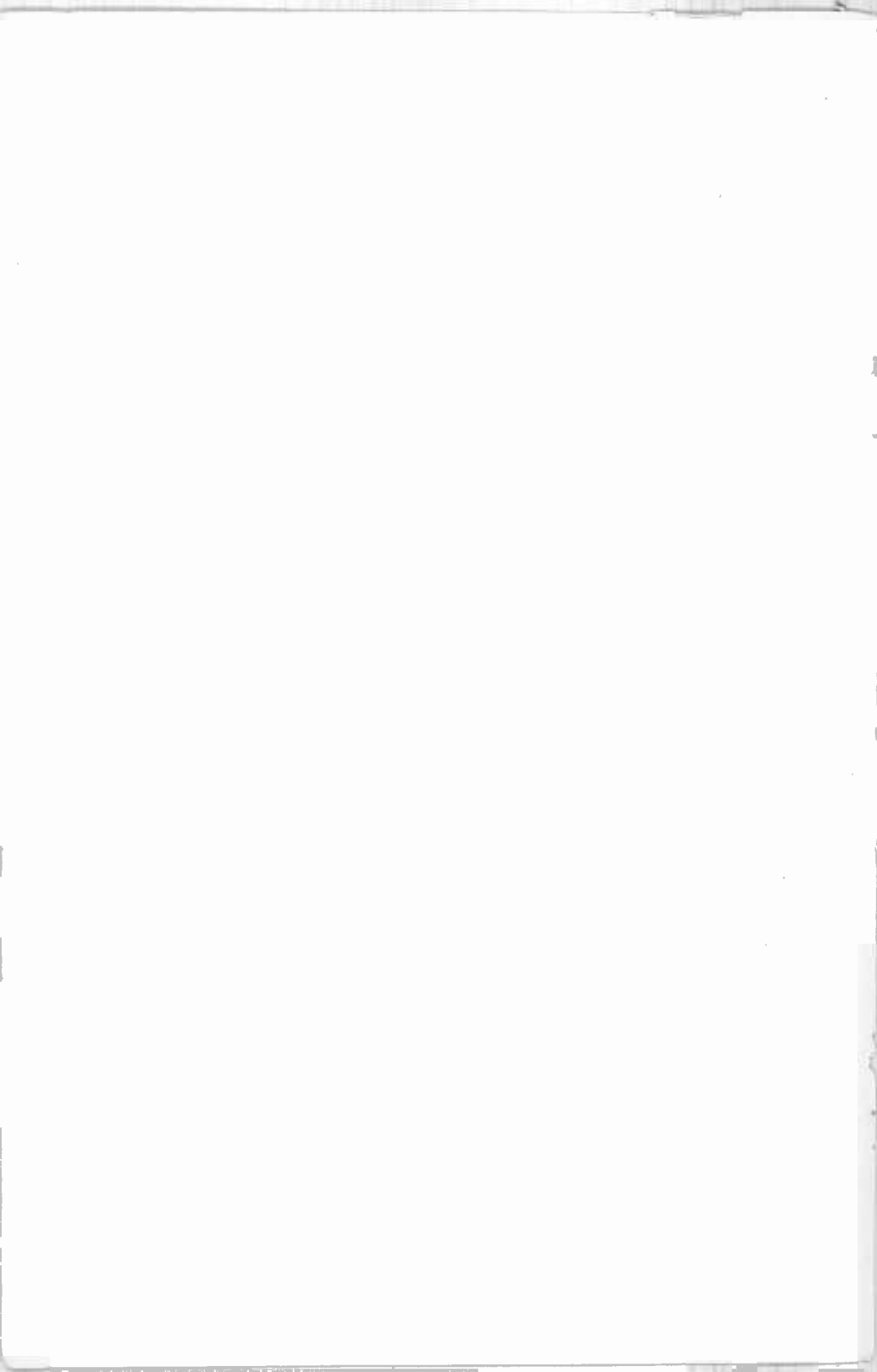


THE CATHODE-RAY
OSCILLOSCOPE
Lesson RRT-20



DE FOREST'S TRAINING, INC.
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RRT-20





LESSON RRT-20

THE CATHODE-RAY OSCILLOSCOPE

CHRONOLOGICAL HISTORY OF RADIO AND TELEVISION DEVELOPMENTS

January 1, 1949—Fifty-five television transmitters in operation, and 951,135 television receivers in use.

January 11, 1949—Coaxial Cable connection established between Eastern TV network and Midwest network.

January 20, 1949—Presidential inauguration ceremonies televised. It was estimated that 10,000,000 viewers witnessed the affair.

DE FOREST'S TRAINING, INC.

2533 N. ASHLAND AVE., CHICAGO 14, ILLINOIS

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-20

THE CATHODE-RAY OSCILLOSCOPE

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Nothing really is impossible—there are ways that lead to everything, and if we have sufficient will, we will always have sufficient means. It is often merely as an excuse that we say things are impossible.

—Selected

THE CATHODE-RAY OSCILLOSCOPE

Most of the previous explanations, concerning the electrical actions in radio circuits and testing instruments, involved the generation and measurement of alternating voltages and currents.

Also, in most cases, proper operation of the equipment can be determined by checking at certain points in the circuit for the amplitude or frequency of an alternating voltage or current.



Cathode-ray oscilloscope with all controls clearly marked for quick and easy adjusting.

Courtesy Precision Apparatus Company

However, in radio and particularly television, there are circuits in which the a-c waveform is of major importance.

Conventional types of meters can measure the average, effective or peak amplitudes of a-c and its frequency can be measured by checking against the output of a calibrated oscillator. For these tests, the waveform is unimportant or assumed to be correct, and although a distorted waveform may affect the reading, the meter can not indicate this condition. For example, when the output of a speaker is distorted, the waveform of its input differs from that of the original signal and the operation is not satisfactory although the input may be of proper amplitude and frequency. Therefore, some type of equipment is needed to indicate the actual waveform of a-c voltages which exist in circuits under test.

In many explanations, it is common practice to represent an alternating voltage by means of a picture or graph, which shows the changes of amplitude and polarity during the period of time necessary to complete one or more complete cycles.

An amplitude-time graph, of the type illustrated in Figure 1, gives most of the information about a waveform without necessitating any mental calculations

to interpret the picture. It is desirable, therefore, that the waveform determining device produce a graph of this kind so that an alternating voltage can be studied thoroughly by an observer and this is accomplished with an instrument known as a "Cathode-Ray Oscilloscope".

The cathode-ray oscilloscope, abbreviated "cro" and sometimes called an "Oscillograph", has been described as a vtvm which, as an indicating device, employs a luminous pattern on a screen in place of a pointer that moves across a calibrated scale. Although this instrument can be employed for voltage amplitude measurements as well as many other indications, its primary purpose is to permit the observation of voltage waveforms. The most important component in the cro, and that which makes the visual observation of the waveforms possible, is an evacuated electron tube, called a "Cathode-Ray Tube", larger in size than an ordinary receiving tube. Because of its somewhat complex construction, and the fact that its mode of operation is different from that of the tube types described so far, a brief explanation of the cathode-ray tube will be given first.

THE CATHODE-RAY TUBE

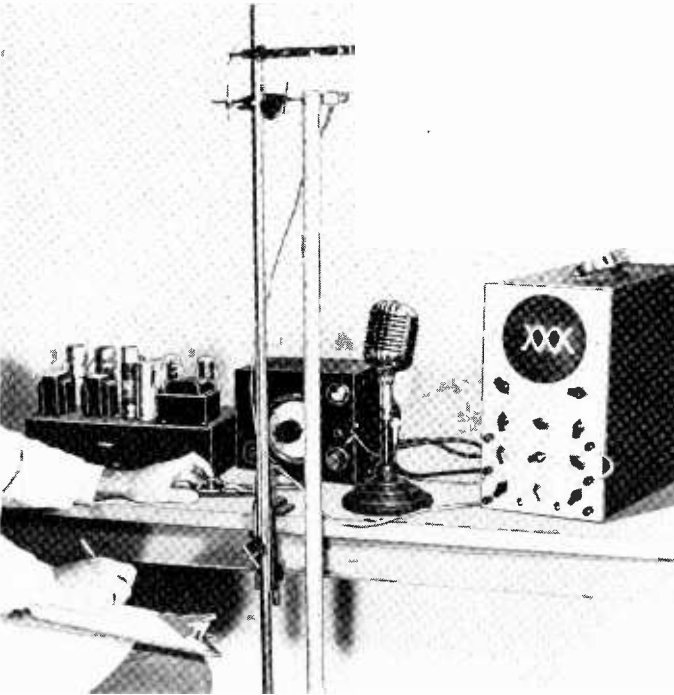
Many types of cathode-ray tubes have been developed and as uses for these tubes increased, it

became necessary to design them with characteristics to satisfy the new requirements. Cathode-Ray tubes are employed in television cameras and receiving equipment, radar, laboratory apparatus, etc., but in this lesson, only the type used in the cro will be described.

As illustrated in the drawing in Figure 2, the general con-

struction of this type of cathode-ray tube, abbreviated "crt", includes a heater, a cathode, a grid, several anodes and deflection plates; while the inner surface of the large end of the glass envelope is coated with a fluorescent material called the screen.

As in ordinary radio tubes, the cathode is the source of electrons, but in the crt, they are attracted toward the screen by the anodes that operate at high positive po-



Experimental set-up showing how cathode-ray oscilloscope is used to check the frequency characteristics of chime tubes.

Courtesy Revere Copper and Brass Incorporated

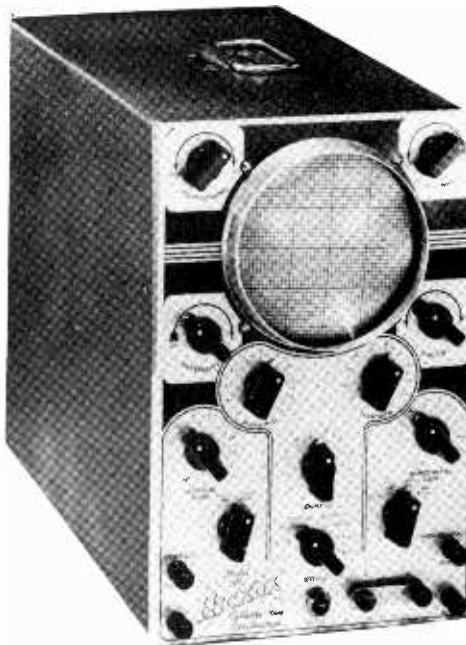
struction of this type of cathode-ray tube, abbreviated "crt", includes a heater, a cathode, a grid,

several anodes and deflection plates; while the inner surface of the large end of the glass envelope is coated with a fluorescent material called the screen. The intensity of the electron stream is determined by the bias voltage applied to the

control grid, while its lateral movements are determined by the voltages applied to the vertical and horizontal deflection plates. Thus, the entire action of the cathode-ray tube depends upon the proper control of the elec-

THE ELECTRON

All matter is made up of at least 92 fundamental constituents commonly called elements. These elements can exist, either in the free state such as iron, oxygen,



All-purpose 5-inch oscilloscope suitable for the development laboratory and service shop.

Courtesy Hickok Electrical Instrument Company

trons, and before taking up the details of these controls, it will be well to review a few facts concerning the electron itself.

carbon, copper, aluminum, sulphur, lead and mercury, or in chemical combination with other elements as they are found in

compounds. The smallest unit into which an element can be divided and still retain all of its original characteristics is the atom. Combinations of atoms, or subdivisions of compounds, result in another fundamental unit, the molecule, which is the smallest unit of any compound.

Theoretically, the atom has been subdivided further into a positively charged center region or "nucleus", and a surrounding cloud of negatively charged particles called electrons. In the atoms of metallic elements, some of the electrons are held loosely and hence move about, even shifting from one atom to another. Whenever conditions are such that a large number of the free electrons move in the same direction at one time, a "flow" of electricity is said to be taking place.

Within the metal atoms, the electrons revolve around the central nucleus at extremely high speeds, and if heat is applied, their velocities are increased. When the metal becomes hot enough to glow, some electrons acquire sufficient speed to break away from its surface. This action, which is most prominent when the metal is heated in a vacuum, is utilized in most electron tubes to produce the needed supply of electrons; the metal in this case being called the cathode.

The mass of an electron has been estimated by scientists to be

approximately 9×10^{-28} gram. It would require 346 billion, billion, billion such minute particles to weigh one ounce. In a crt employing an accelerating potential of 2000 volts, the speed of the electrons is approximately 2.67×10^9 centimeters per second. This is equivalent to 59,700,000 miles per hour and at this speed, they would travel a distance equal to the circumference of the earth at the equator in $1\frac{1}{2}$ seconds. The speed will vary with the square root of the accelerating potential. Therefore, in the above example, it would be necessary to raise the accelerating potential to 8000 volts in order to double the velocity.

ELECTRON GUN

As shown in the cross section view of Figure 2, the cathode-ray tube can be divided into three main sections. 1: The electron gun which contains the various electrodes that produce the cathode ray, 2: The deflection system which, in this case, consists of two pairs of plates and 3: The screen which consists of a coating on the inside of the large end of the glass envelope.

Starting at the left of Figure 2, the cathode is in the form of a cylindrical nickel sleeve, inside of which is the heater that has a coating of insulating material (aluminum oxide) to prevent

its shorting to the cathode. The control grid, also in the form of a cylindrical sleeve, contains a disk near its forward end and is mounted so as to surround the cathode. The first anode is a somewhat longer cylindrical sleeve, and contains two or more disks with openings in the center, like that of the control grid. Finally, also in the form of a sleeve, is the second anode, which is somewhat larger in diameter, and usually contains no disks.

As in ordinary amplifier tubes, the control grid operates at a negative potential with respect to the cathode, but here the first anode operates at a few hundred volts positive, and the second anode at from 1000 to several thousand volts positive. Being attracted by the positive first anode, the electrons are drawn away from the cathode and through the opening in the disk of the grid. Many electrons are collected or stopped by the various disks, and only those which are traveling along the center axis of the tube are able to pass through all the openings and continue in the direction of the screen.

The highly positive potential on the second anode accelerates the remaining fine stream of electrons to a high velocity so that they continue through the tube and strike the screen. This

electron stream, or cathode ray, is very small in diameter, due to the small openings in the disks of the grid and first anode. Thus, the electron beam which strikes the screen is on the order of only two or three hundredths of an inch in diameter. The fluorescent material, of which the screen is composed, glows under the electron bombardment, and thus a small round dot of light appears on the face of the tube.

A second factor which determines the diameter of the electron beam, or dot of light on the screen, is the difference in potential between the first and second anodes. Because of this difference, an electrostatic field of force exists between these anodes, and this field has the effect of confining the electron beam to a small cross-sectional area. Thus, it is possible to adjust or "focus" the spot on the screen by changing the difference of potential between the two anodes. In practical crt circuits, this focusing of the spot is accomplished by means of a potentiometer which permits changing the potential of the first anode, while that of the second anode is kept constant.

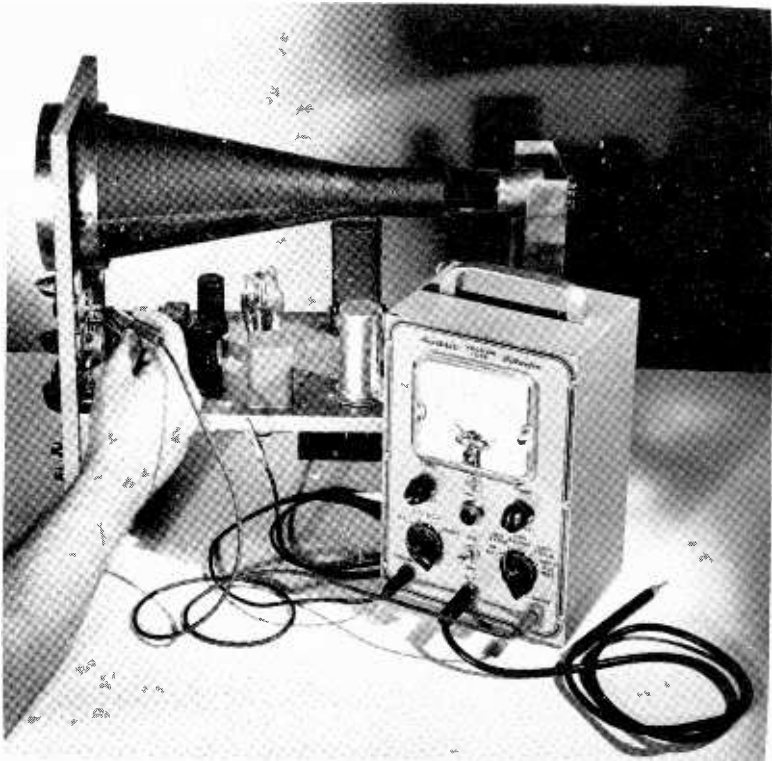
DEFLECTION OF THE BEAM

Up to this point of the explanation, the spot of light would remain stationary at about the center of the screen and in order

that the tube can be of practical use, it is necessary to move the spot so that the desired pattern or waveform can be traced. This is the function of the deflection electrodes, labeled vertical

which they deflect the electron stream, not according to their physical positions in the tube.

This method of electron stream deflection, known as the "electrostatic" system, operates on the



Checking the circuit operation in an oscilloscope with the aid of a high-impedance vacuum-tube voltmeter.

Courtesy Heath Company

and horizontal plates in Figure 2. These consist of metal sheets, having the general shape and location shown, which are named "vertical" or "horizontal" in accordance with the direction in

principle that like electrical charges repel and unlike charges attract. For example, consider an end view of the four deflection plates, shown in Figure 3, with the electron stream

traveling from the cathode of the electron gun out of the page toward you. If a d-c voltage, E_H , is applied to the horizontal plates D_1 and D_2 , so that D_2 is positive and D_1 negative, the negative electrons of the cathode ray will be attracted by D_2 and repelled by D_1 , so that the stream, and consequently the luminous spot on the screen, will be deflected to the right as indicated by the small arrows.

If the polarity of the applied voltage E_H is reversed, so that deflection plate D_1 becomes positive and D_2 negative, the electron stream will be deflected to the left in the figure. The amount of deflection (distance the spot moves from the center of the screen) is determined by the magnitude of the applied voltage. If instead of d-c, the voltage E_H is a-c, the spot on the screen will be moved continually from side to side in accordance with the variations of the applied voltage.

In the same manner, a voltage E_V applied to the vertical deflection plates, D_3 and D_4 , will cause the stream to be deflected upward when D_3 is positive and D_4 negative, and downward when D_4 is positive and D_3 negative. Likewise, if E_V is alternating, the spot will move up and down on the screen in accordance with the variations of the applied voltage. When both a-c voltages, E_V and E_H , are applied at the same time,

the path of the spot on the screen will form a more or less complex pattern, as it will then be controlled by the instantaneous values of the various attracting or repelling potentials of all four deflecting plates.

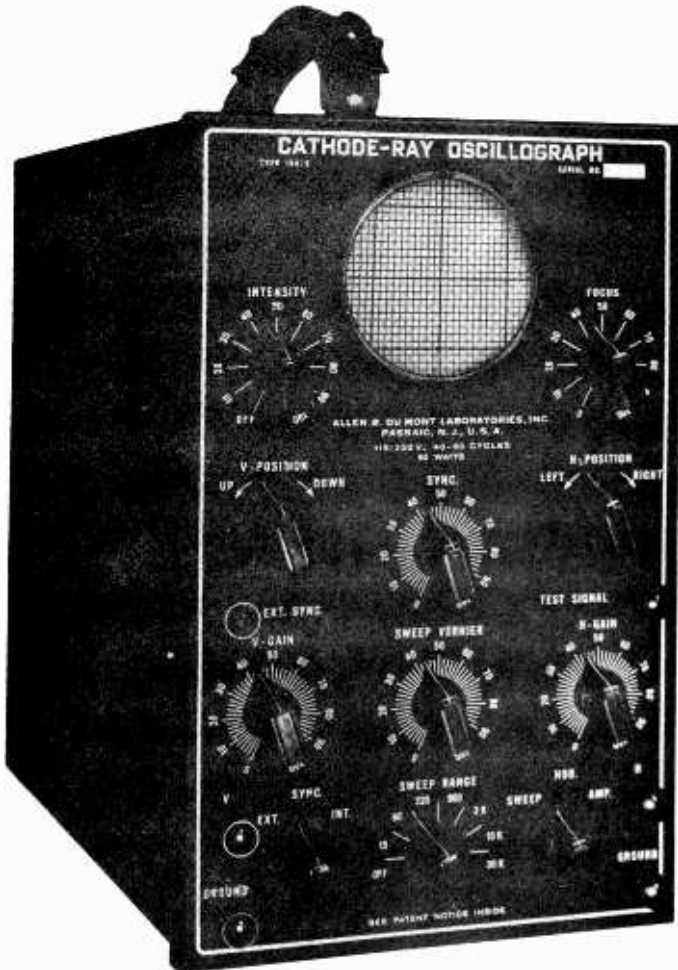
If the screen material were such that, at any instant, it would glow only at the point at which the cathode-ray electrons are impinging, it would be difficult for the human eye to obtain a satisfactory picture of the path of the spot. The human eye retains an image for a short period of time and this ability can be detected by watching a bright spot on a spinning wheel. After a certain speed of rotation is attained, the bright spot may appear as a complete circle. To aid the eye in seeing the path traversed by the spot, the crt screen is coated with a material which glows for a short time after the electron stream has moved to another position. Thus the path of the rapidly moving spot is made to appear as a distinct and stationary line.

Different uses demand various degrees of persistence or duration of this after-glow and the screen of the tube may be referred to as having a short, medium, or long persistence. By employing different kinds of material for the screen, the trace may be made to appear green, yellow, blue or white. For some

applications one color may be preferred to all others.

Information on the crt may be obtained from the tube designation and although the nomenclature is not completely standardized, certain methods of convey-

ing information on tubes are followed by many manufacturers. In this system, the first number denotes the maximum diameter of the envelope in inches. The letter P with a number following it, indicates the type of fluorescent screen. All other letters between



Cathode-ray oscilloscope designed for general developmental and research laboratory work.

Courtesy Allen B. DuMont Laboratories, Inc.

the first number and the letter P denote differences in gun construction, etc., between tubes of the same size and screen material. P1 and P2 indicate green screens; P4 white, and P5 light blue. A tube designated as 9AP4 has a diameter of 9", an accelerating or screen grid, and a white screen. Additional information may be found in tube manuals and catalogs.

As most graphs show amplitude in a vertical direction, the voltage to be observed is usually applied to the vertical deflection plates of the crt. However, if this is the only deflection voltage applied, a vertical line or trace will be produced on the screen, as explained for Figure 3. The length of this line will be indicative of the peak amplitude of the applied voltage, E_v , but no information will be obtained concerning its waveform.

In order to "spread" the trace in a horizontal direction, and thus produce a pattern having the shape of a desired amplitude-vs-time graph like Figure 1, a second deflection voltage E_H must be applied to the horizontal plates. In oscilloscope work, this horizontal deflection voltage is called the "time base" or "sweep."

The waveform of the time base voltage depends upon the application of the crt. In most oscilloscope work, the sweep voltage

requires a waveform that moves the spot at a steady speed from left to right across the screen, immediately snaps it back to the left side, and then starts another steady left-to-right sweep. The left-to-right movement must be at uniform speed in order that equal distances on the horizontal axis of the pattern will represent equal units of time. If a true picture of the wave shape is desired, the common sine wave voltage cannot be used as a sweep because it would cause the horizontal speed of the spot on the screen to vary continuously.

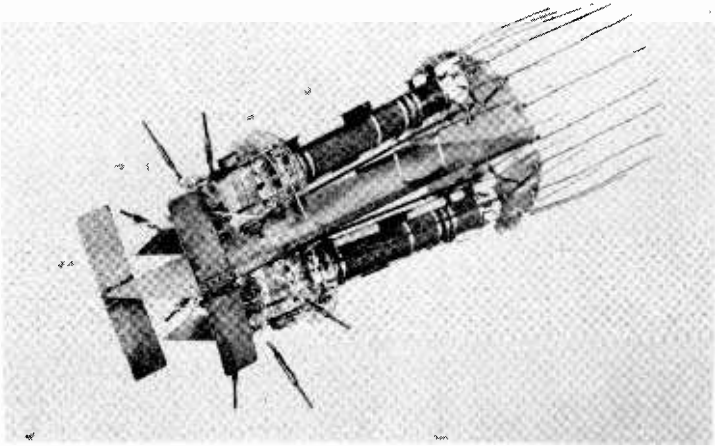
To deflect the cathode-ray beam so that the spot sweeps across the screen at a linear or constant speed, it is necessary to apply a deflection voltage which changes uniformly from zero to maximum, and then almost instantly jumps back to zero. A change of this type is called a "sawtooth voltage" or "linear time base", and has a waveform similar to that shown in Figure 4-A.

CRO TIME BASE CIRCUIT

The portion of the oscilloscope circuit which produces the needed sawtooth horizontal deflection voltage, often termed "sweep voltage", is shown in Figure 4-B. The tube V is a gas-filled triode, called a thyratron, across which any one of a group of four condensers can be connected by means of switch S. Resistors R_2

and R_3 form a voltage divider across the B supply, with the voltage drop across R_3 employed as a bias for the grid-cathode circuit.

However, the condenser will charge through resistor R_1 and the voltage across it and the tube will increase at a steady rate



Internal gun arrangement for a two-gun cathode-ray tube.

Courtesy Electronic Tube Corporation

With the tube in operating condition and switch S in the position shown, when the B supply circuit is closed there will be current in the voltage divider and the resulting drop across R_3 will impress a negative voltage on the grid. Condenser C_1 is connected directly across the tube from plate to cathode therefore the plate voltage will always be equal to its charge. With the condenser discharged there will be no voltage across it and, when the B supply circuit is first closed, there will be zero plate voltage across the tube.

as shown between points 1 and 2 of the curve in Figure 4-A. Due to the drop across R_3 , the tube is biased to plate current cutoff at the reduced values of plate voltage and therefore is non-conductive. As the voltage across the condenser rises to some predetermined value, the plate circuit of the tube becomes conductive and the condenser discharges through it.

Due to actions that will be explained in following paragraphs, the condenser discharge is extremely rapid and the voltage across it reduces as indicated be-

tween points 2 and 3 on the curve of Figure 4-A. With the condenser and plate voltage reduced to zero, the plate circuit of the tube becomes non-conductive and the action repeats as indicated through points 3-4-5. This "saw-tooth shaped" voltage across C_1 is coupled through C_c and appears as the output voltage E_o of the circuit.

HOW THE THYRATRON OPERATES

The ability of the thyatron tube to function in the manner explained above is due to the fact that the gas with which it is filled will "ionize" when a high enough difference of potential exists between the cathode and plate.

In the earlier explanations of gaseous rectifier tubes, ionization was mentioned, but to clarify the operation of thyatron tubes, the following details will be of benefit. Every gas, solid, or liquid is made up of extremely small particles, called molecules, which are composed of smaller parts called atoms that, in turn consist of a positively charged central nucleus and a number of negatively charged electrons. While the electrons are often thought of as being merely negative charges of electricity, it will simplify this explanation to think of them as extremely small particles of matter, each carrying a negative charge.

Because unlike electrical charges attract each other, the positive nucleus of the atom attracts the negative electrons which rotate around it, much as the earth travels in its orbit around the sun. When there are enough electrons to balance the positive charge of the nucleus, the atom is electrically neutral or normal.

In the gas-filled thyatron tube, there are always a few free electrons moving about at random, the neutral atoms having no attraction for them. However, when an external voltage is impressed across the plate and cathode, with the plate positive, these free electrons are attracted by and immediately move toward the positive plate at a rapidly increasing speed. But, traveling through a space which contains the neutral gas atoms, they collide with some of them, dislodge an electron or two from each, and then continue on toward the positive plate.

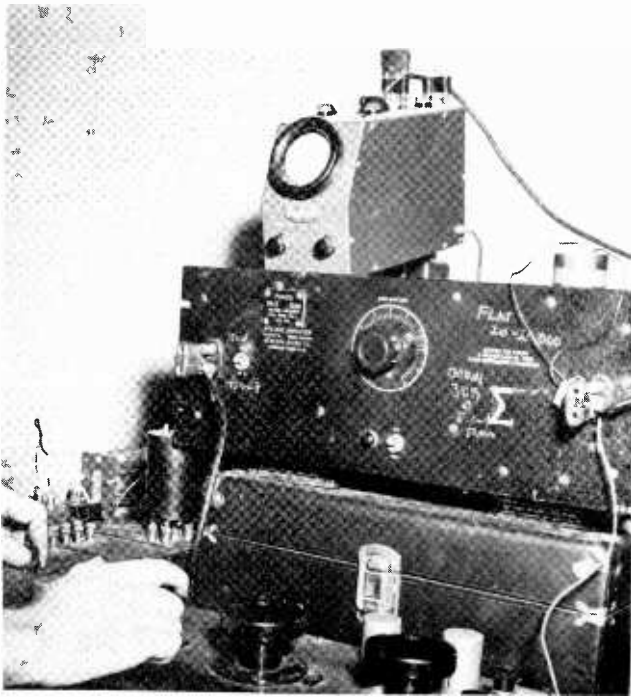
The electrons knocked out of the atoms are also attracted toward the plate, and on their way collide with other gas atoms and free more electrons. Although there were but a few free electrons to begin with, in a very short time a large number are moving toward the plate of the tube.

When an electron is knocked off, an atom is no longer neutral

but has a positive charge, and is called an "ion". With a positive charge, the ion is attracted toward the cathode and tends to move in a direction opposite to that of the electrons. Thus there will be a stream of electrons moving toward the plate and a stream of ions moving toward the cathode.

trons from cathode to plate. This stream of electrons is an electric current and thus the gas, which is normally an electrical insulator, becomes an electrical conductor when ionized.

The external voltage necessary to ionize the gas and "fire" the tube depends upon the type and



The Philco junior 'scope, model 7019, shown here top center, is a compact portable low-cost oscilloscope.

Courtesy Philco Corporation

Electrons which reach the plate are drawn through the external voltage supply and returned to the cathode thus, within the tube, there is a constant stream of elec-

pressure of the gas, the shape and spacing of the electrodes and the bias voltage on the grid. Unlike the high vacuum type of electron tube, in which the grid voltage

controls the plate current at all times, in the thyratron the grid voltage controls only the value of plate voltage at which the tube fires. Once the gas is ionized and plate current is established, the grid loses all control and the current continues until the plate voltage is reduced to a relatively low value.

The value of the "firing" or igniting plate potential can be varied by adjusting the grid bias but, when fired, the tube remains conductive until the plate potential is reduced to the extinguishing or "drop out" value. Going back to the curve of Figure 4-A, points 2 and 4 represent the instants at which the voltage across condenser C_1 and the plate circuit of tube V, Figure 4-B, rises to the igniting value. Acting as an electrical conductor, the ionized gas permits the condenser to discharge almost instantly and the plate voltage reduces to the drop out value indicated by points 1, 3 and 5 on the curve of Figure 4-A.

The frequency of the sawtooth voltage produced by the oscillator or generator of Figure 4-B is determined by the CR time constant of the condenser charging circuit which includes variable resistor R_1 . Different frequency ranges are provided by switch S which connects condensers of different capacitance across the plate cir-

cuit of the tube. Variation of frequency, over any range, is obtained by adjusting the movable contact of R_1 . Usually, the condenser values are such that the frequency ranges overlap slightly and the adjustment of R_1 over each range provides a continuous change of output frequency over all ranges.

An external supply of a definite frequency can be connected across the "SYNC INPUT" terminal and ground. Connected in the grid circuit of tube V, proper adjustment of variable resistor R_s causes the discharge tube to fire exactly in synchronism with the frequency of the external voltage. The drop across the desired portion of R_s is in series with the drop across R_3 in the grid circuit and affects the grid bias. Switch S_1 and variable resistor R_1 are set to provide a frequency approximately equal to that of the external voltage across R_s , then the sliding contact of R_s is adjusted so that the peaks of external voltage will reduce the grid bias sufficiently to fire the tube.

BLOCK DIAGRAM OF A 'SCOPE CIRCUIT

The arrangement of the various component circuits of a cathode-ray oscilloscope is shown by the block diagram in Figure 5. The crt is drawn in semi-schematic form, while the other units in-

clude a vertical amplifier, a time base generator, horizontal amplifier, with low and high-voltage power supplies. The amplifiers are of the resistance-coupled type while the time base generator is similar to that of Figure 4-B and all are operated by the low voltage power supply which is like that of the ordinary a-c type of radio receiver. The high voltage supply develops an output that, in different models, may vary from a few hundred to several thousand volts, and connects only to the electron gun of the crt. It is needed to provide the electrons of the cathode ray with sufficient velocity to produce a bright spot on the screen.

Normally, the voltage to be checked is applied to the binding post VA, which is connected to the input of the vertical amplifier and after amplification, is applied to the vertical deflection plates of the crt. The sawtooth time base generator, adjusted to the desired frequency, is connected through switch S_2 to the input of the horizontal amplifier, the output of which is applied to the horizontal deflection plates.

In order to maintain a stationary pattern on the screen, it is necessary that the sweep voltage frequency have some definite whole-number relationship with the frequency of the voltage under study. This is accomplished

first, by adjusting the frequency of the sweep generator, and second, by applying a portion of the input voltage to the control grid of the sweep oscillator through switch S_1 . If the voltage under study is undesirable for use in synchronizing the sweep oscillator, as in the case of checking certain phase relationships, external synchronization can be obtained from an external voltage by throwing switch S_1 to the lower position, which connects the "EXT. SYNC" binding post to the grid circuit of the sweep generator.

If it is desirable to use an external sweep voltage of a particular type, or if the frequency of an unknown voltage is to be checked, switch S_2 can be set to the lower position. This disconnects the sawtooth input and connects the HA binding post to the input of the horizontal amplifier. This change in connections allows an external voltage to be amplified and then applied to the horizontal deflection plates.

In addition to terminals for the input of the horizontal and vertical amplifiers, most 'scopes have binding posts which permit the application of external voltages directly to the crt deflecting plates. These are indicated by the posts marked VP and HP in the drawing.

HOW SCREEN PATTERNS ARE PRODUCED

Earlier in this lesson it was stated that if a sawtooth sweep voltage is applied to the horizontal plates of the crt, the pattern

circular area "S" represents the screen when looking at the face of the crt.

In this particular case, E_V and E_H are of the same frequency, and therefore, will have the same time



Deluxe five-inch oscilloscope adapted for a-m, f-m, and video servicing.

Courtesy Supreme Instruments Corporation

produced on the screen will be a true amplitude-vs-time graph of the voltage applied to the vertical plates. To follow the action in detail, in Figure 6, curve E_V represents a sine wave voltage to be observed. Curve E_H represents the sawtooth sweep voltage and the

scale. Voltage E_V is applied to the vertical deflection plates so that it causes the electron beam to be pulled upward during the positive alternation of the wave, and downward during the negative alternation, while E_H causes the beam to move from side to

side as explained for Figure 3. The phase of E_H with respect to E_V is such that E_H is at its maximum negative point at the instant that E_V is passing through zero value and going from its negative to its positive alternation. This condition is indicated as time-instant 0, and the information is projected onto the screen area S by means of dotted lines.

One line, projected vertically upward from time point 0 on curve E_H and another line, projected horizontally to the right from time point 0 on curve E_V , intersect at point 0 on the screen S. This intersection indicates the point at which the spot of light will appear at this instant.

Following the same plan, lines projected from points 1 on the E_H and E_V curves intersect at point 1 on the screen. Thus, during the interval between time points 0 and 1, voltage E_V has increased in value while voltage E_H has decreased. Therefore the spot on the screen has moved from point 0 to point 1. In the same manner, by projecting from the time points of both curves in numbered sequence, the intersection points on the screen trace a path almost exactly like curve E_V . However, shortly before curve E_H reaches time point 8, it reverses polarity thereby causing the spot on the screen to move almost in-

stantly from right to left and back to point 8 which corresponds to point 0 as the start of a cycle. This rapid movement is indicated by the broken line which, on the screen, slopes upward slightly from the right end of the solid curve to point 8.

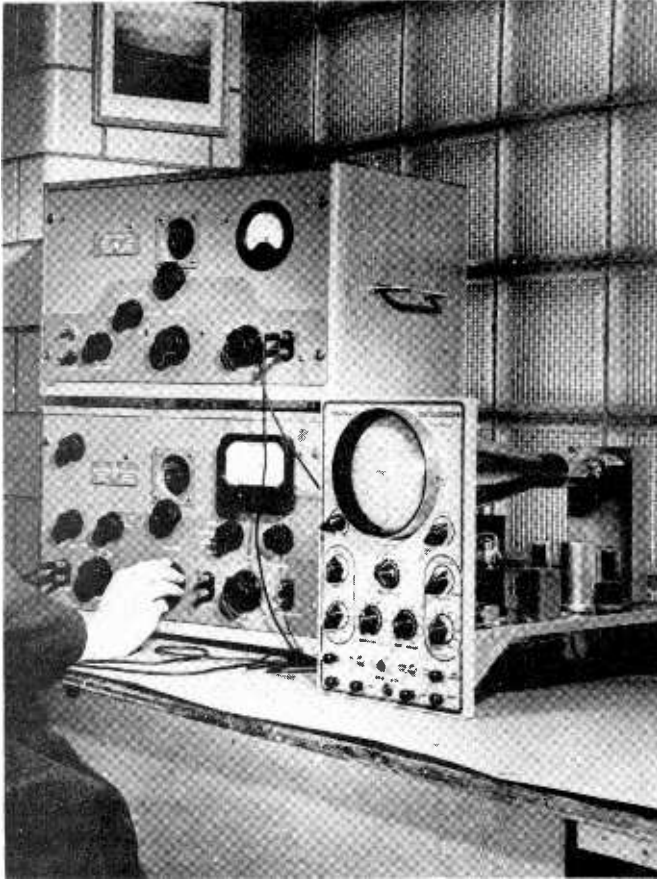
Although it is extremely short, a definite amount of time is required for this right-to-left or "return" sweep of the beam. This is known as the "flyback" time, and during this period, the movement is so rapid that the spot is almost invisible.

The brightness or intensity of the spot on the screen is determined by the value of the bias on the control grid of the crt electron gun, and in some commercial oscilloscopes, means are provided whereby a high negative voltage pulse is applied to the grid during this flyback time. This cuts off the electron beam during this period to prevent the return trace from appearing on the screen.

Assuming voltages E_V and E_H have a common frequency of 400 cycles, the complete sine curve will be traced on the screen of Figure 6 in $1/400$ of a second, and if the action is allowed to continue, the spot will complete 400 traces each second. This speed is possible because of the extremely small mass or weight of the electrons making up the cathode-ray. Due to the fluorescent qualities

of the screen, and the persistence of vision of the human eye, this rapid movement makes the spot appear as an illuminated line or

With E_V and E_H of equal frequency, one complete cycle appears on the screen, but if the frequency of E_V is twice that of



Checking the performance of a Heath 'scope with a Hewlett-Packard signal generator and harmonic analyzer.

Courtesy Heath Company

trace, and thus the sine curve will appear as a uniformly illuminated and stationary pattern on the screen.

E_H , two complete cycles will appear, and similarly for other ratios. However, to maintain a steady pattern on the screen,

there must be a fixed and constant whole-number ratio between the frequencies of E_v and E_h . If such an integral frequency relationship does not exist, the pattern will move constantly and change in appearance.

Different phase relationships or amplitude ratios, between two applied deflection voltages of a given frequency ratio, will produce stationary patterns of different shapes. To sum up, the shape of the pattern produced by the movement of the spot on the crt screen depends upon 1: The frequency relationship, 2. The phase relationship, and 3. The amplitude relationship of the respective deflection voltages. Whether or not the pattern is stationary depends only upon the frequency relationship of the voltages.

OPERATING CONTROLS ON A 'SCOPE

The front panel of the average commercial oscilloscope, as illustrated in Figure 7, contains the crt screen S, the various operating control knobs, and the input terminal binding posts. The actual locations of the various controls will vary with different makes and models but those shown and listed below will be found on most commercial oscilloscopes. According to the numbers shown in Figure 7, the names and purposes are as follows:

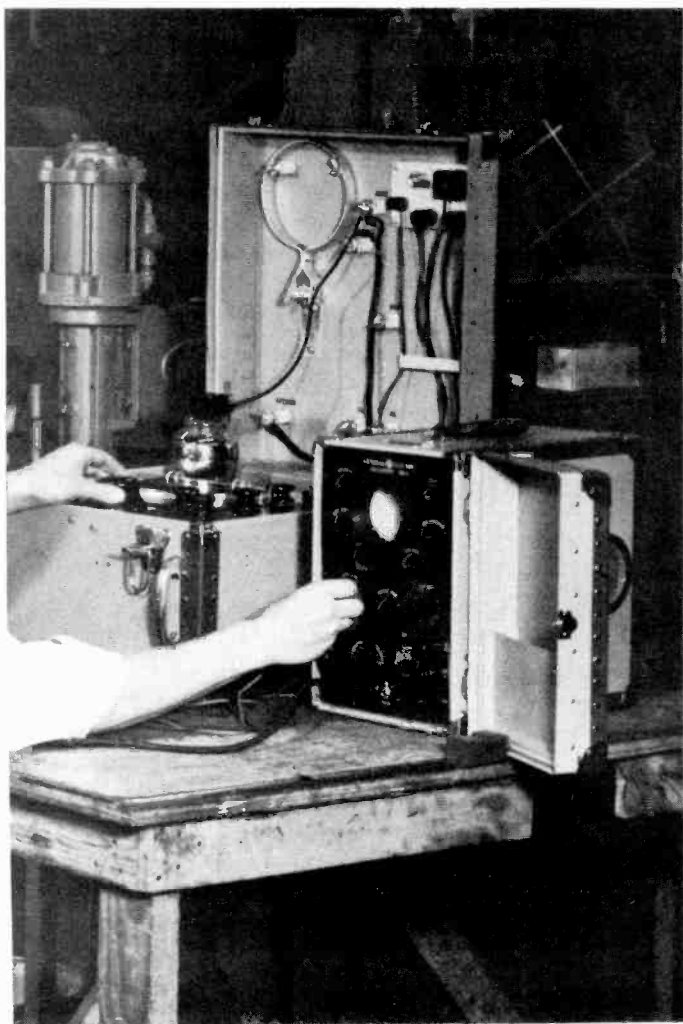
1. **INTENSITY**—Regulates the intensity or brightness of the pattern on the screen by adjusting the crt control grid bias. It should never be turned up higher than is necessary to produce a readable image. Generally this control incorporates the "ON-OFF" power switch for the entire instrument. When neither a vertical nor a horizontal deflection voltage is being applied to the crt, the intensity control should be turned down until the spot is not visible because a bright stationary spot may burn a hole in the fluorescent screen.
2. **FOCUS**—This control adjusts the positive potential on the first anode, and by controlling the diameter of the cathode ray, determines the clearness and sharpness of the pattern.
3. **VERTICAL POSITIONING**—Regulates the value and polarity of a d-c bias voltage applied to the vertical deflection plates, thus permitting the pattern to be shifted up or down on the screen when necessary.
4. **HORIZONTAL POSITIONING**—Permits shifting of the pattern in the horizontal direction on the screen by the same means explained above for the vertical positioning control.

5. VERTICAL GAIN — Determines the vertical height of the pattern by regulating the gain of the vertical amplifier.
 6. HORIZONTAL GAIN — Determines the horizontal size or width of the pattern by regulating the gain of the horizontal amplifier. Both of these gain controls correspond to the volume control in an audio amplifier.
 7. SWEEP FREQUENCY RANGE SELECTOR — A rotary switch for selecting one of several time base frequency ranges. This control is often labeled "Coarse Frequency," and corresponds to switch S of Figure 4-B.
 8. FREQUENCY VERNIER— A continuously variable control, R_1 in Figure 4-B, for adjusting the time base frequency over any one range. This is sometimes labeled "Fine Frequency".
 9. SYNCHRONIZING ADJUST — Controls the magnitude of the synchronizing voltage applied to the grid of the time base generator to cause the pattern to remain stationary on the screen. Corresponding to R_s in Figure 4-B, this control is labeled: "Sync," "Sync Amp", "Locking", etc.
 10. INT-EXT SYNC—A double-throw switch, S_1 in Figure 5, for selecting as the synchronizing voltage either a part of the signal voltage impressed on the vertical deflecting plates, or an external voltage supplied through the "Ext-Sync" binding post (Figures 5 and 7).
 11. INT-EXT SWEEP — A double-throw switch, S_2 in Figure 5, for connecting either the sawtooth voltage output of the internal time base generator, or an external voltage supplied through the HA binding post, to the grid of the horizontal amplifier (Figures 5 and 7).
- The "VP" and "HP" binding posts in Figure 5 are not included in the panel of Figure 7 as they may be located on the side or at the rear of the oscilloscope cabinet. Other binding posts are sometimes provided for special purposes, such as applying a signal to the control grid of the crt and thus permitting the spot to be modulated in intensity as the pattern is traced. An arrangement of this kind is known as the "Z" axis. Another terminal often included, is connected internally to a filament winding of the cro power supply, thus making available a 60-cycle alternating voltage for test purposes.

PRACTICAL APPLICATIONS OF THE 'SCOPE

A large number of uses have been developed for this extremely versatile instrument, both within

and outside of the field of Radio and Electronics. In the field of Radio Servicing alone, the cathode-ray oscilloscope probably has, or can easily be adapted to have,



Checking an electronic power tube with an industrial type oscilloscope and tube checker.

Courtesy General Electric Company

more applications than any other single piece of test equipment.

Although its most important function is the reproduction of a-c waveforms, it can be used also for signal tracing, amplifier gain measurements, as well as frequency bandwidth, phase shift, and distortion tests. It can be employed in receiver alignment, detection of amplifier oscillation and hum voltage, and for frequency determinations. When properly calibrated, the cro can be used as a vtvm to measure current and power in a circuit. The circuit connections and typical waveforms obtained for some of the above mentioned tests and measurements are described in the following paragraphs.

WAVEFORM OBSERVATION

As most radio or amplifier circuit defects result in some distortion of the signal waveform, a study of the output waveform to determine the type of distortion produced, usually provides a convenient method of locating the particular circuit defect. For example, the a-f output circuit of Figure 8 includes a number of points, A, B, C, etc., to which the oscilloscope test prod, TP, can be connected. This test lead is connected to the cro vertical input terminal, while the 'scope ground terminal is connected to a ground point in the circuit being tested.

An undistorted sine wave audio voltage is applied to the grid of tube V_1 , and with prod TP connected to this point, the cro sweep circuit controls are adjusted until the pattern on the screen consists of one, or two stationary sine wave cycles, as shown in Figure 9-A.

With the waveform of Figure 9-A obtained when the test prod is touched to the grid of V_1 , a similar pattern, but inverted due to the phase-reversing action of V_1 , should be obtained when the prod is placed at point A in Figure 8. Likewise, the original pattern should be seen with the cro test prod at point B, the plate terminal of V_2 . The fourth point at which this normal sine wave voltage should be found is with the test prod TP at point C. For this test, the cro ground lead should be placed at point D, as indicated by the dashed line.

A similar waveform may be obtained with no a-f input applied to the circuit in which case the 60 cps power line voltage may be coupled to the input circuit in some way. In this case, the 'scope sweep circuit must be operating at, or at a submultiple of, 60 cps.

If, with prod TP at point A, B, or C, the trace on the screen has the wavy appearance of that of Figure 9-B, improper filtering of the power supply d-c output is indicated, and may be due to an

open filter condenser or shorted filter choke.

Should the coupling condenser C_1 be leaky, then the waveform obtained with prod TP at point A will be as shown in Figure 9-C. This same condition will cause the signal voltage at points B and CD to have the waveform shown in Figure 9-D. With one peak "clipped", this waveform is due to either the above mentioned defect or to any other effect that may cause an improper value of grid bias on tube V_2 .

In the case of insufficient bias, the negative peak of the plate voltage, point B, will be flattened or clipped, and if the bias is too high, the positive plate voltage peak will be clipped. One of these conditions will produce the pattern of Figure 9-D, the other will give this pattern inverted; the particular pattern resulting in a given case depending upon the number of vertical amplifier stages employed in the oscilloscope, the connections to crt vertical plates, etc. As these design details vary in different makes and models of oscilloscopes, no general rule can be given concerning the polarity of the waveforms produced on the screens.

With prod TP at point A, B, or C, the pattern of Figure 9-D (or this pattern inverted) will be obtained in the event that improper tube operating conditions exist

due to a too high or too low B voltage, or to a screen-grid circuit component, R_3 or C_3 , with the wrong value.

The voltage waveform at point B will appear as Figure 9-E if the signal input to the grid of tube V_2 is too great in amplitude, that is, if the stage is "overloaded". Note that severe clipping of both peaks is obtained, and the pattern begins to approach a square wave shape.

If for some reason there should be no voltage at the screen grid of V_2 , the waveform at the plate, point B, will resemble that shown in Figure 9-F. In order to reproduce this waveform, a very strong signal input is necessary.

An open loudspeaker voice coil is one possible cause for the plate circuit of the output tube V_2 being too lightly loaded, in which case the waveform at point B will be similar to that shown in Figure 9-G. On the other hand, if V_2 is loaded too heavily, a condition that could be caused by a shorted voice coil, the wave will take on the form shown in Figure 9-H.

If the cathode bypass condenser C_2 is open, the wave of Figure 9-A, very low in amplitude, will be found to exist at the cathode of V_2 at point E. If this condenser is shorted, the tube bias will be affected, and at

point B, produce the waveform of Figure 9-D as explained above.

The amplifier in Figure 8 may operate as an oscillator and produce a relatively high-frequency voltage if the placement of its components or the wiring happens to be such that sufficient feedback from plate to grid circuit is obtained. With the 'scope test prod placed at point B, this oscillation may cause the cro screen pattern to have the appearance of that shown in Figure 9-I.

SIGNAL TRACING

In the previous lesson on test equipment, the instrument called a Signal Tracer was said to consist of three major parts, namely, a detector, an amplifier, and an indicating device. As the cathode-ray oscilloscope includes an amplifier, and the crt as an indicator, all that is needed to make a complete signal tracer is the addition of some type of detector. This detector may be contained within the 'scope cabinet, in a separate cabinet, or be mounted inside the test probe as in the case of the vtvm and signal tracer described previously. However, to permit checking in the receiver input circuits, usually it is necessary that an additional stage of amplification be employed at the cro input.

With an oscilloscope so equipped, a radio receiver can be "signal traced" in the normal manner, by using either a radio station carrier or a modulated r-f generator as the signal source. As shown on the block arrangement in Figure 10, the cro probe detector is not needed at any points in the circuit following the receiver 2nd detector, as here the required demodulation has already been accomplished. Some commercial type oscilloscopes include a phone jack on their front panel so that a headset can be plugged in, and the voltage at the crt vertical plates can be heard as well as seen when the instrument is being used as a signal tracer.

AMPLIFIER GAIN MEASUREMENTS

The oscilloscope can be employed to obtain a practical approximation of the voltage gain provided by a given amplifier circuit. For this measurement, it is necessary to employ a graphic scale which consists of a transparent material, such as celluloid, that is ruled with vertical and horizontal lines spaced usually one-tenth of an inch apart, and which is shaped to fit over the crt screen. This graphic scale permits direct comparison of the relative amplitudes of the patterns or traces produced on the screen.

To measure stage gain, the test circuit is set up as shown in Figure 11. A signal voltage of proper amplitude is applied to

stage, point A, is applied to the cro vertical input. For this test, the horizontal sweep circuit is turned off, so that the only deflec-



Philco precision visual alignment generator is shown here as it is used for adjusting the performance of an f-m receiver.

Courtesy Philco Corporation

the input of the amplifier tube V_1 , the gain of which is to be measured, and the voltage existing at the grid of the following

tion will be that due to the voltage under test and as it is applied to the oscilloscope vertical input, the trace will have the form of

a vertical line. Then the cro test prod is placed at the grid of tube V_1 , point B, and the ratio of the lengths of the traces produced with the test prod at points A and B is numerically equal to the voltage gain of the V_1 stage.

As an example, suppose that when the oscilloscope test prod is at point A in Figure 11, the vertical line covers exactly 8 divisions on the graph scale, as shown at A in Figure 12. When the prod is moved to point B in Figure 11, the vertical trace has a total length of only two-fifths of a division, as at B in Figure 12. Then the voltage gain G is given by:

$$\begin{aligned} G &= \frac{\text{Output Voltage}}{\text{Input Voltage}} \\ &= \frac{\text{Length of Line A}}{\text{Length of Line B}} \\ &= \frac{8}{2/5} = \frac{40}{2} = 20 \end{aligned}$$

By calibrating the oscilloscope in terms of volts-per-graphic scale division, it is possible to use the instrument directly as a vtvm. However, the accuracy is not high, due to the necessity of estimating the length of the trace and when a high degree of accuracy is required, a vtvm should be used.

AMPLIFIER PASSBAND OR FREQUENCY RESPONSE

The amplitude-frequency response of an amplifier circuit can

be checked by using the oscilloscope as an output indicator with the circuit arrangement of Figure 11.

Again the graphic scale is used with the vertical deflection divisions being recorded on a sheet of graph paper as the signal generator is adjusted to various frequency values in the band over which the tested circuit operates. In this test, the 'scope prod remains at point A; however, it is very important that the input to the circuit under test be maintained at a uniform amplitude as the frequency is changed. A vtvm can be connected permanently to point B in Figure 11, to provide a constant check on this input voltage.

To obtain an accurate test of this type, the vertical amplifier of the oscilloscope must have a uniform or flat frequency response. Although it may be quite linear over the frequency range for which it was designed, distortion will occur if the frequency is made too high. Data on the frequency limits of various makes of oscilloscopes may be obtained from the manufacturer's specifications and the test should not exceed these limits.

However, if the output of the amplifier under test has sufficient amplitude, it may be applied directly to the plates of the cro thereby eliminating possible

errors due to the non-linear response of the oscilloscope amplifier.

FREQUENCY DETERMINATION

The frequency of an unknown alternating voltage can be determined with an oscilloscope by comparing the pattern produced by this voltage with that produced by a voltage of known frequency, or by determining the frequency ratio from the pattern produced when the unknown frequency is applied to one pair of deflecting plates and the known frequency to the other pair.

The first system is an indirect method in that the cro sweep frequency must be determined, after which the unknown frequency is compared with that of the sweep voltage. The advantage of this method lies in the simplicity of interpretation of the screen patterns used.

The voltage E_x , the frequency of which is to be determined, is applied to the cro vertical input and the sweep frequency controls are adjusted until one or more complete cycles appear on the screen. For example, if five sine wave cycles are produced, as shown in Figure 13, it indicates that five cycles of the vertical input voltage occur during the period of time occupied by one cycle of the sweep voltage. There-

fore, the frequency ratio is 5:1. Without touching the sweep circuit controls, the unknown frequency is removed from the cro input and replaced by the output voltage of a calibrated signal generator, the frequency of which is varied until but one cycle appears on the cro screen. At this point, the cro sweep frequency is equal to that indicated on the calibrated dial of the signal generator. If the indicated frequency is 400 cps then, with the predetermined ratio of 5:1, the frequency of the tested voltage is $5 \times 400 = 2000$ cps.

LISSAJOUS FIGURES

The second method of frequency determination makes use of what are called "Lissajous Figures", named after the 19th century French Scientist. These figures are defined as the patterns or curves produced on a cathode-ray oscilloscope screen when a sine wave voltage is applied to each set of deflecting plates. The ratio of the frequencies of the two voltages can be determined from the patterns produced, and by knowing this ratio and the frequency of one of the voltages, the frequency of the other can be found. Note, that in this method the cro sweep voltage does not enter the problem; in fact the sweep circuit is not used at all, the horizontal amplifier being switched to the external

horizontal input terminal HA in Figure 5.

The Lissajous Figure method of frequency determination employs an equipment set-up as shown in Figure 14 where one source of alternating voltage is connected to the oscilloscope vertical input, the other to the horizontal input. For example, suppose the output of Signal Source No. 1 is of unknown frequency, while Signal Source No. 2 consists of a conventional a-f or r-f signal generator, the calibration of which is known to be correct. As explained for the passband test of an amplifier, if the frequencies to be compared are so high that they exceed the rated band pass limits of the oscilloscope vertical and horizontal amplifiers, the input voltages, if great enough in amplitude, can be applied directly to the crt deflecting plates.

Continuing with the example, suppose that the pattern produced on the screen is like that shown in Figure 15. The fre-

quency ratio of the two voltages can be found by means of the mutually perpendicular lines MN and XY, which just touch the edges of the loops. These lines can be imaginary, or they can consist of two of the graphic scale lines with the pattern positioned so that its edges fall directly on the lines. The frequency ratio of the vertical to the horizontal voltage is equal to the ratio of the number of points at which the Lissajous pattern intersects line XY to the number of points at which it intersects line MN. In the example of Figure 15, the horizontal to vertical frequency ratio is 3 to 2. Therefore, if the output of the Signal Source No. 2 has a frequency of 600 cps, as read on its dial, then the frequency of the output of Signal Source No. 1 must be $3/2 \times 600 = 900$ cps. As the frequency ratio increases, it becomes increasingly difficult to interpret the figures and when high ratios are used, accuracy depends somewhat on the skill of the observer.

IMPORTANT WORDS USED IN THIS LESSON

CATHODE RAY—A stream of fast moving electrons under the influence of an applied voltage.

DEFLECTION PLATES—Two sets of parallel plates between which the electron stream in a cathode-ray tube must pass. When electrically excited, the plates deflect the stream in either a vertical or horizontal direction.

ELECTRON GUN—The electrode assembly mounted in the neck of a cathode-ray tube, and consisting of heater, cathode, control grid, and accelerating anodes. It is here that the electron stream is developed.

FLUORESCENCE—To become luminous or give off light when excited by a stream of fast moving electrons.

HORIZONTAL PLATES—The pair of deflection plates in a cathode-ray tube that swing the electron stream from left to right in a horizontal plane.

LISSAJOUS FIGURES—The variety of curves obtained on the screen of a cathode-ray tube when sine wave voltages of different frequencies and phase relations are impressed on the vertical and horizontal deflection plates.

OSCILLOSCOPE—An instrument for developing on the screen of a cathode-ray tube a visual graphic image of a rapidly varying electrical quantity.

SAW-TOOTH—A waveform resembling the teeth of a saw. It rises linearly to a peak value, then drops very rapidly to zero.

SCREEN—The deposit of fluorescent salts on the inner surface of the large end of a cathode-ray tube. This salt glows when excited by a stream of electrons.

SCREEN BURNING—The formation of discolored spots on the screen of a cathode-ray tube due to the electron stream remaining in a fixed position for too long a time. Such burning impairs the sensitivity of the screen in those areas.

SWEEP GENERATOR—An electron oscillator that develops a saw-tooth voltage to deflect the electron stream at a constant rate from left to right across the screen of a cathode-ray tube.

SYNCHRONIZING CONTROL—The oscilloscope control which permits a portion of the vertical input voltage to be impressed on the grid of the sweep generator tube to maintain the image in a stationary position on the screen.

VERTICAL PLATES—The pair of deflection plates in a cathode-ray tube that deflects the electron stream up and down in a vertical plane.

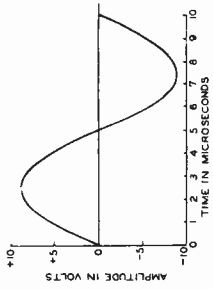


FIGURE 1

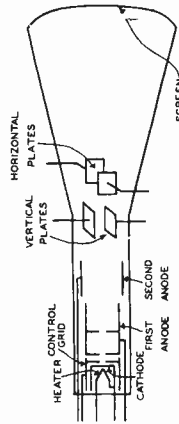


FIGURE 2

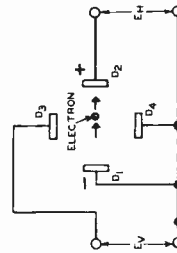


FIGURE 3

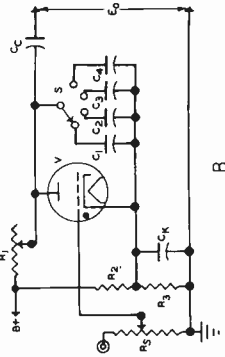


FIGURE 4



FIGURE 5

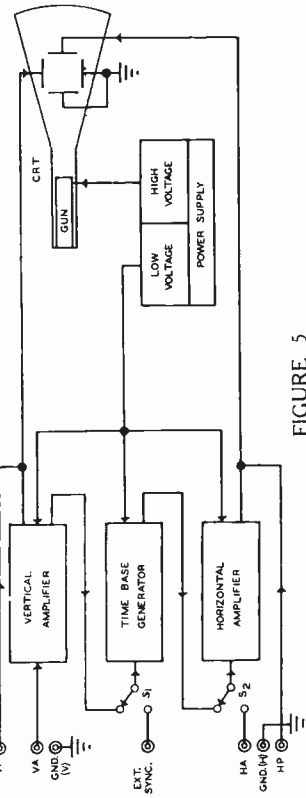


FIGURE 6

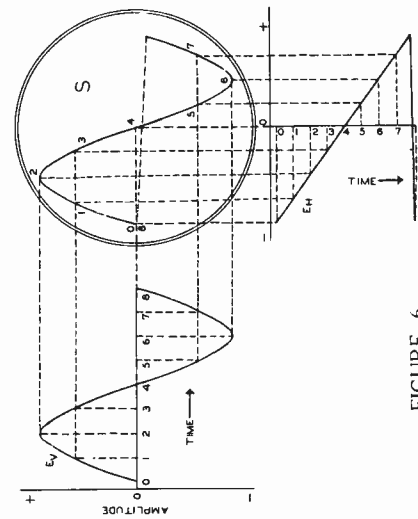


FIGURE 7

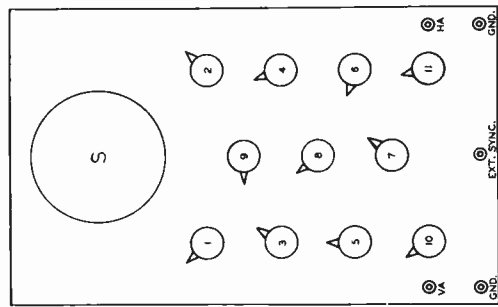


FIGURE 8

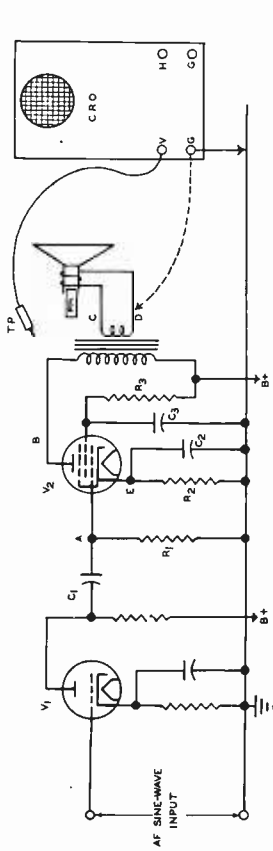


FIGURE 9

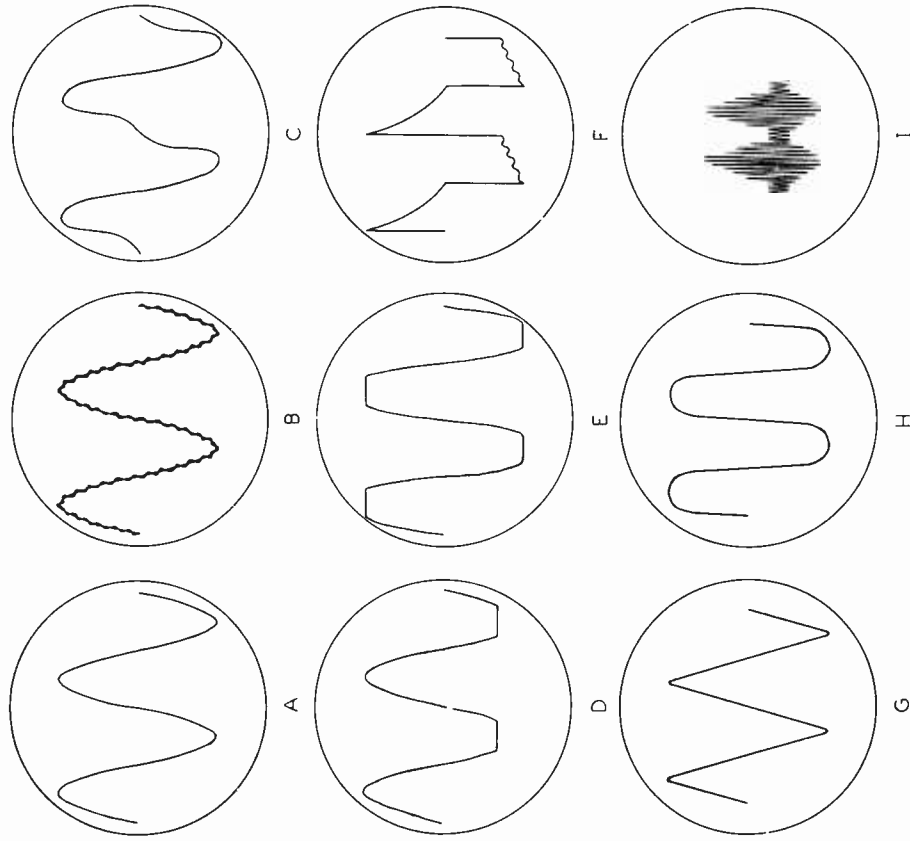


FIGURE 10

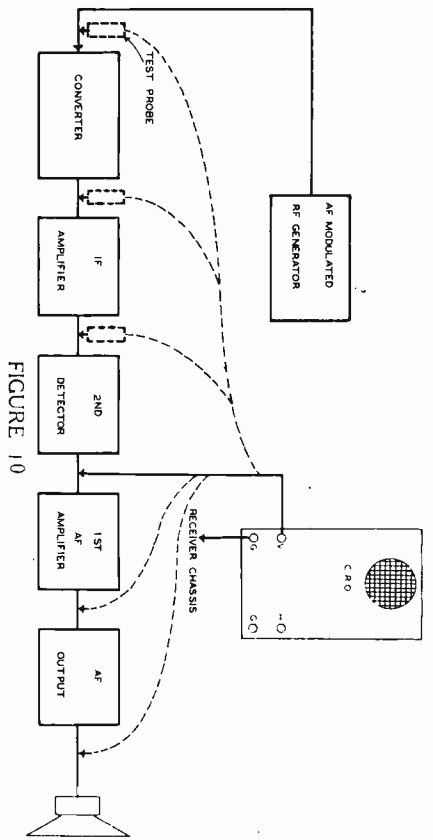


FIGURE 10

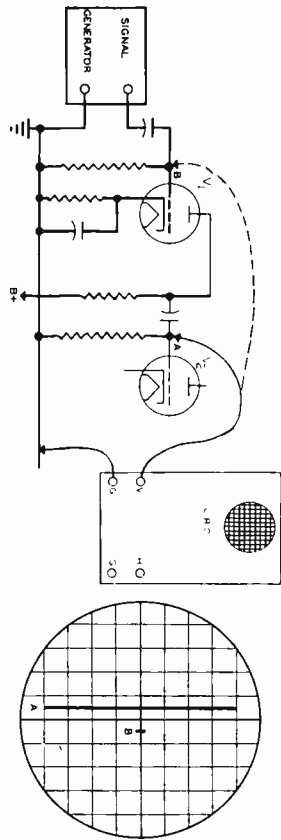


FIGURE 11

FIGURE 12

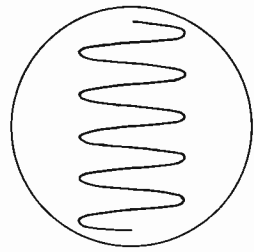


FIGURE 13

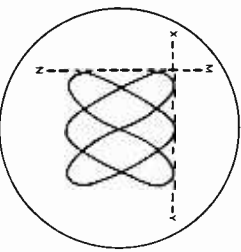


FIGURE 15

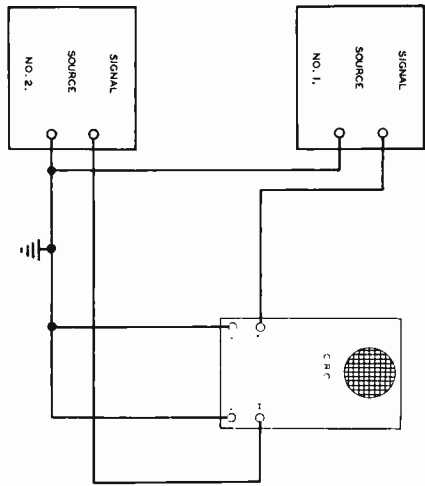
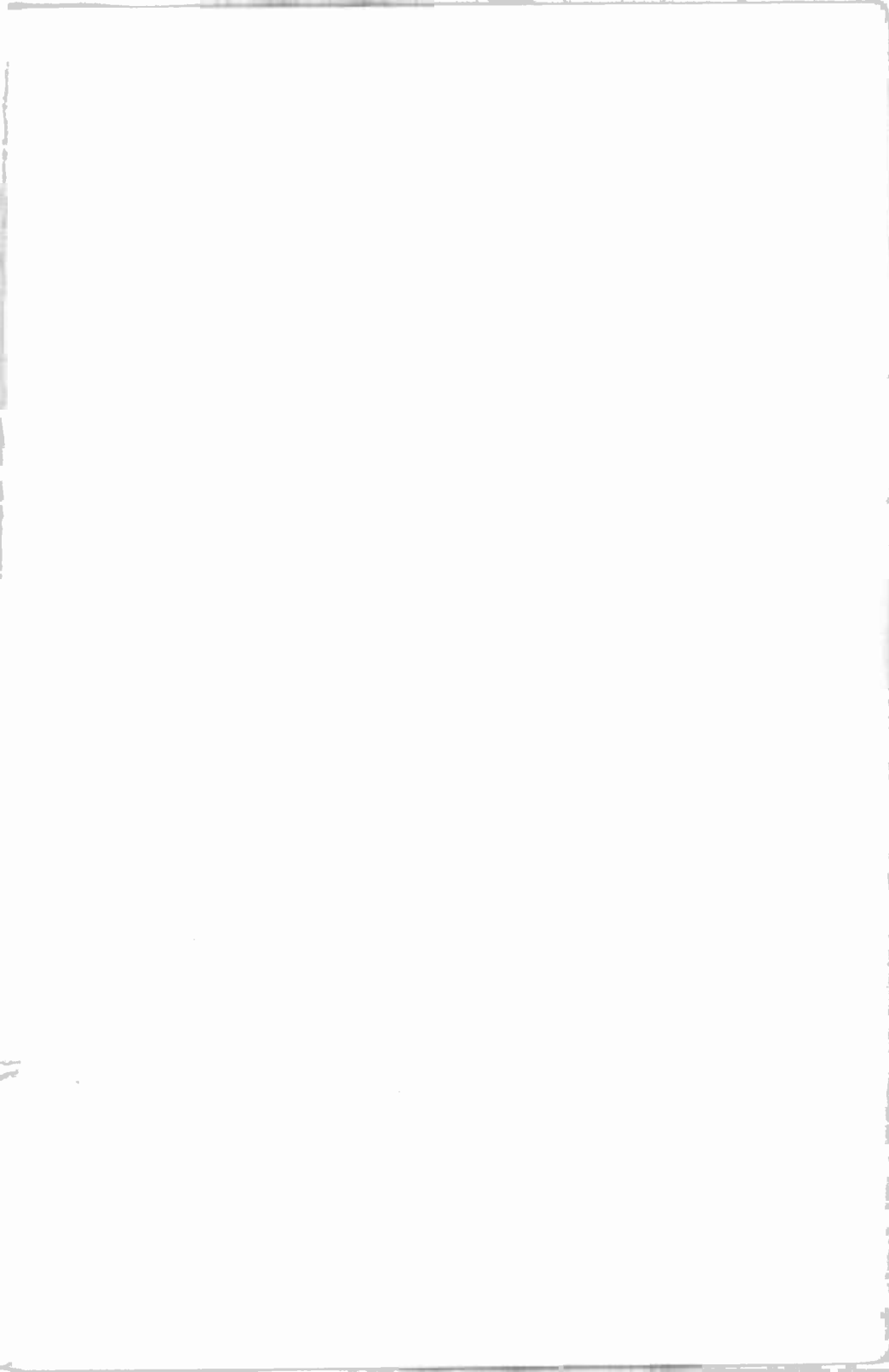


FIGURE 14





FROM OUR *President's* NOTEBOOK

WHY ARE WE ON THIS EARTH?

To help the rest who are on it, not only humans, but "everything that hath life." To show affection, to win friendship. To help the weary with their loads, to encourage and comfort and inspire. To make everyone about us feel the better and not the worse for our existence. To do our utmost to make all lives directly influenced by us a bit less burdensome, a bit happier and more worth while.

From that, if we have any imagination, we shall widen our activity so as to include those outside our personal range. We shall work for the overthrow everywhere of oppression, of unjustifiable privilege. We shall demand a square deal for everybody. We shall put our shoulders to all wheels that are being pushed out of the mud of traditional incompetence and inhumanity on to the high road of progress.

And, being thus occupied, we shall cease to whimper about why we are on this earth. We shall know.

Yours for success,

E. B. Selvy

PRESIDENT