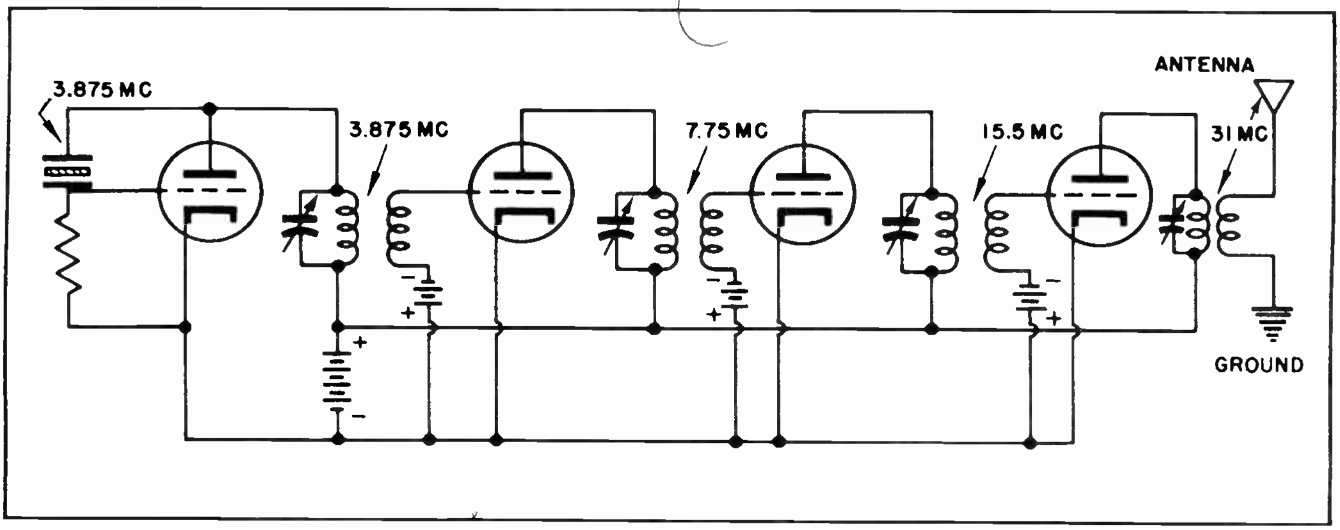

Fig. 11.

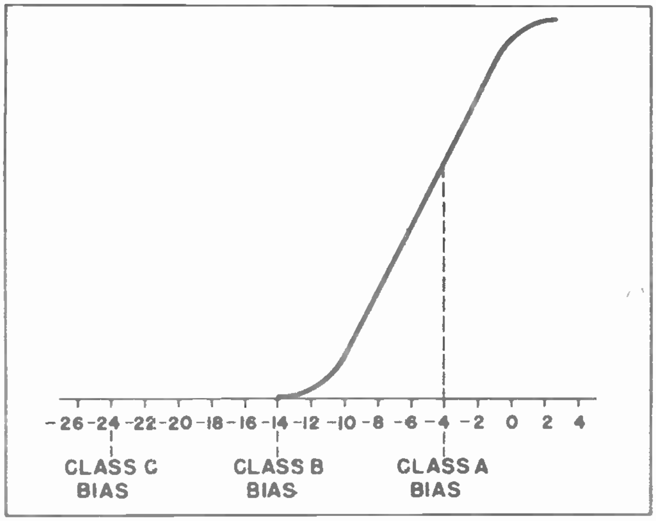

Fig. 12 Biasing Points for Several Classes of Operation.

the grid of the tube is biased so heavily negative that the tube cannot conduct unless a very strong signal is applied to the grid, and will then conduct only on the peaks of the positive cycles of the grid signal voltage.

Fig. 12 shows rather clearly the relative amounts of negative voltage required for various classes of biasing on a typical vacuum tube. The tube would be biased with about 4 negative volts for operation as a Class A amplifier. It would be biased with about 14 negative volts for Class B operation. For Class C operation it would be biased with from 18 to 30 negative volts, with 24 negative volts being a reasonable value for most operations.

Fig. 13 shows how an alternating voltage applied to the grid of a tube biased Class C will cause a series of current pulses to flow in the anode circuit of the tube. If the tube is biased so there are normally 24 negative volts on the grid, an alternating signal voltage of 12 volts will have no more effect on the tube than if it were not applied. The alternating voltage of a value that low will not overcome the effect of the bias voltage, with the result that no current can flow at any time. This is shown in Fig. 13. There we see the 12 volts applied to the grid (6 volts each side of the bias). The positive peaks of the alternating signal voltage are only able to reduce the negative

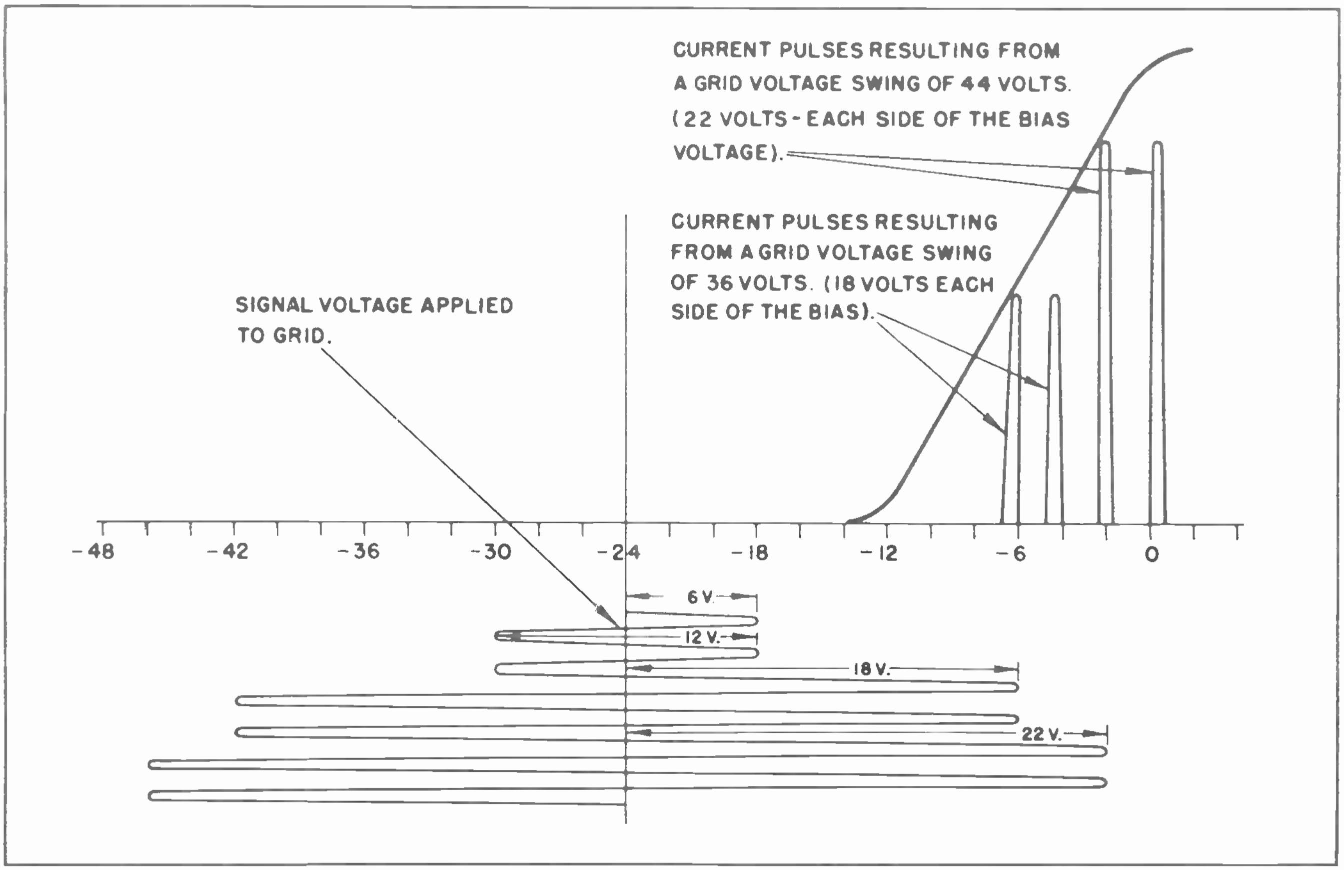

Fig.13. Effect of a Signal Voltage on a Class "C" Amplifier.

voltage on the grid to -18 volts. 18 negative volts is still too much to allow any current to flow in the anode circuit.

If the alternating signal voltage is increased to 36 volts (18 volts each side of the bias) the positive peaks of the signal voltage will reduce the negative grid voltage to -6 volts. 6 negative volts on the grid will allow a pulse of current to flow in the anode circuit during the short interval when the signal voltage is near its positive peak. As soon as the signal voltage drops to a value where the bias voltage cuts off the tube the anode current will cease to flow. No anode current will flow until the next positive peak of the signal voltage comes along. When that happens there will be another pulse of anode current.

If the signal voltage is increased some more so it has a swing of 44 volts (22 volts each side of the bias voltage) the current pulses in the anode circuit will become larger. This situation is also shown by the graph of Fig. 13. The grid voltage does not have to become very much greater in order to increase the value of the anode current pulses considerably. You are probably wondering just what this has to do with your doubler circuit. It is a goodly portion of the secret. But first let's see just how this works in an ordinary tuned circuit.

In Fig. 14 we show the current pulses as they would be in the anode circuit of a Class C amplifier. These pulses follow each other at a certain frequency, the exact frequency being dependent upon the frequency of the original signal voltage. Suppose for the sake of our explanation there are 1,000,000 pulses of anode current each second. This would correspond to a frequency of 1,000,000 cycles per second.

Now suppose we feed these pulses of current into a parallel resonant circuit as shown in Fig. 14, and the circuit is tuned to a frequency of 1,000,000 cycles per second. When the first pulse comes down the wire the current will tend to divide at the top of the tuned circuit; a little of it will go toward the inductance but the most of it will go toward the capacitor as shown at *A* in Fig. 14. A fraction of a microsecond later the capacitor will discharge through the inductance as shown at *B* in Fig. 14. Then the inductance will charge up the capacitor in the opposite direction. A fraction of a microsecond later the capacitor will again discharge in the other direction as shown at *C* of Fig. 14, and again it will discharge through the inductance. The capacitor will again charge up as it was originally, and this will be at the exact fraction of a microsecond that another pulse of anode current is coming from the tube.

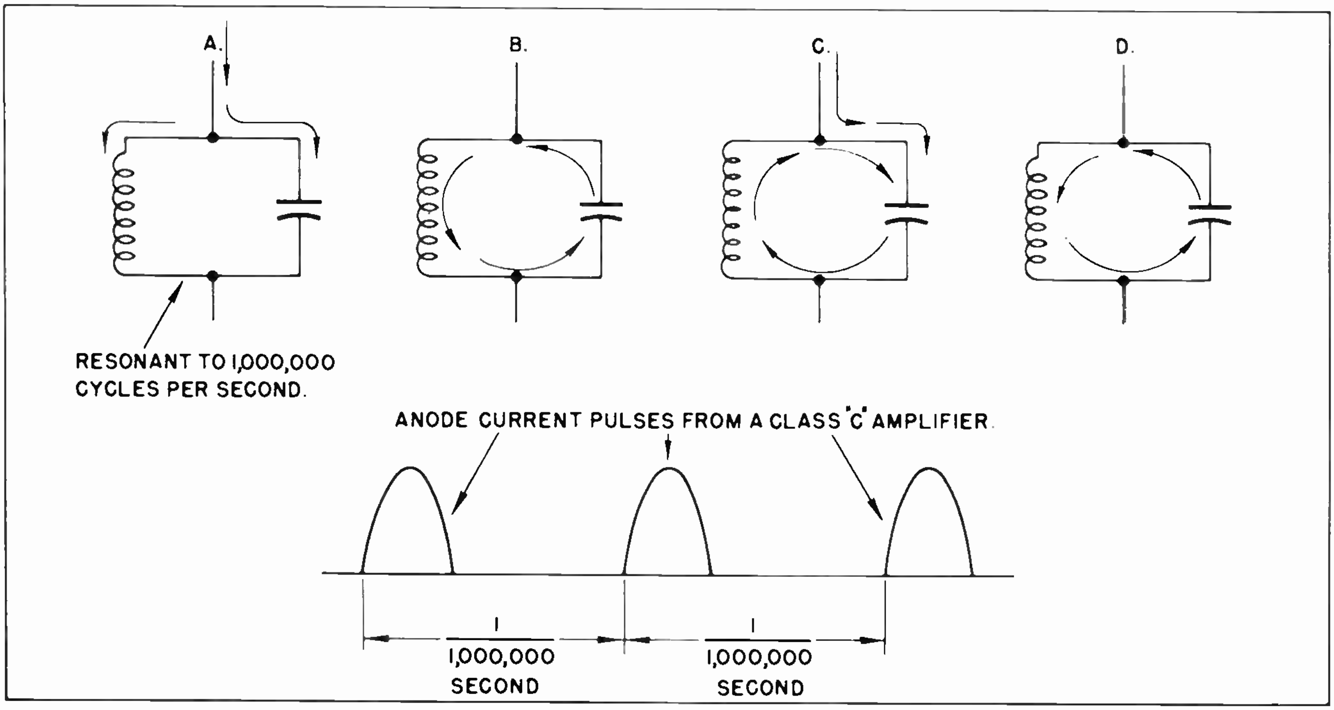

Fig. 14.

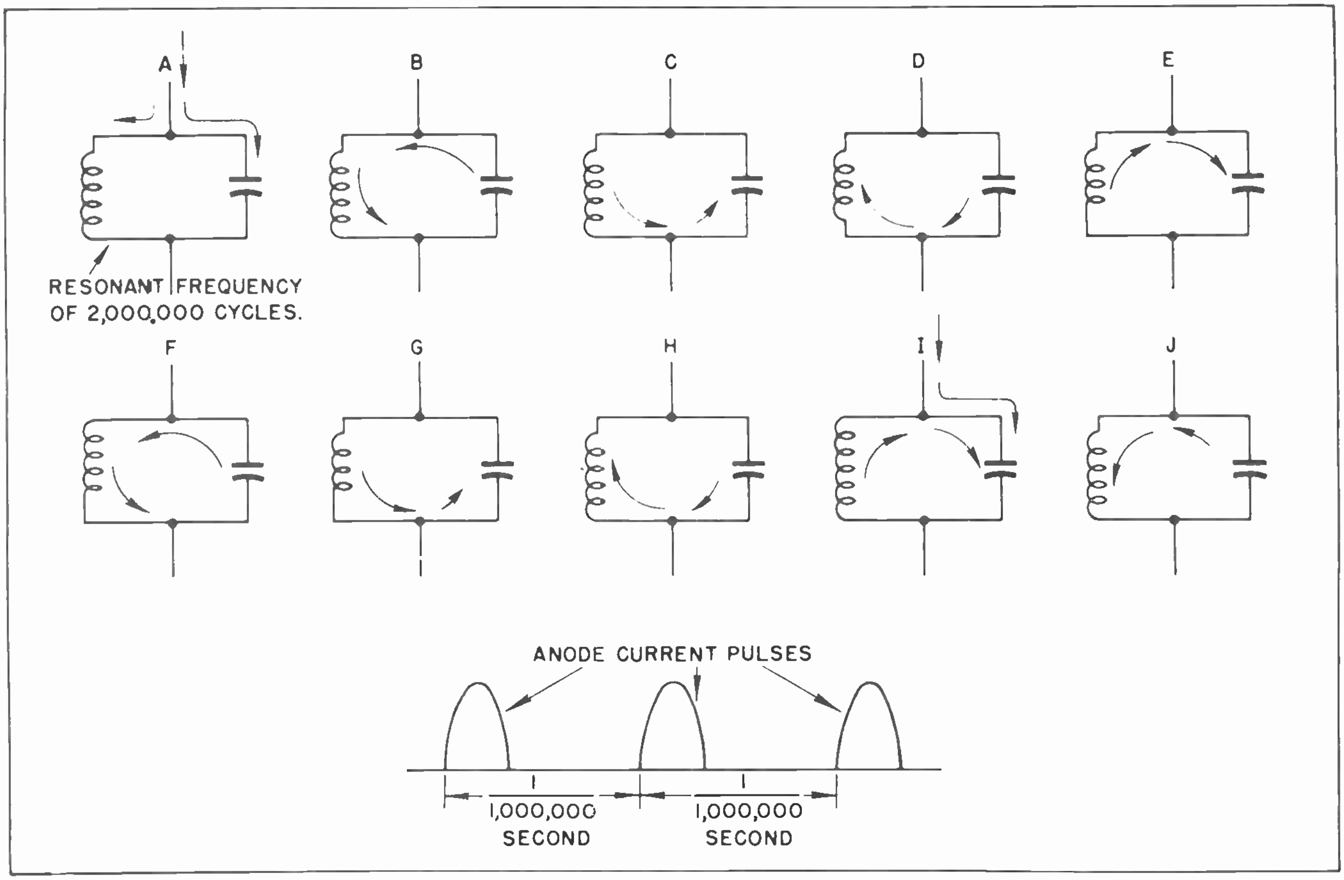

Fig. 15.

The action is then repeated as is indicated by *D* of Fig. 14. This continues over and over each one-millionth of a second. Each time a pulse of current comes down the wire it aids in keeping the oscillating circuit operating.

Now, suppose that we substitute a tuned circuit which has a frequency of 2,000,000 cycles per second for the one which has a frequency of only 1,000,000 cycles. This is the situation in Fig. 15.

In this case the current pulses will again be coming down the wire at the rate of one each microsecond. The first one will strike the tuned circuit as at *A* of Fig. 15. This action will be little or no different from that of *A* in Fig. 14. The next action at *B* and *C* and *D* will be no different from what we have previously learned.

But now note what happens. At *E* of Fig. 15 the current and voltage inside the circuit will again charge up the capacitor very much as it was at *A* of the same illustration. At this instant, however, it receives no assistance from the external circuit from the tube.

Nevertheless, the capacitor is charged up, then discharges again as at *F*. It might be mentioned that from *A* of Fig. 15 to *E* a time interval of only 1/2 microsecond has elapsed instead of 1 microsecond as in Fig. 14.

Now the circuit goes through the same action at *F* and *G* and *H* as it did in *B* and *C* and *D*. Probably the current is not quite so strong at this instant as it was 1/2 microsecond earlier, because there is a certain amount of resistance loss inside the circuit which would tend to reduce the value of the current. Nevertheless it is almost as large as it was before.

Now we come to *I* of Fig. 15. This is similar to *A* and *E*. Here again the circuit gets a boost from the tube through the medium of another current pulse. This aids in charging up the capacitor to its full value again. Next the action is as shown at *J*. This again, is the same as that at *B* and *F*. The entire action will be repeated over and over.

But note that the current and voltage inside the tuned circuit is going through *two*

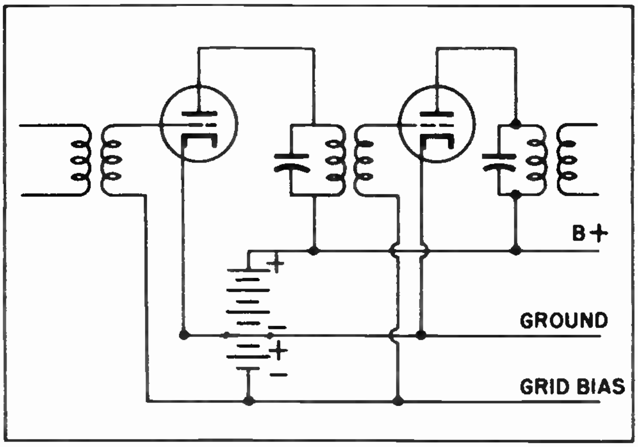

Fig. 16. One Method of Biasing a Class "C" Amplifier.

complete cycles for each pulse of current from the tube. This means that a frequency double that from the tube can be tapped off the resonant circuit.

The pulse of current from the tube acts to charge up the capacitor of the resonant circuit for an instant. That starts the circuit oscillating. Then on every second oscillation of the resonant circuit it will receive another boost from the tube. This is very much like a person pushing a child on a swing. If the child is given a push *every other* time the swing comes back it is easily possible to keep the child swinging. In fact it is possible to keep the child swinging almost as hign by a little push *every other* time as it is to give a push *each* time the swing comes back. This is almost exactly the same thing that takes place in a frequency doubler circuit.

In Figs. 10 and 11 we have shown bias batteries in the circuit for the purpose of providing bias voltage for the tubes. The use of batteries is one way to provide bias. But it is not the best way.

It is rather obvious that this is one place where we cannot use cathode bias. The reason is that cathode bias depends upon a flow of current through the cathode circuit to provide the voltage drop across a resistor which can be tapped off and fed to the grid. In Class "C" operation we bias the tube so negative that NO current can flow. If no current flows in the cathode circuit under normal conditions it follows as a natural result, there would be no voltage drop across any resistor we might place in the cathode circuit.

In Class "C" operation we must provide what is called "fixed" bias. A fixed bias is some kind which is not dependent upon cathode or anode current. There are a number of ways in which this can be done but that shown in Fig. 16 is as good as any. In that illustration the B-plus voltage is tapped so that the cathodes of the tubes are not at the most negative point of the power supply. In a regulated power supply using rectifier tubes much the same thing can be accomplished by using a voltage divider network.

Section 6. **THE TRI-TET OSCILLATOR**

Another common use of harmonics in radio and television work is in the tri-tet oscillator. In many ways the tri-tet is little different from the circuits we have just described, yet in other ways it is dissimilar. The tri-tet oscillator uses a tetrode or pentode tube. The crystal is connected into the oscillatory circuit which is very much like the electron-coupled oscillator.

The circuit is very much like that shown in Fig. 17. In this case the crystal itself is resonant to 1 megacycle. The tuned circuit in the grid circuit is also resonant to 1 megacycle. The tube is biased nearer Class "B" than Class "C"; and when oscillating the resistor-capacitor combination in the cathode circuit tends to keep the grid voltage at or near cut-off. This results in the anode current moving in pulses in much the same manner previously described.

The resonant circuit in the anode circuit can be tuned to 2,000,000 cycles resulting in a doubling of the frequency at the output of the same tube into which the crystal

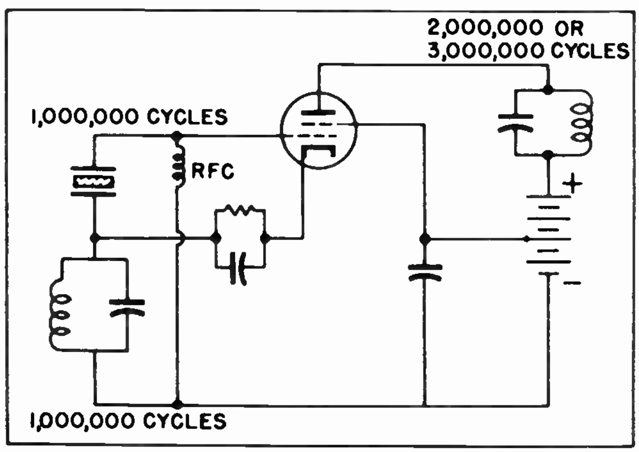

Fig. 17. Tri-Tet Oscillator.

operates. As a matter of fact it is usually possible to tune the output circuit to a frequency three times as high as the crystal frequency -- in this case 3,000,000 cycles -- and obtain very stable and efficient operation. The tri-tet oscillator is very widely used.

Section 7. IMAGE FREQUENCY

You should not confuse frequency doublers and triplers with what is called "image" frequencies, although some novice radiomen have a tendency to do that. Actually there is no similarity between frequency multiplier circuits and image frequencies.

Image frequencies are found in superheterodyne receivers. They result, occasionally, from the peculiar action which takes place in the mixer stage of a superhet.

In a superheterodyne receiver the oscillator frequency is at all times operating at a higher frequency than the incoming radio frequency. For example, if the radio frequency is 1000 kilocycles and the intermediate frequency is 465 kilocycles, then the oscillator frequency will be 1465 kilocycles.

In many superheterodyne receivers the signal from the antenna is fed directly to the control grid of the pentagrid converter. The single tuned circuit at the grid of the converter will tend to favor one signal over all the others. This will be the desired signal. Further than this it will tend to discriminate against all other signals. All this is what it is intended to do. And in most cases everything is fine.

But suppose you have a radio receiver which has its I-F tuned to 465 kilocycles. You want to tune in a station which is operating on 660 kilocycles. When you tune your input circuit to 660 kilocycles you will also be tuning your oscillator in the receiver to 1125 kilocycles. Thus the difference between the oscillator frequency of 1125 kilocycles and the carrier frequency of 660 kilocycles will provide the necessary 465 kilocycles for the I-F stages.

This part is all well and good. But suppose there is a powerful station in the vicinity operating on 1590 kilocycles. What do we have in this situation? We have a radio carrier frequency of 1590 kilocycles; we have a local oscillator frequency of 1125 kilocycles; and we find the difference frequency between these two is 465 kilocycles, which is just right for amplification of the I-F stages.

This 1590 k.c. frequency would be the "image frequency" which could be obtained when you tune to 660 k.c. In the Chicago area we have exactly this situation. A similar one prevails in many other localities. Chicago station WMAQ, the NBC outlet, operates on 670 k.c. Evanston station WNMP, a short distance away, operates on 1590 k.c. Very frequently a person trying to tune in WMAQ at 670 k.c. will find they are tuning in WNMP at 660, and wonder why they are getting that station at that location on their dial.

The image frequency is always twice the value of the I-F frequency *above* the frequency you are tuning. In the case of station WNMP, if you tune that station in when the dial of the radio reads 660 k.c. it is because your radio has an I-F frequency of 465 k.c.; and 1590 k.c. is two times 465 k.c. above 660 k.c.

Twice 465 is 930. 930 added to 660 is 1590.

Should a listener in the Chicago area tune in WNMP at 680 k.c. it would be good evidence that the I-F of the receiver was tuned to 455 k.c. instead of 465 k.c. Both 455 and 465 are commonly used frequencies in the I-F stages of modern superheterodyne receivers.

In the earlier days of radio receivers it was a very common practice to use an I-F frequency of 175 k.c. That frequency was eventually abandoned because of the many points where images would interfere. The I-F frequency was raised to 455 or 465 in most receivers. Since for many years the lowest spot on the broadcast band was 550 k.c. and the highest was 1500 k.c., these I-F frequencies practically overcame the trouble from image frequencies. As an example, when tuning in 550 k.c. on a receiver with an I-F frequency of 465 k.c. the image frequency was 1480 k.c. It was extremely rare that these two frequencies would be found in the same locality. Thus there would be no interference. The image frequency of any station above 570 would be entirely outside the broadcast band.

Thus it can be seen that using the higher I-F frequencies practically overcame the trouble from image frequencies. But since the recent war the FCC raised the top of the

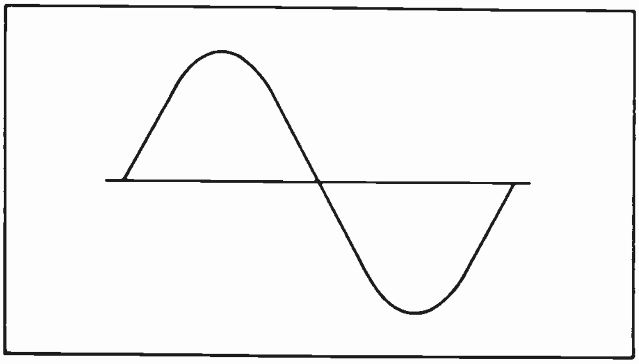

Fig. 18.

broadcast band from 1500 k.c. to 1600 k.c. In some localities there will be found some trouble with images between certain stations. Trouble from images often develops on the higher communications frequencies which lie above the broadcast band.

Section 8. **TROUBLE FROM HARMONICS**

We have seen how a knowledge of harmonics can be useful to us. Now we will see how harmonics can be a real problem. Although we will not go into it at this time we can say that in some cases the problems introduced by harmonics being where they are not wanted can place gray hairs on the head of the radioman who must eliminate them.

One example of this is the operator of a transmitter. The FCC notifies the engineer that his transmitter is putting out a strong signal on a harmonic of his assigned frequency. Suppose it is an amateur operating on 28 megacycles. If his transmitter is putting out a strong signal on his second harmonic it would mean his transmitter was putting out a strong signal at 56 megacycles. Since one of the television bands operates around 56 megacycles it is easy to understand that his transmitter would be playing havoc with a regular television broadcast.

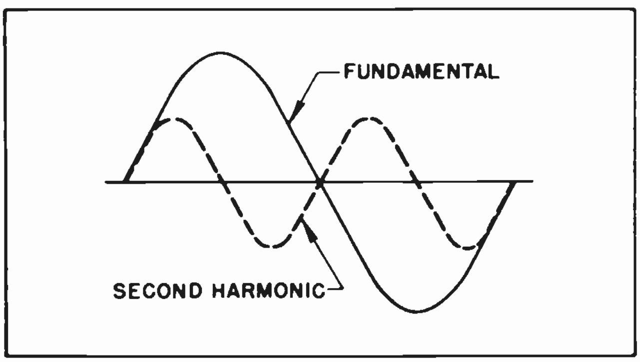

Fig. 19. Second Harmonic Superimposed on the Fundamental.

Or suppose it is an FM transmitter operating 95 megacycles. The second harmonic of that frequency would fall within another television band operating just above 188 m.c. Interference between such services cannot be tolerated. If such interference is not eliminated the many signals on the air would jam things up so badly nobody would be able to get any benefit from radio and television.

Section 9. **OTHER TROUBLES FROM HARMONICS**

Another trouble the radio and television man will meet even more frequently in everyday work is distortion introduced by a defective amplifier stage. When a stage of amplification is not functioning properly, and the signal comes out of the stage with a different wave form from that in which it entered the stage the most likely trouble is that unwanted harmonics have been introduced into the signal by the vacuum tube. It is not our problem at the moment to figure out just how an amplifier stage can introduce harmonics into a signal; suffice it to say that such things happen.

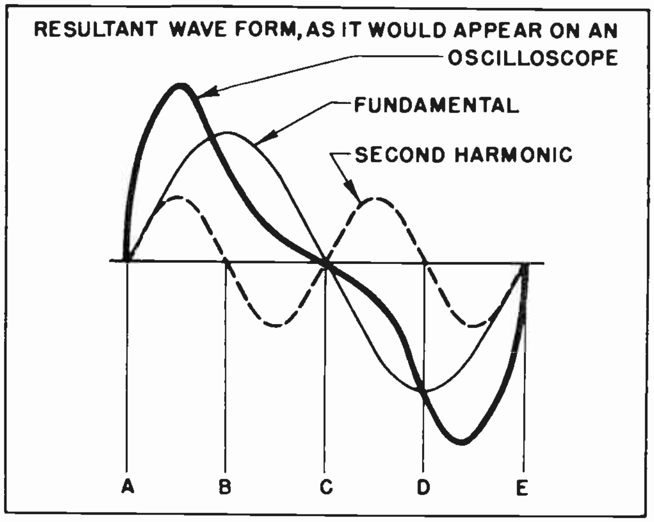

Fig. 20. Resultant Wave Form When Second Harmonic is Combined with the Fundamental.

In Fig. 18 we have drawn an ordinary sine wave. This is exactly like the many other sine waves we have studied from time to time.

Now suppose that an improperly functioning amplifier stage introduces another signal which is the second harmonic of the original signal we have placed on the grid of the tube. If the two signals are graphed together they will appear as in Fig. 19. Note that the second harmonic goes through a complete cycle while the fundamental is going through the first half of its cycle.

In Fig. 20 we can see exactly what happens to the output wave form as a result of the action of combining the fundamental and second harmonic frequencies. Note that between points *A* and *B* in Fig. 20 the fundamental and the harmonic tend to add together. That makes the resultant much higher, or greater, than either the fundamental or the harmonic by itself. Then between points *B* and *C* the second harmonic tends to subtract from the fundamental. This results in the output being somewhat less than it would have been had not the harmonic been present. In the next half cycle much the same thing again occurs. Between *C* and *D* the harmonic subtracts from the fundamental, and between points *D* and *F* they add together again.

Note the difference in the shape of the resultant graph and that of the original fundamental sine wave. In audio circuits the second harmonic does not distort the output enough to make it disagreeable to the ear under normal circumstances. But in video circuits we must always be on the watch to guard against the introduction of second harmonics into our wave forms.

The introduction of third harmonics *always* causes troubles, whether the circuit is audio or video. Fig. 21 shows what happens when a third harmonic is introduced into the circuit.

One of the principle effects of the third harmonic is to oppose the fundamental right at the time the fundamental is approaching

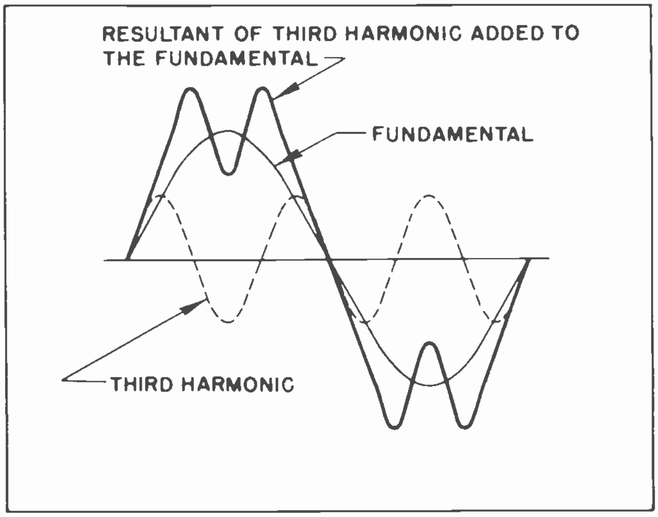

Fig.21. Effect of the Third Harmonic.

its peak. This causes a deep dip in the resultant curve right at the point where it should be a maximum. Adding the third harmonic to any frequency, whether electrical or musical, tends to cause serious discord. It grates on the ear, and produces a very unpleasant sensation.

We could go on and show the effects of the fourth, the fifth and higher harmonics. Normally, the third harmonic is the one which causes us the most trouble in amplifiers. As the harmonics go higher and higher their strength, or amplitude, becomes less and less. Above the third harmonic the strength of the odd harmonics has been reduced to a value where they are not generally troublesome. In video circuits, however some of these higher harmonics must be guarded against to avoid introducing unwanted wave shapes, and giving us results we do not want.

NOTES FOR REFERENCE

Harmonics in electrical wave forms are very similar to harmonics in music.

Harmonics can be very useful to radiomen in some applications, and can be very annoying if they creep in where they are not wanted.

In sound work the third harmonic is the most annoying of all. It is the one to watch for when using an oscilloscope to study signal wave forms.

Frequency doublers and triplers are used to build up the frequency from a low frequency to a high one.

The tri-tet frequency multiplier is widely used in radio and television work.

(over)

The frequency multiplier makes use of a Class "C" amplifier and an output resonant circuit tuned to a harmonic of the fundamental frequency.

Class "C" amplifiers are biased at some point beyond cut-off. The FCC rates an amplifier as being Class "C" when the tube is biased with a voltage with two to four times the negative voltage needed to keep the tube at cut-off.

Class "C" amplifiers require some type of fixed bias.

Cathode bias cannot be used on Class "C" amplifiers. However, many Class "C" amplifiers make use of a certain amount of cathode bias to guard against complete loss of bias if the bias voltage fails for some reason.

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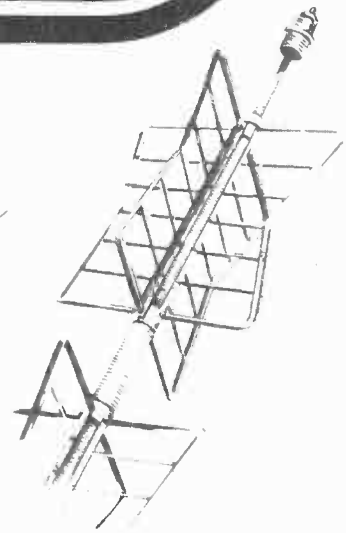
Types of Receivers



Types of Receivers

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RADIO TELEVISION

TYPES OF RECEIVERS

Section 1. INTRODUCTION

The phenomenal advance in the science of radio and television during the past few years has brought with it scores of improvements. New methods have been devised to achieve better transmission and reception. In some cases, new equipment was designed and built to more efficiently overcome the limitations which existed in the older types -- limitations which were threatening even some of the more modern devices with obsolescence. As a result the radio and television repairman has been faced with a continually increasing complexity in the equipment it is his job to repair.

During our previous studies we have investigated the construction and operation of many of the individual parts which go to make up a radio or television receiver. It is now time we see how these various parts can be put together to actually make an operating receiver.

In its broadest sense a "radio receiver" is any type of electronic device which will pick up an electromagnetic signal from space and convert it to some form which is sensible to one of the human senses. Included in this broad coverage are such things as Sonar, Loran, Radar, and Television as well as the thing we most commonly refer to as "Radio".

In a narrower sense the term "Radio Receiver" is by common usage reserved for those devices which deal exclusively with audible, or sound, signals. The term "Television Receiver", on the other hand, is used to describe those devices which bring to us a visual picture, with its accompanying sound effects, of some event which is taking place at some distant place. To a technical man television is little more than another phase of radio -- but a considerably more complicated phase. Many of the circuits, and much of the action, in a television receiver has its counterpart in an ordinary radio receiver designed to receive only voice. Other circuits, and other actions, are exclusive with the tele-

Fig. 1. Radio-Phonograph Television Console Combination. (Courtesy Admiral Radio Corp.)

vision receiver. It is a good practice to first learn those circuits which are to be found in both types of receivers. When these circuits are thoroughly mastered we will take up the circuits found *only* in the television receiver.

Let it be perfectly understood -- a sound and fundamental knowledge of radio receivers is essential to understand even the most elementary principles and equipment employed in television.

Section 2. BASIC REQUIREMENTS

In order to accomplish their purpose all receivers, whether radio or television, must perform three specific tasks:

1. Select one desired signal.

2. Extract the audio or visual component of the signal.

3. Supply sufficient strengthening of the signal to make it clear and comfortable to watch or listen to.

Other requirements of receivers which must be considered are: convenience of size and weight, power consumption within reasonable limits, cost and maintenance within reasonable limits, and in many cases their ability to fit into the design and beauty of a modern home.

These requirements, and many other incidental ones, have resulted in a truly wide variety of receivers, each different from the others in many ways. Their use in home or car, for instance, has demanded that each type be especially designed for its own special application. The portable receiver that we take to the park on picnics must differ radically from the console-combination which graces our living room at home. (See Fig. 1.)

It is not only in their exterior appearance, shape, size, and weight that these receivers differ from each other. Because of their divergent applications, receivers differ in their signal and power supply circuits. They may differ in the size, type, and number of loudspeakers which they drive. They may differ in the type of signal they receive, whether that signal is voice, music, or Morse code. Communications receivers, for instance, will look different and operate in a slightly different manner from an ordinary broadcast home receiver. Television receivers, in addition, use picture tubes in a variety of sizes, and some have a wider range of controls than others.

However, despite their many differences in circuit design and external appearance, each receiver must accomplish the tasks for which it is selected: namely the selection of the desired signal from all other signals, the extraction of the audio and visual component from the desired signal, and the necessary amplification which will make the signal clear enough to understand.

Radio receivers may be divided into two general groups:

1. The Tuned Radio Frequency Receiver, nicknamed the "TRF", in which all tuned circuits are resonant to the same frequency, that to which the receiver is tuned.

2. The Superheterodyne Receiver, conveniently condensed to "superhet," in which the various tuned circuits are not all resonant to the same frequency, but which introduces a new principle of high-gain amplification based upon the beat-frequency principle. All television receivers operate on the Superheterodyne principle.

Section 3. THE TUNED RADIO FREQUENCY RECEIVER

As the name implies, the "TRF" receiver is made to receive the station signal through a series of tuned circuits, each of which resonates to the signal frequency. Note that in Fig. 2 all the resonant circuits have their variable tuning capacitors mechanically coupled together. This is indicated by the dashed lines connecting the variable capacitors. As we change one of them, we change the others by a like amount. In selecting the desired station we turn the tuning knob, which rotates the variable capacitors to the proper dial setting. All tuned circuits in the receiver therefore respond by resonating at the same frequency.

Using Fig. 2 as a guide, we can understand the TRF receiver operation in the following manner: Signals are introduced at the antenna without any distinction between their frequencies, since the primary of the antenna transformer is not tuned. The secondary of the antenna transformer is paralleled by one section of the variable ganged tuning condenser assembly, and is therefore a resonant circuit. This permits the selection of the desired signal, favoring it and discriminating against all other signals passing through the antenna transformer primary. Selection in the first tuned circuit, however, is not always perfect due to the unavoidable amount of resistance in the coil winding which results in the low *selectivity* inherent in low-Q coils. Nevertheless, the first step in the selection process is accomplished in the first tuned circuit, and the desired signal, in radio frequency form, is then applied to the grid of the first RF amplifier tube, the 6SK7 tube in the upper left of Fig. 2.

The bias employed in the first RF amplifier stage is normally *Class B*, meaning a high negative bias, permitting a high efficiency in operation. This results in high gain of the signal. The gain is from an extremely weak input value to an output amplitude at least fifty times as high. Note that the volume control is electrically located in both the cathode and antenna circuits.

This manner of connection is bi-lateral, and serves to vary the volume of the signal while altering the gain of the stage at the same time. We will have more to say about the TRF volume control later.

The output of the first RF amplifier now takes the form of a pulsating D-C current, at radio frequency, flowing in the plate load of the first RF amplifier. As can be seen by referring to the diagram in Fig. 2, the plate load of the first RF amplifier is the primary of the transformer which couples the first RF amplifier to the second RF amplifier, another 6SK7 tube. This pulsating D-C current in the primary, which of course bears the modulation of the impressed audio signal, induces a voltage at the same frequency and amplitude in the secondary of the first RF transformer. The secondary of this transformer is similar to the *antenna* transformer secondary.

The signal, strengthened in amplitude by the first RF amplifier tube, is again selected from all the undesired frequencies which managed to break through the first tuned stage. Again discrimination takes place in favor of the desired signal. The signal is next applied to the second RF amplifier tube grid. The input to this stage is far stronger than that to the first

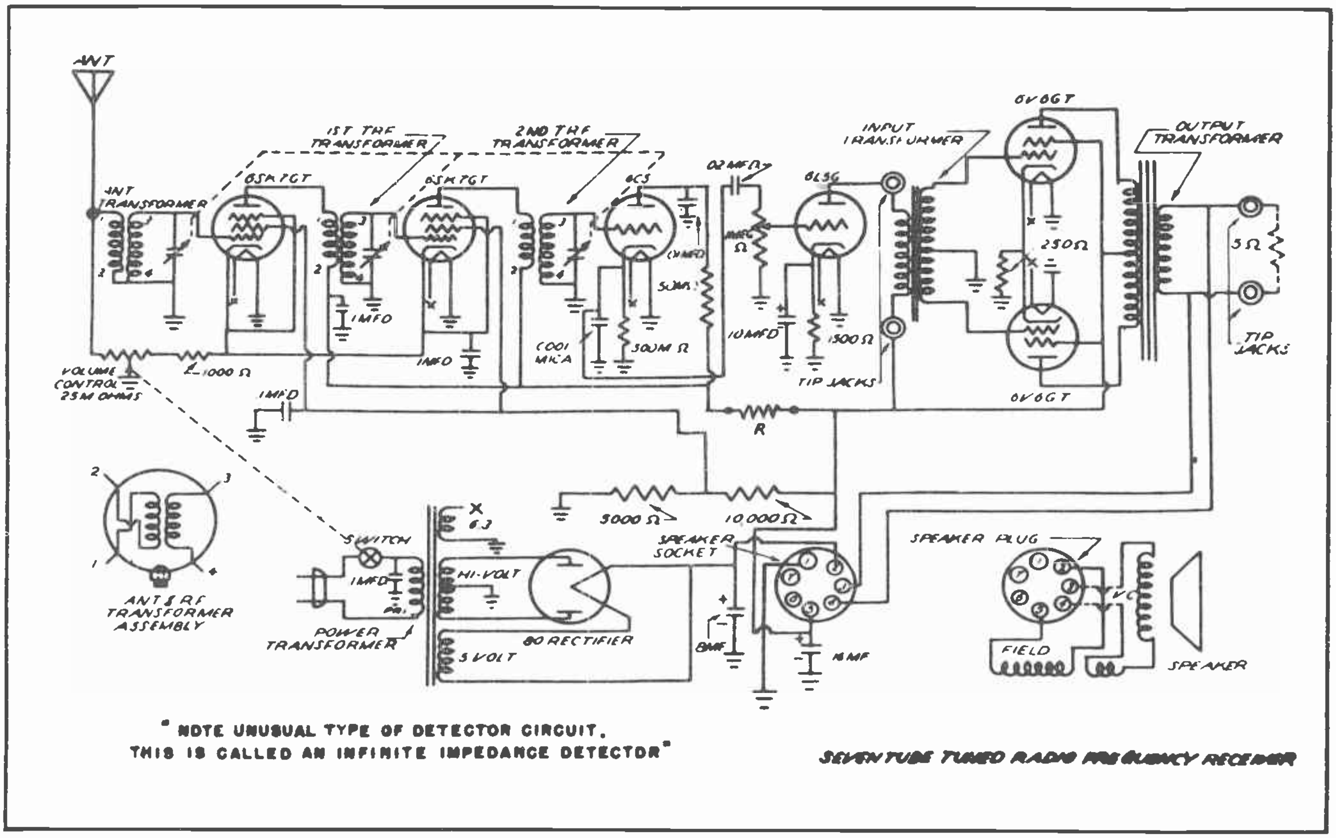


Fig.2. Seven Tube Tuned Radio Frequency Receiver.

RF amplifier, but the audio modulation is carried through faithfully in its original form.

Thus far we have seen our radio signal go through:

Selection ------ in the first tuned circuit.

Gain ------ in the first RF amplifier stage.

Selection Again- in the second tuned circuit.

More Gain ------ in the second RF amplifier stage.

The output of the second RF amplifier is, as in the case of the first RF amplifier, a current which pulsates at radio frequency and carries the original audio modulation in the form of amplitude changes. Since this pulsating current traverses the primary of the second transformer primary, its secondary will have induced in it a voltage corresponding to the primary current changes. Here again, the secondary feeds the grid of the third stage, a 6C5 tube, with a signal further augmented in amplitude by a factor of at least fifty times. The variable condenser paralleling this winding causes the circuit to resonate at the same frequency as the previous tuned circuits. A further selection of the desired signal, and discrimination against all undesired signals, is thus accomplished. But the job of the third tube is not yet done.

Notice, in Fig. 2, the resistance used as the plate load in this stage for the 6C5 tube. The cathode resistor, also, is unique in its high resistance. The cathode bias developed across this resistance permits this stage, called the detector amplifier, to operate as Class B, which means the tube operates near its cut-off point. The use of a plate load resistor, also, gives this stage a special function -- that of performing as an infinite impedance detector, or a *plate detector.*

A plate detector, as will be further explained in the lesson on Detectors, has the property of providing gain to a radio

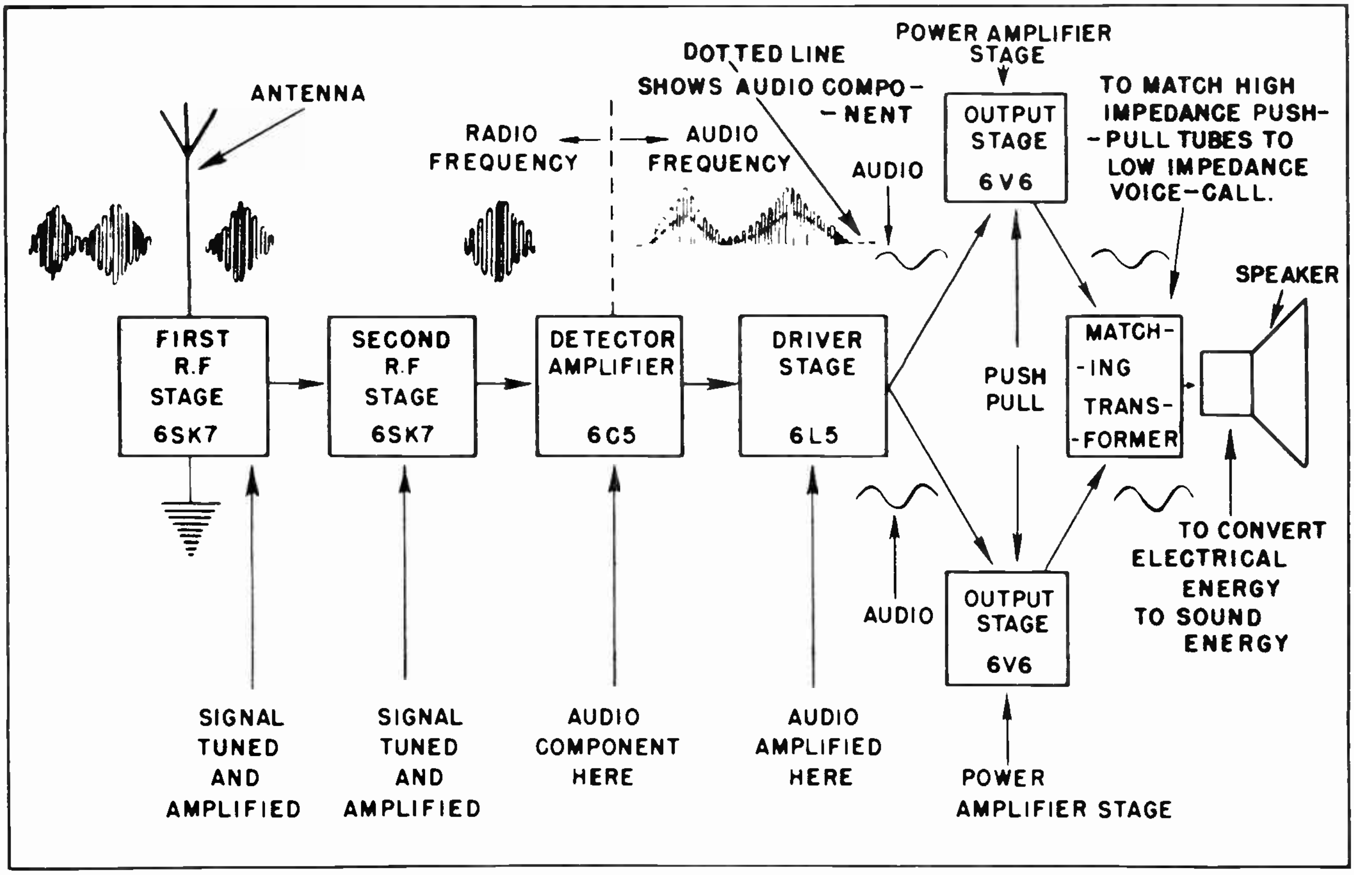


Fig.3. Block Diagram of TRF Receiver.

frequency signal in addition to extracting its impressed audio frequency component. It might be well to mention, however, that the principle purpose of the detector is to separate the audio signal from its high frequency carrier. The small RF by-pass condenser located in the cathode circuit of this stage serves to by-pass the now unneeded radio frequency component to ground, leaving the audio component practically untouched for delivery through the coupling condenser to the 6L5 tube grid.

The output stages constitute a push-pull power amplifier designed to produce heavy current changes during moderate voltage changes on the grids. Since the driving voltages on the grids are at audio frequency, the speaker matching transformer is fed with current at audio frequency. The speaker voice coil, properly matched to the plate circuits of the output tubes, will conduct very heavy current at signal frequency and the speaker cone will respond by reproducing the signal as created in the microphone at the transmitter.

Fig. 3 illustrates, in block diagram form, the functions of the stages of a TRF receiver and indicates the wave shapes at the input and output of each stage.

The above discussion describing the action and characteristics of a TRF receiver has reference to the *type* of signal circuit only. At one time, all radio receivers in use operated on the Tuned Radio Frequency principle. While the discussion of power supplies for radio receivers will be given in detail in later lessons, note this important fact: *A TRF receiver may have one of several different power supplies.* The TRF receiver, like the superheterodyne receiver, may be powered by a full wave rectifier, by a half-wave rectifier, or by a battery. Most TRF receivers, are powered by either a full wave or half wave rectifier, making them either pure A-C, or AC - DC power supplies. A scattered few are powered by voltage doublers. The various kinds of rectifiers have been discussed in a previous lesson. They will be taken up again in a later lesson when their troubles will be studied in detail.

Section 4. VOLUME CONTROL

Previous mention was made of the bi-lateral (2-way) action of the volume control in a TRF receiver. Notice that in Fig. 2 if we move the sliding tap of the manual volume control over to the right, the cathode of the first RF stage is brought closer to ground potential. This decreases the negative bias on that stage, increasing its gain. At the same time, this position serves to place more resistance between the antenna and ground, resulting in a stronger signal applied to the windings of the antenna transformer primary and hence through the whole receiver.

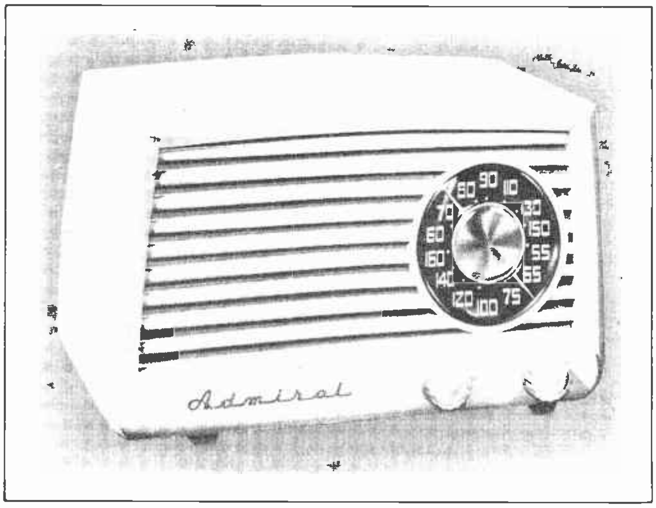


Fig.4. Table Model TRF Radio.
(Courtesy Admiral Radio Corp.)

If we move the volume control sliding tap toward the *left*, the opposite action takes place: More resistance is placed in the cathode of the first RF amplifier, increasing its bias and *reducing* its gain, while less resistance between ground and the antenna serves to progressively shunt more and more of the antenna signal to ground. This, in TRF receivers, is an almost universal practice, and provides proper range for the manual volume control.

The fact that the TRF volume control is electrically different from that of the superhet receiver suggests very strongly that any trouble-shooting in a radio receiver volume control should be guided by the type of receiver to which it belongs.

Section 5. THE SUPERHETERODYNE RADIO RECEIVER

As will be explained later in this lesson, the superheterodyne receiver embodies important improvements over the TRF receiver. Let us first, before making systematic comparisons between the two types of receivers, examine the details of superheterodyne operating principles.

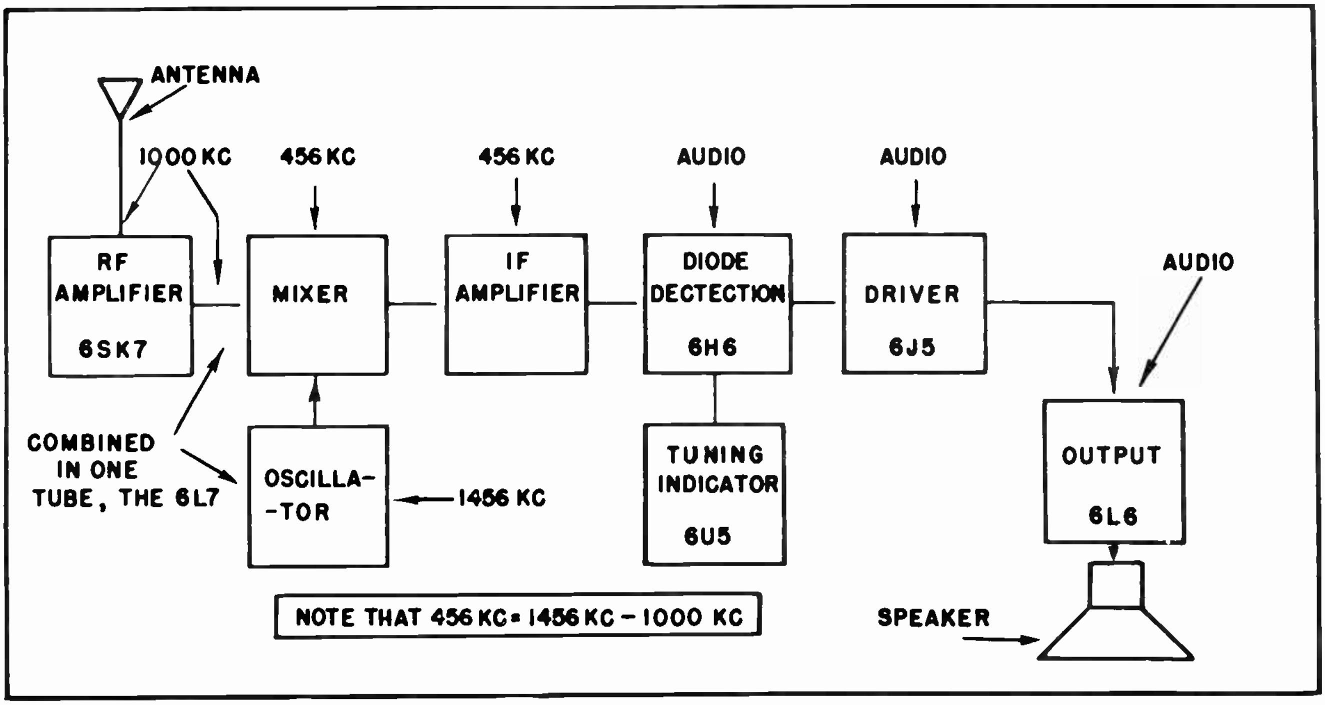


Fig.5. Block Diagram of Superheterodyne Receiver.

Fig. 5 presents a block diagram of a typical superheterodyne receiver, and indicates the frequency relationships between the component circuits. Fig. 6 shows the *schematic* diagram for a superhet receiver.

The superhet receiver contains four significant frequencies:

a. The incoming signal, to which the receiver is tuned.

b. The oscillator frequency.

c. The intermediate frequency, which is usually shortened to *I-F-*.

d. The audio frequency, or video frequency, the faithful reproduction of which is the main purpose of the receiver.

Keeping these four significant frequencies in mind, we may now trace a signal from antenna to the loudspeaker, showing the frequency changes that occur in the course of its journey through the receiver.

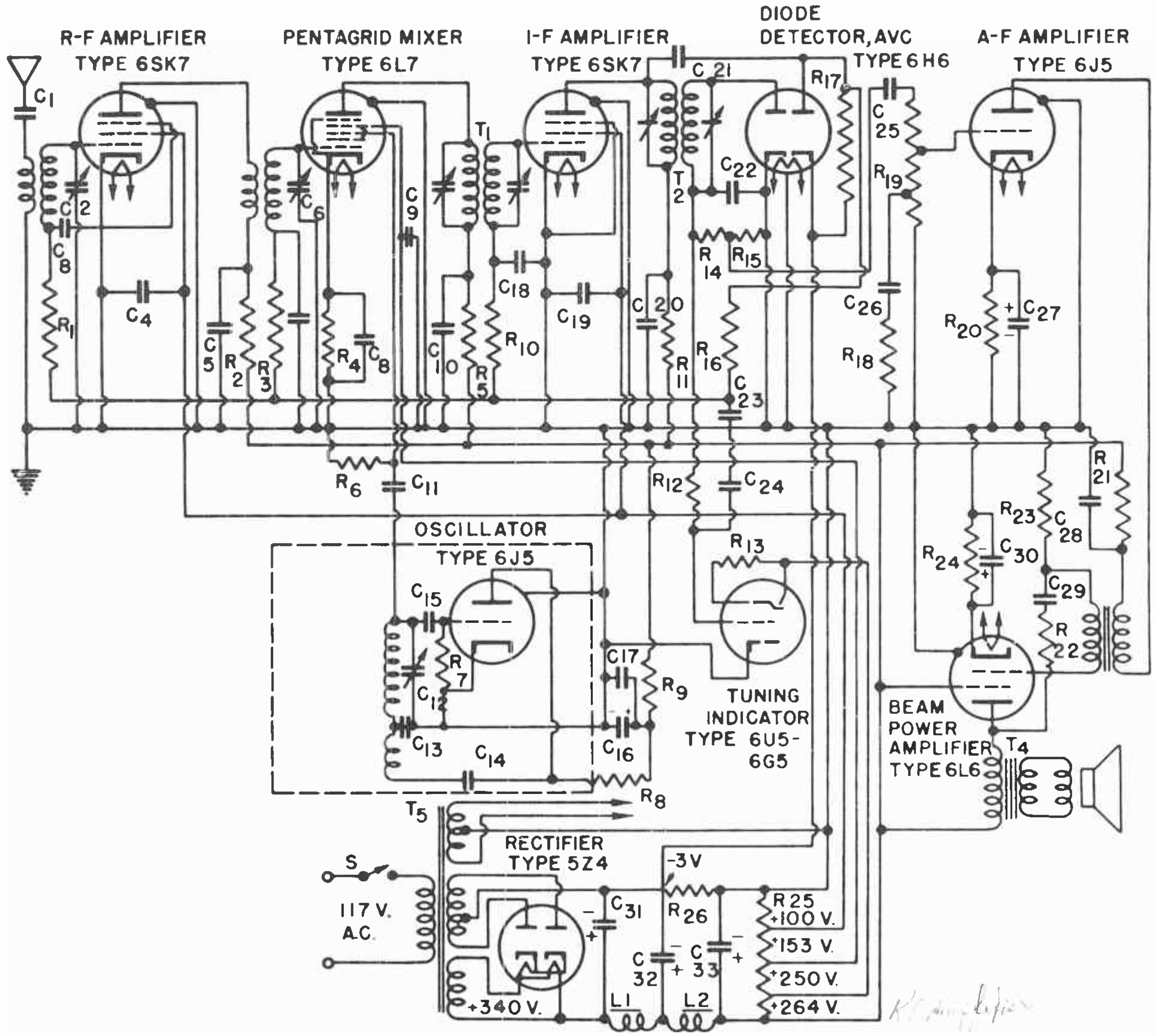
As in the case of the TRF, the signal is introduced at the antenna, from where it is fed as primary current to the RF transformer. The secondary of this transformer picks the signal up as voltage changes and applies the selected signal (selected by the tuned circuit of which the transformer secondary is the inductance) to the mixer tube control grid.

At the same time, the oscillator frequency is being fed to another grid of the mixer tube. Because these two frequencies are being mixed in the mixer stage, a *non-linear* amplifier, the output of this stage will contain not only these two frequencies, but their sum and difference frequencies as well.

Without a selective (tuned) plate load for this stage, all the frequencies produced in the mixer would flow into the remainder of the receiver. However, since we are interested only in the *difference* between the frequency of the radio signal and that of the oscillator, the plate load impedance of the mixer stage is tuned to that frequency which we call the intermediate frequency.

Note that the original modulation signal borne through space by the station carrier frequency was mixed with a constant-amplitude frequency from the oscillator. Their result is the I-F frequency difference, which also bears the modulation of the radio carrier; that is, the audio component itself.

The reason for this apparently elaborate method of operation can now be disclosed: If the difference between the radio station signal and the oscillator can be kept a *constant frequency*, and it *can* be kept



C_1 = 50 to 200 μμf
C_2 C_6 C_{12} = Ganged tuning condensers, 365 μμf
C_3 C_7 C_{18} C_{23} C_{24} C_{25} = 0.05 μf paper
C_4 C_9 C_{19} = 0.25 μf paper
C_5 C_8 C_{10} C_{17} C_{20} = 0.1 μf paper
C_{11} C_{22} = 100 μμf
C_{13} = Oscillator padding condenser
C_{14} C_{24} = 0.01 μf
C_{15} C_{21} = 50 μμf
C_{16} C_{31} C_{32} C_{33} = 8 μf electrolytic, 500 v.
C_{27} = 10 μf electrolytic, 25 v.
C_{28} = 1 μf paper, 400 v.
C_{29} = 0.5 μf paper, 400 v.
C_{30} = 25 μ electrolytic, 25 v.

R_1 R_3 R_{10} = 100000 ohms, 0.5 watt
R_2 R_{11} = 2000 ohms, 0.5 watt
R_4 = 260 ohms, 0.5 watt
R_5 = 3300 ohms, 0.5 watt
R_6 R_7 R_{14} = 50000 ohms, 0.5 watt
R_8 R_9 = 20000 ohms, 0.5 watt
R_{12} = 2 megohms, 0.5 watt
R_{13} R_{16} R_{17} = 1 megohm, 0.5 watt
R_{15} = 200000 ohms, 0.5 watt
R_{18} = 27000 ohms, 0.5 watt
R_{19} = 1 megohm volume control with tap at 250000 ohms for tone compensation
R_{20} = 900 ohms, 0.5 watt

R_{21} = 2000 ohms, 0.5 watt
R_{22} = 90000 ohms, 0.5 watt
R_{23} = 10000 ohms, 0.5 watt
R_{24} = 170 ohms, 2 watts
R_{25} = 20000 ohms, 5 watts
R_{26} = 25 ohms, 0.5 watt
L_1 = 20 henries, 100 ohms 120 ma.
L_2 = 500 ohm speaker field, 8 watts.
T_1 T_2 = I-F transformer
T_3 = Input transformer
T_4 = Output transformer; primary impedance, 2500 ohms
T_5 = Power transformer, 300-0-300 volts RMS, 120 ma d.c.

Fig. 6. Schematic Diagram of Superheterodyne Receiver.

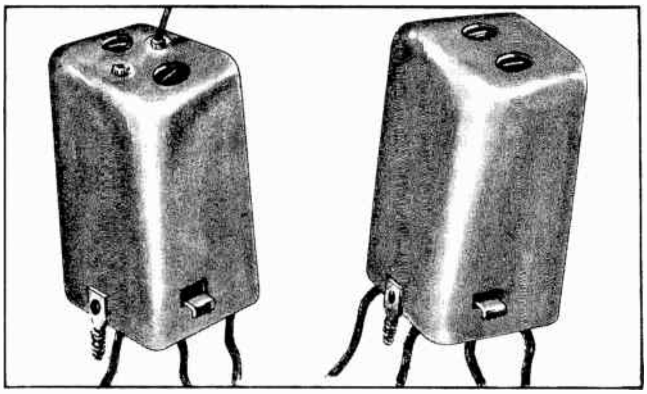


Fig.7. I-F Transformers. The Screw Slots on Top are for the Trimmer Adjustments.

constant, and if the audio component is retained, we can build an amplifier system which will amplify with extremely high efficiency. This is because the amplifier system can be designed to amplify at one frequency only. Such an amplifier system is the I-F section of a superhet receiver.

One or more high-gain stages, coupled by circuits tuned in both primary and secondary windings, achieves the double objective of precise selectivity and exceedingly high gain. Since the tuned circuits in this section are fixed at the RF-oscillator *difference* frequency, and since this frequency always remains constant no matter what station we tune on the dial, the I-F stages need no *variable* capacitors of the ordinary type. (Small trimmer capacitors, which are used for alignment purposes, are supplied within the same housing with the transformers, but these trimmers are fixed during the alignment operation.) (See Fig. 7.) The signal, now at the I-F frequency, is built up to comparatively high amplitude in the I-F amplifiers and fed into the second detector stage for extraction of the audio component.

This second detector is generally a diode stage whose current is drawn up from ground through the cathode circuit, through the last I-F secondary and delivered groundward again through the manual and automatic volume control circuits. See Fig. 6 for the circuit diagram of a superheterodyne receiver. An RF by-pass capacitor, usually of .00025 mfd value removes the radio frequency component at this point and permits the audio to be coupled across the volume control capacitor to the first audio amplifier, called the driver stage.

The driver stage is a triode voltage amplifier whose gain is about fifteen or twenty, and builds up what is now the audio signal to an amplitude suitable for delivery across the final coupling condenser to the grid of the output stage. The output stage, of course, feeds the primary winding of the matching transformer with its plate current at audio frequencies, enabling the speaker voice-coil to convert its electrical energy into sound energy.

The following table is presented for convenient reference:

FREQUENCY	WHERE PRESENT	PURPOSE
Station signal	From antenna to mixer grid	Carrier Wave.
Oscillator	Oscillator to mixer grid	To beat with the station carrier signal to produce the I-F.
I-F	From mixer output to 2nd detector	To have a constant frequency, regardless of which station is selected, for high gain and selectivity.
Audio	From 2nd detector to loudspeaker	To listen to.

Without discussing in great detail at this time the relative merits of the two different types of volume controls in the TRF and superheterodyne receivers, please note that there is a distinct difference in their electrical action. This difference will be thoroughly analyzed later when studying volume control repairs.

It may be to our advantage at this time, however, to make a comparison between TRF and superhet circuits as shown on following page.

TRF	SUPERHETERODYNE
Excellent tone response	Poorer tone response, but compensated for by other advantages
No "image" frequencies"	Subject to "image" interference
Not selective enough	Extremely selective
Not sensitive enough	Extremely sensitive
Inconveniently large	Conveniently small, where necessary
Heavy and bulky	Light and compact, where necessary
Contains only two significant frequencies	Contains four significant frequencies
No oscillator, no mixer, no I-F	Oscillator, mixer, I-F
Simpler circuits	More complex circuits
Poorer overall performance	Superior overall performance

Let us re-emphasize the fact that the distinction between TRF receivers and superhet receivers is a distinction of signal circuits only. It is therefore obvious that any trouble-shooting procedure which employs signal tracing through a radio receiver must be applied with rigid respect for the type of signal circuit a receiver uses.

In actual practice, the radio and television repairman will find that most receivers are of the superheterodyne type, and that the number of TRF receivers is rapidly growing smaller. Nevertheless, the technician should know the TRF receiver as well as he knows the superhet, because it embodies principles of radio technique of which the superheterodyne receiver is but a refinement.

A later lesson is especially designed to show the techniques of TRF trouble-shooting, and includes the necessary information to positively identify a TRF type of radio receiver. (See Fig. 8.)

Section 6. CONSOLE MODEL RADIO RECEIVERS

Fig. 1 shows a modern console type combination radio and television receiver. It is not hard to understand that in addition to being a source of entertainment for the entire family, it is also a piece of furniture that people select for beauty as well as for performance. It is a "living room piece," which "belongs" in the most used room of the home. It is usually the center of attraction in the living room and as such must fit into the general design and beauty of the home.

The console combination pictured in Fig. 1 is truly a versatile instrument. It contains three separate radio channels and an automatic record changer suitable for three record speeds. The three radio channels include the regular broadcast band, shortwave, and frequency modulation.

The record changer can be used for recordings of 78, 33-1/3, and 45 revolutions per

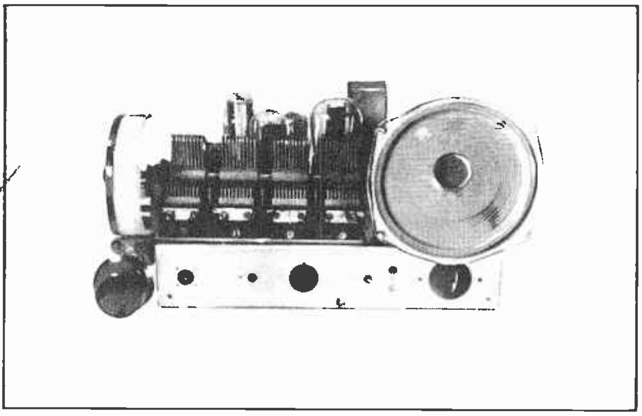


Fig.8. Chassis of TRF Receiver.

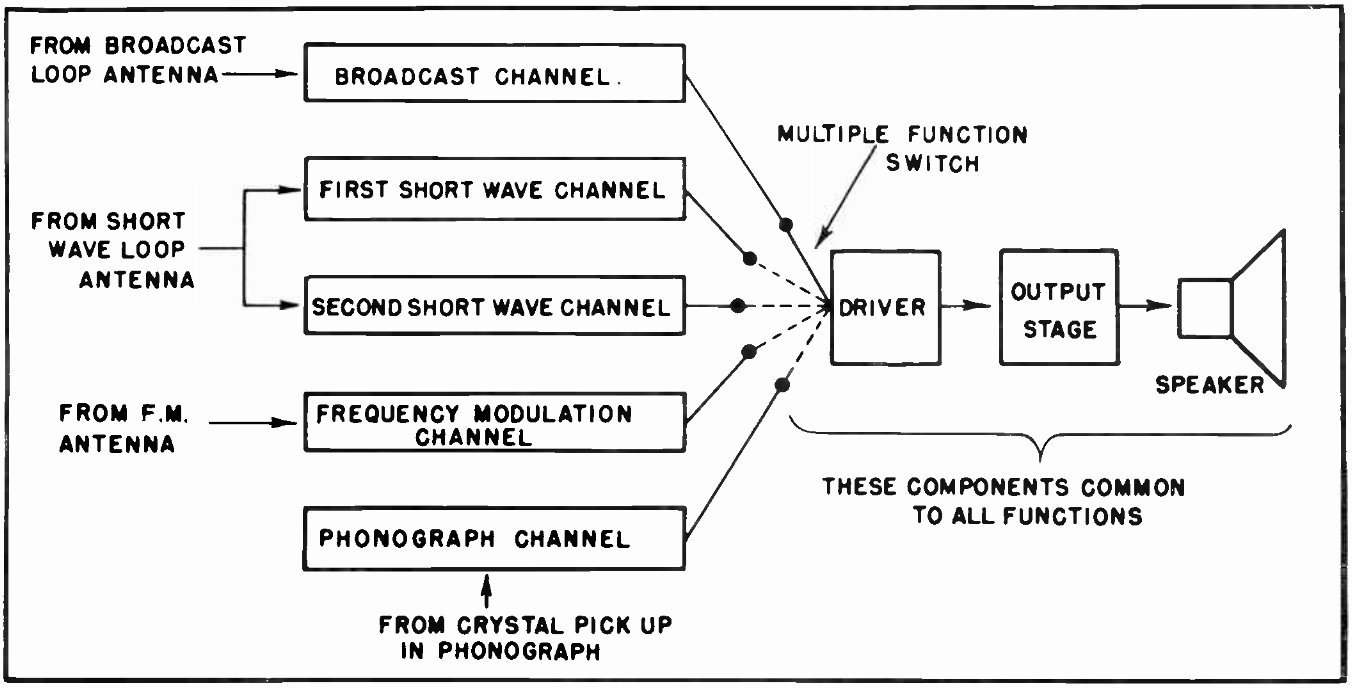


Fig.9. Block Diagram of the Audio Channels.

minute. It can provide a variety of entertainment almost incredible in one compact unit.

A console combination of this type is ingeniously designed for greatest efficiency, convenience, beauty, and economy. Fig. 9 shows a block diagram of the functional components of this type of receiver. As you can see, conservation of parts and space make it advisable to utilize every part in every possible way.

The audio section, for instance, is common to all of the functions of the combination. The power supply, too, is designed to provide power in proper form for any of the component circuits. That radio engineers and technicians can devise such wide variety of performance in so small a space is a tribute to modern skill and ingenuity.

At this point one may wonder how it is possible for a radio and television repairman to quickly and accurately analyze trouble occurring in such an elaborate arrangement of components, each of which is elaborate in itself. The answer to this can be summed up in the following statement:

The more elaborate the equipment the easier it is to localize, and eventually find, the trouble.

This may be hard to believe at this time -- certainly it is hard to explain -- but you will learn the truth of it as you progress with your studies.

Console model radio receivers, with their attendant accessories, are generally powered by full-wave rectifier systems; that is, they are designed to operate on A-C only. However, this rule is not iron-clad. Some models which appear the same as the one illustrated are designed for AC - DC operation. Nevertheless, these are the exception rather than the rule.

Some of the models of console receivers with associated phonograph equipment, are operated as AC - DC radio receivers, but their phonograph driving motors are designed for A-C only. This feature limits their use to A-C areas only, for grave damage would occur to the phonograph motor were D-C applied to it. For this reason, their nameplates always warn the user against use on any other power except 60-cycle A-C.

Section 7. TABLE MODEL RADIO RECEIVERS

By far the most popular receiver in use today is the table model. They probably outnumber all other receiver types combined by a ratio of 2:1. Because they are so popular, they deserve considerable attention.

Fig.10. Table Model Radio-Phonograph Combination.
(Courtesy Admiral Radio Corp.)

These sets come in a wide variety of shapes and external appearance. The average radio dealer's display window will often include a dozen or more table model receivers, each suited to its own location in the home, and each appearing different from the others. Yet their signal circuits, power supplies, and general features will be as alike as peas in a pod. Moreover, the large majority of troubles in this type of receiver are surprisingly similar, regardless of the make or model of the receiver.

The bulk of these table model radio receivers are limited to the single function of broadcast reception within the range of 550-1600 kilocycle frequencies. They are purposely made so, in order to keep their size, weight, and cost down to levels which justify their tremendous popularity.

A fair number of table model receivers also have the additional feature of a record player built into the same cabinet, as illustrated in Fig. 10. These record player combinations are not so elaborate as the console combinations, but with the growing popularity of record changers with different speeds, they often include a changer that is adaptable to at least two speeds. Many of these table model radio-phonographs in the lower price bracket are not equipped with record changers, but simply with ordinary non-changing record-players.

The power supplies of this group of radio receivers, the table model, are almost always of the AC - DC type. But here again an associated record player, designed for A-C only, will limit the use of the phonograph to A-C areas only. The radio, if it occurs without the phonograph, can be used equally well on A-C or D-C and is therefore suitable to use in almost any area where commercial power is available. Hence its great popularity.

While table model receivers are almost universally AC - DC sets, there still remain in use a scattered few table models which are powered by A-C only. We will reserve a later section of this lesson for a discussion of power supplies.

Section 8. PORTABLE RADIO RECEIVERS

Fig. 11 shows a picture of a modern portable receiver. Portable receivers are becoming more and more popular, and, due to circuit and production refinements, are becoming smaller and smaller. The well-designed small portable receiver today will, in its own way, match the performance of a receiver three times its size built only a few years ago. The main feature of portable receivers, is, of course, their portability. They can be used almost anywhere. The many uses of the portable receiver are both too obvious and too numerous to list.

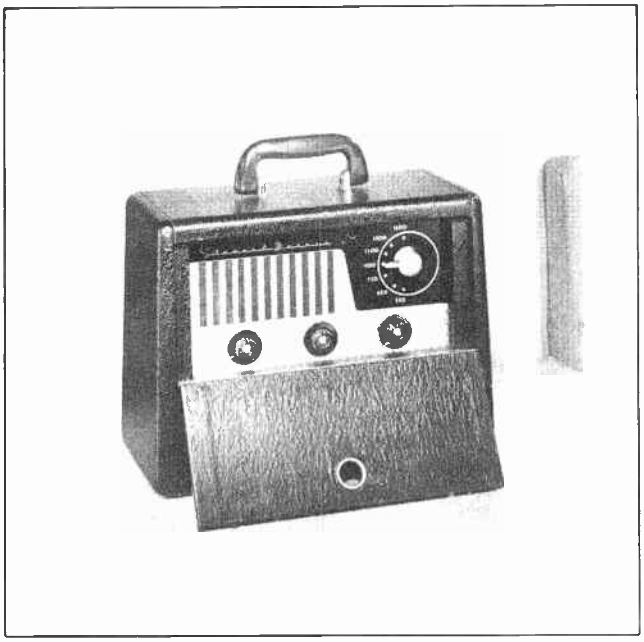


Fig.11. Portable Radio Receiver.
(Courtesy Stewart-Warner)

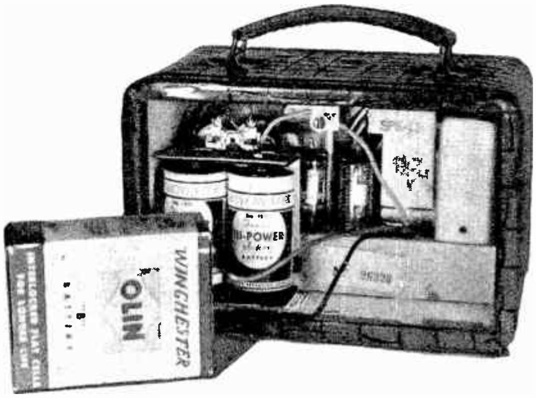


Fig. 12. Picture of Back of Portable Receiver.

Certain characteristics of the portable receiver are important enough to consider. Because of the portability feature of this type of receiver, it must necessarily contain its own power supply as well as its own antenna. The loop antenna, to be explained in detail in later lessons, is ideally adapted to portable receivers. While the great majority of portable receivers are designed for ordinary broadcast reception, some manufacturers, such as Zenith and Hallicrafters, produce a portable that includes short-wave reception as well. In these receivers, manufacturers build a whip antenna, which can be telescoped down when not in use, for better short-wave reception. These sets also include the loop antenna for ordinary reception; the loop is standard antenna equipment in practically all portables.

The ideal application of a self-contained power supply for portable receivers necessitates the use of batteries. Fig. 12 shows the rear view of a portable receiver with its batteries installed in special spaces provided. The batteries are usually an *A* battery, to deliver current for heating tube heaters, and a set of *B* batteries to supply the plate power for the set. Sometimes a battery "pack" is used, which contains both the A and B battery in the same package. (See Fig. 13.)

The three-way portable is another variety of this type of receiver. As the name indicates, this set will operate on its own battery system when commercial power is not available, or on either A-C or D-C commercial power. To conserve the life of the batteries, and to widen the use of a single receiver for both indoor and outdoor use, the users of 3-way portables are urged to use the batteries when using the portable outside the house, but to plug into the power line of their homes when indoors. This arrangement, of course, needs a power rectifier and filter system built into the chassis, and a method of switching from batteries to house-power when the occasion demands. Fig. 14 shows a typical switching system to accomplish this plan.

A further refinement of the 3-way portable is the self-charging portable battery receiver. In this type, the power supply is a 2.2 volt lead-acid cell which drives a vibrator-rectifier system to provide high voltage plate power. Heaters are heated directly from the low-voltage battery, which is periodically charged by a step-down-transformer-rectifier system which is plugged into the 117-volt A-C power line. While a little complicated, this method of operating a portable receiver eliminates the need for frequent battery replacement and thus is economical. This type of power supply is identical in principle to that used for automobile receivers.

Section 9. AUTOMOBILE RADIO RECEIVERS

The automobile radio receiver, installed as it is in a mobile vehicle, presents special problems of its own for the designer, installer, and serviceman. The automobile in which it is installed must provide its own power supply and, of course, must carry its antenna along wherever it goes. The limited size of a necessarily short antenna calls for exceptional high gain in the

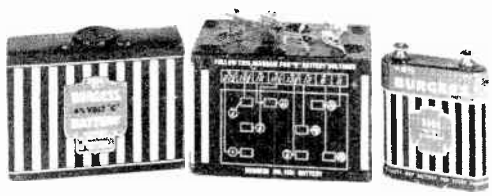


Fig. 13. Picture of Battery Pack.

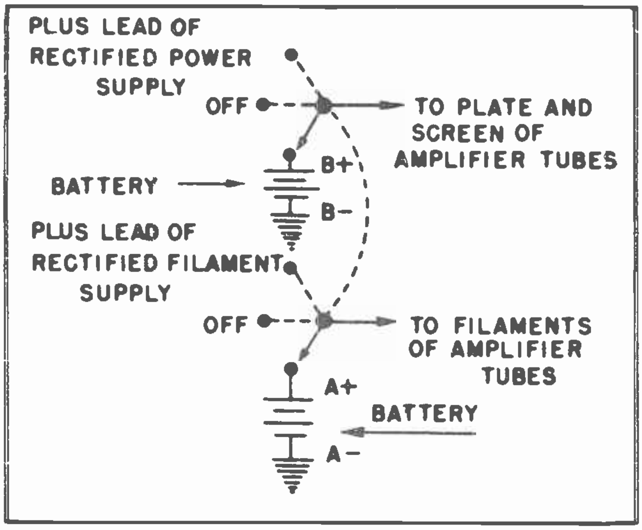


Fig.14. Switching Arrangement on Portable Receiver.

amplifying circuits of the receiver, and auto radio receivers are designed with this consideration in mind.

Likewise, the power supply, originating in the 6-volt battery, must provide plate supply power on the order of over two hundred D-C volts. This is easily accomplished in the automobile receiver by use of either a vibrator-transformer system, or by a dynamotor, with the ability to convert 6 volts D-C to well-filtered 200 volts D-C.

As mentioned under rechargeable portable batteries, the vibrator-transformer system is almost universal in ordinary auto receivers. The synchronous type vibrator is primarily designed to eliminate the use of the rectifier tube, thus drawing less power from the battery. Synchronous vibrators have been gradually becoming less popular, primarily through the application of the cold-cathode auto receiver rectifier tube, the OZ4, which has no filament and therefore is economical with battery power.

In addition to power supply and antenna requirements that are special in auto receivers, these receivers must cope with the threat of various types of static interference which is seldom found elsewhere. Ignition sparking, generator interference, and wheel and tire static are the chief offenders. The radio repairman will often have car static to remove. This task is met in several ways, depending upon the exact nature of car static interference. Ignition noise can be minimized generally by the use of shielding on RF leads and ignition suppressors. Suppressors can be installed easily either at the center wire of the distributor, or on each spark plug individually. Shielding is of the utmost importance. Generator noises are lessened usually by the installation of a by-pass capacitor at the high side of the generator output. Wheel static can be minimized by the proper device installed in the hub-cap, or by special techniques in the tire installation. All of these methods, and a complete discussion of auto receiver trouble-shooting, are included in a special lesson later.

Because of the characteristic type of power circuit and antenna arrangement in an automobile receiver, certain troubles arise which cannot occur in other receivers. In other words, an automobile receiver, in addition to having all the troubles that are inherent in any other type of radio receiver, has an entire family of troubles peculiar to itself. The radio and television repairman will be indeed wise to take all factors into consideration when shooting trouble in such receivers. The car radio receiver's possible troubles can often be narrowed down to a few probable faults by a superficial, but intelligent, observation of trouble symptoms.

Section 10. COMMUNICATIONS RECEIVERS

Communication radio receivers are a family of their own, differing from consoles, table-models, portables, and mobile receivers. Communications receivers are so named because they are primarily designed for the reception of speech signals, or code signals, which take the place of speech. They are widely used by airlines, police radio systems, radio press organizations, and by radio amateurs. Their chief advantage is that they are adapted especially to signal or code reception, and are extremely sensitive. They are also designed so they are highly selective, being able to choose between two frequencies which are very close together.

One cannot mention communications receivers without calling attention to the essential part that these receivers played in winning the late war. For military purposes alone, large manufacturers of communication receivers allotted their entire production to the armed services. For war work, as well as in peacetime, these receivers have to be of the highest possible quality.

Communications receivers may have a variety of power supplies, determined by the exact application to which this equipment is put. In an airplane, communications receivers are either made to operate from the D-C battery supply, usually 24 or 28 volts, or from an A-C converter operating to produce 400 cycle, 120 volts for use throughout the plane.

In mobile communications receivers, the power supply may be of the vibrator-transformer type, or may be a dynamotor with a high-voltage D-C output.

In the armed services, combination power supplies were developed for wider versatility. This entailed the presence of a 6-volt D-C power supply, a 117-volt A-C power supply, and a system for plugging into a 220-volt supply, A-C or D-C -- all of these power supplies being located, with the proper switching provisions, in the same receiver. This made it possible to use such a receiver in a car, in a district where domestic voltages are of the 117-volt value, or in a foreign land, where, perhaps the local power available is 220-volts.

The use of communications receivers has been augmented by the army of ever-increasing radio amateurs. These hobbyists of the science of radio and television are licensed by the Federal Government for experimental operation of transmitters and receivers on certain frequencies. Many amateurs build their own transmitters; however, most amateurs avail themselves of the very excellent, standard communications receivers now on the market. Communications receivers differ from most other types in their ability to receive signals at almost any frequency which is broadcast. They are fitted with a provision enabling the operator to switch from one band to another very readily. Their calibration is such that the accurate reading of the frequency of an unknown signal can be immediately determined. This is done by a "coarse" reading of the signal frequency on the regular dial. In addition a vernier, or "band spread" dial is also provided for hairline tuning.

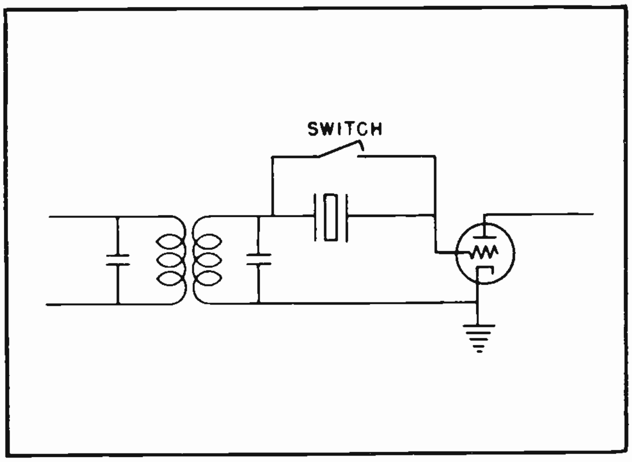


Fig.15. Quartz Crystal Filter.

Because a communications receiver must be able to receive code signals as well as speech, a special circuit is included in these receivers that enable the set to receive the so-called "CW" (continuous wave) signals. These are usually sent by other amateurs, or press services, in the form of interrupted unmodulated dot-and-dash signals. The circuit in a communications receiver designed to pick up these continuous wave code signals does so by a simple principle of heterodyning two inaudible frequencies to produce their difference as an audible signal. The circuit involved is called the BFO (beat-frequency-oscillator), and the operator has the privilege of switching this feature on or off, as the occasion demands, during a period of listening. For easy access, this switch is located on the front panel of the communications receiver.

Crystal phasing is another feature of communications receivers peculiar to its own family. To accomplish extremely high gain in the I-F stages of these receivers, especially when the incoming signal is very weak, the operator flips a switch that inserts an oscillatory crystal, usually made of quartz, into the I-F system. Since the desired signal is in code (continuous wave), we need not fear cutting out the side bands that normally contain audio speech. The result is super-gain at the desired frequency. When the message has been received, and the operator wants to tune in a speech broadcast, the crystal phasing switch is closed again and the I-F tuned circuits again possess enough band-width to bring in the speech with sufficient clarity. (See Fig. 15.)

Modern communication receivers, like most other types of modern receivers, employ the superheterodyne signal circuits.

Trouble-shooting the communications receiver is similar, of course, to trouble-shooting receivers in general. However, like other types, the communications receiver may develop troubles in circuits which are peculiar to itself, and therefore may have no analogy in other types of receivers.

NOTES FOR REFERENCES

CLASSIFICATION OF RADIO RECEIVERS

Classification	Types
Signal Circuits	TRF and Superheterodyne
Power Supply	A-C, AC - DC, battery portable, 3-way portable, rechargeable battery portable, auto radio receiver with vibrator or dynamotor
Application	Console, including phono-combinations; table-model, auto receiver, portable, communications receiver

Identification of both the signal circuit and the power supply is the logical starting point in trouble-shooting a radio receiver.

Don't look for troubles in a receiver which cannot possibly have those troubles.

To *eliminate* the possibility of a certain trouble in a certain type of receiver is the first step in the right direction.

Radio and television troubles are located quickly and accurately in most cases by a keen sense of observation and a thorough understanding of the functions of the parts.

Locating the trouble is the biggest part of receiver trouble-shooting. The actual repair is generally a simple mechanical operation, such as replacing the defective part, or making necessary adjustments. It is finding the trouble that presents the challenge to the radio and television repairman.

Every effort in the learning process involved in radio and television trouble-shooting should be bent in the direction of quickly and accurately locating the trouble -- in the shortest possible time and with the least chance for error.

The four important steps in radio and television trouble-shooting are:

1. Identification of the receiver and recognition of the symptoms.
2. Testing and analysis of the results of testing.
3. Verification by correction, which may include the replacement of the suspected component, or the necessary adjustment.
4. Testing the repair job. This should last as long as time permits, or at least long enough to prove beyond a reasonable doubt that the defective part has been replaced or repaired.

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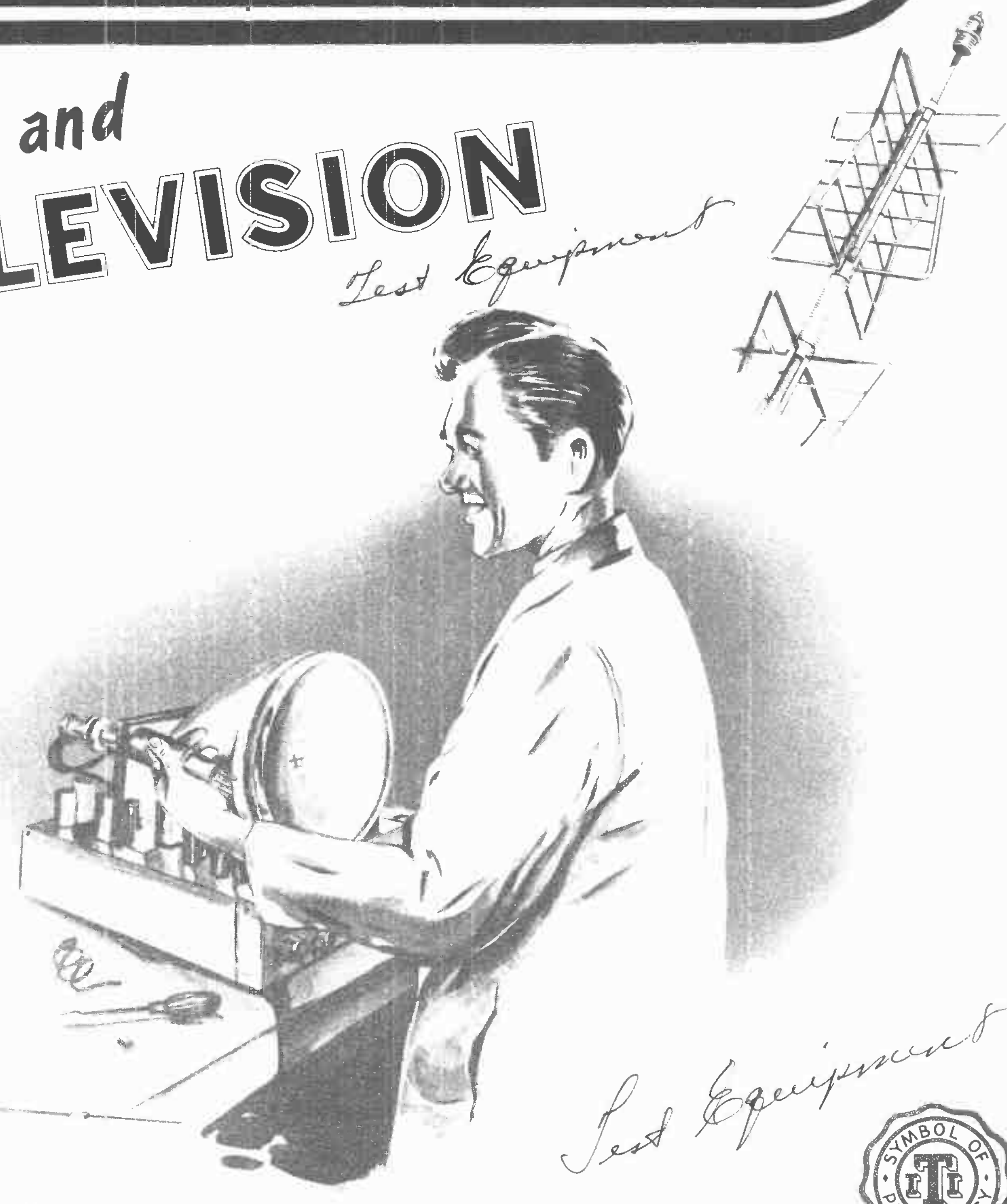

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RADIO TELEVISION

TEST EQUIPMENT

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Section 1. INTRODUCTION

The radio and television repairman has available to him a group of instruments and test equipment which greatly extends his ability to investigate the troubles which are so often found in radio and television receivers. The human senses are inadequate to give us accurately measured values of voltages, currents, and resistances. In servicing radio and television receivers the need for accuracy has required the development of precise testing instruments and equipment.

We are not content merely to know the presence or absence of voltages; we must know, within a reasonable tolerance, the actual number of volts present. Likewise, the difference between *any* number of ohms resistance between two points in our circuit and the *exact* number of ohms may be the difference between locating the trouble quickly and accurately or searching in vain for a trouble that we have completely missed through inaccurate readings.

Section 2. THE VOLT-OHM-MILLIAMMETER

Fig. 1 shows a model of a typical modern volt-ohm-milliammeter. In reality, it is three test instruments in one. Since the voltmeter, the ohmmeter, and the milliammeter all use a basic meter unit, the three functions can be combined in one compact unit with switching arrangements providing for the selection of the function desired. This makes for economy in cost, space, and time. This volt-ohm-milliammeter, whose name is shortened to "V-O-M," or

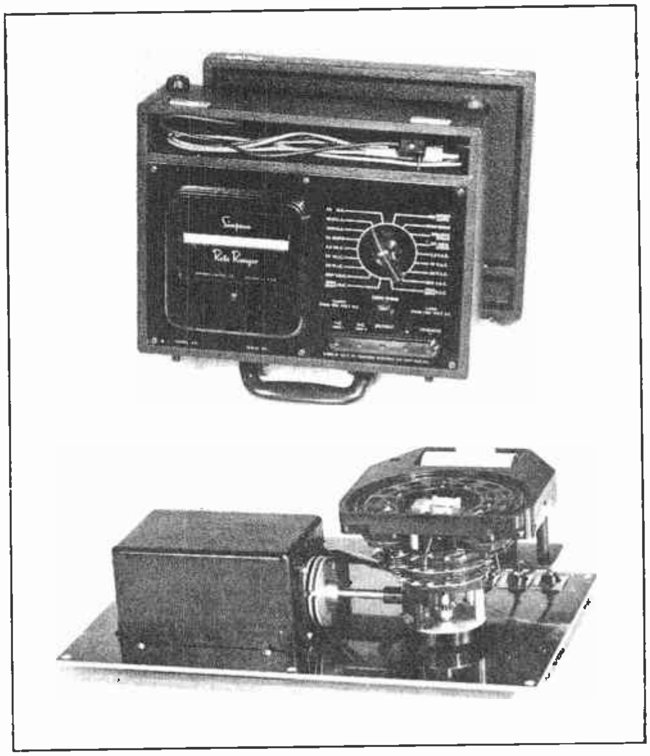
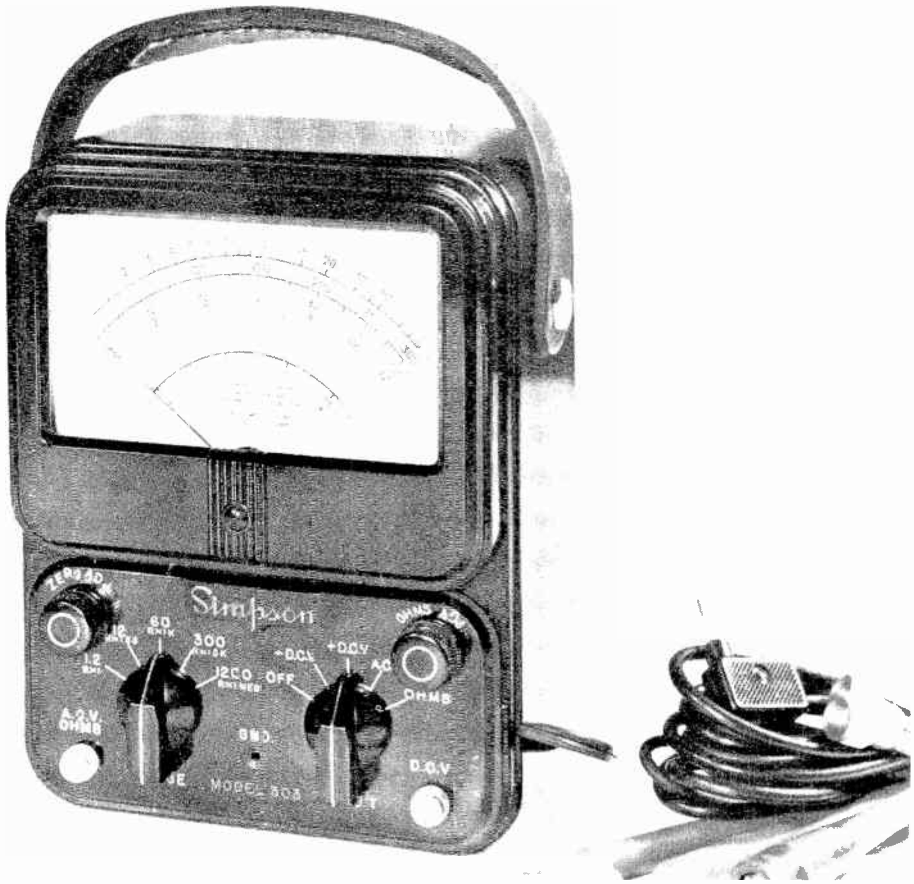
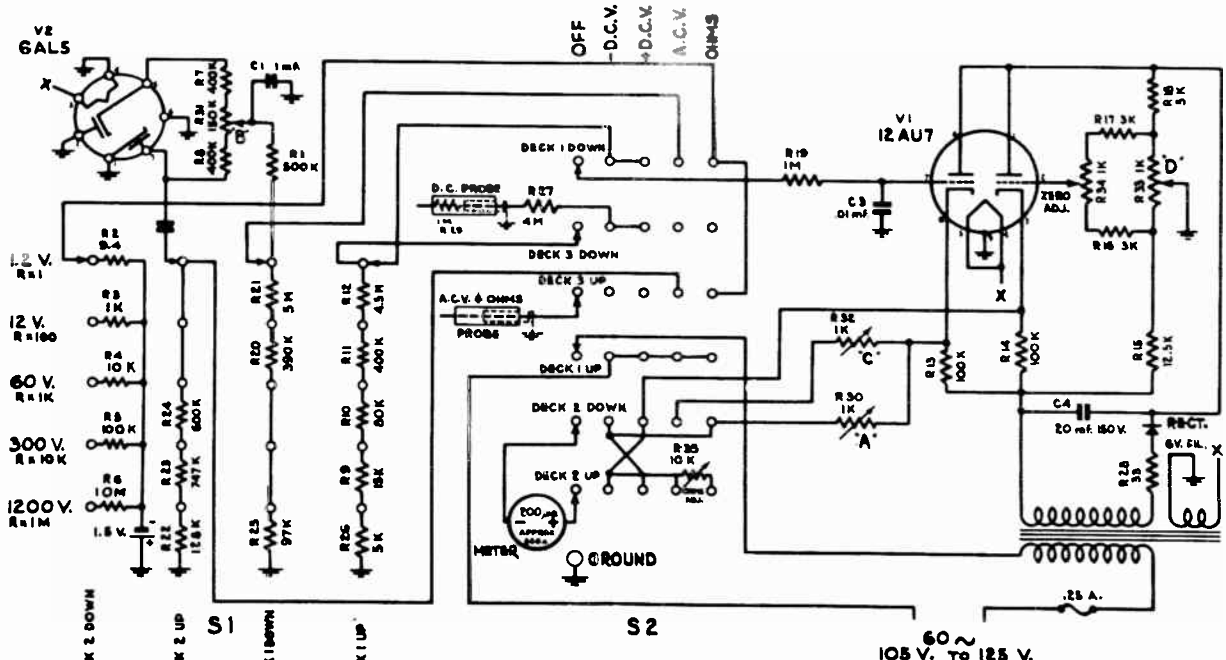


Fig.1. Volt-Ohm-Milliammeter. (Courtesy Simpson Electric Co.)





Model 303 Schematic Diagram

Fig.2. Electronic Voltmeter.
(Courtesy Simpson Electric Co.)

Multi-meter, will read A-C and D-C voltages on several scales of convenient values, measure currents of commonly needed values, and show the number of ohms of resistance between two test points. The resistance scale consists of a "high-ohms" and "low-ohms" calibration which widens the accuracy range of the ohmmeter. See Fig. 29.

Section 3. **VACUUM-TUBE-VOLTMETER**

Illustrated in Fig. 2 is a modern electronic voltmeter. This instrument is also called the *vacuum tube voltmeter.* The short name adopted by electronic men is "V.T.V.M." Notice that the VTVM, like the VOM, has many different scales and selecting switches. In fact, the VTVM, because of the nature of its electrical construction, does what the VOM does, does it better, and does it more accurately.

The basic characteristic of the VTVM is its ability to read voltages without "loading" (and therefore without altering) the circuit which is being measured. For much radio and television work such a high degree of accuracy is not essential, the tolerance of the VOM being ordinarily sufficient. However, both radio and television receivers contain some special high impedance circuits where the use of a VOM will substantially alter the reading and reduce accuracy. In such cases the VTVM is indispensable.

Section 4. **THE SIGNAL TRACER**

The signal tracer is a helpful and practical device in radio and television trouble-shooting. An illustration of a signal tracer is shown in Fig. 3. Complete instructions for building such a unit for yourself are contained in a later lesson.

The main characteristic of the signal tracer is its ability to locate radio or television trouble by determining just where in the circuit the signal drops out. This is accomplished by the signal tracer's ability to convert a radio frequency signal in any stage in the receiver to an identifiable audible signal. Starting at the antenna, the signal tracer, which is basically an amplifying demodulator, is applied to each stage in succession until the signal is lost. The stage in which the signal is lost is obviously the defective stage. A detailed analysis of this stage with the use of other test equipment will quickly reveal the guilty component.

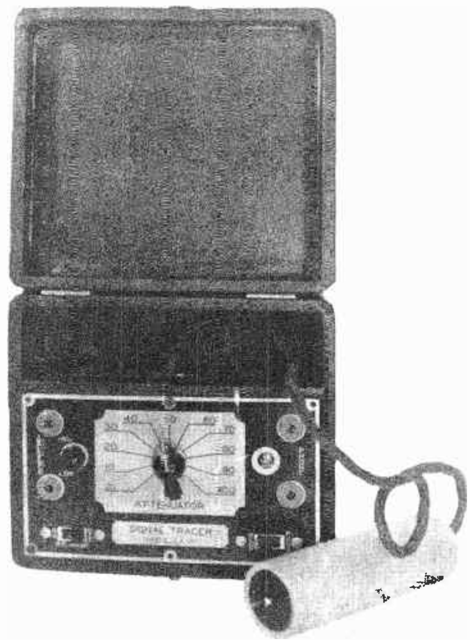


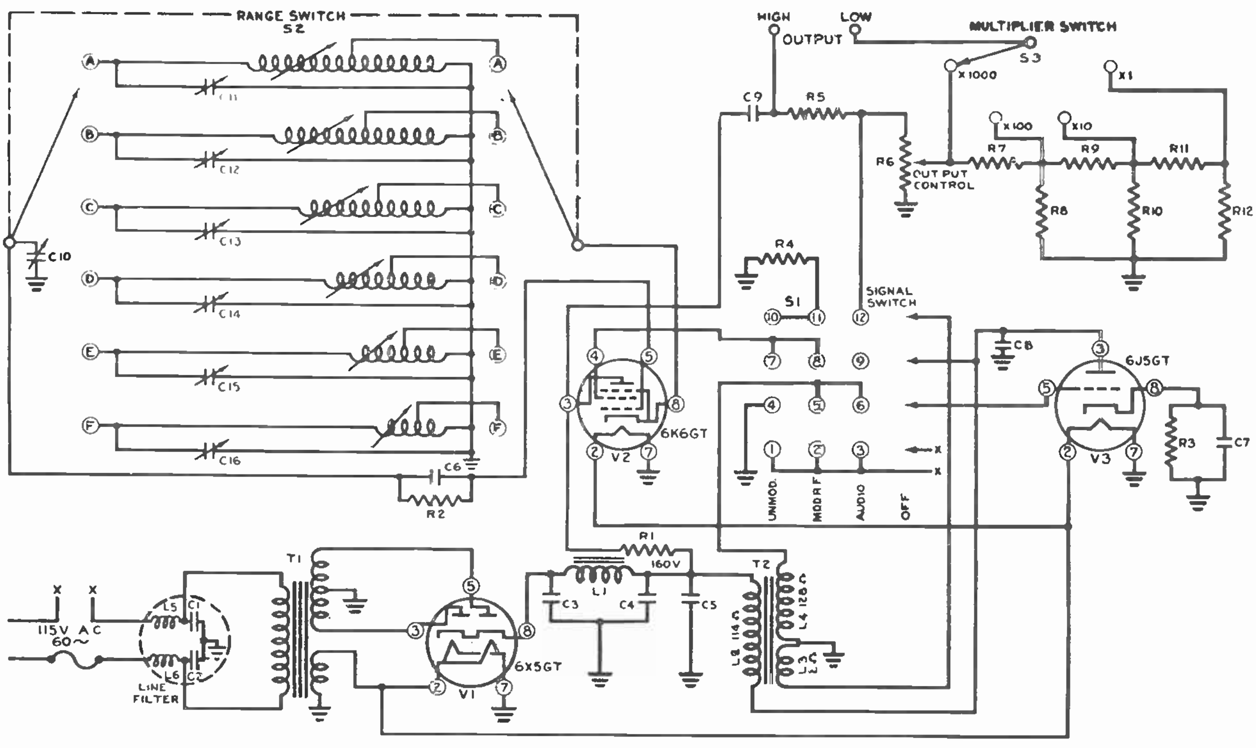
Fig.3. Signal Tracer

Section 5. **SIGNAL GENERATOR**

The signal generator, illustrated in Fig. 4 is another ingenious testing device especially adapted for radio and television. The model shown is a Radio Frequency signal generator. Fig. 5 shows an audio frequency signal generator. In many cases, the two signal generators are installed in one unit, which thus becomes a versatile test instrument for almost any conceivable type of signal circuit.

The purpose of the signal generator in radio and television trouble-shooting is to feed a known, and controllable, signal into any given circuit and to enable the technician to monitor the output of this circuit to determine the quality of its operation. Any circuit which passes this known signal with proper gain and fidelity can be said to be in good order. Any circuit which fails to do this is at once suspected of faults. Here, too, the detailed analysis of the suspected circuit will soon disclose the exact guilty component.

One of the chief differences between applying a signal generator and a signal tracer to a defectiver receiver is this: The signal tracer starts analysis at the



R1—500 ohms
R2—20 K ohms
R3—750 ohms
R4—45 ohms
R5—10 K ohms
R6—200 ohm Pot.
R7, 9, 11—970 ohms
R8, 10, 12—120 ohms

C1, 2, 9—.05 MF
C3, 4—10 MF
C5—.25 MF
C6—.0002 MF
C7, 8—.5 MF
C10—440 MMF
C11, 12, 13—Trimmers
C14, 15, 16—Trimmers

T1—Power Transformer
T2—Modulation Transformer
L1—Filter Choke
L5, 6—RF Choke
S1—Signal Switch
S2—Range Switch
S3—Multiplier Switch

RANGES

75-200 KC
200-600 KC
600-1700 KC
1.5-4.5 MC
4.5-12 MC
10-30 MC
40-120 MC

Model 340 Schematic Diagram

Fig.4. RF Signal Generator.
(Courtesy Simpson Electric Co.)

antenna and works toward the loudspeaker - while the signal generator starts at the loudspeaker and works *backwards* toward the antenna. The reasons for this reversal of method will be better understood when we take up the use of test equipment in specific instances.

In addition to its function as a helpful ally in locating troubles in radio and television equipment, the signal generator serves another important purpose. It is ideal for aligning (adjusting) the many critically sensitive RF circuits in a receiver. While radio receivers seldom need a complete alignment procedure, there are times when a signal generator, and nothing but a signal generator, will accomplish the desired correction. Slight trimming adjustments can often be done on a radio receiver by ear, but for the alignment procedure the signal generator is made to order. A signal generator is indispensable in aligning the I-F transformers in a television receiver.

In conjunction with the oscilloscope (to be treated in detail in later lessons) the signal generator can be used to set the proper band width of intermediate frequency amplifiers, assuring the passage of all desirable components of the signal and thus bringing in the full tone carried by the broadcast signal. A special circuit of the signal generator is employed for this application. This circuit is called a "wobbulator" and in essence comprises an I-F signal output modulated at a comparatively slow rate by frequency deviations. This procedure will be more fully explained in the lessons on Oscilloscopes.

Section 6. THE TUBE-CHECKER

Probably the most widely used radio and television test instrument is the tube-checker. Fig. 6 shows a typical modern tube-checker designed for use at the test-bench. A somewhat similar model has been designed for portability so it can be carried to the customer's home. Both units are identical in their operation and the information they give about a tube.

The tube-checker's great utility is based upon the fact that most troubles in radio and television receivers originate in the tubes. While the radio and television repairman must be well prepared to find troubles that do not originate in the tubes, the routine check of all the tubes in a

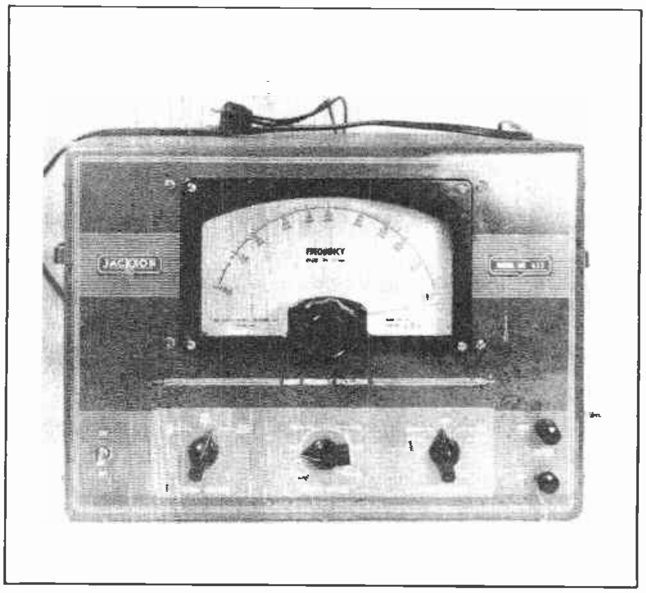


Fig.5. Audio Signal Generator.

receiver, or at least those which are suspected of faults, is the first procedure. Once we are convinced that the tubes are in good order, a scientific procedure for finding an unknown trouble can then be set up.

Eliminating possible tube troubles, or correcting them, is a major step in solving any radio or television trouble.

The tube-checker can supply a wealth of information regarding the state of the tubes in a receiver.

The tube-checker will give the following information about the tubes:

It will tell if there are any internal short-circuits in the tubes.

It will tell if there are any open circuits in the tubes, including the heaters or filaments themselves.

It will tell whether the emission from the cathode emitting surface is good or bad, and it will indicate the degree of emission.

It will reveal "gassiness" in a vacuum tube.

It can reveal high resistance leakage between the elements in a tube.

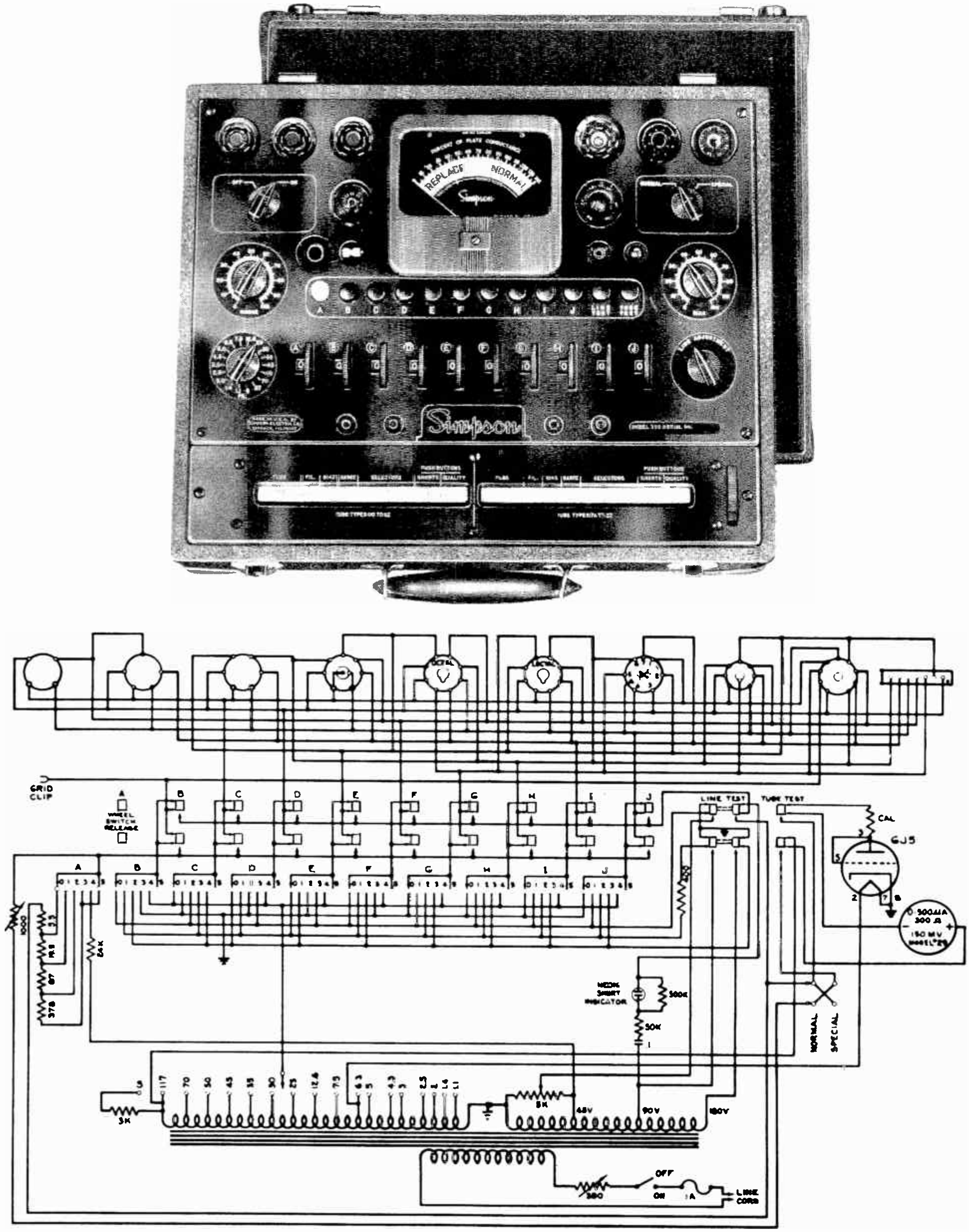


Fig.6. Tube-Checker.
(Courtesy Simpson Electric Co.)

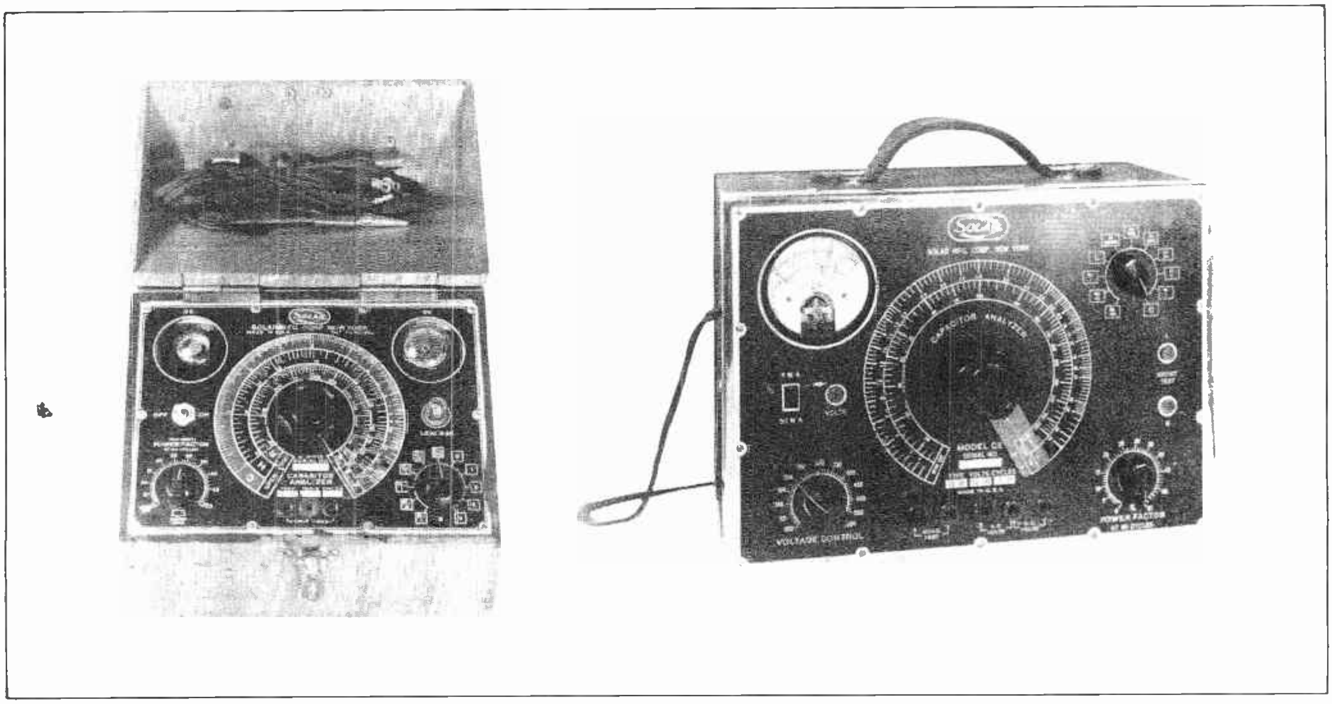


Fig.7. Capacity Analyzers.

It can, in some models, indicate whether or not a tube is noisy.

It can also, in many models, actually give us a direct reading of the transconductance of an amplifier tube. Transconductance, or mutual conductance, is a property of an amplifier tube which indicates the degree of amplification possible in that tube.

The tube-checker can be ordinarily employed to show intermittent, or temporary, faulty conditions in a tube.

While the tube-checker is in itself a miracle of performance it, nevertheless, has some important limitations. These limitations are not inherent in tube-checkers, nor are they due to the failure of the manufacturer to include a more elaborate circuit in the tube-checker. The limitations we speak of are, rather, inherent in the nature of the tubes themselves. Among them are the pilot-tapped AC-DC heater tubes, and the pentagrid converter tubes. Both of these classes of tubes may contain serious deficiencies, but through no fault of its own, the tube-checker will still indicate they are good tubes.

Section 7. **CAPACITY ANALYZERS**

The capacity analyzer, illustrated in Fig. 7, is designed to meet the radio and television repairman's need for determining the quality or value, of the capacitors employed in the equipment on which he works. The capacity analyzer is a relatively simple instrument to use. Many different models of this device are available. Sometimes a capacity analyzer is made a part of a more elaborate multimeter which thus is given extremely wide versatility.

Basically the capacitor analyzer applies an alternating voltage to a circuit containing the unknown capacitor, and the analysis of the value and electrical quality of the capacitor are indicated on a meter which measures the current, but which is *calibrated in capacitance.* Since the capacitance of a capacitor, together with the voltage and frequency, determine the current through the capacitor, we can work backwards with this information and can determine the value of the capacitance to be measured. All this the capacity analyzer does automatically and indicates the result on the calibrated scale.

Often it is possible to determine the quality and value of a capacitor without removing it from the circuit, and without applying the capacity analyzer. However, the capacity analyzer has the peculiar ability to *accurately measure* the capacitance in question where other methods are only approximations, or fail altogether.

In addition, the capacity analyzer will indicate a short-circuited condenser, an open condenser, and -- for the electrolytic type condenser -- the power factor of a condenser. Leaky condensers can also be determined with this device. A leaky condenser is one which, while not directly short-circuited, nevertheless has an undesirably reduced resistance between its plates. While dielectric insulation between capacitor plates will never be absolutely perfect, nevertheless there is a minimum amount of permissible conduction between them. The capacity analyzer will indicate when this safe minimum has been overstepped by defects in dielectric insulation, or by any other cause.

Section 8. USING RADIO AND TELEVISION TEST EQUIPMENT

With the wealth of the various types of test equipment available to him the radio and television repairman will often wonder which test unit to use on the radio receiver he is analyzing.

Should he measure critical voltages first?

Should he check the tubes?

Should he make ohmmeter checks before doing anything else?

Should he measure the current through a suspected circuit?

Or should he remove the capacitors one by one and check them on the capacity analyzer?

These questions will have different answers in different cases. Each depends upon the nature of the trouble, its symptoms, and on the technician's own initiative and ingenuity. Some troubles will demand the application of the signal generator before anything specific can be determined. The signal generator will indicate the *stage* in which the trouble occurred, and the logical procedure in this case would be to examine that stage in detail with a voltmeter or ohmmeter. Another case will require that tubes be checked first, and, if they are found to be in good order, the next step would be to make a detailed check of the power supply with a voltmeter. A third case may suggest to the repairman that he use the capacity analyzer first, to verify the suspicion of -- let us say -- a deteriorated filter condenser.

What then, will determine the order in which the radio and television repairman will apply his test equipment to a receiver under analysis? How can he put his test equipment to maximum use to determine first, the *stage* in which the trouble lies; and second, the exact component at fault? And, moreover, how can he do this in the shortest possible time and in the most accurate way?

Quick and accurate radio and television trouble-shooting rests upon several conditions:

1. The recognition and identification of the symptoms presented by a defective receiver -- the result of keen observation.
2. A functional knowledge of the purposes of the components in a receiver -- the result of experience and training.
3. A sound knowledge of the capabilities and limitations of the test equipment used.
4. A clear and concise appraisal of all the known facts, including observed symptoms, voltage and resistance readings, and the findings of other test equipment used.

In these four conditions lie the answer to our previous question: What test unit shall the radio and television repairman use first?

It is easy to say that the order in which test equipment is applied to a defective receiver depends upon the nature of the trouble.

But we do not as yet know the trouble!

All we know are the visual, audible, and electrical deficiencies the trouble (as yet unknown) has caused.

Let us distinguish clearly between a trouble and its symptom. They are separate and distinct, even though the trouble has caused the symptom. The trouble is a defect in a component; the symptom of this trouble is the audible, visual, or electrical *result* of the trouble.

As an example, the *trouble* in a radio receiver could be a short-circuited filter condenser. We cannot look inside this condenser and *see* the short-circuit. Yet the *results* of this trouble can be easily recognized. We notice that the signal and the normal hum are absent from the receiver's loudspeaker; we also note that the rectifier tube plates are red hot. We may also note, if we are alert, that the power transformer is becoming overly warm. These are the *symptoms*, the obvious consequences of a short-circuited filter condenser. These are obvious to anyone, even to the untrained observer. But the repairman goes one step further in his observations. He measures the value of B-plus in the receiver and finds it absent; he also measures the resistance across the filter condenser, and finds it zero (a short circuit).

Test instruments have given the technician more information than the untrained observer possesses. He used a voltmeter to measure voltage and an ohmmeter to measure resistance. Both of these readings are of the utmost importance, for they permit him to appraise all the results of the trouble, and thus indicate which one trouble will result in all of the observed facts.

We may logically conclude, therefore, that the order in which test equipment is applied to a defective receiver is determined by the nature of the symptoms. Do not underemphasize the extreme importance of identifying and recognizing every noticeable symptom in a defective receiver, for they are the starting point of your complete analysis of the receiver. The symptoms point the way toward quick and accurate analysis, and eventual correction of a trouble.

In the following discussion on the use and application of each individual type of test equipment, keep in mind that the best, most elaborate and most expensive test equipment available is limited in usefulness by the knowledge and ingenuity of the man who uses it.

Section 9. HOW TO USE THE TUBE-CHECKER

The tube-checker is immediately put to use as soon as there is even the slightest suspicion that the trouble in a receiver can be caused by bad tubes. Since a large majority of radio and television troubles are due to tube faults, and since bad tubes may cause an almost endless variety of different audible symptoms, checking the tubes of a receiver is a routine matter.

There are many excellent models of tube-checkers available. Fig. 6 shows a model manufactured by Simpson. Fig. 8 is a section of a tube chart for use with a Triplett Tube Checker, Model 3212.

While different tube-checker manufacturers make their products in different ways, and while the operating instructions for each model of each manufacturer may differ, we shall for the moment use the Model 3212 as an example for purposes of explanation.

Suppose a defective receiver displays symptoms that suggest the possibility of a defective tube. Under this supposition, the following facts can be easily ascertained by visual and audible means:

1. The receiver has a normal hum level, but no signal of any kind.

2. All the tubes light up in the receiver.

Since both of these conditions may be present when one of its tubes is defective, let us say the 12SK7, we will find it advisable at this time to put all tubes through a detailed check. In Fig. 8 the 12SK7 is listed numerically and alphabetically, and to the right of its listing we find the tube-checker settings which are used to check this tube.

Following the instructions on the tube-chart, we set the "A" knob on the tube-checker to 3, the "B" knob to 12.6, and the "C" knob to 28. We next insert the tube in its proper socket, and throw the "Up" and "Down" levers as indicated in Fig. 8. Lever 2 is pressed up and lever 7 is pressed to the downward position. (These settings are indicated by the lever numbers printed in bold face type).

This pair of settings, simply applies the proper heater voltage to the 12SK7 and makes it ready for the "short test".

In this model tube-checker, according to the manufacturer's instructions, the "short-test" consists of raising all as yet unmoved levers to the "Up" position one at a time, and observing the neon lamp short-circuit indicator. If the neon indicator lights up during any one of these settings, unless otherwise indicated in the instructions below each tube listing, then that element is short-circuited within the tube. For instance, if when lever 6 is moved upward the neon indicator glows, we would know that the control grid of the tube is short-circuited to some other element inside the tube. (This, of course, would condemn

TUBE CHART

TUBE TYPE	KNOBS A Cir	B Fil	C Load	LEVER POSITION U Up	D Down
12SF7 Test 2	1	12.6	40	**8**	23467
12SG7	3	12.6	19	**2**	357
	(Shows Short on 3 and 5)				
12SH7	3	12.6	19	**2**	357
	(Shows Short on 3 and 5)				
12SJ7	3	12.6	28	**2**	57
12SK7	3	12.6	28	**2**	57
12SL7	3	12.6	28	**7**	12368
12SL7 Test 2	3	12.6	28	**7**	34568
12SN7	3	12.6	29	**7**	34568
12SN7 Test 2	3	12.6	29	**1**	12368
12SQ7	3	12.6	28	**8**	3457
12SQ7 Test 2	1	12.6	40	**8**	23467
12SQ7 Test 3	1	12.6	40	**8**	23567
12SR7	3	12.6	37	**8**	3457
12SR7 Test 2	1	12.6	33	**8**	23467
12SR7 Test 3	1	12.6	33	**8**	23567
12Z3	3	12.6	25	**1**	34
12Z5	3	6.3	25	**4**	12357
12Z5 Test 2	3	6.3	25	**4**	13567
12Z5/6Z5	3	6.3	25	**1**	2346
12Z5/6Z5Test 2	3	6.3	25	**1**	2456
14	3	12.6	36	**1**	45
14A4	3	12.6	27	**1**	78
14A5	3	12.6	33	**1**	78
14B6	3	12.6	31	**1**	45678
14B6 Test 2	1	12.6	58	**1**	234578
14B6 Test 3	1	12.6	58	**1**	234678
	(Shows Short on 4 and 7)				
14A7	3	12.6	28	**1**	78
14B8	3	12.6	30	**1**	78
14C5	3	12.6	25	**1**	78
14C7	3	12.6	26	**1**	78
14E6	3	12.6	31	**1**	45678
14E6 Test 2	1	12.6	65	**1**	234578
14E6 Test 3	1	12.6	65	**1**	234678
	(Shows Short on 4 and 7)				
14F7	3	12.6	29	**1**	23478
14F7 Test 2	3	12.6	29	**1**	25678
14F8	3	12.6	22	**2**	45678
14F8 Test 2	3	12.6	22	**2**	13457
14H7	3	12.6	24	**1**	78
14J7	3	12.6	33	**1**	3478
14J7 Test 2	3	12.6	33	**1**	25678
14N7	3	12.6	28	**1**	378
14N7 Test 2	3	12.6	28	**1**	678
14Q7	3	12.6	24	**1**	78
14R7	3	12.6	20	**1**	3478
14R7 Test 2	1	12.6	50	**1**	235678
14R7 Test 3	1	12.6	50	**1**	245678

TUBE TYPE	KNOBS A Cir	B Fil	C Load	LEVER POSITION U Up	D Down
14S7	3	12.6	19	**1**	378
14S7 Test 2	3	12.6	30	**1**	25678
14W7	3	12.6	19	**1**	478
	(Shows Short on 4 and 7)				
14Y4	3	12.6	28	**1**	678
14Y4 Test 2	3	12.6	28	**1**	378
14Z3	3	12.6	25	**1**	34
15	3	2	55	**1**	45
17	3	12.6	40	**1**	45
18	3	12.6	31	**1**	56
19	3	2	37	**1**	236
19 Test 2	3	2	39	**1**	456
20	2	6.3	48	**1**	4
20J8	3	12.6	28	**2**	78
22	2	3.3	56	**1**	4
24A	3	2.5	35	**1**	45
25A6	3	25	27	**2**	78
25A7	3	25	27	**2**	1678
25A7 Test 2	3	25	23	**2**	134578
25AC5	3	25	31	**2**	78
25B5	3	25	46	**1**	256
25B5 Test 2	3	25	37	**1**	356
	(Shows Short on 2)				
25B6	3	25	23	**2**	78
25B8	3	25	25	**2**	13467 10
25B8 Test 2	3	25	25	**2**	15678
25C6	3	25	25	**2**	78
25D8	3	25	30	**2**	13478 10
25D8 Test 2	3	25	26	**2**	15678
25D8 Test 3	1	25	40	**2**	134567 10
25L6	3	25	22	**2**	78
25N6	3	25	55	**2**	378
25N6 Test 2	3	25	35	**2**	478
25X6	3	25	27	**2**	3478
25X6 Test 2	3	25	27	**2**	4578
25Y4	3	25	25	**2**	78
25Y5	3	25	30	**1**	2346
25Y5 Test 2	3	25	30	**1**	3456
25Z5	3	25	25	**1**	2346
25Z5 Test 2	3	25	25	**1**	3456
25Z6	3	25	24	**2**	3478
25Z6 Test 2	3	25	24	**2**	4578
26	3	1.5	46	**1**	4
27	3	2.5	44	**1**	45
28D7	3	25	21	**1**	5678
28D7 Test 2	3	25	21	**1**	2468
28Z5	3	12.6	38	**18**	467
28Z5 Test 2	3	12.6	38	**18**	347
29	3	2.5	26	**1**	4
30	2	2	35	**1**	4

Fig.8. Typical Tube Chart for Use with Tube-Checker.

the tube and further tests of the tube would be unnecessary). However, let us assume that no short-circuits are indicated by the tube checker in this example.

We are now ready for the "value" test of the tube. This test will tell us if the tube cathode will emit its rated current when proper voltages are applied to its various components. The data in Fig. 8 tells us that the value test is made by setting lever 5 down and turning the "value" knob to the right. Accordingly, when this is done and if the tube is good, the meter pointer should swing to the right of the indicating scale into the "good" area. If this happens, the tube can be assumed good. If, however, the meter pointer does not move at all, or if it only goes to the "bad" or "questionable" area of the scale, then we can infer that emission is not taking place properly and the tube should be replaced.

While it may be interesting to determine exactly which element is responsible for lack of emission in the tube, the tube-checker, as a rule, does not give us this exact information. Nevertheless, since any trouble in a tube condemns the entire tube, the tube-checker tells us what we want to know about the tube. It is either good or bad. If it is bad, replace it; if it is good, look for the trouble elsewhere.

On some tube-checkers the "leakage" test is made at the same time as the test for internal short-circuits. This is true of the Triplett Model 3212. On other tube-checkers the "leakage" test is another procedure and is always fully explained by the instructions supplied with each unit. Above all, before attempting to use any instrument read all instructions covering its use. Read them through carefully, then go back and read them again.

During the "short" test, it is a good idea to tap the tubes and look for intermittent (on-again-off-again) short circuits. The flashing on and off of the neon short indicator is sufficient evidence to replace a tube showing intermittent short-circuits.

Previous mention was made of the limitations of tube-checkers, with reference especially to two types of tubes being tested. Figs. 9 and 10 will show why the average tube-checker will show these two types of tubes to be good, in spite of the fact that they may contain serious faults.

Fig. 9 is a circuit diagram of a pentagrid converter tube, used extensively in almost all modern superheterodyne receivers. Let us suppose, as in the diagram, that the signal grid of this tube somehow becomes disconnected from the base pin to which it should be electrically connected, a fairly common trouble in this type of tube. How will the tube-checker indicate this defect?

Reference to Fig. 9 will show that in this tube the signal grid is at some distance from the cathode, there being two other grids between them. We know from previous lessons that any grid located within the electron stream will gather electrons and if these electrons cannot find a leakage path, the aggregate of all the negatively charged electrons will soon block the tube. Why don't they block the pentagrid converter

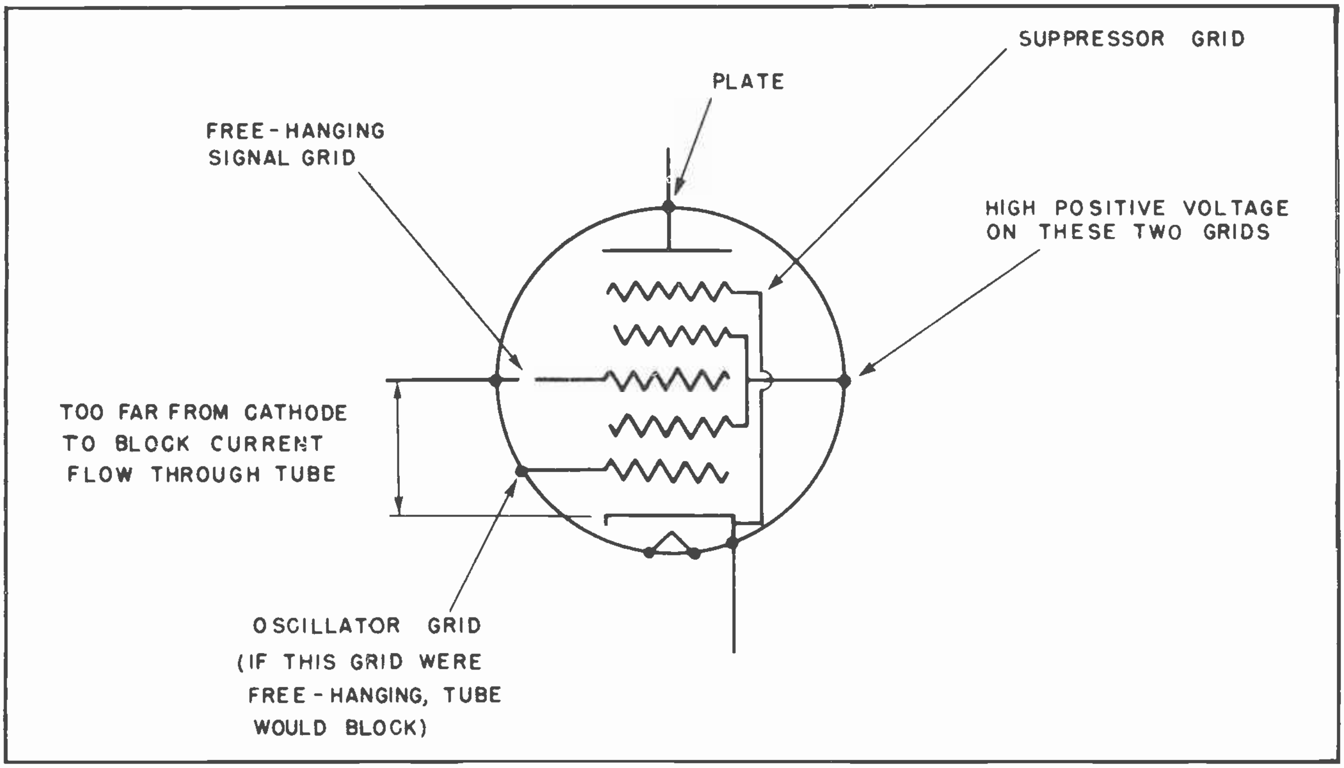
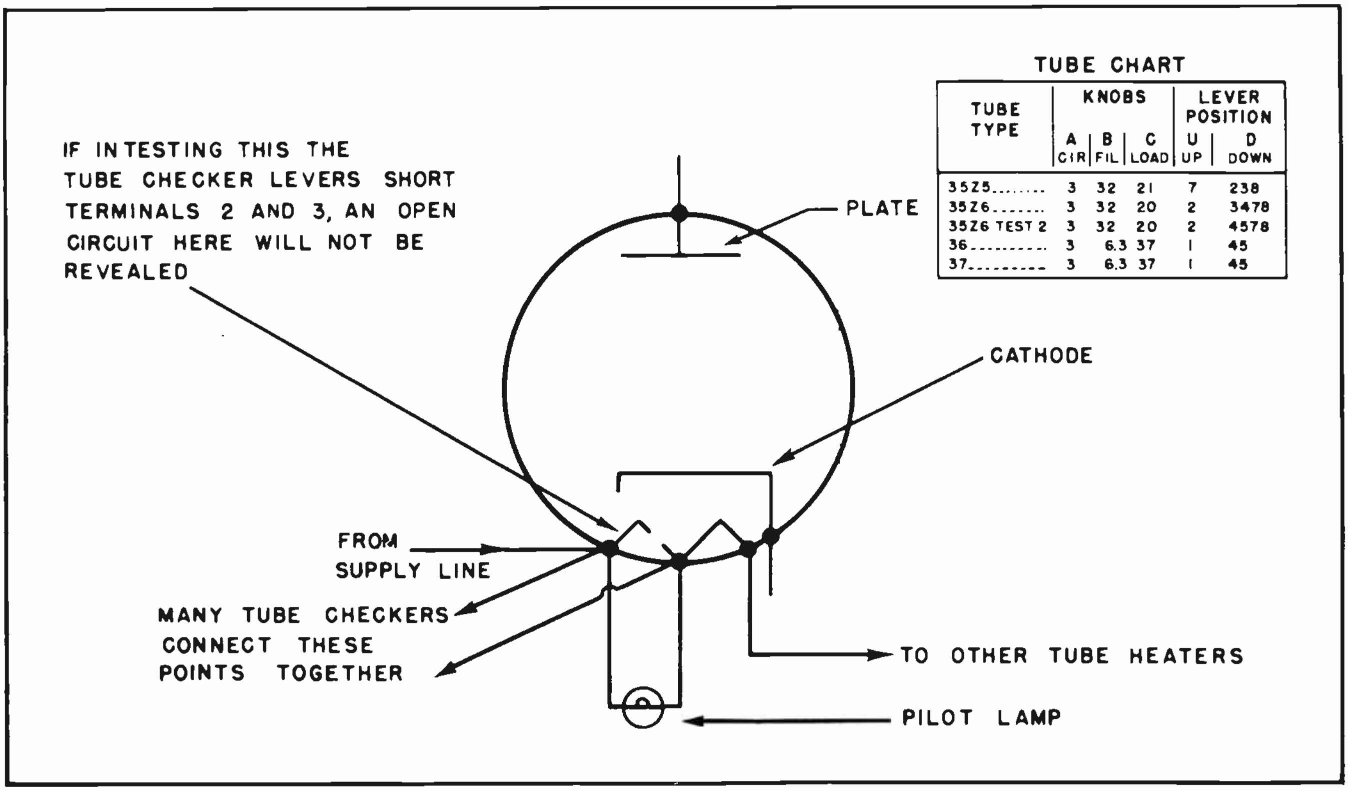


Fig.9.



TUBE CHART

TUBE TYPE	KNOBS A CIR	KNOBS B FIL	KNOBS C LOAD	LEVER POSITION U UP	LEVER POSITION D DOWN
35Z5........	3	32	21	7	238
35Z6........	3	32	20	2	3478
35Z6 TEST 2	3	32	20	2	4578
36..........	3	6.3	37	1	45
37..........	3	6.3	37	1	45

Fig. 10.

tube? The power that a grid has of controlling the flow of electrons through a tube depends on the closeness of the grid to the cathode. Notice that in the pentagrid converter tube, the signal grid is at a considerable distance from the cathode. Hence it will not have the same power to affect the flow of electrons through this tube as a grid closer to the cathode. It is true that the amount of current flowing through the plate circuit will be reduced, but -- and this is the significant point -- the reduction of tube current due to a free-hanging grid so far from the cathode will not bring the indicator pointer back far enough to indicate a "bad" tube during the value test. In other words, the indicator pointer will point to "good" with or without a free-hanging signal grid in a pentagrid converter tube.

Trouble-shooting oscillator-mixer stages, then, requires that even if the pentagrid converter tube checks good, it should be replaced by another of its type, *known to be good*, before checking the circuit for other troubles. Experience has shown that where the oscillator-mixer stage is suspected, replacing the tube will remove the trouble in the vast majority of cases. Another limitation of even the best of tube-checkers is illustrated in Fig. 10. According to the tube-checker data for a 35Z5 the heater setting for the levers are as follows:

Lever 7----up

Lever 2----down

Lever 3----down

The schematic diagram of this tube shows it is a typical pilot-tapped heater type of rectifier tube common to most AC-DC radio receivers.

Fig. 10 illustrates the manner of supplying voltage to the pilot lamp, and shows that terminals 2 and 3 of this tube constitute a voltage divider tapped across the heater extremities between terminals 2 and 7. If we set levers 2 and 3 down we connect these two points together and short-circuit the voltage divider at these points. This is done only for test purposes. However, suppose that the heater of this 35Z5 is really burned open between terminals 2 and 3. The tube-checker setting, just described will, in short-circuiting these points, permit current to flow through the lever connections and the result will be that the rest of the heater (between terminals 3 and 7) will heat up in the normal way. The value test will show the tube to be good, no short-circuits will be indicated, and we may mistakenly assume this bad tube to be good.

Without going too deeply into this subject at this time, it may be interesting to know how one would check for this trouble in a 35Z5 tube. An ohmmeter test between terminals 2 and 3 would immediately disclose this fault. Also, a burnt-out pilot lamp would strongly suggest that the 35Z5 is open between terminals 2 and 3.

Section 10. WHEN TO USE THE TUBE-CHECKER

A routine check of all the tubes in a receiver is, in most cases, a time-saver. Even experienced radio and television repairmen make use of the tube-checker at the very start of analysis, for such a procedure will be most likely to uncover the most probably troubles -- those within the tubes themselves.

It is strange but true that despite the high quality of materials and workmanship that go into the modern vacuum tube, a large number of radio and television troubles still originate in the tubes. In many cases, the tube-checker may be the only type of test equipment used.

Therefore an initial check of all the tubes in a defective receiver is advisable.

Individual tubes should be checked at once if they show any indication of physical faults, or sparking within the tube.

The tube-checker should be employed to check the tubes if one or more of them do not light up (or warm up, in the case of metal tubes) when power is applied to the receiver.

The tube-checker should be used to verify the suspicion of unbalanced emission of the two push-pull tubes in the output stage of the larger receivers. This suspicion would be indicated by the presence of an annoying hum that cannot be removed by any other method.

In brief, the tube-checker should be employed wherever and whenever there is the slightest suspicion that the trouble may lie in the tubes of a defective receiver. It is always a good idea to employ it first when starting analysis of a receiver.

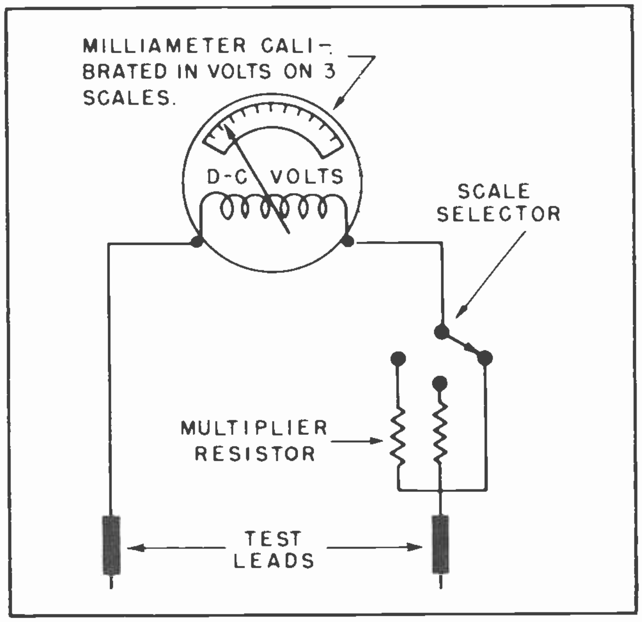


Fig.11. Voltmeter Circuit.

Section 11. HOW TO USE THE VOLTMETER

Another test unit that has again and again proved its usefulness in the early stages of radio and television trouble-shooting is the voltmeter. After the tubes have been checked, the repairman may want to know if normal voltages are present throughout the receiver. The voltmeter supplies this information to him easily and quickly.

Fig. 11 illustrates the basic circuit comprising a voltmeter.

Reference to Fig. 11 will help to understand the essential character of the voltmeter. The test leads are placed across any two points in a circuit whose difference of potential is to be measured. The potential difference (or voltage) between these points drives current through the meter coil, deflecting the pointer in proportion to the amount of current flowing. The meter movement, however, instead of indicating the actual amount of current, is calibrated in the number of volts required to drive that much current through the coil. The use of a multiplier resistor in series with the meter coil will enable the user to adjust the scale of volts to a convenient value. This is illustrated in Fig. 11.

A word of caution may be mentioned here. In using the voltmeter on an unknown voltage, it is wise, for protection of the meter, to read the voltage on the highest possible scale first, reducing the scale

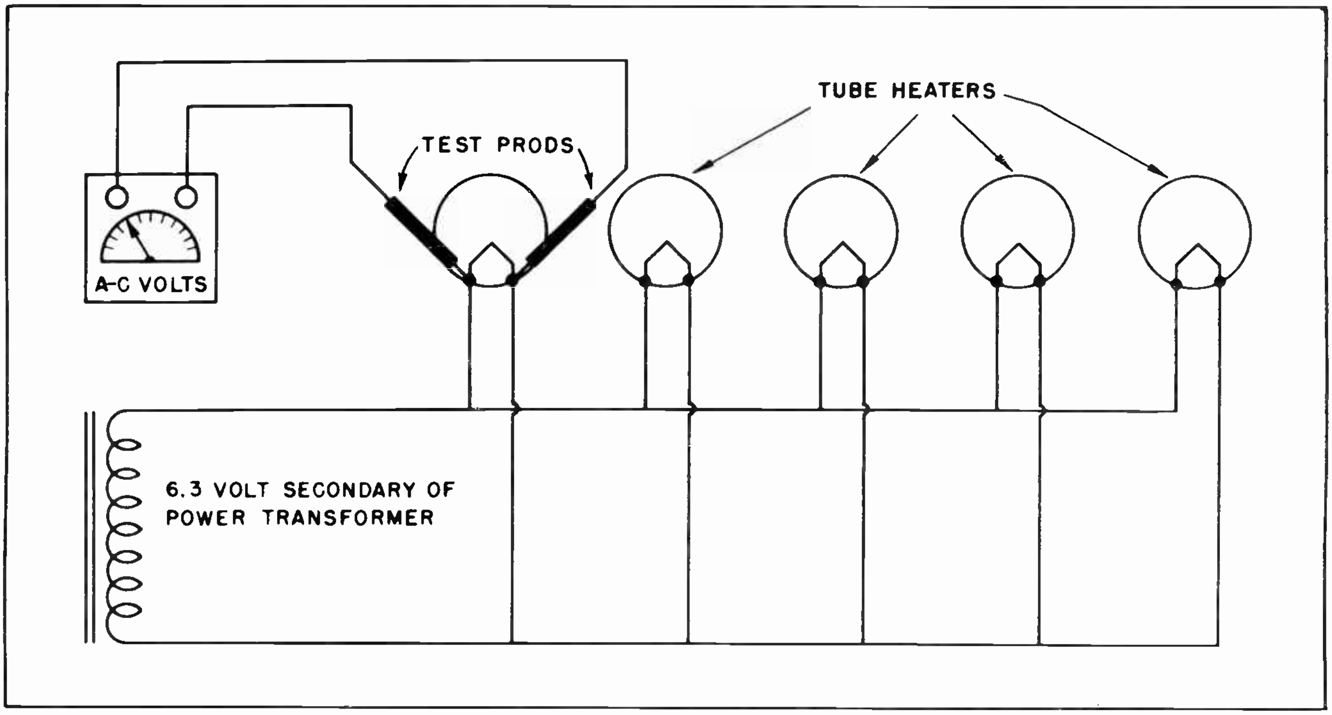


Fig. 12. Using Voltmeter to Measure Filament Voltage Drops.

as convenient. This will prevent overdriving the meter movement and subsequent damage to the coil or pointer. Once the technician has become familiar with the magnitude of the average voltage in a radio or television receiver, he will automatically set the voltage scale of his meter to the proper value.

Section 12. WHEN TO USE THE VOLTMETER

The voltmeter can be used in a thousand ways to determine faults in a receiver. In a receiver in which none of the tubes light, the voltmeter can be used to trace the input voltage from the wall plug to the

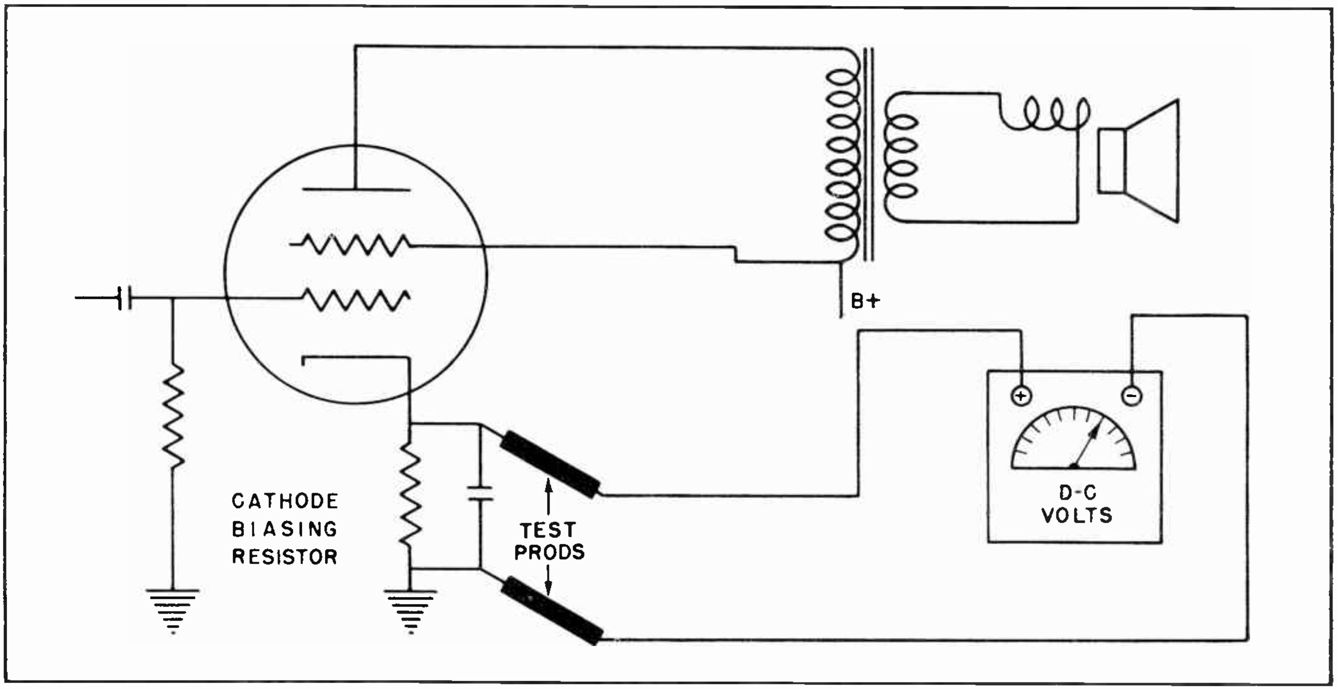


Fig.13. Using Voltmeter to Measure Drop Across Cathode Resistor.

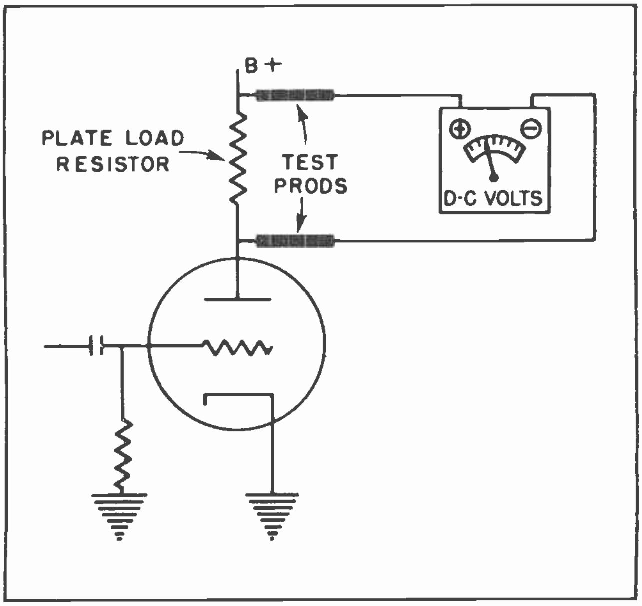


Fig.14. Using Voltmeter to Measure Drop Across Anode Load Resistor.

power supply. Open line cords, open power switches, open transformer windings can be easily determined by the proper use of the A-C voltmeter in this application.

Also an A-C voltmeter can measure the heater voltage on any tube which fails to light. Please note in this connection that we assume that tubes have all been checked on the tube-checker in advance. (See Fig.12.)

The voltmeter is commonly employed to determine the presence or absence of B-plus voltages at critical points throughout the receiver. In this instance, the negative lead of the voltmeter is placed at B-minus (the negative side of the filter condensers) and the positive lead can be placed at any high voltage point for investigating the extent of the voltage at that point.

Also, the voltmeter can be used to determine the drop in a resistor. Fig. 13 shows how this is accomplished in the output stage cathode resistor of a typical receiver.

In addition to measuring the drop in the cathode resistor, indicating the bias on this stage, this test also tells us that the output tube in this stage is conducting. For, if it were not conducting, the drop across the cathode resistor would be absent. If the drop is present, and of the proper value, then we know that the tube is conducting current normally.

The voltmeter, on the proper scale, can be used as a substitute resistor for temporary verification of a resistor that is open. Fig. 14 illustrates how a plate load resistor of a resistance-coupled amplifier stage can be shunted with a voltmeter.

If the plate load resistor is open, then the resistance inside the meter will now complete the circuit. The signal, which may have been distorted or absent before, will now come in clear and loud.

Fig. 15 shows a similar case of using the voltmeter as a temporary substitute, this time in the AVC circuit. Where the signal was fuzzy or absent, which would be the case if the AVC resistor were open, shunting the meter resistance across the suspected component will bring the signal in with almost normal volume.

Open cathode resistors and shorted cathode by-pass condensers reveal themselves readily by the use of a voltmeter in this circuit. (See Fig. 16.)

Fig. 17 indicates how a voltmeter reading will indicate an open primary winding in an intermediate-frequency stage, or in a radio-frequency stage.

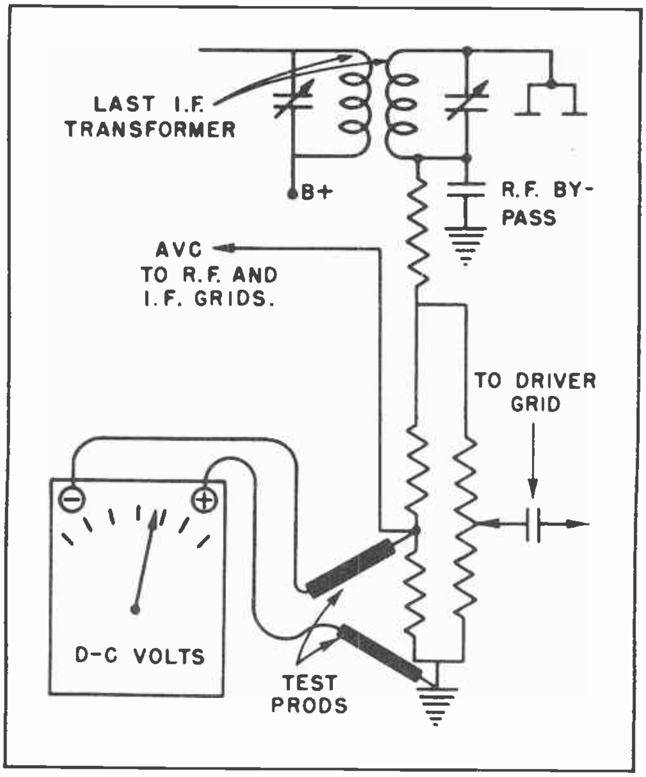


Fig.15.

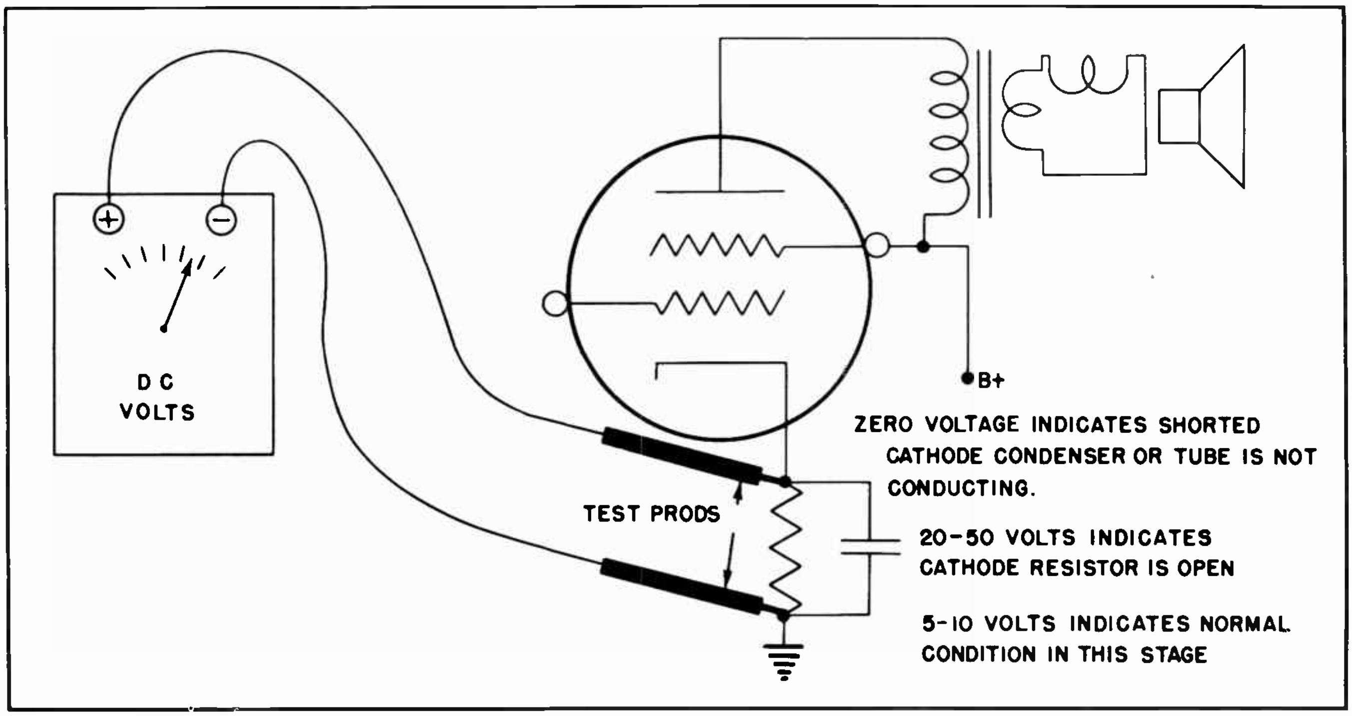


Fig.16.

Section 13. HOW TO USE THE OHMMETER

Fig.18 shows the basic circuit used in measuring resistance by the use of a current milliammeter. While the meter movement responds to current values, the scale of an ohmmeter is calibrated in *ohms,* and indicates the amount of resistance required to limit the current to a specific value when being driven through the resistor by standard battery voltage. The polarity of the test leads of an ohmmeter is unimportant since the circuit within and without the meter are of a D-C nature. To use the ohmmeter, simply set the scale at the proper value, and place the test leads on the two points between which we want to read the resistance. An open in this circuit will be indicated by no deflection of the meter pointer. A short-circuit will be indicated when the meter is deflected all the way to zero. If the pointer settles at any point between zero and infinity, read that value of ohms and multiply it by the scale setting of the ohmmeter. See also Fig. 29.

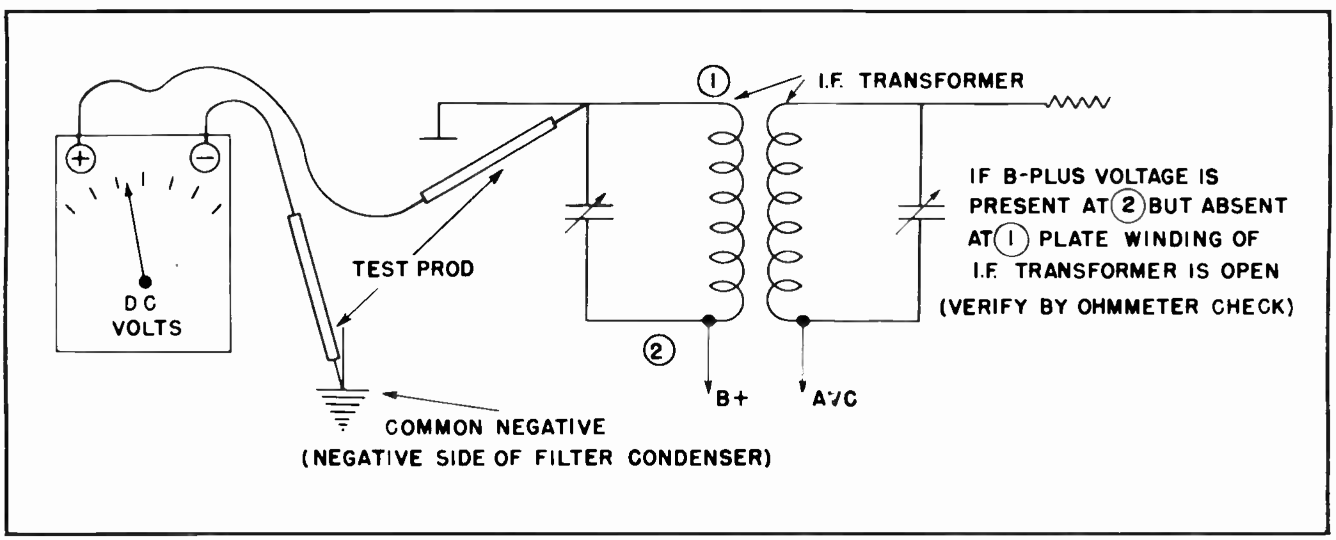


Fig.17. Using Voltmeter to Check for an Open Circuit in I-F Transformer Primary.

Section 14. WHEN TO USE THE OHMMETER

The ohmmeter can be used to verify the presence of an open circuit in any of the power supply wires or components. This, like all other ohmmeter measurements, is always done with the power turned off. Point-to-point continuity checks along the power wires or through transformers or switches will give the repairman a complete picture of the condition of these circuits.

The ohmmeter is ideal for verifying the suspicion of an open signal component, such as the primary or secondary of I-F or RF transformers. Fig. 19 shows how this may be easily accomplished.

The ohmmeter can also be used efficiently to determine the condition of a suspected plate load or cathode resistor. The plate load resistor is measured on the high ohms scale, while the cathode resistor may be measured on the low ohms scale.

Loop antenna continuity can be easily measured with the ohmmeter.

An interesting and useful test on the speaker transformer primary, secondary, and voice coil can be made by the use of an ohmmeter. (See Fig. 20.) In this test, three separate components can be tested simultaneously by placing the ohmmeter leads across the two leads of the primary of the transformer. If a click is heard in the speaker, then the primary, secondary, and voice coil are all known to be in good order. Besides, while making this test,

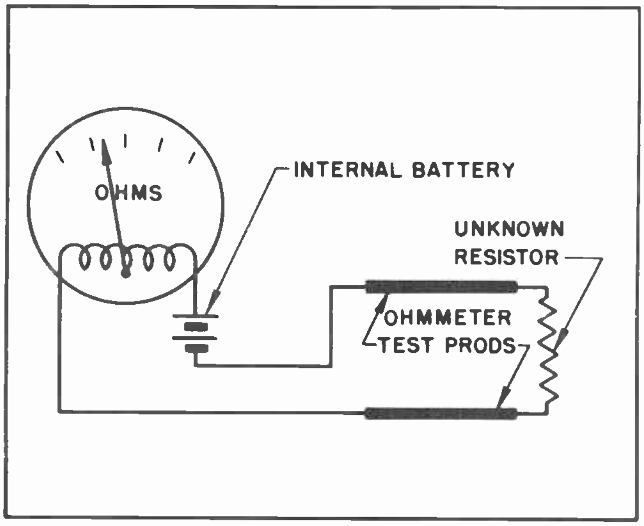


Fig.18. Using an Ohmmeter to Read Resistance.

the ohmmeter will read the ohmage of the transformer primary.

The ohmmeter, as mentioned previously, can be used to check the continuity of the heater of a pilot-tapped AC-DC rectifier tube, such as the 35Z5. Where the tube-checker may easily miss this defect, the ohmmeter will reveal it at once.

Section 15. PRECAUTIONS IN THE USE OF THE OHMMETER

The ohmmeter is constructed to operate with comparatively low driving voltage. Therefore, to protect the ohmmeter against serious damage, make *sure* that power to the receiver being tested is turned off while

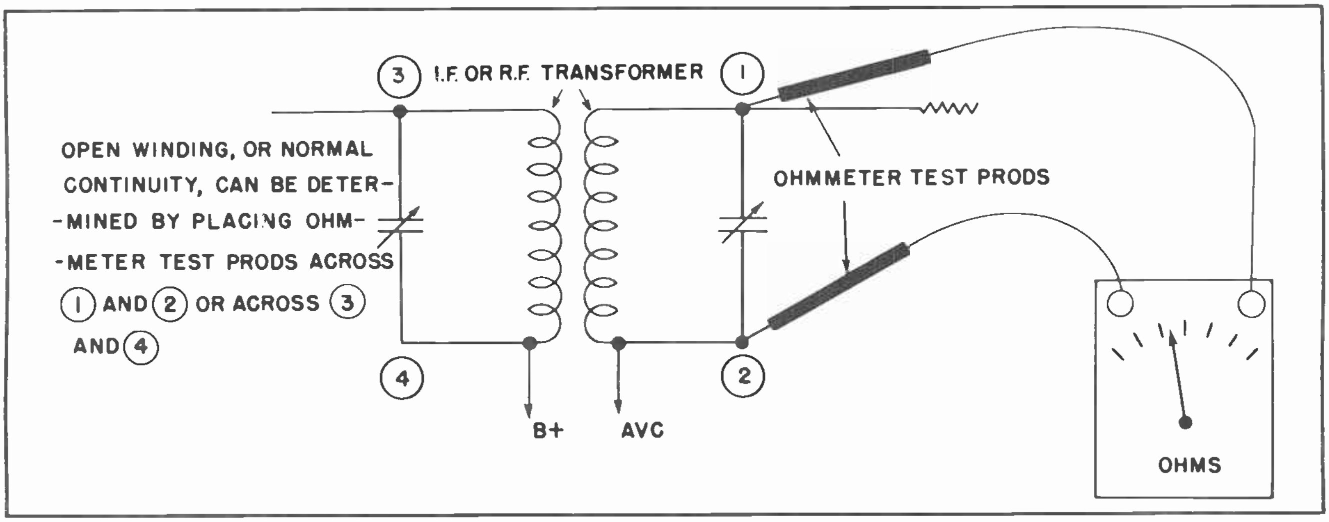


Fig.19. Using an Ohmmeter to Check an I-F Secondary

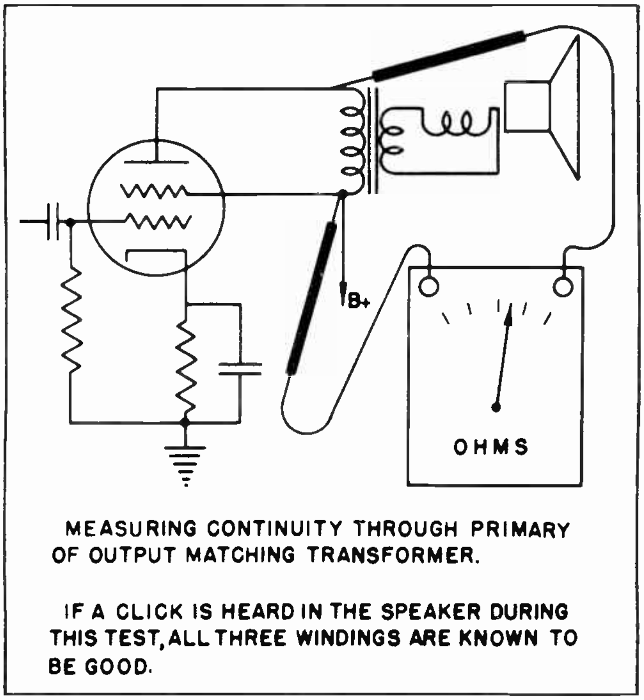


Fig.20.

the ohmmeter is being used. The ohmmeter will measure the resistance between any two points in a circuit to which its test leads are touched. Make sure, in ohmmeter readings, that *nothing else* is in parallel with these two points except the suspected component you are testing. See Fig. 21 for illustration of this important precaution. It can be seen that in this test the meter is reading *two* paths in parallel. The result cannot be accurate. It is not hard to see that if two paths are provided it will be possible for the current from the ohmmeter battery to follow both paths. Part will travel through the resistance to be measured; this is all right. But the extra -- unwanted -- path will also allow additional current to flow. The current through the second path will cause the meter of the ohmmeter to read a different value than would be the case if the second path were not there.

Section 16. HOW TO USE THE MILLIAMMETER

The milliammeter function of the multimeter is seldom used in radio and television repair work. However, should the need arise in some special instance the milliammeter, like other test equipment, can supply you with indispensable information. Fig. 22 indicates how the milliammeter is connected into the circuit whose current is to be measured. Note that the circuit must be opened and the meter placed in series with the current path to indicate the value of current passing.

Section 17. WHEN TO USE THE MILLIAMMETER

This test unit is mostly used when excessive, or insufficient, current is suspected. Its applications are rare in radio and television.

Whenever it is found that a suspiciously large or small current is flowing in a circuit, use the milliammeter to verify this fact. It will give you the exact amount of current in the circuit with which it is in series.

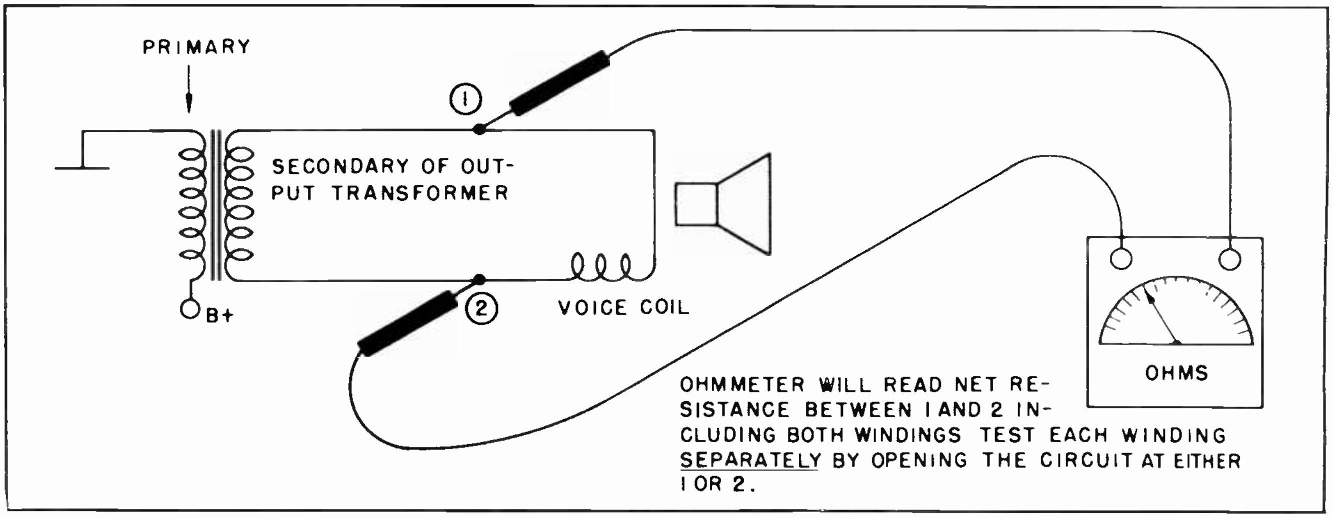


Fig.21. Wrong Way to Read Resistance.

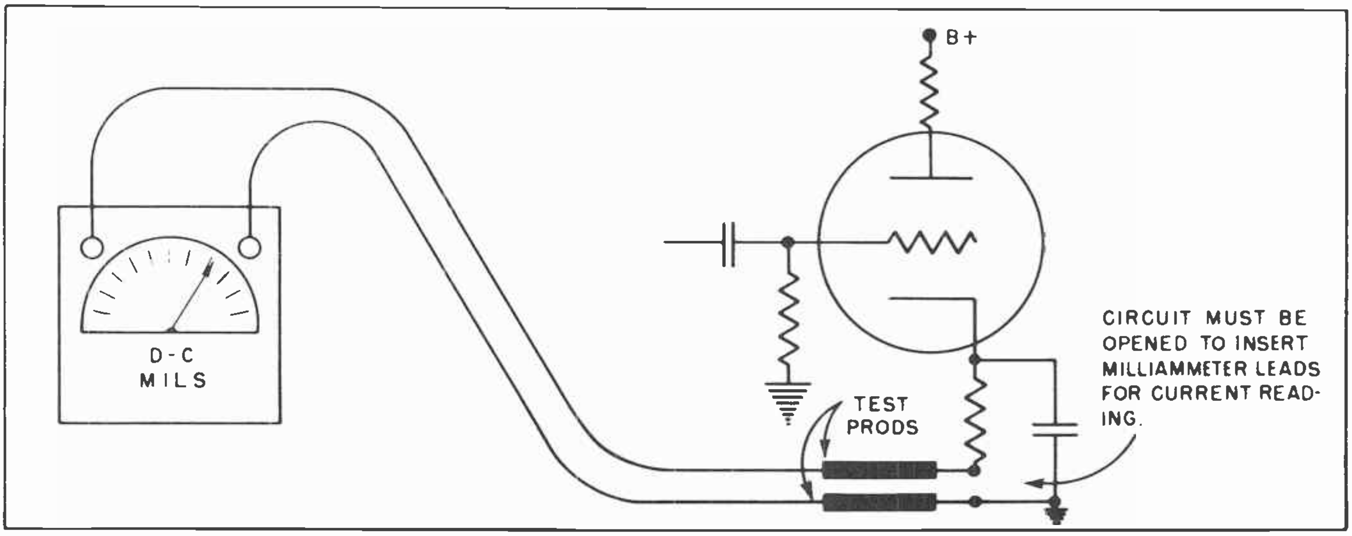


Fig.22. Using a Milliammeter.

Precaution: The milliammeter has very little internal resistance and should therefore always be placed in series with the load rather than directly across the voltage. Damage to meter and equipment may result from lack of care in handling the milliammeter. Note milliammeter circuit in Fig 29.

Section 18. HOW TO USE THE SIGNAL GENERATOR

Study Fig. 23 carefully. It is a graphic picture of the method of applying a signal generator to the many circuits of a superheterodyne receiver.

Fig. 24 shows the circuit diagram for a modern signal generator and illustrates the manner in which the operator can select various frequencies for testing the receiver circuits.

After determining that a signal generator is to be used on a receiver under analysis, follow the instructions supplied by the manufacturer of the signal generator for producing the 400-cycle audio frequency output. Place the test probe on the grid of the output stage, turn the receiver power on, and listen for the 400-cycle audio note in the speaker. This is test point #1 indicated by the arrows in Fig. 23. If the signal is heard, move the test probe to test point #2 shown in Fig. 23, which is the grid of the driver stage, using the same 400-cycle note from the signal generator.

If the signal is heard in the speaker again, correct operation of these two stages is indicated.

Now, following the manufacturers instructions, adjust the output of the signal generator to the I-F frequency and apply the test probe to test point #3 in Fig. 23, which is the plate winding of the last IF transformer. If in proper order, the 400-cycle note, now in the form of amplitude modulation on the IF voltage, will be passed to the detector where it is demodulated and thence fed to the audio stages for amplification and conversion to sound energy. At this time, turn the adjusting screws of the IF trimming capacitors in this I-F transformer until the signal from the speaker is at its maximum value.

Test point #4 is the plate of the oscillator-mixer stage, where the signal generator is still producing the same frequencies as during the previous step. Here we adjust the screws of the first I-F transformer trimming capacitors for maximum signal from the speaker.

Test point #5 is the antenna of the receiver. Follow the manufacturer's instructions for setting the frequency of the signal generator to some radio frequency, then introduce it at the antenna. The steps to follow now are:

Turn the tuning knob on the receiver to exactly the same frequency as the signal generator. Notice if the signal generator can now be heard in the speaker. "Rock" the tuning knob of the receiver to see if the signal generator can be heard better at any other place on the dial. If the receiver picks up the signal generator at any point on the dial other than the

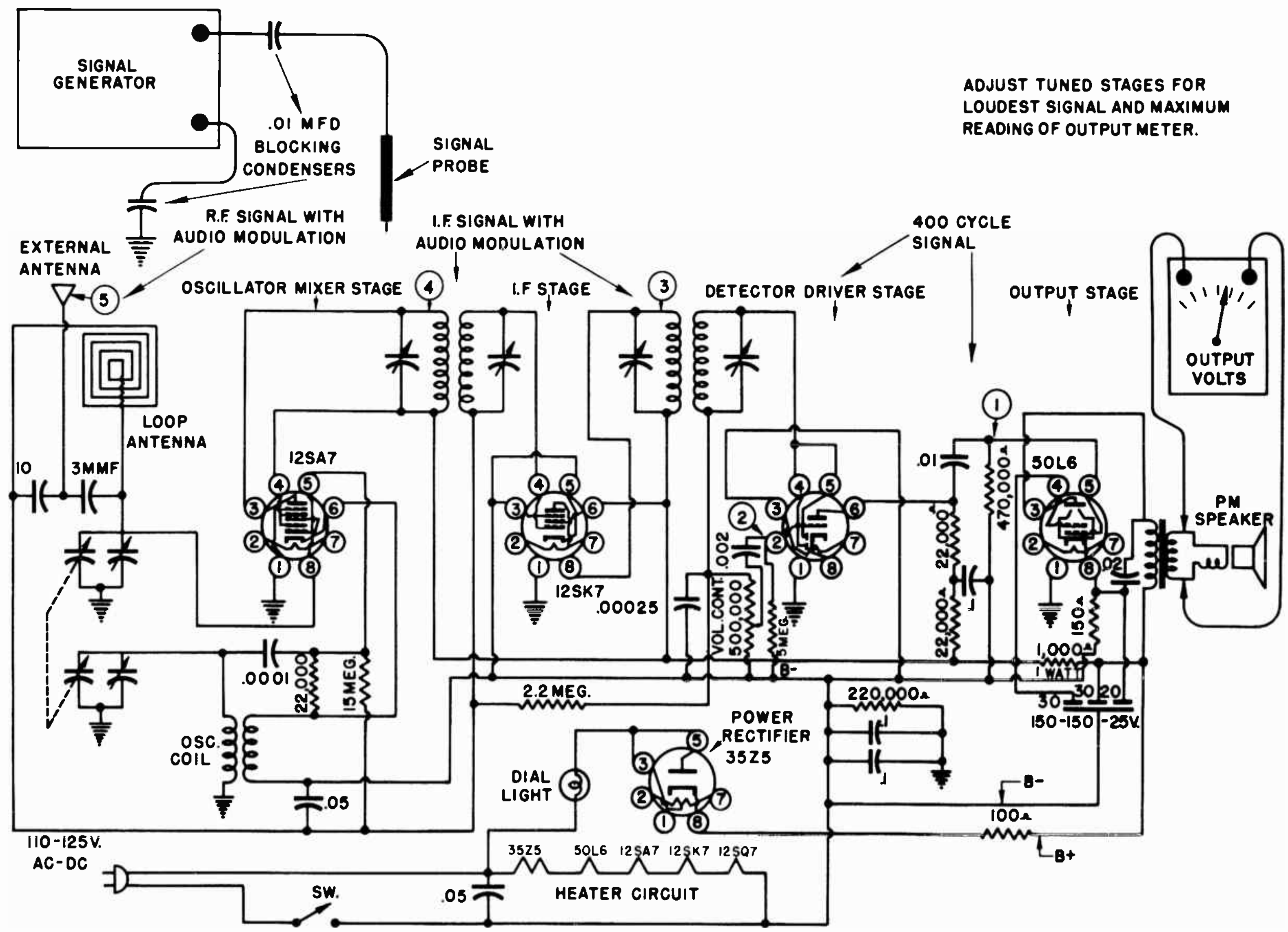


Fig. 23. How to Use Instruments to Test a Receiver.

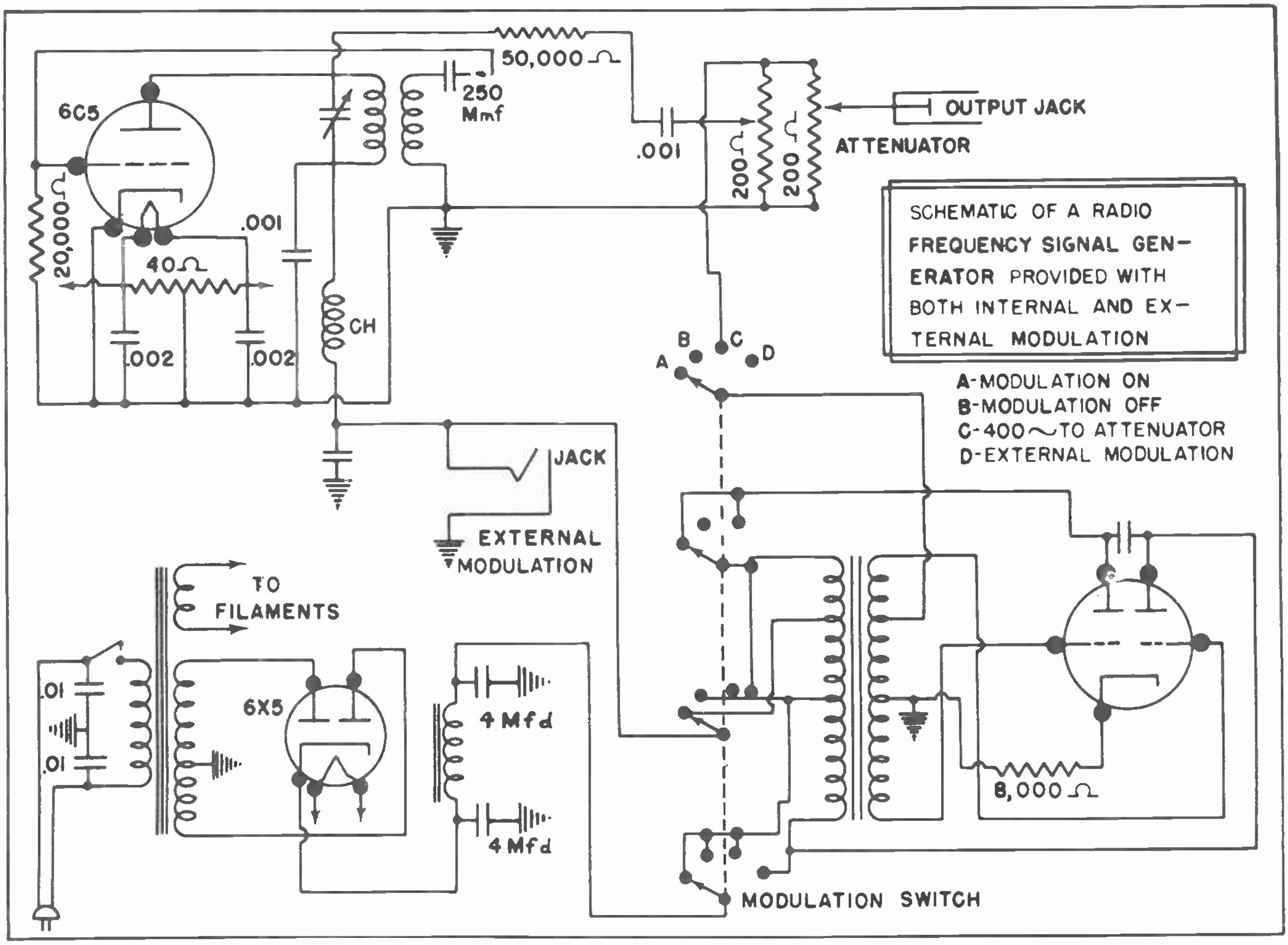


Fig.24. Signal Generator Circuit.

frequency at which the signal generator is set, adjust the oscillator trimmer condenser to bring the signal in at maximum at the test frequency.

The next and final step is to adjust the RF trimming condenser for maximum reception at the upper end of the dial. Set both the signal generator and the receiver station selector at 1500 KC and adjust the RF trimmer, usually located on the ganged variable condenser, for maximum loudness.

The above procedure is general and is meant only to demonstrate the points at which the signal generator's output is introduced into a receiver for test purposes. We have assumed that the receiver is almost perfectly aligned. This assumption may not necessarily be true. However, it is evident that if we lose the signal during any step of the above general procedure, the trouble of the receiver must lie in the stage in which the signal was lost. This is our first step in trouble-shooting by this method. We would now use an ohmmeter or voltmeter, or both, to examine the defective stage in detail and thus locate the exact faulty component part. After studying each of the individual stages we will again explain the use of instruments in trouble-shooting those stages.

Note that we have referred to manufacturer's instructions in making the proper setting for the desired outputs from the signal generator. Each manufacturer makes many models of signal generators. Naturally, therefore, no general procedure can suffice for even a small number of signal generators. Each model is unique in itself and the operating instructions for each model will, therefore, be different.

Study the manufacturer's instructions and study the signal generator you use. Careful and exact attention to instructions will make the signal generator a potent tool in your hands for locating and correcting radio and television troubles.

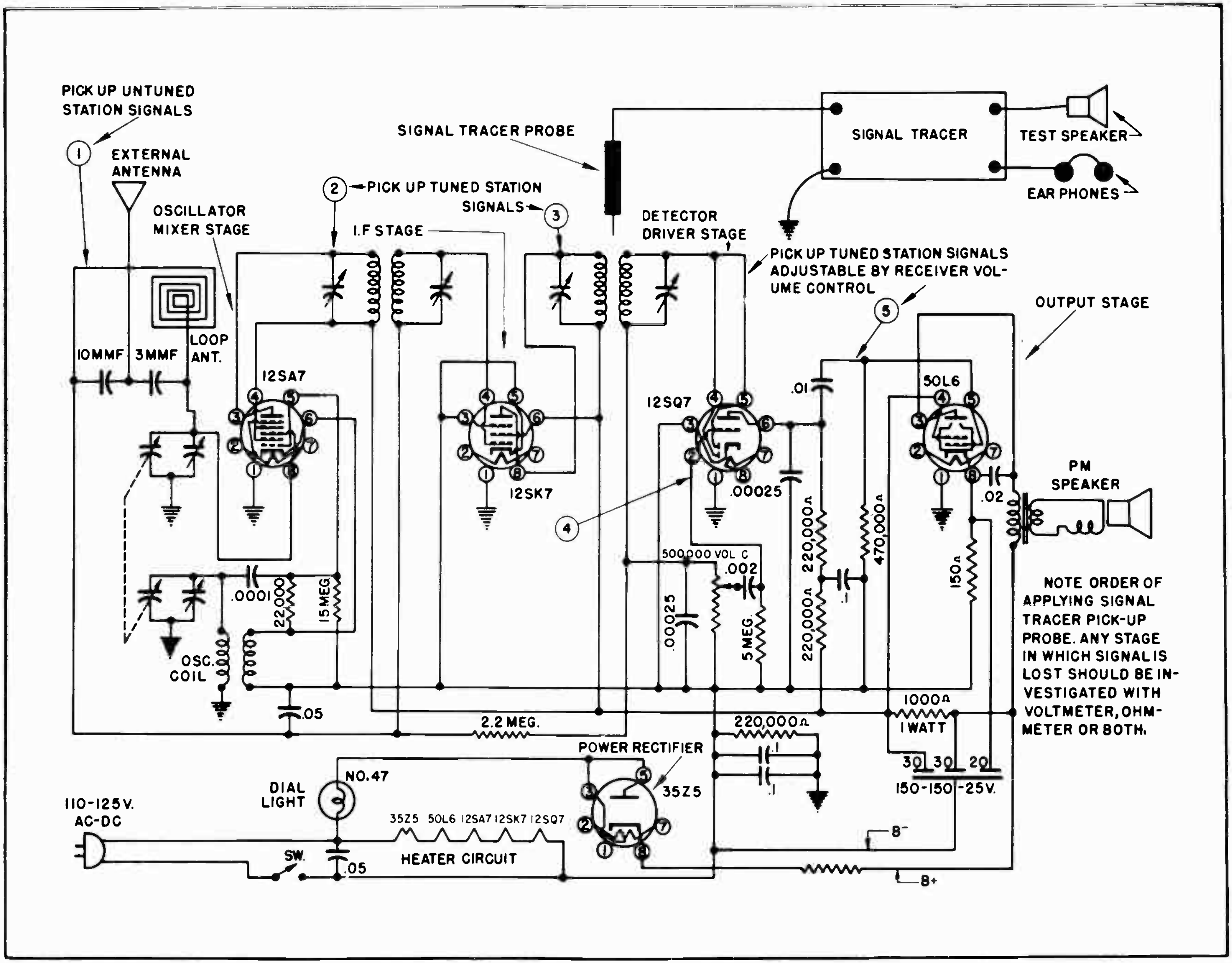


Fig. 25. Trouble-Shooting with a Signal Tracer.

The signal generator is used primarily to balance and adjust the critical RF circuits in a receiver. It is also widely used to locate the stage in which a defective part of a receiver is located.

Section 19. HOW TO USE THE SIGNAL TRACER

The signal tracer's application to trouble-shooting can best be illustrated by Fig. 25, which shows the same diagram as illustrated in Fig. 23, but with the test points in reverse order. Here, using the signal tracer, we first place our test probe on the first stage plate and listen for the signal. Then we move progressively toward the other end of the receiver, monitoring the signal at each test point.

We can see that if the signal is lost anywhere along the way, the stage in which it is lost will be the defective stage. A voltmeter or an ohmmeter, or both, can then be applied to this defective stage to locate the exact faulty component part.

It is evident that an approximate alignment of the critical RF stages can be accomplished in this manner; however, note that such an alignment is only approximate and subject to some small degree of error.

Section 20. FREQUENCY MODULATED GENERATOR

Earlier in this lesson we went into considerable detail concerning the construction and operation of a signal generator. At that time we devoted much of our time to describing how an accurately calibrated test signal could be generated by a special type of test instrument. We also explained how an RF (radio frequency) signal could be modulated by an audio signal so it could be followed through the equipment being tested.

The signal generator we previously described had its output radio frequency signal modulated by the use of *Amplitude Modulation*. We have previously discussed amplitude modulation, and how it involves the changing of strength, or amplitude, in accordance with some superimposed audio frequency.

For many years such a signal generator was the only type needed by a serviceman. The reason, of course, was that for many years all radio equipment was designed to handle only amplitude modulated signals.

During and since the recent war a different method of modulating the RF signal has come into prominence. This newer method is called *Frequency Modulation*, or more commonly, merely *FM*. The sound portion of all television programs is frequency modulated. Since a receiver designed to respond to frequency modulation will not respond to amplitude modulated signals it is understandable that a different kind of signal generator must be used to service such receivers. For this reason a *Frequency Modulated* signal generator has been designed.

Many of the later models of signal generators combine both types of modulation in their outputs, and are thus able to service either kind of receiver. Such a signal generator is shown in Fig. 26. The controls on such a generator are so arranged that the operator can select any RF signal he needs, and then modulate it through frequency modulation or amplitude modulation as best fits his needs.

The circuit diagram of the signal generator in Fig. 26 is shown in Fig. 27.

We have not as yet studied the frequency method of modulation. It is such an important phase of your studies that we have devoted several entire lessons to this one subject alone. For that reason we will not go into detail at this time about the operation and use of the FM signal generator.

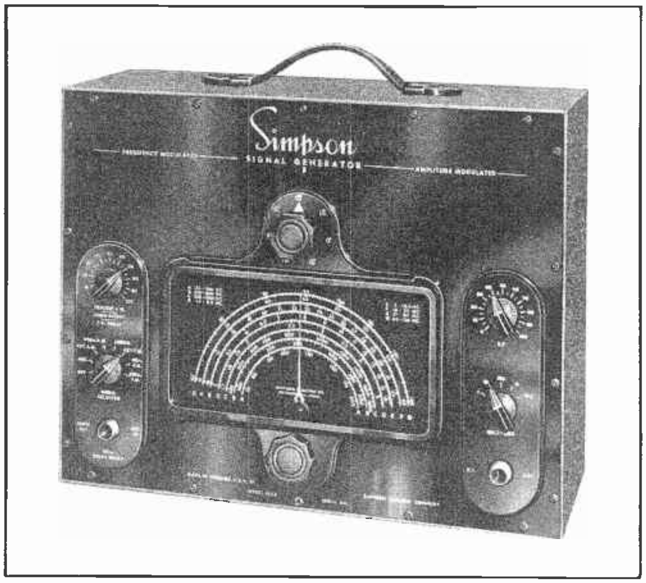
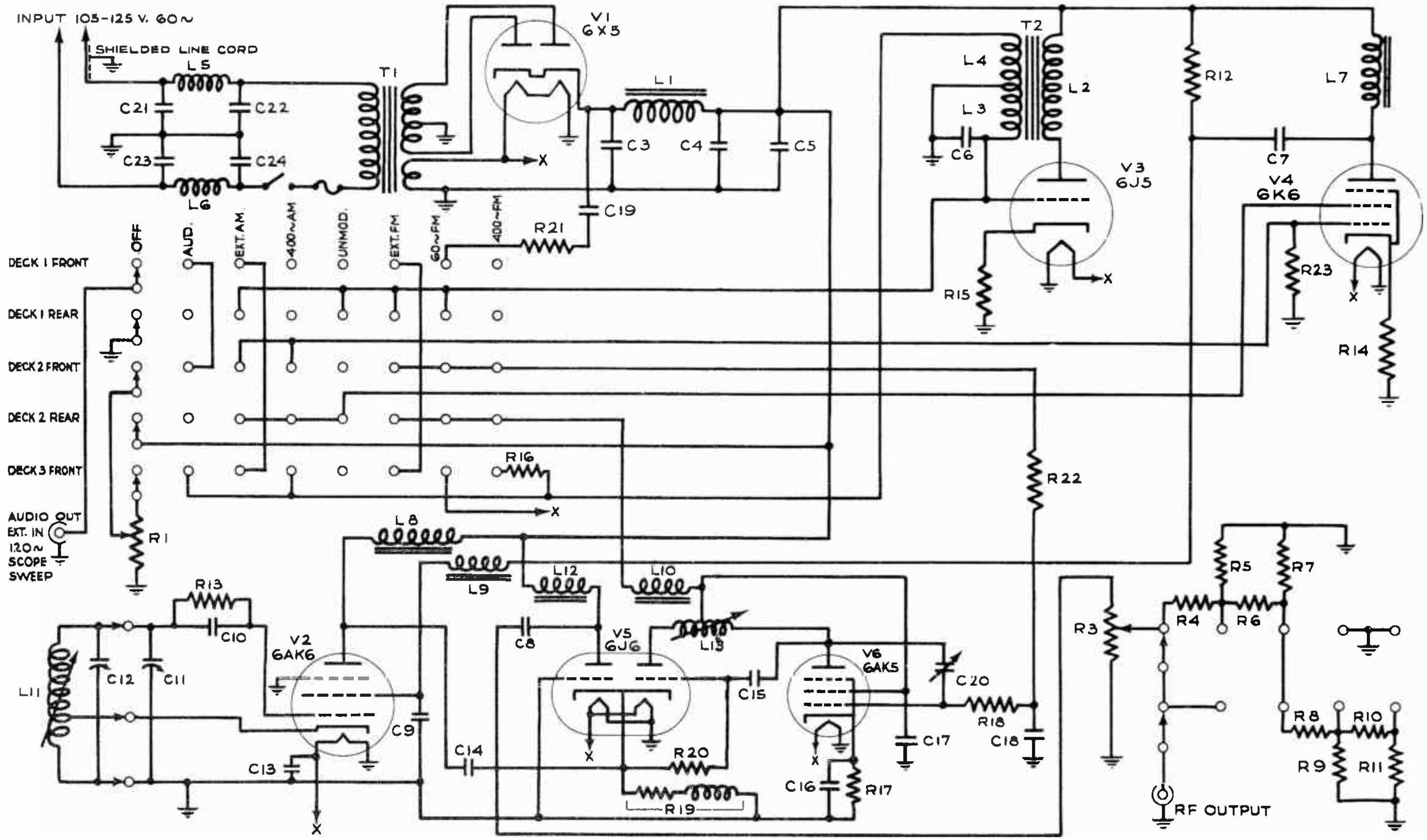


Fig.26. F-M Signal Generator.
(Courtesy Simpson Electric Co.)

Fig.27. Schematic of F-M Generator.



R1 - 10,000 ohm Pot.
R3 - 200 ohm Pot.
R5, R7, R9 - 120 ohms
R4, R6, R8, R10, R14, R15 - 1000 ohms
R11 - 110 ohms
R12, R13, R20 - 20,000 ohms
R16 - 150 K ohms

R17 - 1000 ohm bobbin
R18 - 50 ohms
R19 - 225 ohm bobbin
R21 - 200 K ohms
C6, C7 - .5 MF
C8 - .002 MF
C9 - .001 MF

C11 - Tuning Condenser
C12 - Trimmer
C13 - .008 MF
C14, C15 - .00005 MF
C16, C17, C18 - .0005 MF
C19 - .01 MF
C20 - 5 -20 MMF

C21, C22, C23, C24 - .05 MF
T1 - Power Transformer
T2 - Feed-Back Transformer
L1, L7 - Filter Choke
L5, L6 - Dual 250 MMH RF Choke
L8, L9, L10, L12 - 3 MH

Model 415A Schematic Diagram

Section 21. **TV ANTENNA COMPASS**

Another instrument we might mention at this time without going into great detail concerning its construction and operation is the TV Antenna Compass.

As you progress in your studies you will learn that the actual physical location of the TV Antenna is often a very critical matter. In many cases the positioning of the antenna only a few feet in one direction or another often means the difference between good reception and poor or impossible reception. Radio waves at the high frequencies used with television often act very much like light waves. The waves are often reflected by smokestacks, water tanks, billboards and even trees and other buildings.

Frequently it is most difficult for one man working alone to find the proper location where all television signals come in equally well. This is particularly true where the antenna is on the roof of a two or three story building and the receiver is on the first floor or basement.

To make installation easier it is a frequent practice for at least two service men to work together when installing a television receiver. One man will stay on the roof. He will try locating the antenna at various places. The other man will stay with the receiver, trying the various

Fig.28. TV Antenna Compass.
(Courtesy Simpson Electric Co.)

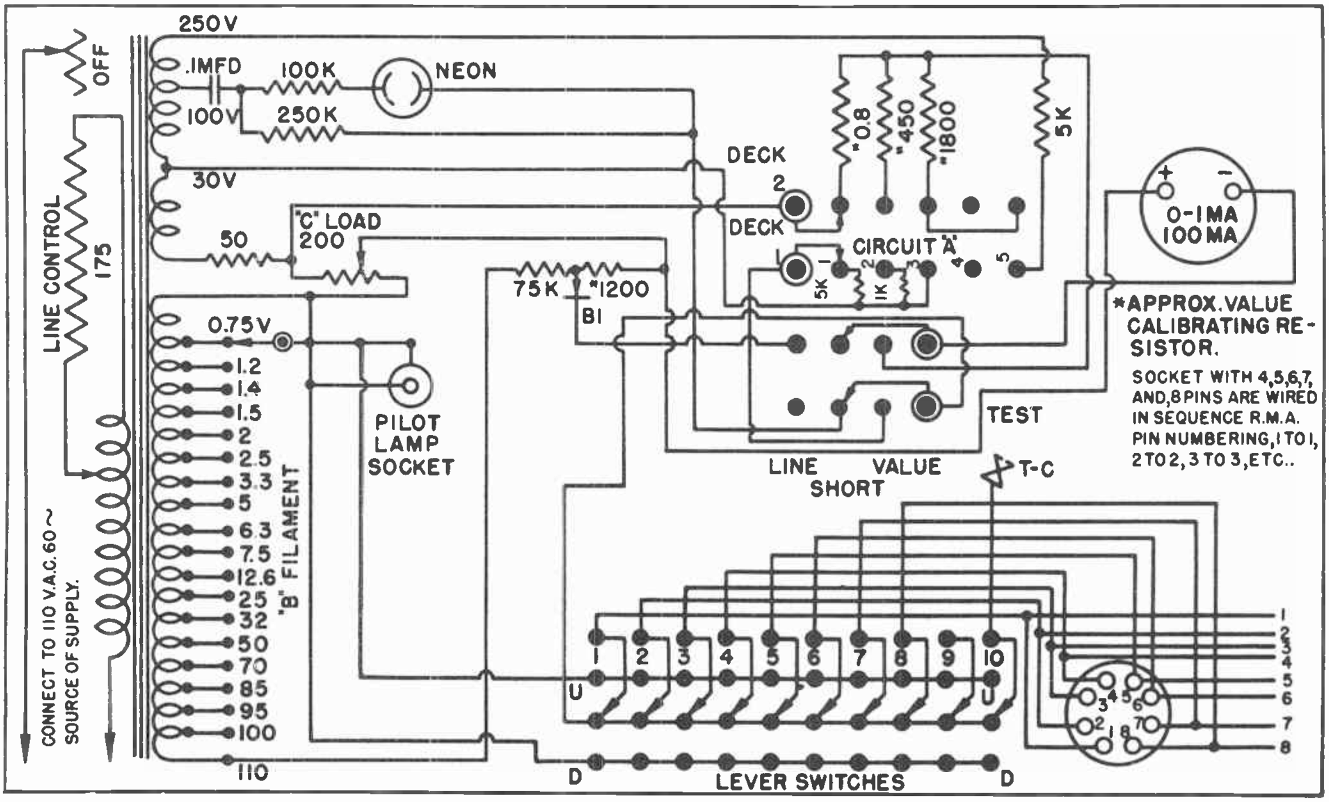


Fig.29. Schematic Diagram of Tube Tester.

stations as the antenna is moved from place to place. To overcome the need for two men the Simpson Electric Co. designed the *TV Antenna Compass*. They claim that by using the compass one man can do a better job in locating the antenna than two men without the compass. The TV Antenna Compass is illustrated in Fig. 28.

NOTES FOR REFERENCE

Use the signal tracer to locate the stage in which a faulty component is situated. Then examine that stage in detail.

Use the capacity analyzer to determine the capacity of a suspected condenser, to find the power factor of an electrolytic condenser, and to locate a short-circuit in a capacitor when other tests are not feasible. Notice that the capacitor may have to be completely removed from the circuit for testing with the capacity analyzer.

The vacuum-tube voltmeter, or electronic voltmeter, is a meter which has a high degree of accuracy. Use it when measuring circuits that are extremely critical, such as grid biases, AVC voltages, and oscillator grid and plate circuits.

Remember this important fact: The best test equipment in the world will be of little help to the man who doesn't know how to use it.

Study the instructions supplied with each test unit. They are the most dependable source of information about that specific unit.

Take good care of your test equipment. Much labor and engineering skill have gone into them. They are precise and delicate. They will give you honest and important information about the circuits under test — but only so long as you show respect for their precision and delicacy through faithful and considerate care.

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SYMBOL OF PROFICIENCY

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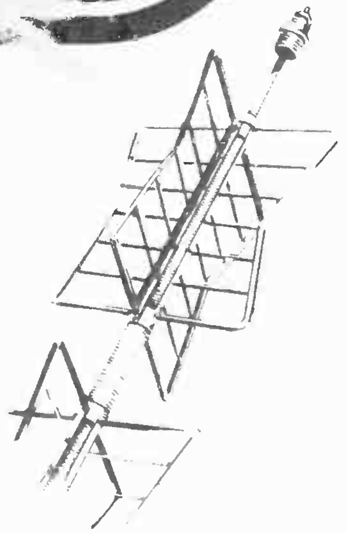
Radio and TELEVISION

The Oscilloscope



The Oscilloscope

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RADIO TELEVISION

THE OSCILLOSCOPE

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Section 1. INTRODUCTION

Modern man is continually finding more and better ways to improve his way of life. Year after year -- almost day by day -- nature yields more and more of her many secrets to the questioning of modern science.

Sometimes she answers the questions directly, sometimes indirectly. Sometimes she answers questions like a riddle by asking other questions whose answers we do not know. Sometimes she gives us several possible answers from which to choose.

Yet under the tireless questioning barrage of man's investigations, the walls which veil nature's secrets are being slowly broken down. While there are still (and probably always will be) a multitude of questions demanding answers, we have succeeded in wresting thousands of important secrets from nature. These secrets have been useful to humanity in a multitude of ways.

One fact which should be kept foremost in our minds is this: The first half of the 20th Century contributed more scientific knowledge to civilization than all other previous centuries combined! What the second half will contribute no cautious man will hazard a guess.

We can speed thousands of miles in an airplane in a few short hours. Modern telescopes can bring the moon to an apparent distance of only 100 miles, instead of its true distance of 240,000 miles. We can send our voices to the opposite side of the earth in a fraction of a second. When man seeks information about atomic energy, he sometimes finds it in light beams which have been traveling through limitless space for

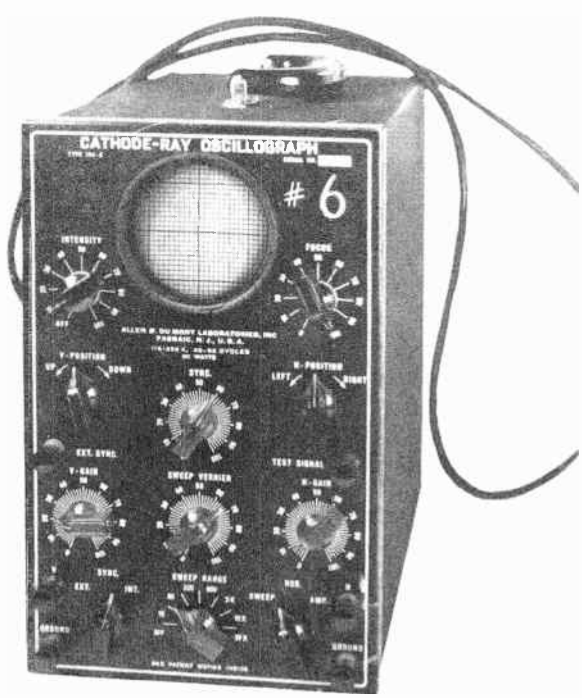

Fig.1. Oscilloscope.

a hundred centuries. Yet it was not until 1905 that scientist Albert Einstein announced his theory that such a thing as atomic energy was even possible. Now scientists go straight into the heart of the atom and find there other important information. Man has had to reach out to almost inexpressibly great distances, and down into equally inexpressibly small physical sizes and time intervals, to satisfy his thirst for knowledge.

Section 2. THE INCREDIBLE OSCILLOSCOPE

While the electron microscope divides the inch up into one hundred thousand equal parts, the oscilloscope can divide a second of time into one hundred million equal parts. Not only will the oscilloscope tell us when each of these tiny intervals has expired, but it can also take a "snapshot" and tell us what events occurred during every part of that one-hundred-millionth of a second.

You may well ask, "What could possibly happen that would be of interest to us in such a ridiculously small interval of time?"

Here are some of the answers:

A radar transmitting tube can go through three hundred complete cycles of a sine wave output during one one-hundred-millionth of a second.

A magnetic field can collapse or partially collapse, in this period of time, creating voltages which, if not controlled, may easily damage equipment or bring harm to personnel.

A television carrier signal, carrying its allotment of amusement or other intelligence, can go through several cycles of oscillation.

A spark plug in an automobile can discharge in this period of time. The manner in which it discharges may be important to the designer, the manufacturer, and eventually, of course, to all users of spark plugs.

Using somewhat longer intervals of time on his oscilloscope, the engineer at the radio transmitter can monitor the quality of the signal sent out by his station.

The electrical power engineer uses the short time interval of the oscilloscope to analyze the output of, and the disturbances on, his multi-million dollar equipment.

The radio and television designer, the craftsman, and the repairman all are interested in these short time intervals. At the high frequencies which are used for radio and television these short time durations determine the nature of equipment used, how they are to be made and -- by no means least -- how they are to be maintained and repaired. Just as a microfarad is one-millionth of a farad, and a microhenry is one-millionth of a henry, so also is a *microsecond* one-millionth of a second.

For a transmitting frequency of 1000 k.c. (one megacycle) the time interval of each *cycle* is one microsecond. A station broadcasting at 1000 k.c. is located approximately in the middle of the standard broadcast band. More than half of the broadcast stations operate at frequencies higher than 1000 k.c. At the highest broadcast frequency -- 1600 k.c. -- a cycle is an interval of .625 microseconds.

A short-wave transmitter operating at two megacycles (2,000,000 cycles per second) will have a cycle interval of 1/2 microsecond. A television transmitter operating at 200 megacycles will go through two hundred complete cycles during the brief time interval of one microsecond.

Because radio and television receivers are built to respond to the signal transmitted from the broadcast station they, too, must be designed to operate at these high frequencies. The man who repairs and maintains radio and television equipment must be interested in the small time intervals represented by such frequencies.

Section 3. APPLICATIONS OF THE OSCILLOSCOPE

There are numerous applications of the oscilloscope to radio and television repair and maintenance. In general, these applications can be stated as follows:

To measure the *amplitude* of high frequency voltages.

To determine the *wave shapes* of voltages operating at high frequencies.

To accurately indicate the rates of the frequencies.

To determine and facilitate adjustment of the band-width of a tuned circuit operating at a high frequency.

To examine an audio frequency or video frequency signal for distortion.

To analyze the presence and source of undesirable transient and hum voltages.

To locate the *source* of trouble, by one or more of the above methods, in a radio or television receiver.

The manner of using the oscilloscope for radio and television trouble-shooting is the subject of later lessons.

At present we shall devote our attention to the electrical and mechanical structure of the oscilloscope, and thus show how an ingenious array of ordinary electronic equipment, such as tubes, condensers, coils, and resistors can when assembled in a special way, perform the miracle of dividing time up into chunks so small they almost stagger the imagination.

Fig. 1 shows a photograph of a modern oscilloscope.

Fig. 2 illustrates a close-up of the face of an oscilloscope, detailing the names and locations of the controls. (The term "oscillograph" is also used to denote this instrument, but the most commonly used name is "oscilloscope".)

Fig. 3 is a functional block-diagram of an oscilloscope, indicating the inter-relationship among its parts.

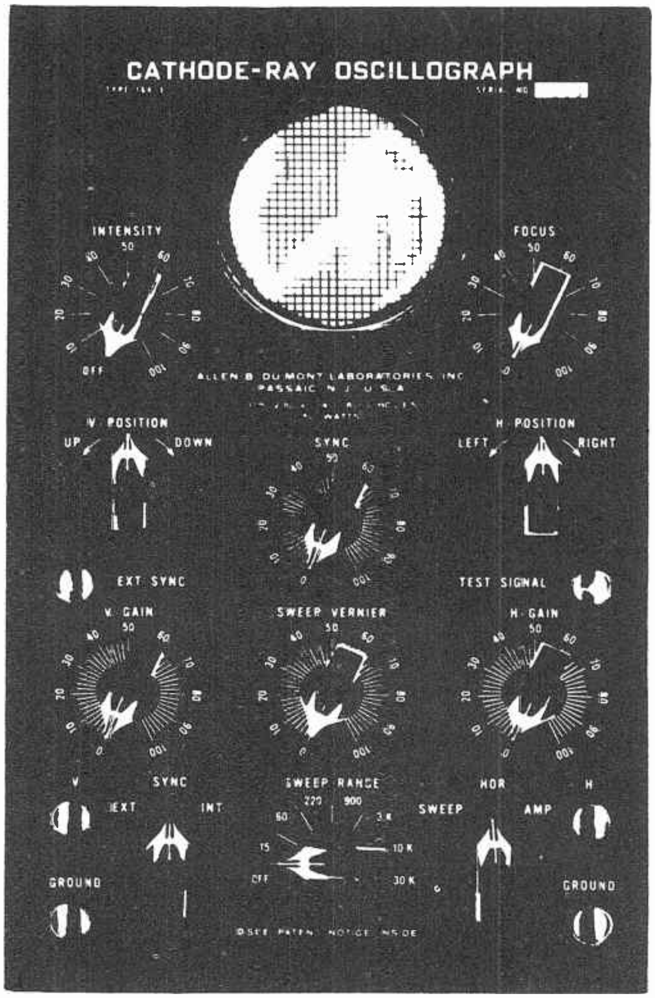

Fig.2. Control Panel of Oscilloscope.

Section 4. **THE SECTIONS OF AN OSCILLOSCOPE AND THEIR FUNCTIONS**

As reference to Fig. 3 will demonstrate, the oscilloscope can be divided into four general sections:

1. The sweep, or timing section, and its controls.
2. The vertical amplifier section, and its controls.
3. The power supplies.
4. The cathode-ray tube itself together with its controls.

We can also explain the general purposes of these four sections at this time:

SECTION	PURPOSE
Sweep	To present a linear time-base with which we can examine an unknown voltage.
Vertical Amplifier	To strengthen a weak signal, or voltage, for presentation as a visual picture.
Power Supplies	To supply necessary driving power to the amplifier and sweep generator circuits, and to make possible the physical position of the electron beam.
The Cathode-Ray Tube	To convert an electrical impulse of almost any frequency into a visual picture of its wave-form.

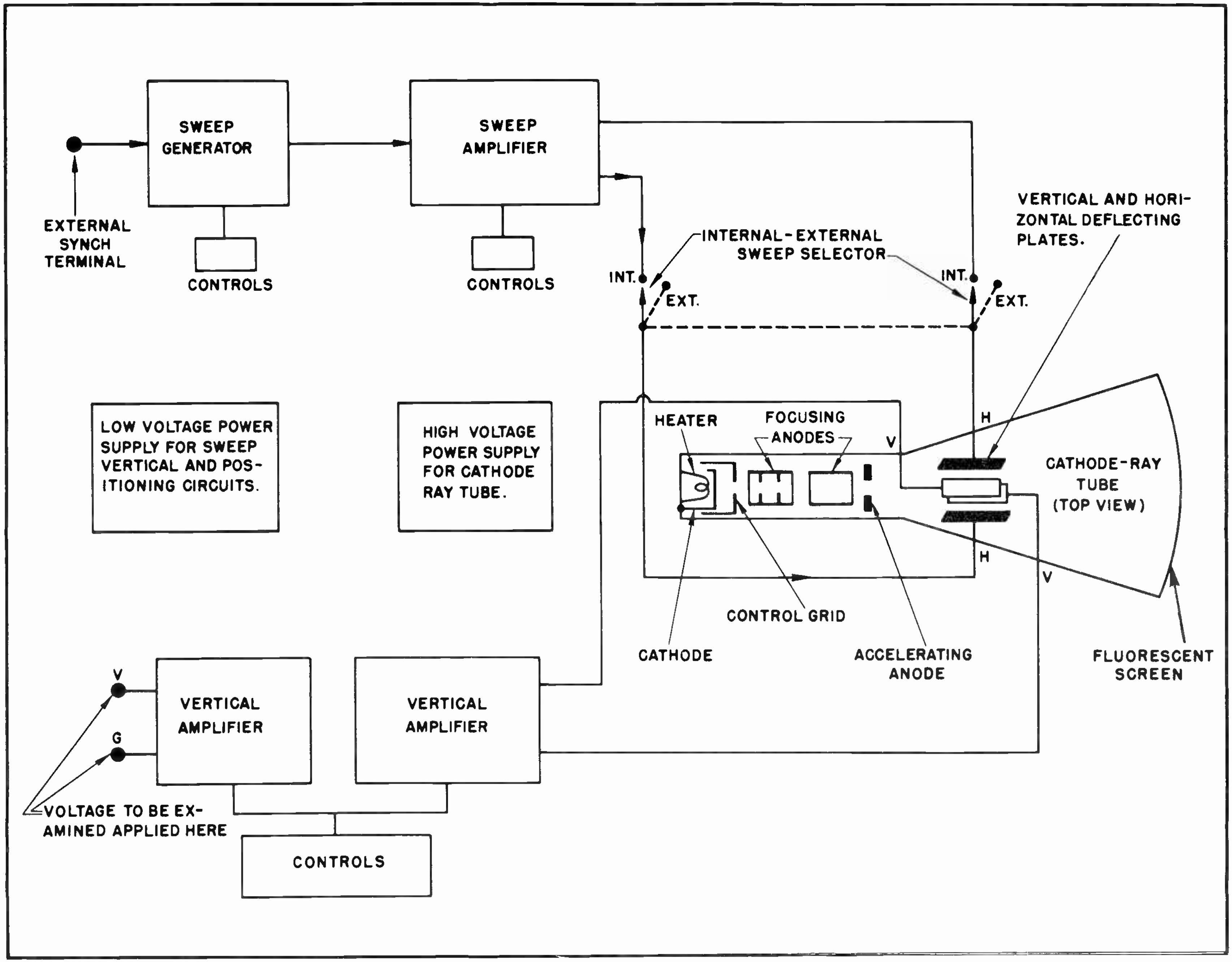

Fig.3. Block Diagram of Oscilloscope.

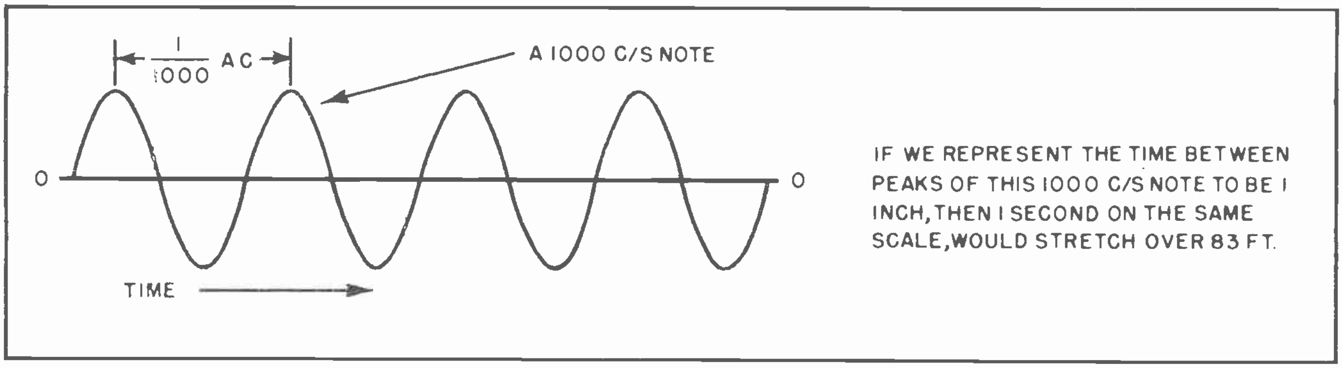

Fig.4. At 1000 Cycles per Second Each Cycle is 1/1000 Second Long.

Section 5. A STATEMENT OF THE PROBLEM

Before discussing each section of the oscilloscope in detail, let us state the general problem of how the oscilloscope can give us certain information in which we are interested.

Suppose you have an audio amplifier which has suddenly become badly distorted. This distortion is obvious to anyone who listens to speech or music through the amplifier. But you as a repairman of electronic equipment, have the task of locating and repairing the trouble. Suppose we enter upon this task together.

We decide that we shall use the oscilloscope to first determine that a true electrical distortion is taking place, and then proceed to locate the component responsible for this failure. An electrical distortion is an electrical voltage whose wave-form has been changed in some manner. We ask ourselves the question: What do we need to supply us with the necessary information about the wave-shape of the signal through this defective audio system?

Let us bear in mind the following important facts:

The signal we are attempting to examine is a combination of a multitude of ever-changing frequencies, the lowest of which is about 30 or 40 cycles per second and the highest of which may approach 20,000 cycles per second.

The amplifier through which this signal is being fed *should* consist of a series of distortion-less stages, where each stage amplifies, and faithfully reproduces in its every detail, the signal with which it is fed. No harmonics can be omitted from the original sound, and no new ones must be introduced. The distorted signal must be examined visually. We actually want to *see* the wave-shape of the signal at different points in the amplifier circuit. Likewise, if a stage in the amplifier system is properly operating, we want to know that, too. We can learn this by observing visually its wave-shape.

Our eyes cannot clearly distinguish details of a picture that lasts for only a small fraction of a second. By the time we can direct our attention to details, the picture is gone.

Our eyes are not responsive to either voltages or currents. These impulses, in order to be visible, must somehow be converted from electrical energy into visual rays to which our eyes *are* responsive.

The statement was made earlier that the audio frequencies with which we are dealing may vary anywhere from 30 to 20,000 cycles per second. Let us simplify both our understanding of the problem and our task of trouble-shooting this amplifier by introducing at the input of the amplifier an audio frequency of 1000 cycles per second. We can be reasonably sure that whatever happens to this 1000 cycle note will also happen to other similar frequencies within the audio range.

At 1000 cycles per second the time interval of each cycle is only one one-thousandth of a second! This is a very short duration of time, to be sure. (See Fig. 4.)

If we hope to examine the wave-shape of a single electrical impulse that lasts for only one one-thousandth of a second, we will be disappointed. But, suppose that we create a series of wave-forms, each

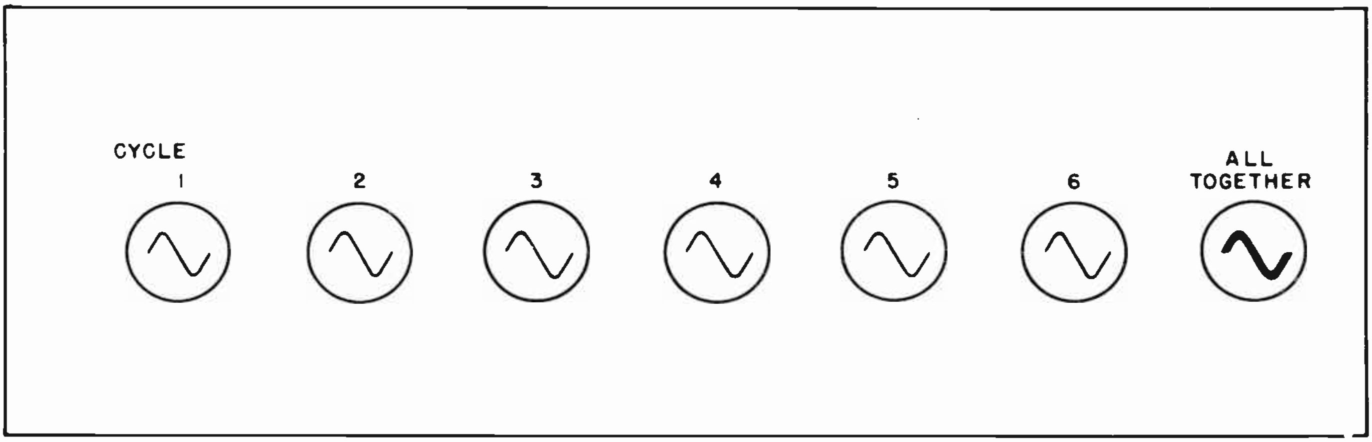

Fig.5. How Several Waves Exactly Alike are Placed on Top of Each Other to Form a Strongly Visible Pattern.

identical with all the others, and that we find a method of viewing every one that occurs. Then suppose we place all of these wave-forms in rapid succession right on top of each other. The result will apparently be a single stationary picture. The individual pictures will be changed a thousand times each second, but the composite result is a steady, stationary image on the visual screen.

The task of the sweep circuit in an oscilloscope is to permit each one of the thousand pictures to be placed on the screen of the oscilloscope for one one-thousandth of a second, each to be removed at the end of this interval and followed immediately by another. Fig. 5 suggests how the eye adds up the separate images and combines them into a steady, related picture.

If each wave-form is like the one that precedes it, and like the one that follows it, we have a steady stream of pictures of them all, but they appear as one image. Whatever happens to one of them will happen to the others. The desired effect of "stopping" the wave form through a small interval of time is thus achieved, accomplished by the sweep circuits of the oscilloscope. The sweep circuits can be adjusted to "stop" the action which occurs during 1/60th of a second, 1/500th of a second, 1/1000th of a second, or during any other interval of time. The method of accomplishing this task will be discussed later.

Section 6. APPLYING THE OSCILLOSCOPE TO THE PROBLEM

A review of the conditions with which we are working will probably show that the amplifier has a defective component to which the distortion is due. If we attempt to determine the stage in which distortion originates, we may have to examine the wave-shapes at all the stages.

In early stages, or from the microphone itself, we will encounter signal voltages on the order of one millivolt and even less. This will depend upon the type of microphone used, and the strength of the music or speech. All of which means that our oscilloscope must be sensitive enough to respond to such low values of voltage.

The ordinary amplifier, or radio or television receiver, depends for its final success on the *gain* or amplification of its circuits. The oscilloscope to be successful in arranging signal voltages for visual observation must, where the signals themselves are very weak, supply sufficient gain to build them up to observable values. As in radio and television, the ability of an oscilloscope to amplify a weak signal to a sufficiently strong one for observation is accomplished by the use of amplifiers. These amplifiers, together with their controls, comprise the "vertical amplifiers" in the block diagram of Fig. 3.

In this connection, an important point should be stressed. Not only must our vertical amplifiers build up weak signals to the required strength, but they must in no way affect the wave-form of these signals. Remember, we cannot omit any harmonics present in the original sound, nor must we introduce any new ones. The exact shape of the signal voltage must remain untouched. Otherwise, we would not be sure of our results, and might confuse distortion in the oscilloscope with distortion in the circuit we are analyzing.

The answer to this special problem of high fidelity is the use of perfectly distortionless vertical amplifiers over a wide range of frequencies. That this is actually accomplished will be evident from our discussion of the details of the vertical amplifier circuits.

In our previous discussion we have presupposed that we converted an electrical impulse into a visible picture. This concept is based upon the ability of the cathode ray tube to specifically accomplish this task. The property of the cathode ray tube to convert electrical impulses into visual pictures is important in television receivers and in oscilloscopes. This ability rests upon the fact that when certain compounds are bombarded by fast-moving electrons, the striking-points on the surface of these compounds emit a fluorescent light.

The problem of converting an electrical impulse into a visual picture which retains the wave-form of the impulse is met by directing an electron stream at various points on a fluorescent screen in accordance with the impulse changes. This is done by directing it over the same path many times in quick succession, and by permitting the screen to fluoresce only along that path.

The retention of the fluorescence along the traced path, or the "persistence" of the screen as it is more commonly called, is easily accomplished by the proper selection of chemical compounds. A screen may be made with almost any degree of "persistence".

Section 7. **THE CATHODE RAY TUBE**

The cathode ray tube, in accomplishing its task of converting electrical impulses into visual images, must be made in a certain way.

In addition to its mechanical structure, the cathode ray tube must be supplied with a certain kind and amount of electrical power in order to achieve proper operation. The power for the cathode ray tube is provided by the high-voltage power supply, shown in the block diagram of Fig. 3. Parts of the cathode ray tube employ voltages somewhat less than that which the final anode of this tube uses. This lower voltage, some of which is also delivered to the sweep and vertical amplifier circuits, originates in the low-voltage power supply of the oscilloscope, also indicated in the block diagram of Fig. 3.

Fig. 6 illustrates an enlarged drawing of a typical cathode ray tube, showing in detail the internal structure and the elements of this tube. The primary purpose of

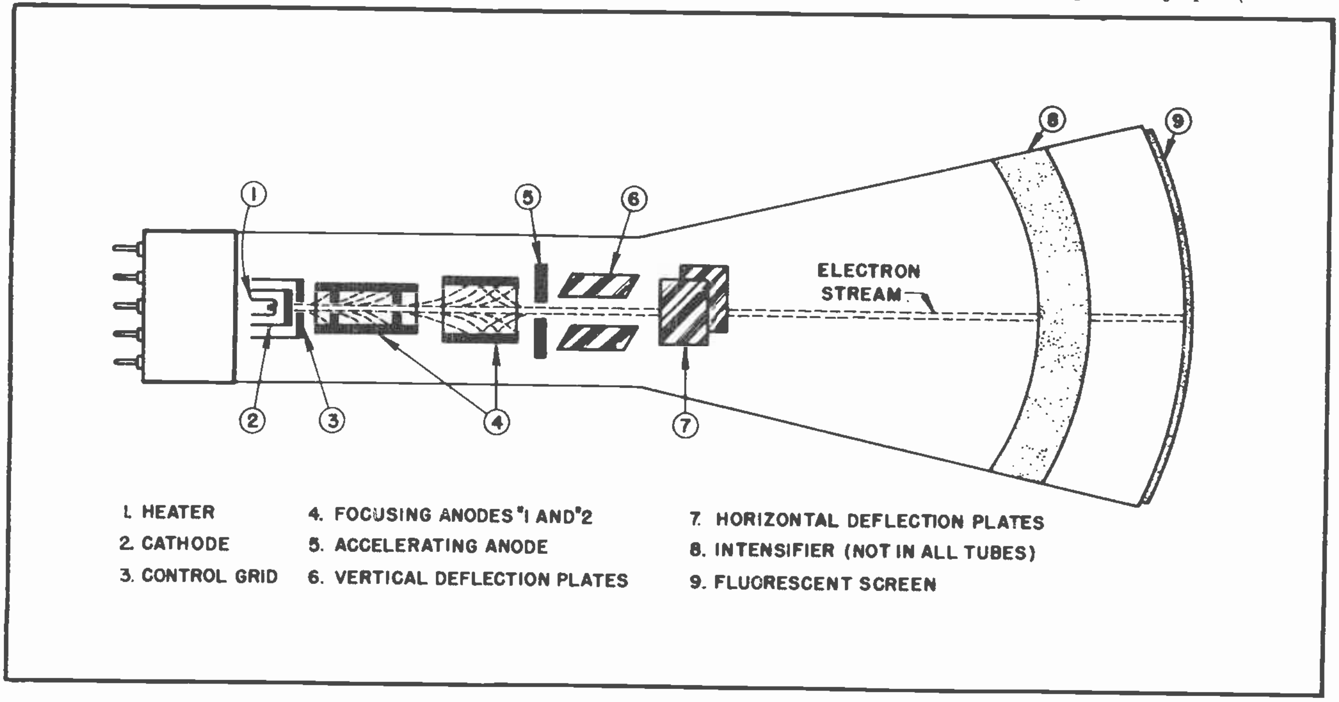

Fig.6. Elements Within the Cathode Ray Tube.

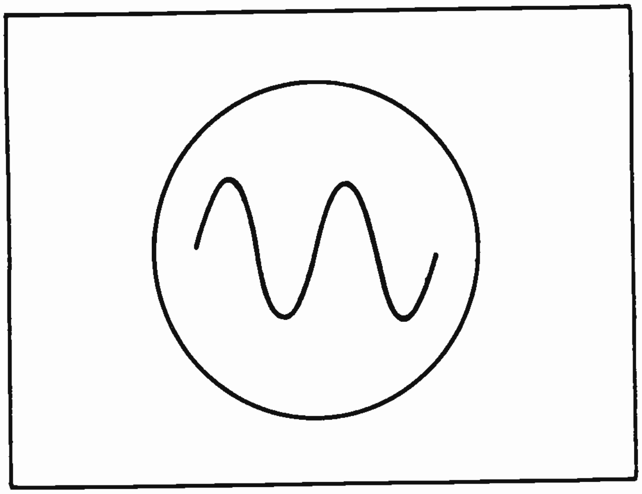

Fig.7. Front View of Screen Showing a Sine Wave Pattern.

this tube is to convert an electrical impulse into a visual picture containing all the characteristics of the impulse. Fig. 7 shows how a typical picture of a sine wave would appear on the viewing screen when observed from its front end.

At the opposite end of the tube we find the heater. It is supplied with proper current and voltage for raising its temperature. Immediately surrounding the heater is the cathode which emits the electrons to be drawn forward by positive potentials at other elements in the tube. The heater is marked element #1 in Fig. 6, while the cathode is element #2.

Fairly close to the cathode, and surrounding it completely except for a small hole at the center, lies the control grid. This element, marked #3 in Fig. 6, is supplied with a negative potential, the value of which determines the amount of electrons passing toward the right to their destination on the viewing screen. The setting of the "intensity" control on the front panel of the 'scope will control the negative voltage of this grid, which results in the desired brightness of the picture on the screen. The action of the cathode in emitting electrons under conditions of high temperature, and the controlling of the flow of these electrons toward the anodes are ordinary applications of vacuum-tube principles.

However, note the special shape of the grid in this tube. It not only governs the number of electrons flowing, but also directs these electrons through the small opening in the center of the element. The electron emission, therefore, instead of spreading toward the anodes, is confined to a narrow beam. It is thus provided with easier deflection properties and a narrower series of striking-points upon the fluorescent screen. The narrowness of this electron beam will determine the sharpness and the clarity of the visual picture on the screen. The hole tends to prevent spreading or spraying of the electrons as indicated in Fig. 8.

The electron beam, after leaving the cathode under the control of the grid, next comes under the influence of the first focusing anode, marked element #4 in Fig. 6. With respect to cathode and grid, this focusing anode has a high positive potential, and its structure is such that the stream of electrons is further confined by the small holes which limit the diameter of the beam.

The second focusing anode #4 in Fig. 6 toward which electrons next flow, is still more positive than all previous elements, including the first focusing anode. The results of this arrangement are illustrated in Fig. 9 and can be briefly described as follows:

The first and second focusing anodes constitute an *electron lens* whose function is to focus the electron beam sharply on the screen. Since there is a difference in potential between the first and second focusing anodes an electrostatic field is developed between them. The action of the field, as shown in Fig. 9, will be to cause the beam to converge in or near the second focusing anode. Just where it converges will depend upon the relative potentials between these anodes. If the beam first converges at Q, an increase in the focusing voltage, manually controlled from the front

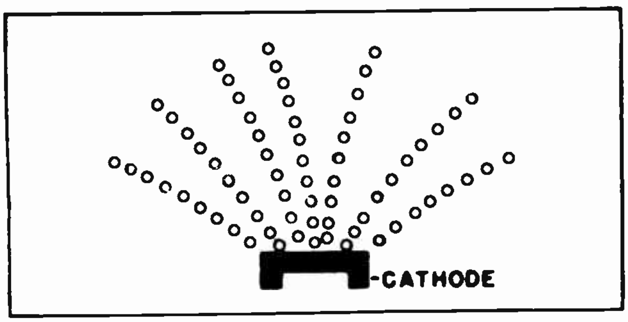

Fig.8. Electrons Repelling Each Other Causes Them to Spread Out.

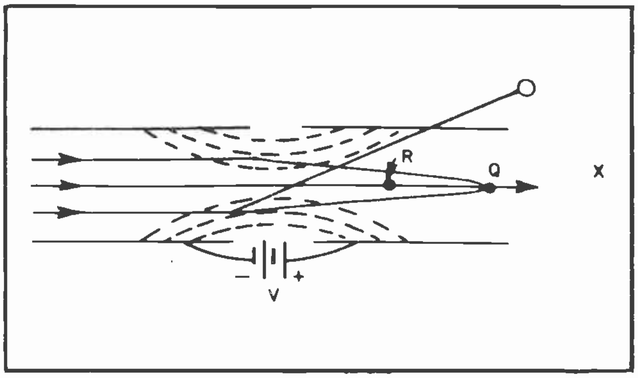

Fig.9.

panel, will make the beam converge at *R*. If we decrease the focusing voltage, the beam can be made to have a longer "focal length" and converge near *X*. The focusing voltages described originate in the low-voltage power supply of the oscilloscope.

Figs. 10 and 11 demonstrate the effect of proper and improper adjustment of the focusing elements, and show visual pictures of how the electron beam diameter determines the clearness of the image on the fluorescent screen.

After leaving the control area of the focusing anodes, the electron beam next meets the effects of the accelerating anode. The purpose of this anode, as the name suggests, is to accelerate the electrons and impart to them a velocity high enough to send them crashing against the viewing screen at the front of the oscilloscope. The action of this anode, a flat disc with a hole in its center, can be likened to that of the screen grid in a beam power amplifier tube. A high potential on this element, marked #5 in Fig. 6, draws the electrons toward itself with a tremendous force. The reason why the electrons thus drawn are not completely captured by this anode is that they have already been pre-focused to the center of the hole by the focusing anodes. Thus the accelerating anode can perform the task of imparting high velocity to the electrons without drawing many of them away from the beam.

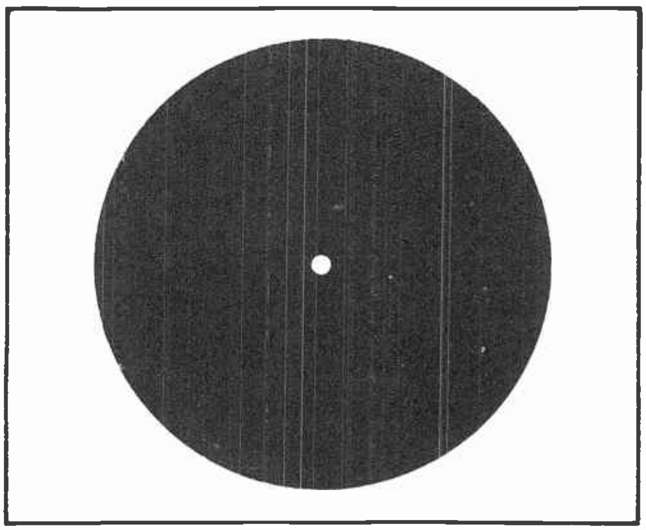

Fig.11. Sharply Focused Beam.

Section 8. DEFLECTION PLATES

So far we have discussed the action of the cathode, the control grid, the focusing anodes, and the accelerating anode of the oscilloscope.

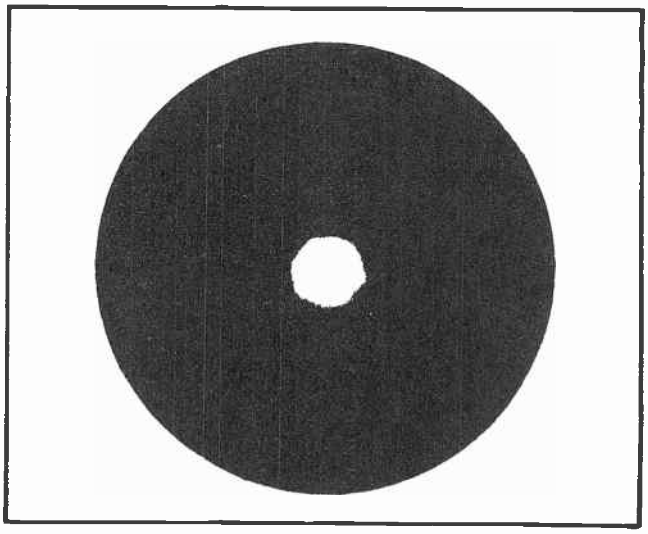

Fig.10 Improperly Focused Beam Causes an Undesirable Halo Effect.

These elements are called the *electron gun*, and perform the function of shooting out a series of electron "bullets" in a steady and directed stream. Since it is the lateral and vertical motion of this electron beam which will trace out our desired wave-pattern on the fluorescent screen, we will now examine the action of the deflecting plates. These are element pairs #6 and #7 in Fig. 6, producing the deflection which creates the picture on the viewing screen.

If we could open up the wide, or viewing, end of a cathode ray tube, the deflection plates would appear as shown in Fig. 12. H_1 and H_2 are the left and right horizontal deflecting plates, while the vertical deflecting plates are marked V_1 and V_2.

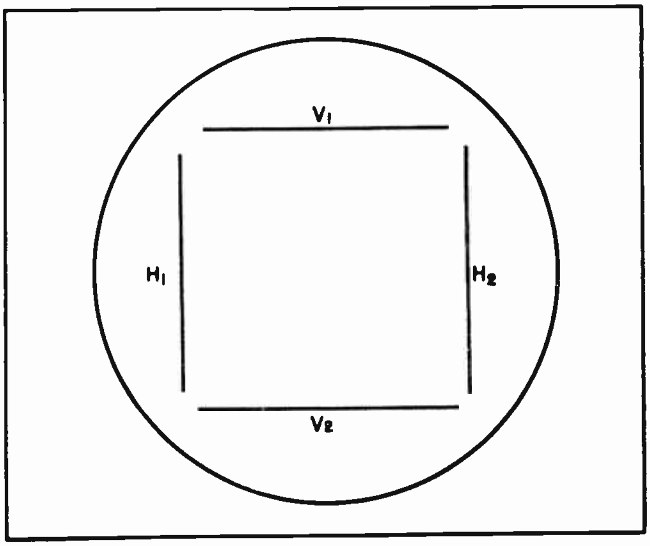

Fig.12. How the Deflection Plates Would Look if We Could Look at Them Through the Screen at the Front of the Tube.

If the voltages on both horizontal plates are equal, and the voltages on both vertical plates are equal, then the electron beam will not be deflected by either pair of plates and will strike the viewing screen at a point at the center.

Suppose, now, that we apply the voltages on the horizontal plates as shown in Fig. 13, leaving the voltages on the vertical plates still equal to each other. The electron beam will be drawn toward H_1 (or C) and away from H_2 (or D), the reason for this action simply being that a positive potential attracts negative electrons, while a negative potential repels them. The visual result of this action will be the motion of the fluorescent spot on the viewing screen in the same direction, and to the same extent, as the electron beam which causes the spot. With potentials on the horizontal plates as shown in Fig. 14, and with the vertical plates still of equal potential, the electron beam will be drawn toward the positive potential at H_2 and away from the negative potential at H_1. This will cause the spot on the screen to act likewise, moving from left to right.

It is easy to see that the degree of deflection of the electron beam will be exactly proportional to the voltage difference between the two plates. It is further evident that the horizontal plates acting alone can impart only a lateral, or sideways, motion to the electron beam. They cannot make this beam rise or fall in a vertical manner.

By the same token, the vertical deflection plates V_1 and V_2, (See Figs. 15 and 16) will cause the electron beam to rise and fall in proportion to the voltage difference between these two vertical plates. The vertical plates are able to impart only a vertical motion to the electron beam. These plates make the electron beam, and therefore the spot that they create, move *up and down only*, and not sideways.

Section 9. **VOLTAGES ON BOTH SETS OF PLATES**

While the vertical plates can deflect the electron beam in a vertical manner only, and while the horizontal plates can deflect it in a horizontal manner only, it is evident that if we have a potential difference between the vertical plates at the same time there is a potential difference between the horizontal plates, they will both act at the same time. The vertical plates will move the beam vertically, while *at the*

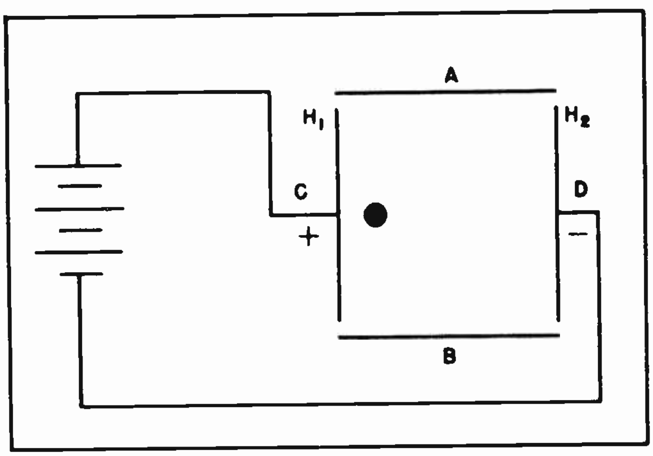

Fig.13.

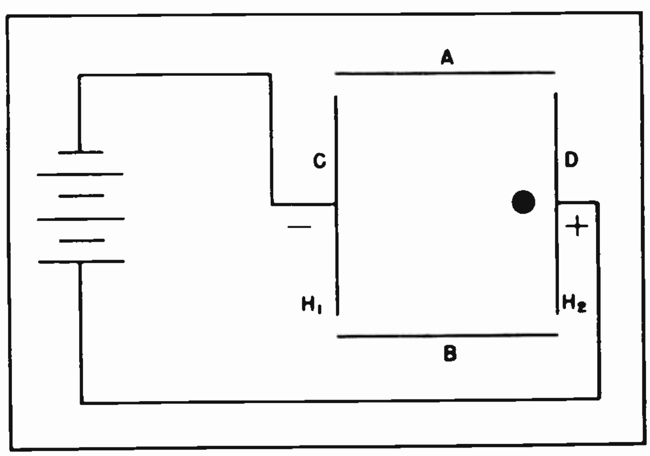

Fig.14.

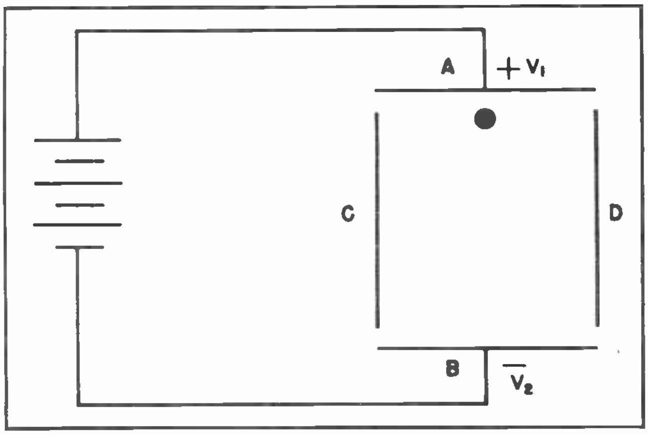

Fig.15.

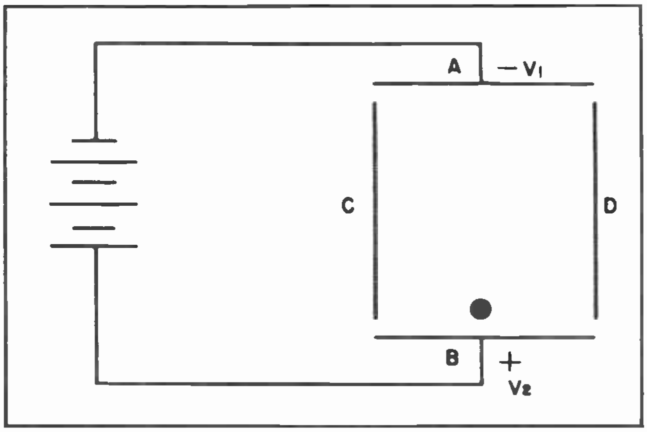

Fig.16.

same time the horizontal plates will move it horizontally. This is illustrated in Fig. 17, which shows that the electron beam will now move under the influence of both sets of deflecting plates, being drawn upward by potential difference in the vertical plates and toward the right by potential difference in the horizontal plates.

Fig. 18 indicates the motion of the electron beam, and therefore of the spot on the screen, when the polarities of Fig. 17 are reversed.

Let us now go one step further.

During any arbitrary period of time, let us say one-hundredth of a second, suppose we apply a sawtooth voltage, whose period is one one-hundredth of a second, to the horizontal plates. Let us, during this same interval of time, apply a sine wave of the same period to the vertical plates. These two waves and their characteristics are shown in Fig. 19.

The sawtooth voltage will draw the electron-beam horizontally toward the right, at a relatively slow rate. While this is occurring, the sine wave voltage on the vertical plates will raise and lower the beam in accordance with its sine wave character. After the beam has been slowly drawn all the way across to the right side it suddenly "flies back" to the left and starts over again. The electron beam can respond to both forces at the same time and will move through the path described in Fig. 20.

Our example of a sine wave and sawtooth voltage combination whose periods were both one one-hundredth of a second was for the purpose of explanation. However, in a modern oscilloscope, the frequencies of the voltages applied to the deflection plates can be of an extremely wide range. This makes for the great utility of this instrument. In addition, the periods of the voltages on the pairs of plates need not necessarily be equal, although the period of

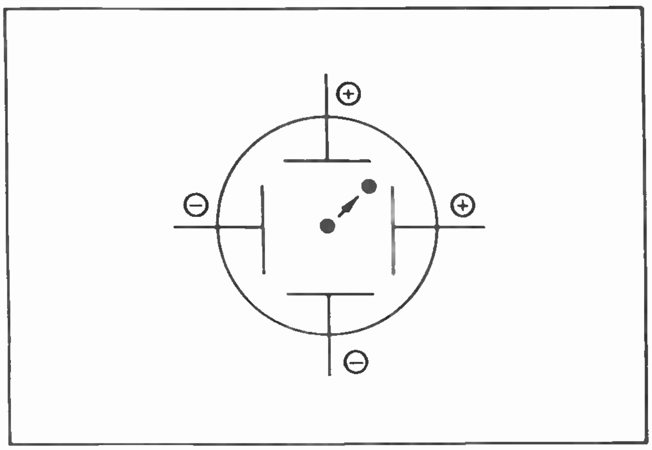

Fig.17.

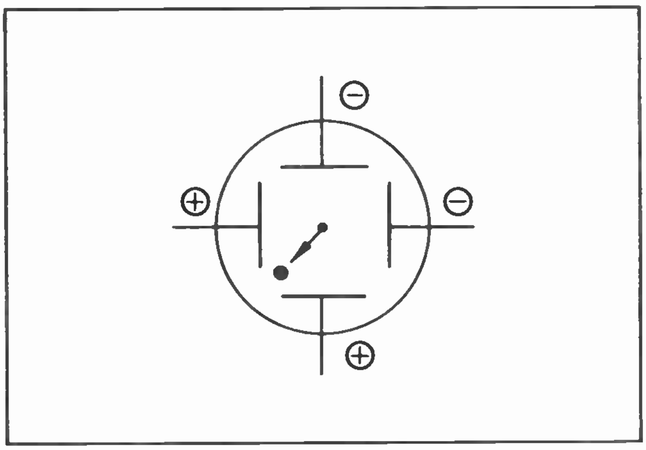

Fig.18.

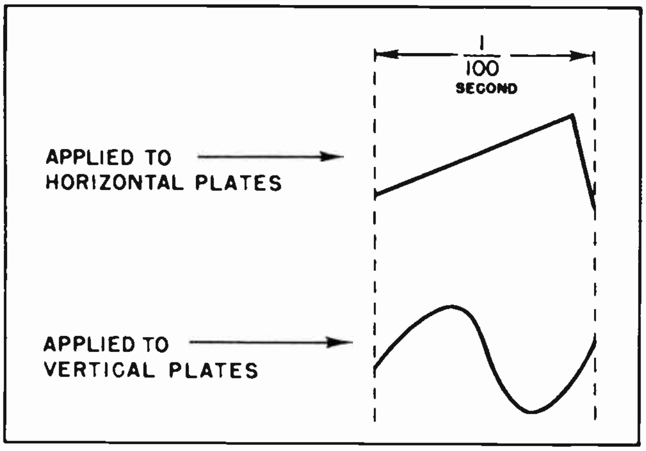

Fig.19. How different Kinds of Voltage Wave Forms are Applied to the Deflection Plates.

the voltage on the horizontal plates is usually most useful when it is a submultiple of that on the vertical plates. This is illustrated by the wave form of Fig. 21, where the ratio of frequencies is 3:1 on the vertical and horizontal plates, respectively. The voltage on the vertical plates is going through three cycles to each one cycle on the horizontal plates. For example, if the vertical frequency was 180 cycles per second the horizontal frequency would be best when set to 60 cycles.

In some special applications of the oscilloscope to radio and television work, we will also find that the horizontal plates need not *always* carry a sawtooth voltage, as will be explained in later lessons. However, the sawtooth voltage provides a *linear time* base, which, we shall soon see, is capable of analyzing *whatever* wave we apply to the vertical plates in the most useful way. The sawtooth wave is a voltage which increases linearly for a relatively long period of time. Then it reverses and returns to zero almost instantly. Such a horizontal voltage will move the electron beam slowly from left to right, then bring it back from right to left instantly. The beam will show on the screen only while moving from left to right.

Section 10. OTHER CR TUBE ELEMENTS

The fluorescent screen (See Fig. 6) has already been mentioned. It is the final stage in the oscilloscope and represents the transformation of energy from the kinetic form to the visible form. In simpler language, the nature of the screen is such that if it is struck by a stream of fast-moving electrons, it will light up at the striking point. While extremely interesting, the physical and chemical action of this process is not necessarily within the scope of this lesson.

Basically, we can say of the fluorescent screen that upon its surface the energy of motion (of the electrons) is converted into the energy of visible light. But what happens to the countless billions of electrons after they have struck the screen? Do they just disappear inside the vacuum that fills the cathode ray tube? No, that cannot be, as we well know. Neither matter nor energy can be destroyed.

After striking the fluorescent screen, the electrons have given up their energy of motion and find their way back, at relatively slow speeds, to the nearest element carrying a positive potential. This element leads them back to the power supply, where they are again available for another trip through the cathode ray tube.

In certain special applications, such as radar, the cathode ray tube is supplied with an additional element, sometimes called an "intensifier", shown in Fig. 6 as element #8. Another application of the same principle is the "Aquadag" element, not shown in Fig. 6 but which is a metallic component of the fluorescent screen serving to return the

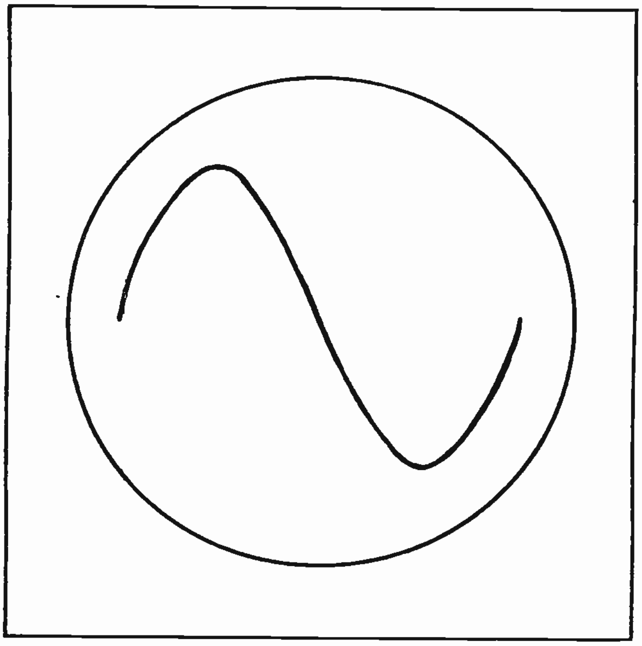

Fig.20. The Pattern Which Will Appear on Screen of Scope as a Result of the Voltages in Fig. 19.

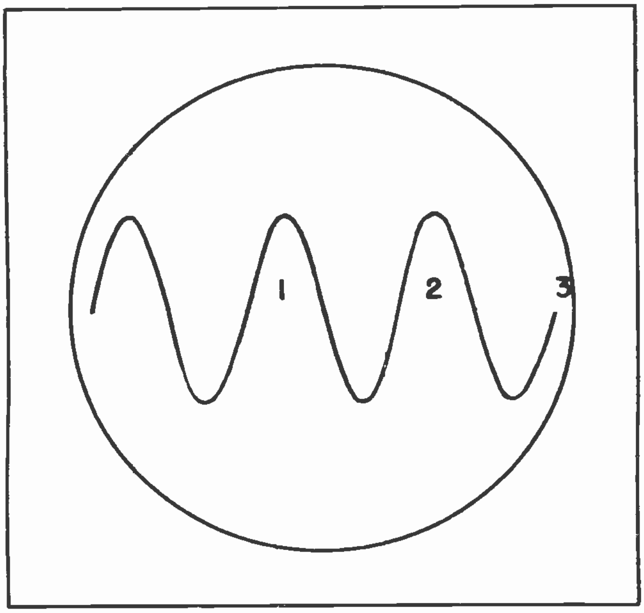

Fig.21. The Scope Pattern Which Will Result When the Frequency of the Vertical Voltage is Three Times That of the Horizontal Voltage.

electrons back to their power supply. Summarizing the elements of the cathode ray tube, we find:

1. The heater, to supply energy for the release of electrons.
2. The cathode, the surface of which emits the electrons.
3. The control grid, whose negative potential, at the will of the operator, determines the amount of electrons striking the screen, and therefore the intensity of the spot.
4. The pair of focusing anodes, which direct the electron stream to the proper focus.
5. The accelerating anode, which imparts the necessary high speed to the electrons.
6. The deflecting plates, a vertical pair and a horizontal pair, which bend the electron stream in accordance with their impressed voltages.
7. The viewing screen, which makes this electrical action visible to the eye

Section 11. THE SWEEP SECTION OF THE OSCILLOSCOPE

Earlier mention was made of the Sweep, or Timing Section of the oscilloscope. It is one of the four main divisions of the oscilloscope, the others being the Cathode Ray Tube, the Vertical Amplifier, and the Power Supplies.

The purpose of the sweep section is to provide a linear time base with which to examine the nature of any voltage whose wave-shape is to be studied.

What is a *linear time base*?

A linear time base is the path followed by anything that moves equal distances, at a uniform rate, over equal intervals of time.

A car moving at sixty miles per hour covers a distance of one mile in one minute. If the road the car travels is straight, every one of the miles it travels is a linear time base with a duration of one minute. However, we need not limit the time base to one minute, representing one mile. Let us select another time base -- one second. A simple computation shows that in one second, traveling at the same rate, the car will move a distance of 88 feet. Likewise, in 0.1 second, the car will cover a distance of 8.8 feet.

No matter what time interval we select, the rate of travel of the car (60 miles per hour) is the same. This is known as uniform motion in a straight line, providing the car does not speed up nor slow down, but maintains a constant velocity.

Uniform motion in a straight line has a linear time base.

Let us now apply the principle of uniform motion in a straight line to the oscilloscope. Our aim is to provide the horizontal deflection plates with a method of deflecting the electron beam (in a horizontal manner only) over a fixed distance, in a fixed length of time, and at a uniform rate. Let us examine the requirements for this aim.

Electrons are negative and hence are attracted by a positive potential and repelled by a negative potential. Moreover, a stream of electrons, such as those leaving the "electron gun" of a cathode ray tube, will be bent in exactly the same manner as its component electrons are bent; that is, away from a negative potential and toward a positive potential.

Any required sideways motion of the electron beam can be accomplished by impressing

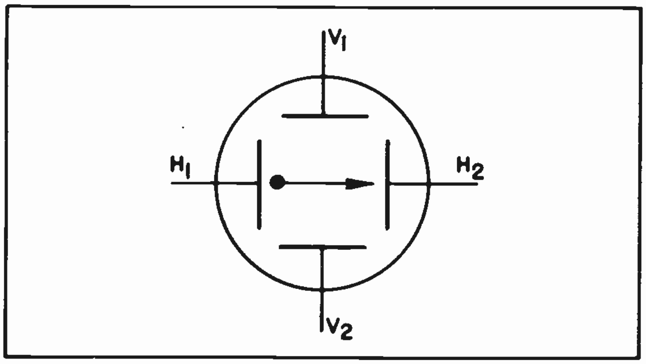

Fig.22. How Changing Voltage on the Deflection Plates Causes the Dot of the Beam to Move.

a negative voltage on one horizontal plate and a positive potential on the other. Our aim, however, is to make the electron beam move sideways at a uniform rate and to cover a certain lateral distance in a certain interval of time. If we are to use a voltage on the horizontal plates for this purpose, it must be a certain special kind of voltage, one having a uniform rate of change between a fixed minimum and fixed maximum.

At this time it is wise to bear in mind that when we speak of the potentials on the horizontal plates, we mean the potential difference between them.

If the left horizontal deflection plate has an increasingly negative potential applied to it while the right horizontal deflection plate is impressed with an increasingly positive potential, then the electron stream, and the spot that it causes on the screen, will move from left to right. This is pictured in Fig. 22. If the changes of voltage on the plates take place in a uniform manner, then it can easily be seen that the electron beam, and the spot, will move in a uniform, or linear manner from the left to the right.

The voltage wave-form on the horizontal plates fulfilling all the requirements is surprisingly easy to picture. (See Fig. 23.) The wave-form on the left-hand plate is called a "negative-going" sawtooth voltage, and that on the right-hand plate is a "positive-going" sawtooth wave.

Fig. 24 is a single positive-going sawtooth wave, with voltage plotted against time.

Fig. 25 shows a series of sawtooth waves.

We now understand that the sawtooth waveform represents a uniform, or linear, voltage change between certain fixed limits. We need this uniformly changing voltage to move the electron beam, and therefore the spot it causes, from left to right in a linear manner. It moves the spot from left to right in a definite period of time. Then having reached the right side the voltage suddenly reverses and the beam is brought back to the left instantly.

Fig. 26 is a simplified circuit diagram of the sweep generator, sometimes called the timing oscillator, of the oscilloscope. This circuit originates the sawtooth waveform applied to the horizontal deflection plates. We will see that this circuit not only originates the sawtooth wave form

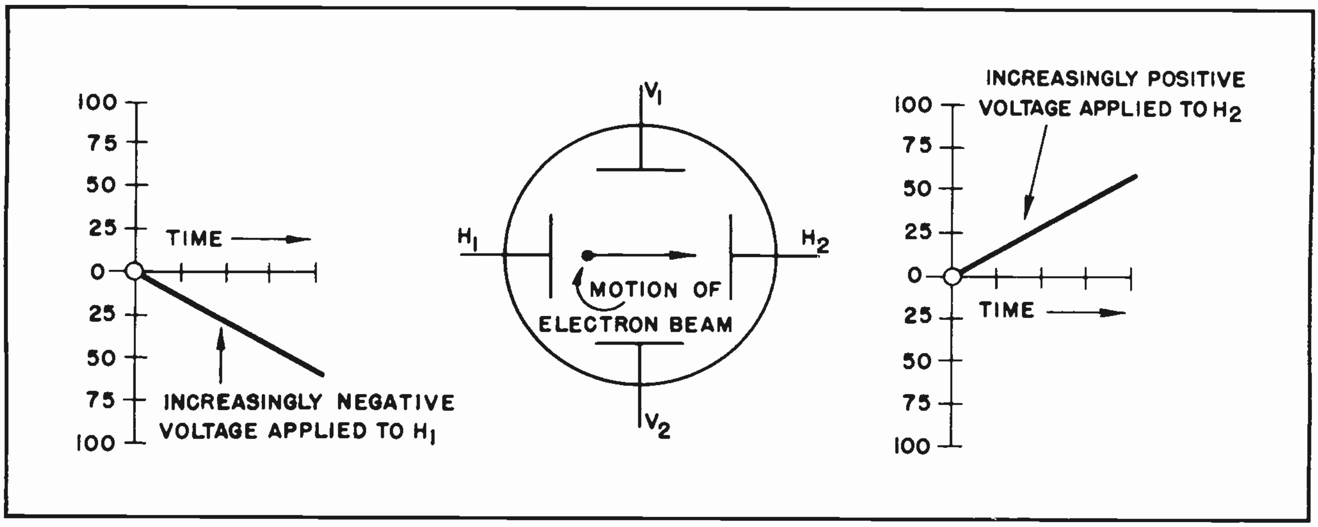

Fig.23.

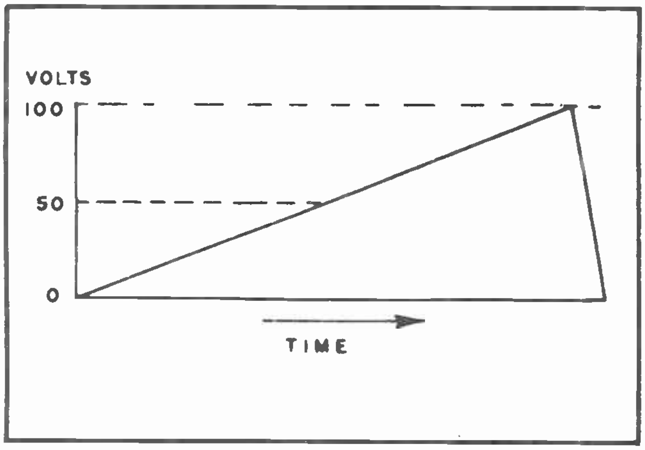

Fig.24. Sawtooth Sweep Voltage.

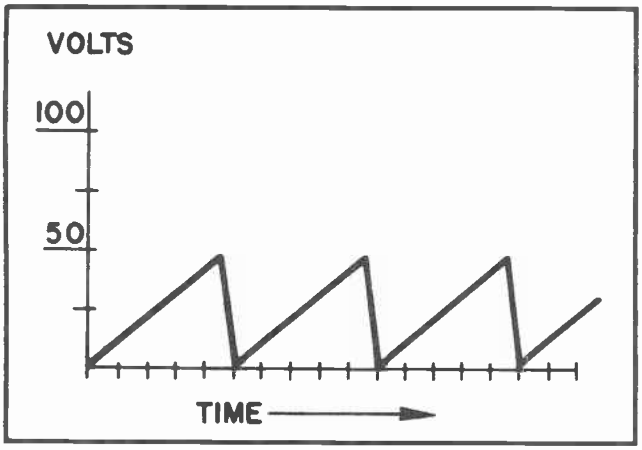

Fig.25. A Series of Sawtooth Voltages.

required for our purposes, but also that this wave-form is repeated over and over in exactly the same form for as long as we desire.

In Fig. 26, action begins when heat is applied to the cathode, and B-plus to the plate of the 884 gas thyratron. This tube is initially biased at cut-off, which prevents it from firing until enough electrons from the upper plate of the condenser flow toward B-plus, creating sufficient potential difference across the condenser plates to fire the tube. While the 884 tube is firing, a condition which is practically instantaneous, it short-circuits the condenser by supplying a path from ground to the upper condenser plate. After discharging, condenser will again begin to charge up. While the complete charging rate of the condenser is not exactly linear for all practical purposes, it is linear for a limited time. The sawtooth output is tapped off between the plate of the tube and ground. The circuit is so adjusted as to take only that part of the charging voltage which approximates linearity.

The minimum voltage of the sawtooth output will be the drop in the plate load subtracted from B-plus. Its maximum voltage will be the firing voltage of the 884 tube. Adjustment of the circuit constants makes it possible to select only a small, but the most linear, portion of the charging curve. The frequency of operation of this sweep oscillator will be determined by the values of resistance and capacitance in the tube plate circuit.

The fact that the sawtooth wave pattern is repeated time after time deserves mention. Earlier in this lesson reference was made to the need for presenting in rapid suc-

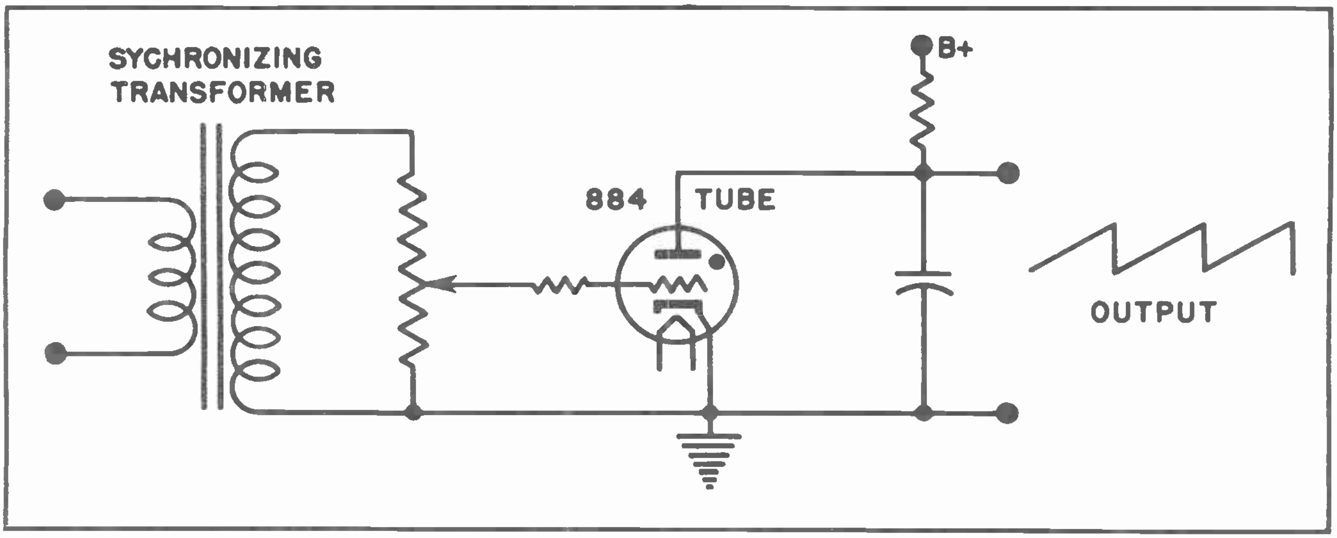

Fig.26. Sweep Voltage Generator

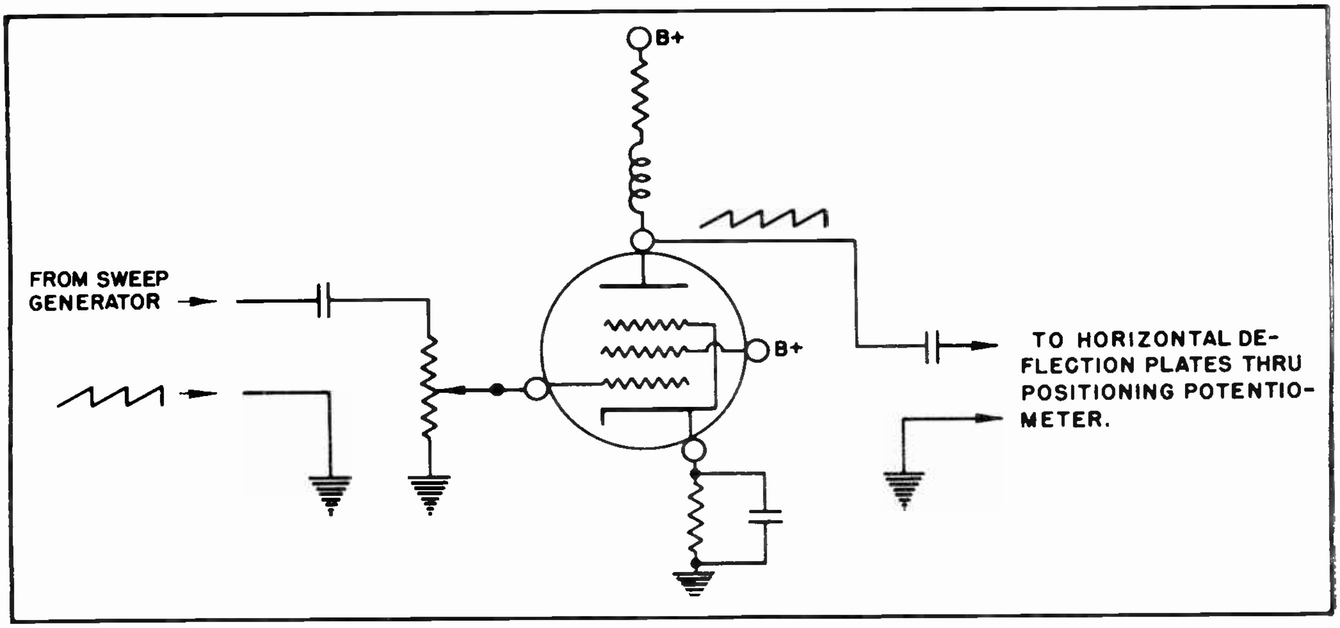

Fig.27. Sweep Voltage Amplifier.

cession a series of the same picture on the screen. By so doing the eye could add them all up into one composite and steady image. The sweep oscillator's action in producing a repetitive sawtooth wave-form serves this requirement exactly. The synchronizing transformer, shown in Fig. 26, connects to the "External Synch" terminal on the control panel of the oscilloscope, and provides for grid control of the 884 thyratron firing in order to keep the sweep in step with the frequency of the signal voltage under examination. During the very brief time the tube is firing, the sawtooth wave drops

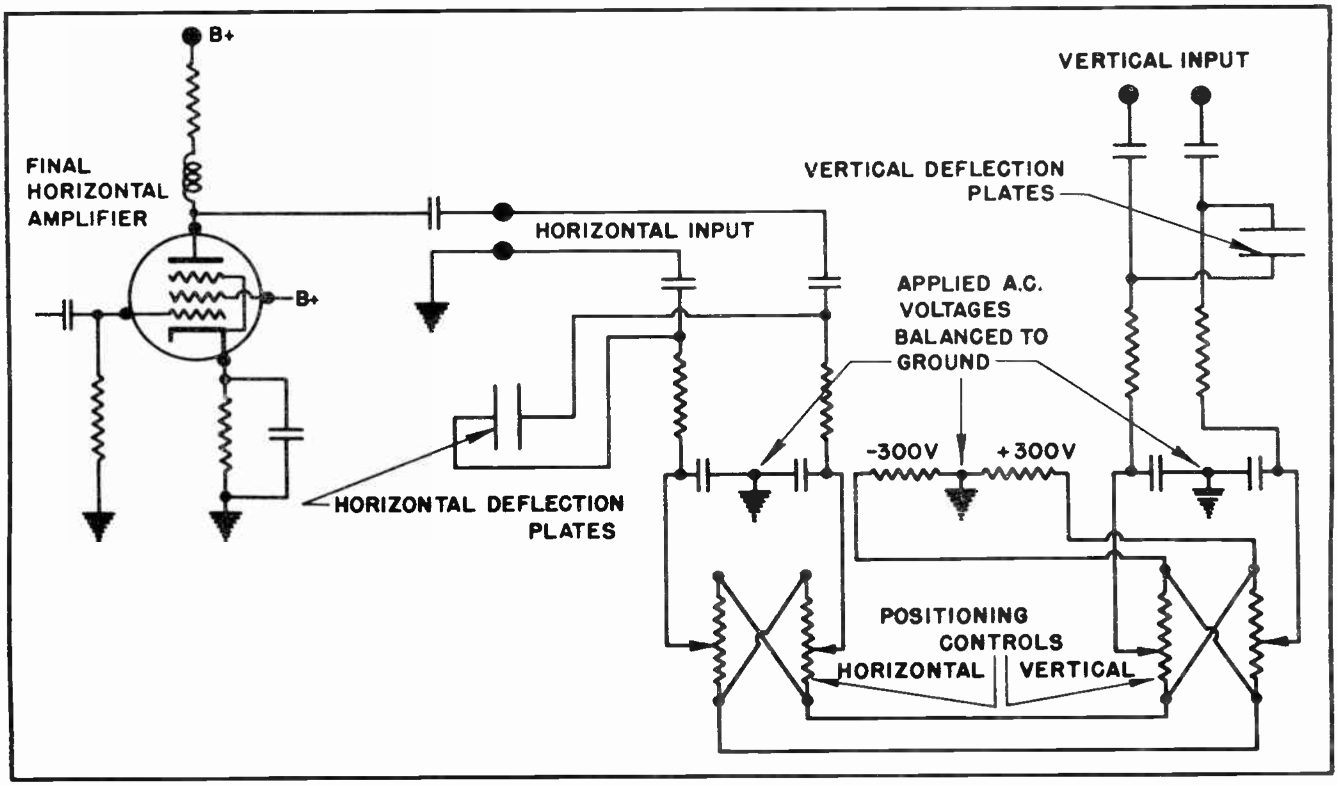

Fig.28. How the Sweep Voltages are Balanced to Ground.

to minimum potential. During this instant of time, the electron beam quickly flies back to its stable position within the tube, and this position is fixed as the starting point of every sweep cycle. By the proper application of a negative pulse of voltage on the control grid, this "fly-back" trace can be blanked out, in order to keep it invisible.

Another part of the sweep section of the oscilloscope is the sweep amplifier. This stage serves to amplify the output of the sweep generator without altering its waveform, and must operate with extremely high fidelity. The circuit for the sweep amplifier is shown in Fig. 27, and reference to the diagram will show that this amplifier is a resistance-coupled stage whose plate load -- being essentially of pure resistance -- does not discriminate against the high frequencies which compose the sawtooth wave.

This stage also has the important function of balancing its output to ground, as illustrated in Fig. 28. This is achieved by applying the sawtooth voltage across a resistance-capacitance network which is center-tapped to ground and accomplishes the purpose of rendering the left-hand deflection plate increasingly negative while at the same time causing the right-hand deflection plate to become increasingly positive. The action of the deflection plates is thus a *push* against the electron beam from the left, and a pull toward the right.

Section 12. THE VERTICAL AMPLIFIER

In turning our attention from the sweep section to the vertical amplifier section, we should keep in mind that the voltage originating in the sweep section and that amplified by the vertical amplifiers are *both* applied to their respective pairs of deflection plates. This means that the amplifiers in both sections must have one thing in common -- high fidelity. Fig. 29 shows the circuit diagram of the vertical amplifier section of the oscilloscope. Our example consists of two stages, resistance-coupled, with enough total gain to build up even an extremely weak input to a value which will appreciably deflect the electron beam of the 'scope when applied to the vertical deflection plates. High-gain pentodes are used here.

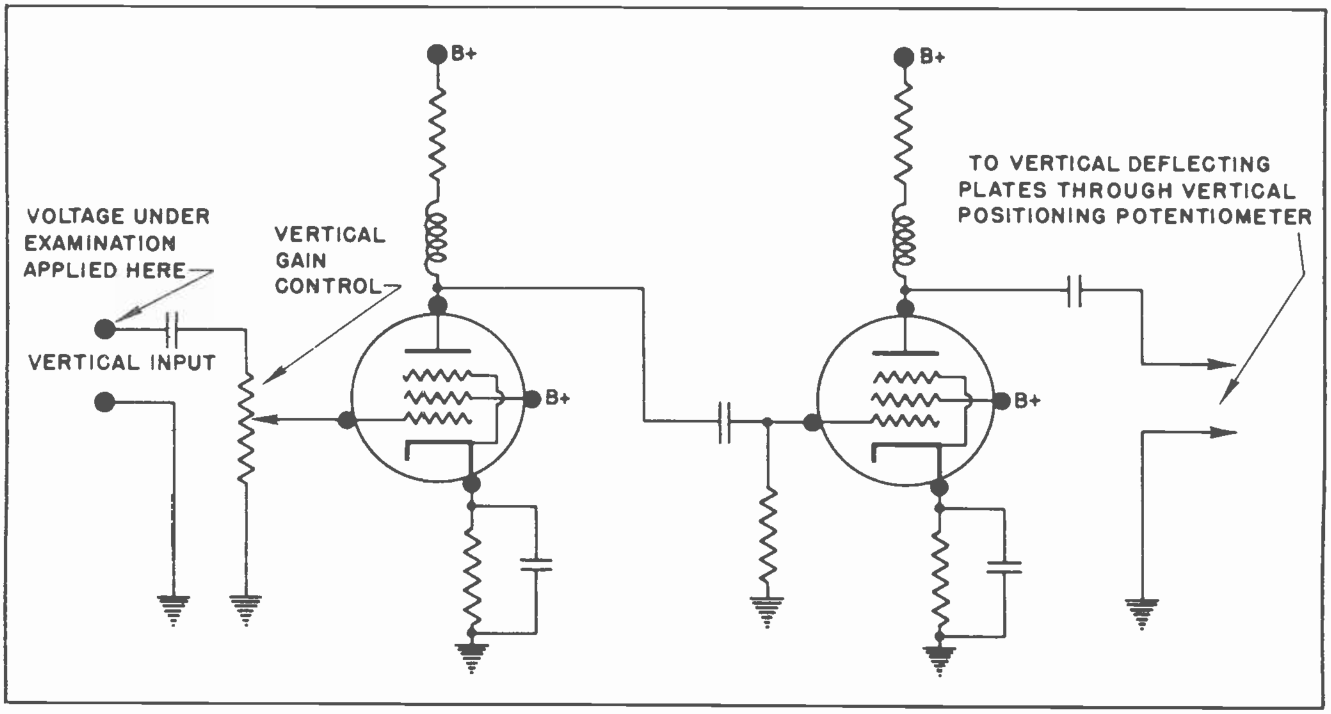

Fig.29. Vertical Amplifier

An important consideration is that we are interested in maintaining the *phase* relationship of the voltage to be examined. We must take into account the 180° phase-shift present in resistance coupled amplifiers. Since the plate voltage output of this type of amplifier is 180° out of phase with the grid voltage, a single stage of voltage amplification will turn the waveform of the voltage under investigation upside-down. In some applications this is not too important. In others, however, it may be of great importance. The second stage of the vertical amplifier section, in addition to providing additional gain for extreme sensitivity, also serves to re-invert the input signal back to its original phase.

As in the case of the sweep amplifier, the output of the vertical amplifier section is balanced to ground by center-tapping the voltage-drop across the load of the final stage. The purpose here, as in the case of the sweep amplifier, is to minimize "hum" interference and to permit a push-pull action of the vertical deflection plates acting upon the electron stream.

Section 13. **THE POWER SUPPLIES**

Fig. 30 is a circuit diagram of the combined power supplies of a typical oscilloscope. As can be seen from this diagram, the system is really two power supplies in close association with each other. Connections to the elements comprising the electron gun correspond to those of Fig. 6. Inspection of the diagram will show that the most negative potential in the entire system originates in the upper of the two rectifier tubes (the 80's). This is the high-voltage power supply, a half-wave rectifier and filter system whose most extreme negative potential is applied to the control grid and the cathode of the cathode ray tube.

Note that the accelerating anode is tied directly to ground, and that the focusing anodes are variable at a point relatively close to ground. Since the cathode is about 1000 volts *below* ground, the potential of ground and the accelerating anode are 1000 volts *above* the cathode.

The voltage positioning of the positive side of the high-voltage power supply is a safety precaution. Most of the controls are at a high positive potential. If the

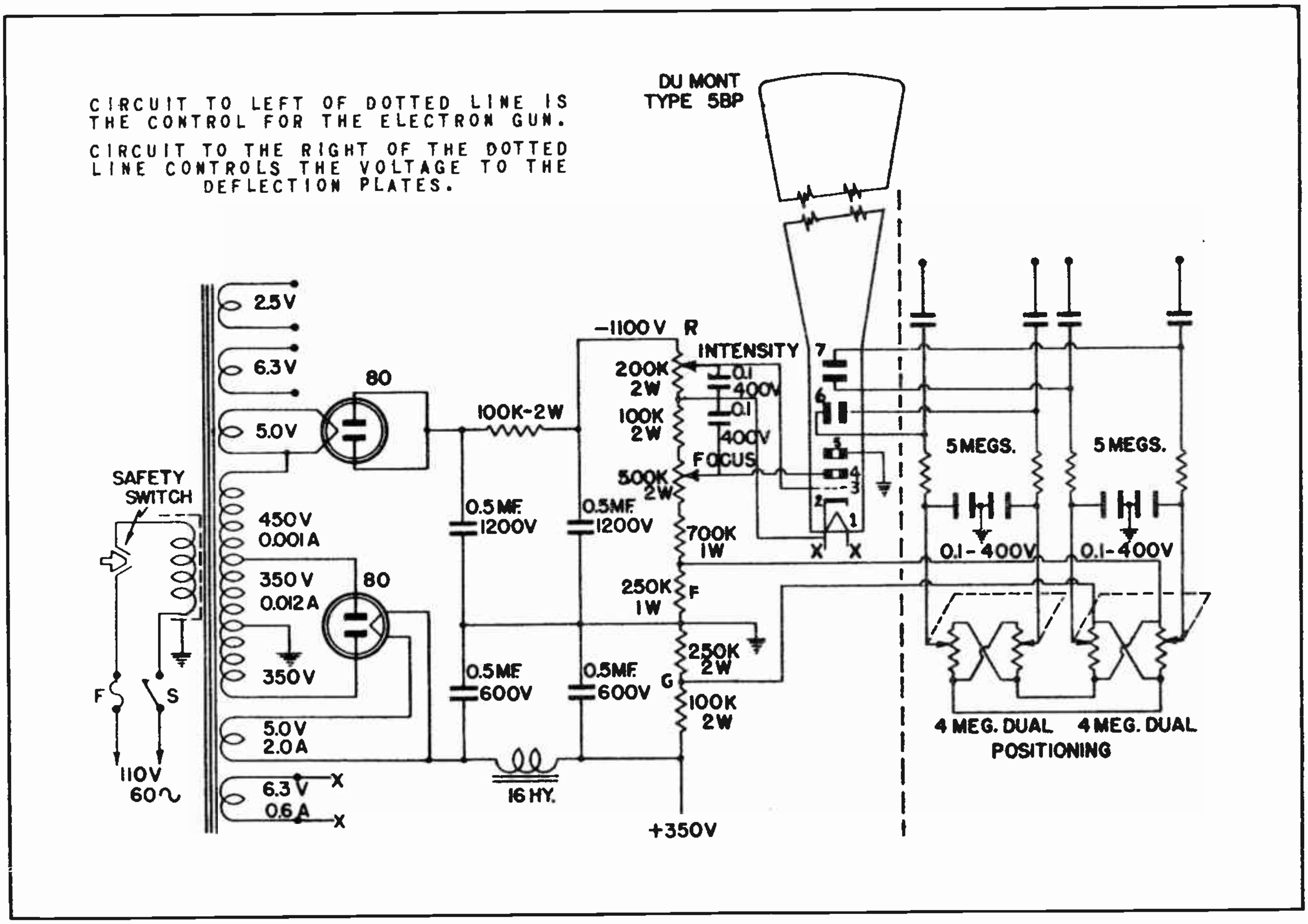

Fig.30. Schematic Showing the Power Supply of an Oscilloscope.

operator were to handle these controls while they "float" at a high positive potential, there would always be a risk of obtaining a severe accidental shock. The operator is usually at ground potential, and if the controls are also at ground potential he is less likely to suffer any ill results from accidentally coming into contact with positively charged electrical circuits.

The low-voltage power supply originates in the full-wave rectifier shown in Fig. 30, and its most *negative* voltage is tied directly to ground. The positive 350 volts are fed to the plates and screens of the amplifier stages, to the plate of the sweep generator, and to the dual potentiometers utilized to position the electron beam at the vertical and horizontal deflection plates.

The low-voltage power supply uses a Pi-type LC filter, in contrast to the PI-type RC filter in the high-voltage power supply.

The low-voltage secondaries of the power transformer are required for powering the heaters of the various tubes.

The entire system is fused and provided with a safety "interlock" which opens the 60-cycle power input circuit when one of the case panels is removed for adjustment and servicing.

CONTROLS AND CONNECTIONS ON THE OSCILLOSCOPE

PANEL CONTROL	ELECTRICAL LOCATION	PURPOSE
Intensity	Control grid of CR Tube	Brighten or darken the spot on the screen.
Focus	Focusing anodes	To sharpen the image on the screen.
V-Position	Vertical Deflecting Plates	To properly position the electron beam in a vertical plane.
H-Position	Horizontal Deflecting Plates	To properly position the electron beam in a horizontal plane.
Sync.	Grid of the 884 gas triode (sweep generaator)	To synchronize the sweep voltage and keep it in step with the signal under investigation.
V-Gain	Control grid of vertical amplifier	To raise or lower the amplitude of the signal under investigation.
H-Gain	Control grid of the horizontal amplifier	To raise or lower the amplitude of the sweep voltage.
Sweep Range	Selectable capacitors in the plate circuit of the sweep generator	Coarse control of sweep frequency.
Sweep Vernier	Variable resistor in the plate circuit of the sweep generator	Fine control of sweep frequency.
Ext-Int Sync.	Sweep generator input	To assist in "locking in" whichever type of synchronizing voltage used.
Sweep Selector	Input to horizontal amplifier	Selects between internal or external sweep voltages.

The V-Ground pair of binding posts are the input connections for the voltage under examination. They lead to the vertical amplifier.

The H-Ground pair of binding posts are the input connections for an external source of sawtooth voltage, if used. They lead to the horizontal deflecting plates.

The Ext. Sync. binding post is the connection to the input of the sweep generator, and is used when exact and undrifting synchronization between sweep and signal is required. This generally results in a 1:1 ratio of horizontal to vertical voltage frequencies.

The on-off switch is physically connected to the Intensity Control, whose maximum counter-clockwise position turns the power to the oscilloscope off.

Section 14. **GENESCOPE**

The Simpson Electric Co., of Chicago, has designed a test instrument for FM and Television Servicing which combines into one unit several of the instruments we have studied. It is called a Genescope. Its appearance is clearly shown in Fig. 31.

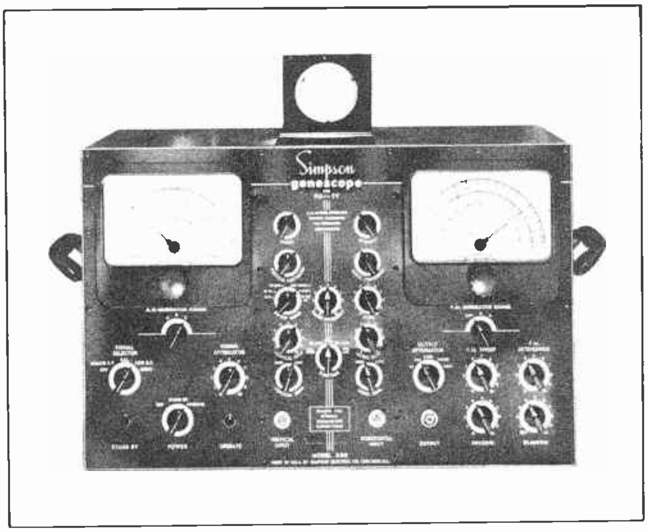

Fig.31. Genescope.
(Courtesy Simpson Electric Co.)

The Genescope combines an ordinary audio and RF signal generator with an FM signal generator and an oscilloscope. To increase its usefulness the instrument is semi-portable. The cost of the Genescope is somewhat less than the total cost of the individual test instruments it replaces.

The Simpson Model 480 Genescope has been designed to supply all the signal sources necessary to properly align all types of FM and TV Receivers. Built into the same unit is a highly sensitive oscilloscope. The 'scope includes all the latest features of advanced design, and is equipped with a high frequency crystal probe which is a useful aid in signal tracing.

The left hand side of the Genescope as shown in Fig. 31 contains a 400-cycle audio signal generator, an RF signal generator covering 3 RF frequency ranges, and a special crystal calibrator. By means of the crystal calibrator it is possible for the user to check the output frequency of the generator at intervals and make certain the generator is accurate.

The right hand side of the panel as shown in Fig. 31 controls the FM frequencies. These frequencies are useful in working with FM radio receivers and the sound channels of Television Receivers. The FM generator is so constructed that it can put out signals which range in frequency from 2 megacycles (2,000,000) to 260 megacycles (260,000,000).

The center portion of the control panel operates the oscilloscope. The screen end of the cathode ray tube can be seen projecting at the top of the cabinet. The operation of the oscilloscope section of the Genescope is very similar to that of the 'scopes we have been discussing in this lesson.

NOTES FOR REFERENCE

The oscilloscope is the most powerful weapon at the serviceman's command.

The oscilloscope uses and handles high voltages. BE CAREFUL.

The oscilloscope enables the serviceman to look directly into the inside of an electrical circuit and "See" what is happening there.

In many ways the construction and operation closely resembles the Video section of a television receiver.

The oscilloscope can generate its own sweep voltages, or can be synchronized with some external frequency.

The Genescope combines the features of the oscilloscope with those of other test instruments.

NOTES

SYMBOL OF PROFICIENCY

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