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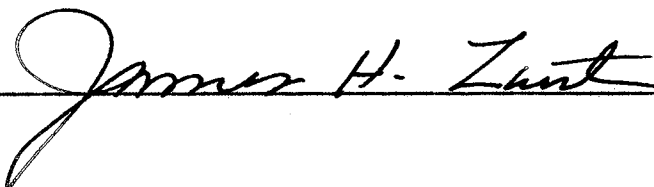
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Summary: Physics is a science which may make excellent use of the demonstration as a teaching device. But if the number of articles written concerning the cathode ray oscilloscope indicates the extent to which the oscilloscope is used in high school demonstrations, then little use is being made of this versatile electronic device. It is the purpose of this paper to acquaint the high school teacher of physics and general science with some of the uses of the oscilloscope in classroom demonstrations and to supply some specific circuits and instructions which can be readily used by the teacher or student in setting up and performing the demonstrations. All demonstrations have been chosen to require the minimum of equipment and expense, yet many variations are suggested to fit various needs with respect to amount of equipment available and ability of the students. Introductory experiments suggested use the oscilloscope to show the presence of static electricity. The bulk of the demonstrations deal with current electricity since the cathode ray oscilloscope is an electronic device designed to show voltage or current fluctuations on a screen. Methods are given for producing and visualizing on the screen of the oscilloscope various wave forms, transformer operation, rectification of alternating current, rectifier filter circuit effects, voltage amplification by means of a vacuum tube, and hysteresis effects. Any transient phenomenon which may be converted to electrical voltage or current fluctuation may be viewed on the oscilloscope. Thus, since sound waves can readily be changed into an electric current by means of a microphone, many demonstrations showing the nature of sound are included; the demonstrations are particularly suited at the general science level. For the more advanced student a demonstration in atomic physics is included. With the aid of this paper a nucleus of high school demonstrations utilizing the oscilloscope is made available to the teacher and thereby help to increase the teaching effectiveness of topics which can be visually demonstrated by means of the oscilloscope.

ADVISOR'S APPROVAL



HIGH SCHOOL DEMONSTRATIONS
WITH THE OSCILLOSCOPE

by

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Bachelor of Arts

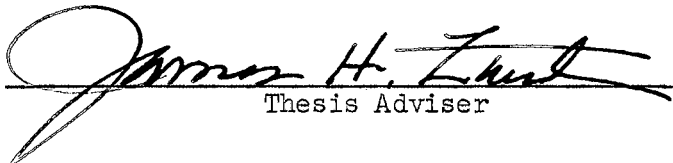
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WITH THE OSCILLOSCOPE

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CHAPTER I

INTRODUCTION

"There is, I believe, no better teaching or learning device than a demonstration, and physics lends itself beautifully to this kind of instruction."¹ With this in mind, it would appear that the cathode ray oscilloscope, one of the many devices available today which may be used to help the teacher explain and clarify the laws of physics, has often been neglected. If information regarding basic applications of the cathode ray oscilloscope together with detailed instructions for setting up demonstrations were made available, the teacher could learn of the value of the instrument for purposes of high school demonstrations.

It is the purpose of this report to (1) acquaint the high school teacher of physics and general science with some of the uses of the cathode ray oscilloscope in classroom demonstrations, and (2) supply some specific circuits and instructions which can be readily used by the teacher or student in setting up and performing the demonstrations. These suggested demonstrations and circuits should supply a nucleus of basic demonstrations for high school use by both the teacher and student.

¹J. S. Miller, "Summer Session Course in Demonstration Experiments for High School Physics Teachers" American Journal of Physics, XXVI (October, 1958), 477.

Although the demonstrations suggested are largely for use in the high school physics class, the simpler demonstrations may be used to advantage in freshman general science and physical science classes. The demonstrations on sound are particularly applicable to lower level classes. A brief introductory description of the function of the oscilloscope, however brief and elementary, should precede the first demonstration involving the instrument.

In many instances, the teacher may not be well acquainted with the cathode ray oscilloscope, its possibilities or how to operate it. Very often, the teacher may feel that the cost of such a device is beyond the limits of the typical high school science budget.

The cathode ray oscilloscope, more frequently referred to simply as oscilloscope, is an instrument commonly used to give a visual account of voltage or current fluctuations in a variety of electronic circuits. Any phenomenon which is not electrical in nature, but which can be converted to electrical voltage or current fluctuations may be visualized with the aid of an oscilloscope.

The teacher, or even the advanced student in high school, will find that learning to use an oscilloscope is not difficult. Generally, a manual of instruction is available to supply necessary operating information.

Cost need not be a problem although many oscilloscopes presently on the market are priced above the limits of most high school budgets. Some oscilloscopes may be obtained in kit form at very reasonable prices.

Two such instruments available in kit form and priced under fifty dollars are the Heathkit² and Knight³ general purpose scopes. Both are more than adequate for class demonstrations and for student use. Complete, easy to follow assembly instructions are included in each kit. The only tools required to assemble such kits are screwdriver, long-nose pliers, wire-cutters, and soldering iron or gun. Assembly time averages from twelve to twenty hours depending upon the skill and the experience of the kit builder.

For the instructor with some electronic equipment construction experience and who wants a larger screen instrument for lecture room use, Patronis⁴ provides the necessary circuit diagrams for an oscilloscope using a 21-inch television picture tube. Or, as another interesting alternative, any operating television set may be modified without destroying the use of the television receiver. In addition, the audio section of the television set can be used to listen to the sound of all patterns shown on the screen. Circuit diagrams and instructions for the additional needed variable horizontal sweep generator and power amplifier are provided by Sossen.⁵

²Model OM-3, Heath Company, Benton Harbor, Michigan.

³Model 83 YU 146, Allied Radio, 100 N. Western Avenue, Chicago 80, Illinois.

⁴E. T. Patronis, jr., "Large Screen Oscilloscope," American Journal of Physics, XXII (May, 1954), 341-343.

⁵H. Sossen, "Demonstration Oscilloscope from a TV Set," School Science and Mathematics, LII, (June, 1952), 483-484.

CHAPTER II

REVIEW OF THE LITERATURE

Mack,¹ in his article concerning classroom uses of the oscilloscope, points out that if the amount of written material presently available is any indication of the extent to which oscilloscopes are being used for demonstration purposes in high school science, then little use is being made of the oscilloscope. It is true that many articles have been written concerning the oscilloscope, but few of these articles deal with applications to classroom demonstrations of principles in basic physics. The majority of articles are directed toward the radio and television serviceman listing applications of the oscilloscope to servicing these devices while other articles list specifications for cathode ray tubes and suggest uses in the field of industrial control.

The Education Index proved to be most valuable in providing listings of articles which could apply to demonstrations at the high school level. A total of twenty-two articles listed under cathode ray oscillograph were written over the period of years from 1935 through 1959. But

¹Joseph A. Mack, "The Oscilloscope in High School Physics Demonstrations," School Science and Mathematics, LI (January, 1951), 41.

of these listings, less than half contained information directly applicable to high school use. Perhaps the one most useful and comprehensive article was written by Mack.²

A much greater volume of listings was found in Readers' Guide to Periodical Literature. However, these articles were primarily concerned with applications of the oscilloscope to radio and television servicing. For this reason, none of these articles were of much value in applications to classroom demonstrations and are not included in this report. However, some of the better high school physics students may be interested in such articles and could undoubtedly make use of some of the applications suggested.

Textbooks that list information concerning oscilloscopes generally fall into one of two categories. In one group are texts which describe the circuit employed in the construction of the oscilloscope along with descriptions of the internal structure of the cathode ray tube. The other group is devoted to describing ways in which the oscilloscope may be applied to radio and television service and repair. Only rarely can information be found which can be applied directly to demonstrations at the high school level.

Jacobowitz³ presents a short but very thorough and easy to read description of the construction and principle of operation of the cathode

²Ibid. pp. 41-58.

³Henry Jacobowitz, Electronics Made Simple, (New York, 1958), pp. 36-40.

ray tube used as the "picture tube" in oscilloscopes. This may be of particular use in explaining to the student prior to any demonstrations involving the oscilloscope just how the instrument functions.

One useful text however, written by Ruiter,⁴ has made an attempt to give a complete picture of the oscilloscope from discussions of how and why the oscilloscope works to a variety of applications and common uses of the instrument. To anyone who is using or contemplating the use of the oscilloscope, this book should be considered as a valuable reference to keep at hand.

For the instructor who wishes to earnestly pursue the many possibilities of the oscilloscope, or to learn of more detailed applications, a comprehensive volume has been prepared by Rider and Uslan.⁵

⁴Jacob H. Ruiter, Jr., Modern Oscilloscopes and Their Uses, (rev. ed., New York, 1955).

⁵John F. Rider and Seymour D. Uslan, "Encyclopedia on Cathode-Ray Oscilloscopes and Their Uses," (New York, 1950).

CHAPTER III

DEMONSTRATIONS WITH THE OSCILLOSCOPE IN STATIC ELECTRICITY

Although applications of the oscilloscope to the study of static electricity are quite limited, this topic offers a good opportunity to introduce the oscilloscope to the high school science class. After the teacher has discussed electric charges and movement of electrons, an excellent opportunity is provided for a partial explanation of how the cathode ray tube makes use of moving electrons and how the oscilloscope functions.

The oscilloscope can be used at this point to supplement the many experiments which show the attraction of unlike charges and the repulsion of like charges. A dot should appear on the screen of the oscilloscope when the instrument has been turned on and allowed to warm up. Setting the horizontal selector of the oscilloscope at 60 cycles and the horizontal gain control near fifty should cause the dot to then appear as a horizontal line across the screen. Slight adjustment of the phase control may be necessary to get a perfectly straight line. By then holding a highly charged glass or hard rubber rod near the face of the cathode ray tube, a slight repulsion or attraction of the line may be noted. Since the line appearing on the screen is the result of electrons hitting the screen, a repulsion or attraction of these negatively

charged particles will determine the nature of the charge on the rod in question. Thus, the student should discover that the charge on a rod may be one of two different kinds and which kind of charge is on a given rod.

The physics teacher with previous experience in static charges will be well aware that optimum atmospheric conditions are necessary if the desired high charge is to be produced on the glass and hard rubber rods. Hence, the success of the preceeding demonstration may not be very dramatic. Ainslie¹ suggests that, since the glass rod and silk commonly used for the production of positive charges is not satisfactory in humid weather, other materials such as Neoprene rubber and Lucite plastic or polystyrene rods are much more satisfactory. In any case, a more pronounced deflection, and one that can be determined by adjusting the controls of the oscilloscope, depends upon the amplification by the oscilloscope.

With the oscilloscope settings as before but with the vertical gain controls set at or near maximum, a good indication of the presence of static charge can be demonstrated by bringing a charged rod near or in contact with the vertical input binding post of the oscilloscope. A sharp vertical deflection of the horizontal line on the face of the screen should be noted. In addition, the student can be shown the effect of repeated charging of the rods by comparing the change in amount of

¹D. S. Ainslie, "Demonstration Experiments in Electrostatics," American Journal of Physics, XXVI (November, 1958), 549-551.

vertical deflection of the line on the oscilloscope screen as the charge is increased. Although this demonstration does not give the student any indication of the kind of charge on each rod, it does give a visual indication that the charges are different and that static charges can be built up by continued charging of an object.

The preceding demonstration will give good results even when high static charges can not be obtained. Comparatively small charges will cause good deflections if the vertical gain controls are kept at maximum.

A similar demonstration may be performed using charged capacitors rather than charged rods. Simple plate capacitors charged by electrostatic methods should be used first, to be followed, if desired, by regular capacitors such as those commonly found in radio and television sets. These more common capacitors may be charged by direct current sources and thus serve as an introduction to current electricity. Caution must be observed if current electricity is used in charging capacitors, particularly if the capacitance is above a few micro-microfarads, since electric shocks are a potential danger. Again the oscilloscope may be used to show quantitatively the charge stored in a capacitor and hence indirectly compare the capacitance of one capacitor with another.

Another good method of producing positive charges makes use of a simple apparatus consisting of a brass tube with a sliding polystyrene or Lucite plastic tube inside.² The static charges produced are

²Ibid.

sufficient to light a neon glow bulb. If desired, the bulb may be replaced by connections to the vertical input and ground connections of an oscilloscope.

CHAPTER IV

DEMONSTRATIONS WITH THE OSCILLOSCOPE IN CURRENT ELECTRICITY

Probably the greatest number of applications of the oscilloscope in classroom demonstrations is found in the study of current electricity. It is important for the student of physics to understand the nature of current electricity because of its importance in everyday life.

Most high school physics textbooks in use today tend to emphasize direct current electricity with only a few brief pages set aside for the study of alternating currents. Yet, the number of applications of alternating currents, particularly in household appliances, is more than the number of applications of direct currents. Except for the automobile, alternating currents are more frequently encountered in everyday life. As a result, it becomes highly desirable to acquaint the students with basic principles of alternating currents as well as with direct currents. Although a strict mathematical discussion of alternating current circuits is not possible with high school students, it is possible to give the students a fundamental understanding of some of the commonly used electrical devices by using oscilloscope demonstrations.

Effective use of the oscilloscope may be made at the end of a given discussion to fix in the student's mind the law or principle which has

been under discussion. The remainder of this chapter is devoted to the discussion of the uses of the oscilloscope in connection with some of the electrical circuits in common use.

The first demonstrations in current electricity with the oscilloscope may be with direct current. Often the patterns obtained are not particularly interesting since the horizontal line on the screen may only be displaced upward or downward a distance related to the voltage applied to the vertical input terminals. However, two demonstrations in direct current, suggested by Mack,¹ do present interesting wave forms. If the St. Louis Motor, or its equivalent the Genemotor, is run as a direct current generator at very low speed, a pronounced ripple can be obtained with a very unusual wave form. Similarly, an automobile generator driven by belting to a household motor can be used as another source for direct current pulse demonstrations. In each case the vertical input terminals of the oscilloscope are connected to the output of the generator under test.

It is with alternating currents that the many interesting wave forms appear on the screen of the oscilloscope. Probably the first demonstration will be to show the familiar sine wave curve characteristic of alternating currents. Preceding this demonstration, early discussion of alternating currents will normally involve methods of generating such a current. The teacher will probably discuss the rotation of a loop of wire in a magnetic field. A varying current will be induced in the loop

¹Mack, pp. 43-44

of wire as the wire cuts magnetic lines of force. As the loop progresses through successive parts of the circle of rotation, the magnitude of the induced current will vary due to the variation in the rate of cutting magnetic lines of force. A graph in which the magnitude of the induced current is plotted against the time for one loop rotation will show the typical sine wave curve.

The small test voltage supply found on the front panel of most oscilloscopes can be used to show the sine wave curve of alternating current. This low alternating voltage varies from one to several volts; it is obtained from a secondary winding in the transformer of the oscilloscope. With the horizontal and vertical gain controls set at low levels, the horizontal selector set at sixty cycles, the synchronizing selector set at internal, and a wire connected from the test voltage terminal to the vertical input terminal, a typical sine wave curve should appear on the screen. Some slight adjustment of the vertical and horizontal gain controls may be necessary to get the sine wave in proper proportion.

Since the oscilloscope contains its own amplifiers, impressed electrical transient may easily be distorted and thus falsified images produced. Mack² suggests that great care should be taken with this first demonstration of the sine wave so that it is shown in its true proportions. Later, however, most students may prefer the distorted amplified trace rather than the true sine wave in proper proportions.

²Ibid., p. 42.

A more effective demonstration, because the student is more familiar with the household line voltage, gives the same sinusoidal pattern. Two wires from any electrical outlet may be connected directly to the vertical input and ground terminals of the oscilloscope. Because the line voltage is much higher than the test voltage supply, the vertical gain and vertical input controls will have to be adjusted in order to keep the sine wave pattern within the limits of the oscilloscope screen.

Wave forms from the generators, other than the pure sine wave may be demonstrated. Mack³ again suggests the uses of the St. Louis Motor, or Genemotor, this time used as an alternating current generator. A square wave of rather unusual appearance will result. Another different wave pattern may be produced from the hand-driven magneto used on the old style country telephone lines. A neon lamp, NE-3⁴, may also be connected at the same time as the oscilloscope to offer another interpretation of the current produced.

The square wave so often used in electronic applications for checking frequency response may be produced also. The most convenient method is by using a special square wave generator. Such devices may be obtained in kit form with a considerable savings in cost. The output of the generator is connected to the vertical input terminals of the oscilloscope and the frequency controls of the oscilloscope set to correspond with the frequency control of the generator.

It may be interesting to test briefly the preformance of an amplifier. If the signal from the square wave generator is fed through an

³Ibid., p. 43.

amplifier and then to the oscilloscope the frequency response of the amplifier may be visually checked. The amplifier should be under a matched load, such as a speaker. Some possible resultant patterns and their meanings are found in a Knight-kit Oscilloscope instruction manual⁴ and are shown in Figure 1.

Saw-tooth wave forms are of considerable interest because of their application to sweep circuits in electronic devices. The abrupt voltage variation which occurs at regular intervals is used in the sweep circuits of both the oscilloscope and television receiver. The retrace line which appears on the screen of the oscilloscope as the abrupt voltage change causes a rapid adjustment of the electron beam back to the left side of the cathode ray tube is easily observed on most wave forms which appear during the use of the oscilloscope. The same dark retrace lines on television receiver screens may be observed particularly when attempting to pick up a weak signal or when the television set is not properly adjusted.

Saw-tooth waves may be produced by a variety of methods. Mack⁵ suggests three possible ways. In one method, a discharge pulse through a gas filled tube such as a two-watt neon bulb, NE-34, can be used. The tube is connected in parallel with a 0.1 to 0.5 mfd. condenser. This wave generator in turn is connected in series with a two to five megohm rheostat. The circuit may be energized by a 100 volt or more direct

⁴Allied Knight-kit Wide-Band Oscilloscope 83 YU 144, (Chicago, 1955), p. 27.

⁵Mack, p. 43.

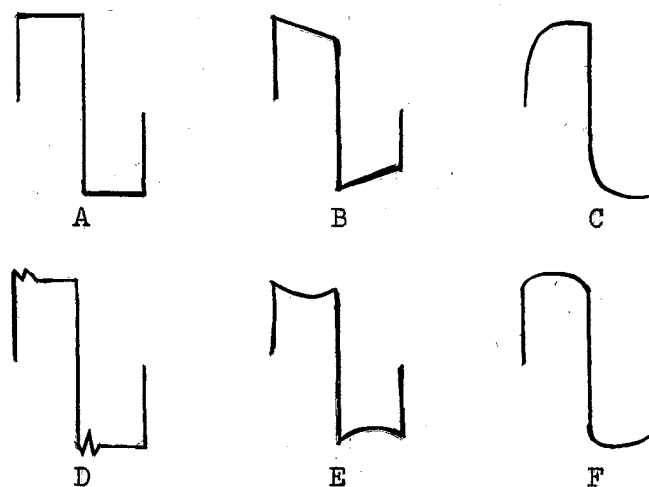


FIGURE 1

TYPICAL SQUARE WAVE PATTERNS

- A. A typical square wave shape obtained from a square wave generator.
- B. Indicates poor low frequency response.
- C. Show effects of good low frequency response but high frequency cut-off.
- D. Indicates excessive high frequency response or even oscillations at high frequencies.
- E. Indicates poor transmission of test frequency in relation to other frequencies passed.
- F. Shows higher transmission of test frequency than other passed frequencies.

current source. This assembly gives a pulse of one per second or more depending on voltage, resistance, and condenser sizes. The oscilloscope is connected across the wave generator.

A second method utilizes a full-wave rectifier with a filter circuit. If only the condensers are used in the filter circuit, a saw-tooth wave should be formed on the screen of the oscilloscope when the vertical input terminals of the oscilloscope are connected to the output of the filter circuit.

This same saw-tooth wave may also be obtained by a third method making use of a voltage double circuit. Such a circuit is shown in Figure 2. Voltage doublers may be of some interest in themselves since they are often employed to lessen the weight of semi-portable radios and may even be used as an inexpensive source of medium range voltages in the science laboratory.

If signal sources of both the sine wave and saw-tooth wave are available, interesting patterns may be shown leading to an introduction of Lissajous figures. Figure 3 shows a few patterns, as described by Rider and Uslan,⁶ formed by various combinations of sinusoidal and saw-tooth waves.

When a point undergoes two simple harmonic motions, which at anyone instant of time are at right angles to each other, the resultant movement of this point traces out a curve which is called a Lissajous figure.

⁶Rider and Uslan, p. 443.

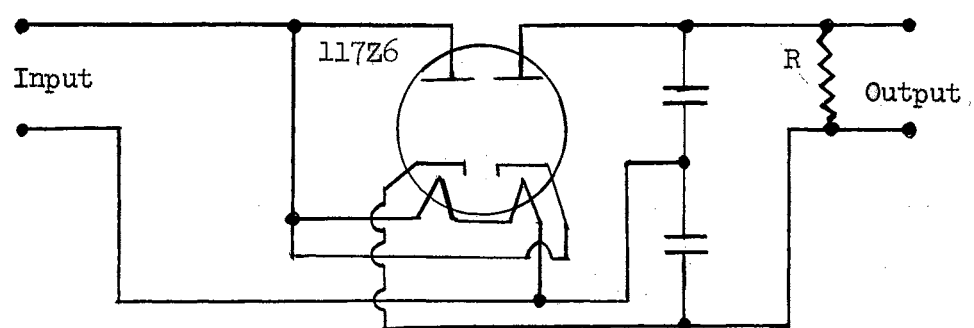


FIGURE 2

VOLTAGE DOUBLER CIRCUIT

R -- 20,000 ohm, 2 watt resistor
 C₁, C₂ -- 20 mfd. dry electrolytic condenser
 Input -- 110 volts A.C.

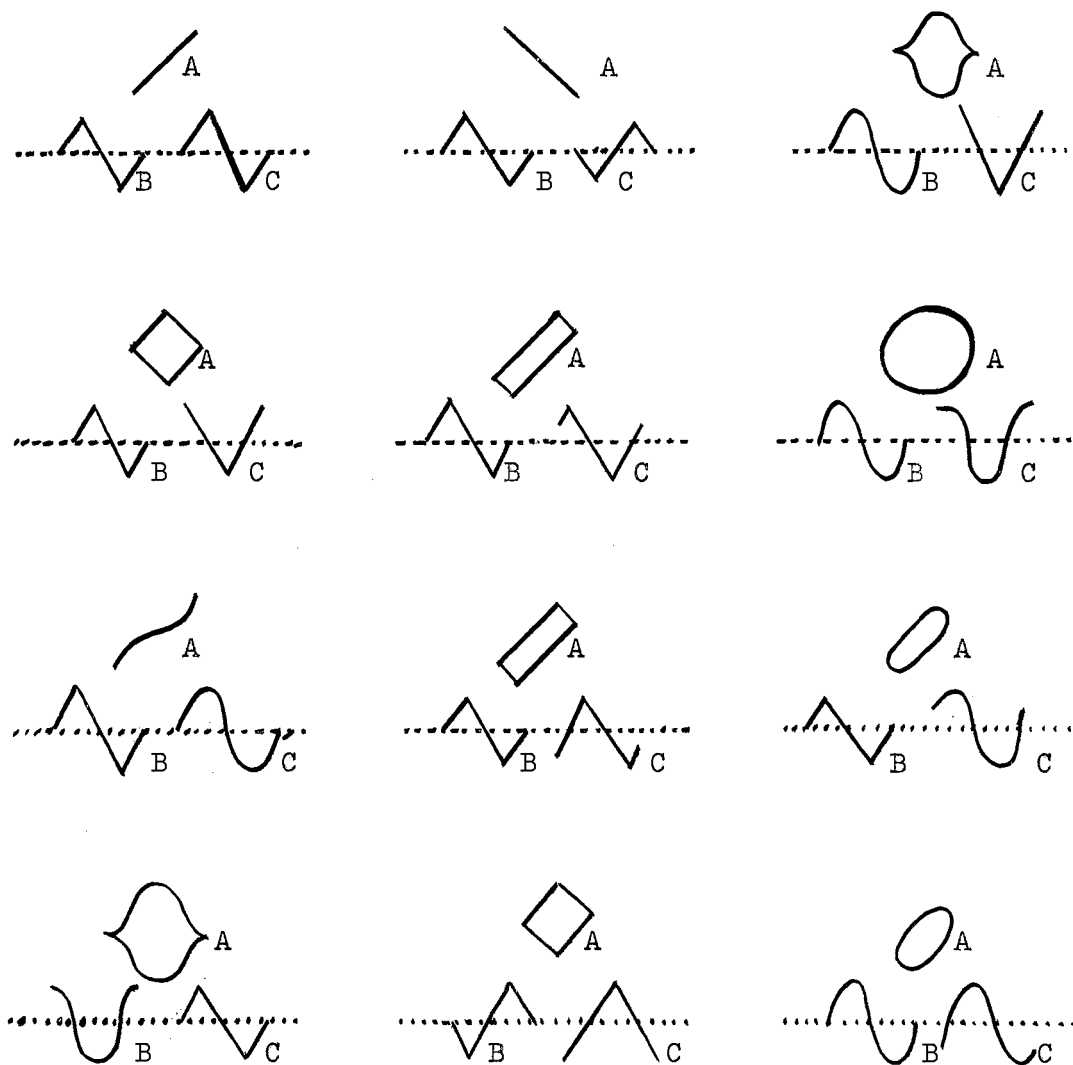


FIGURE 3

EFFECT OF WAVE SHAPE AND PHASE RELATION ON RESULTING OSCILLOSCOPE PATTERNS

In each group A represents the resultant pattern, B the vertical-deflection voltage, and C the horizontal-deflection voltage. Amplitude and frequency of the B and C signals are the same in each grouping.

Lissajous figures, named after the French professor who first demonstrated such figures in 1855 by using beams of light reflected from two plane mirrors at right angles to each other, may be produced on the oscilloscope. Such figures are important in phase and frequency measurements as well as being fascinating in themselves. The Lissajous figure will change if the phase, frequency or amplitude of either or both signals producing the figure are changed.

Phase relationships may be most simply shown on the oscilloscope by connecting the test voltage supply on the front of the oscilloscope to both the vertical and horizontal input terminals. The frequency control must be adjusted for the frequency to be used, in this case 60 cycles per second. By proper adjustment of the horizontal and vertical gain controls an ellipse, diagonal line or circle can be formed. By adjusting the phase control, the pattern will be seen to appear as an ellipse turning its face about an axis. Figure 4 shows the interpretation of phase angle with various positions and illustrates a simple method for determining the phase angle or phase difference. One method of calculating phase angle or phase difference is given by the formula

$$\sin \theta = \frac{\text{Y Intersection}}{\text{Y Maximum}}.$$

Radio service manuals describe how connections may be made to various electronic circuits to measure other phase angles. In all cases, frequency ratio of the two signals is 1:1.

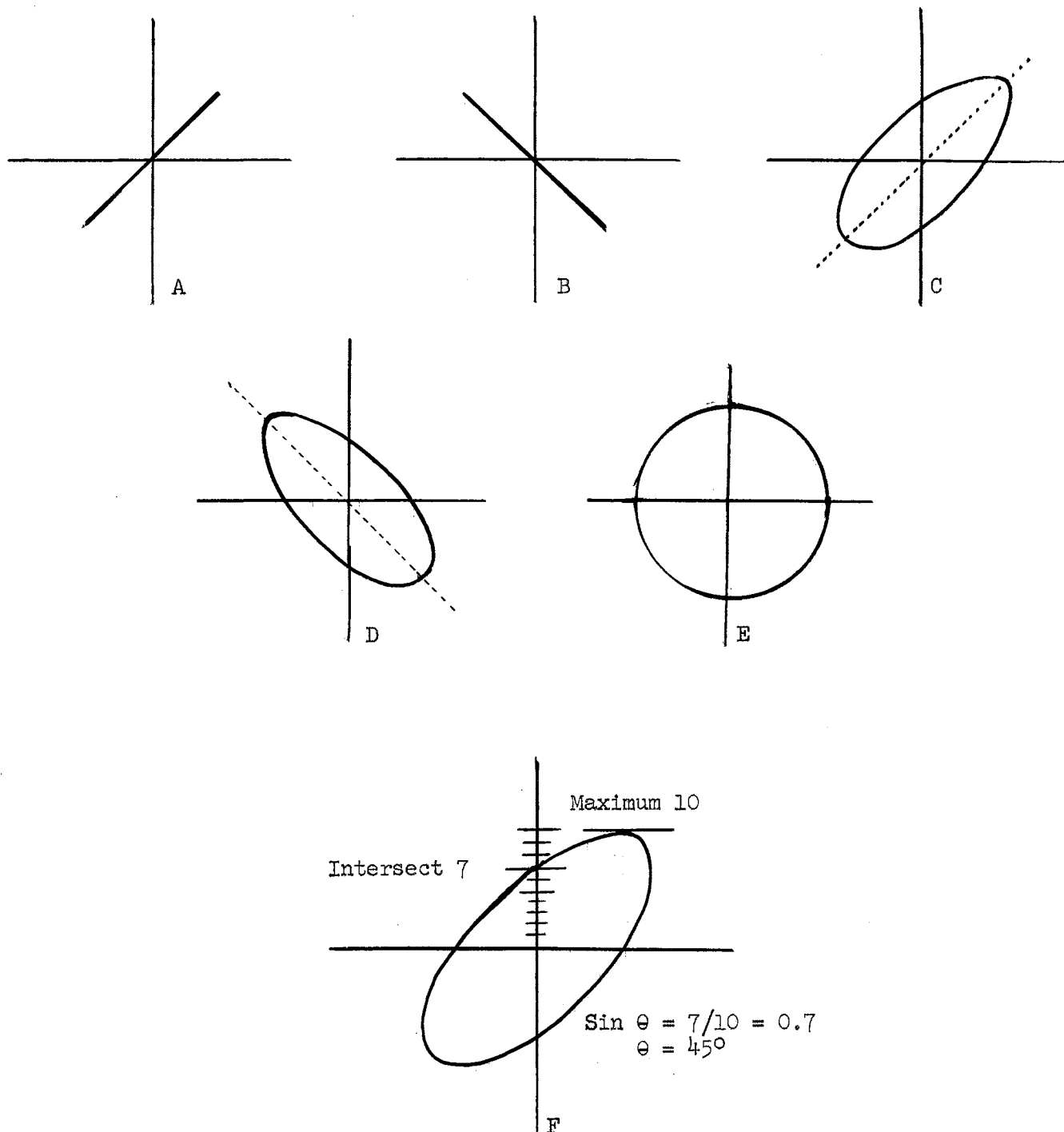


FIGURE 4

PHASE ANGLE PATTERNS

- A -- Phase difference 0° or 360°
- B -- Phase difference 180°
- C -- Phase difference 45° or 315°
- D -- Phase difference 135° or 225°
- E -- Phase difference 90° or 270°
- F -- Method for calculating phase difference:

Frequency measurements may be made using Lissajous figures also. One signal is applied to the vertical input terminals of the oscilloscope while the other signal is connected to the horizontal input terminals of the oscilloscope. Two signal or audio generators may be used for signal sources, or one such generator and the test voltage supply on the front of the oscilloscope.

The Radio Amateur's Handbook⁷ describes a simple method for determining an unknown frequency when a known frequency is applied to the horizontal plates and the unknown frequency is applied to the vertical plates. The unknown frequency is given by

$$f_2 = \frac{n_2}{n_1} f_1$$

where f_1 = known frequency,

f_2 = unknown frequency,

n_1 = number of loops along a vertical edge, and

n_2 = number of loops along a horizontal edge.

Figure 5 illustrates some of the complete Lissajous figures for various ratios. Rider and Usan⁸ suggest that the complete Lissajous figure is easiest to use with lower ratios, but for higher ratios the double image pattern is easier to interpret. The latter pattern is also sometimes called an uncompleted loop pattern because of the appearance of two free ends. Each free end is counted as one-half when using the formula given

⁷The Radio Amateur's Handbook, (31st Edition, West., Hartford, Conn., 1954), p. 483.

⁸Rider and Usan, pp. 457-458.

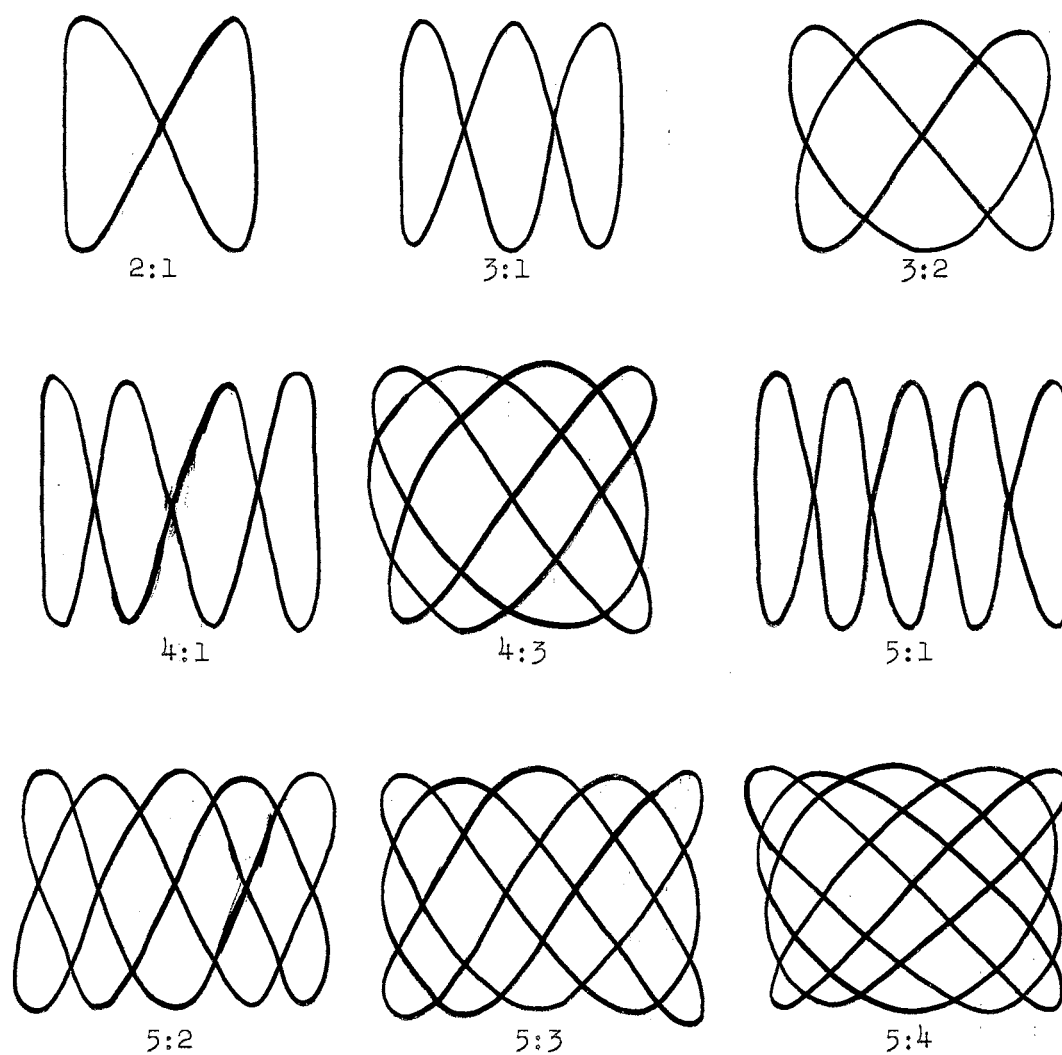


FIGURE 5

COMPLETED-LOOP TYPE LISSAJOUS FIGURES

above. Figure 6 illustrates some of the double image, or uncompleted loop type, Lissajous figures for various ratios.

As a supplement to a voltmeter, the oscilloscope can be used to give a visual account of differences in voltage. This is particularly useful to show visually the difference in voltage across the primary and secondary coils of a transformer. The oscilloscope responds to a voltage change at the vertical input terminals by changes in the amplitude of the sine wave appearing on the screen. In fact, since the vertical input voltage to the oscilloscope is directly proportional to the amplitude of the sine wave appearing on the screen, it is possible to determine the voltage across the secondary of the transformer by observing the increase or decrease in sine wave amplitude between the primary and secondary windings.

In a similar manner, the ratio of turns of the secondary winding to the primary winding of the transformer can be determined by observing the ratio of the amplitude of the secondary voltage to the amplitude of the primary voltage.

Figure 7 is a wiring diagram which can be used to demonstrate the change in voltage which occurs when a transformer is used. The double pole, double throw switch makes it possible to change from the primary to secondary voltage quickly and thus the students may observe the voltage change without any break for rewiring. If an electronic switch is available, it may be used in place of the double pole, double throw switch. In either case, the vertical gain on the oscilloscope should be set so that no adjustment is necessary when switching occurs.

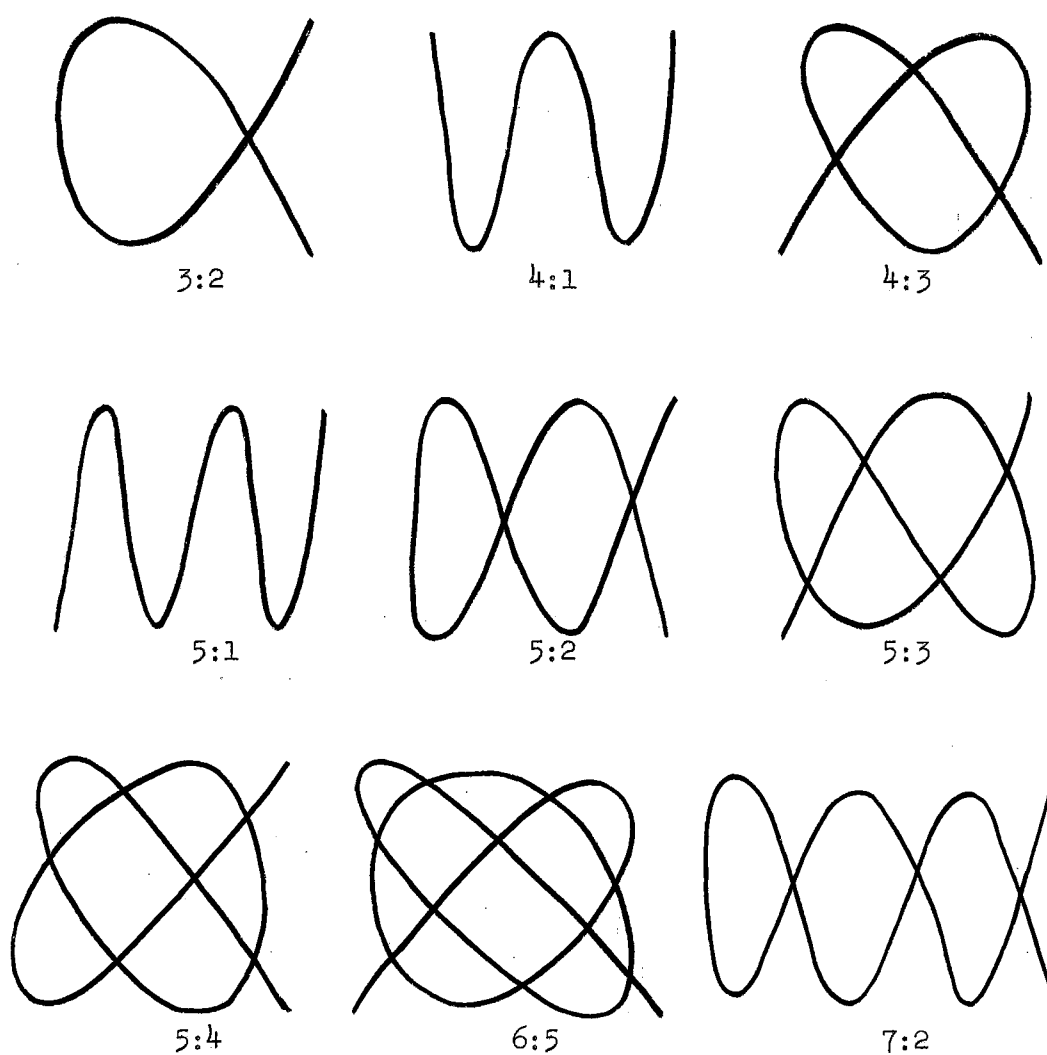


FIGURE 6

UNCOMPLETED-LOOP TYPE LISSAJOUS FIGURES

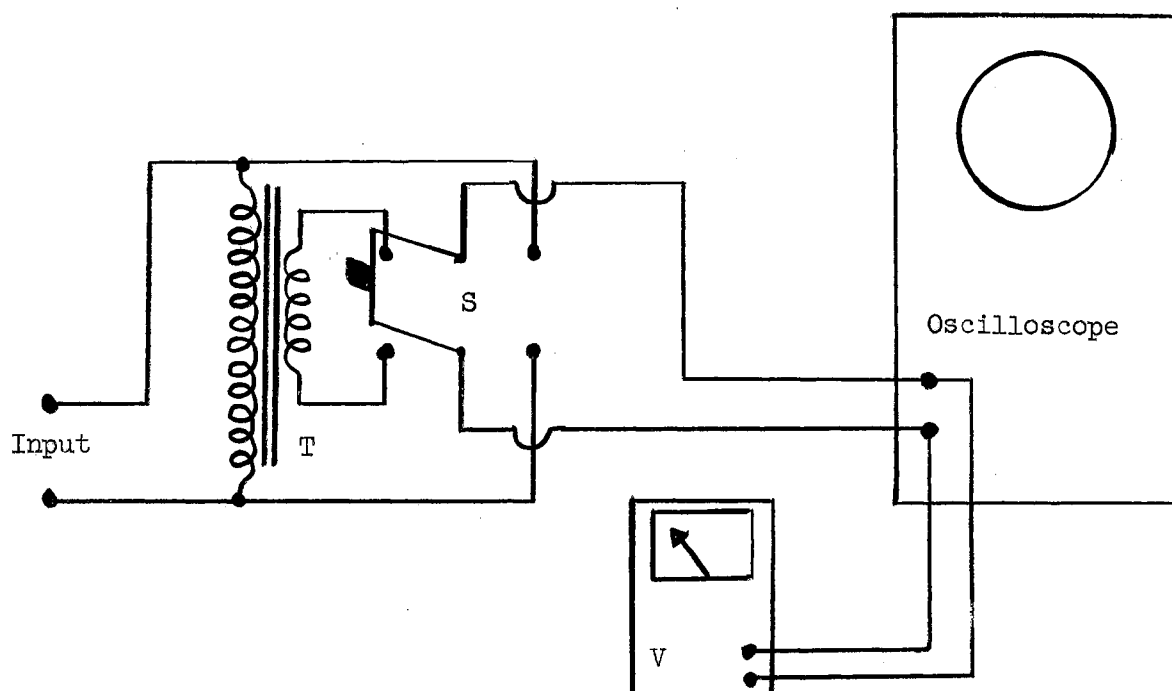


FIGURE 7

CIRCUIT DIAGRAM SHOWING TRANSFORMER CONNECTIONS TO
AN OSCILLOSCOPE AND VOLTMETER

T -- Step down bell transformer
S -- Double pole, double throw switch
V -- A. C. voltmeter
Input -- 110 volts A.C.

A voltmeter may also be connected in the circuit as shown in Figure 7. In this way, the student can observe the actual voltage change on the voltmeter as well as the change in amplitude of the sine wave on the oscilloscope. The voltmeter cannot be used when the double pole, double throw switch is replaced with an electronic switch because switching occurs too rapidly for the voltmeter to read either the primary or secondary voltage accurately.

A small step-down bell transformer or toy train transformer works satisfactorily in the preceding demonstration. However, if an audio frequency generator is available, it is possible for the students or instructor to make a transformer in which the number of turns on the secondary or primary winding can be varied at will. In this way, it is possible to demonstrate the effect of changing the number of turns of wire on either winding on the secondary output voltage. A transformer with fifty turns of wire on the primary and one hundred turns of wire on the secondary, which are tightly wound on an iron core, is sufficient to begin the demonstration. Adjustment of the horizontal selector and frequency vernier of the oscilloscope will be necessary to coincide with the audio frequency being used.

The use of an audio frequency generator in place of a regular line voltage transformer eliminates any danger which may be incurred by the use of higher voltages. However, the students will be less familiar with an audio frequency generator and some explanation of the similarities between the voltage of the generator and line voltage may be necessary.

Although transformers are generally considered to be quite efficient, small energy losses do occur. Part of these losses are due to the phenomenon called hysteresis. Whenever an alternating current is applied to a coil of wire wound on an iron core, the changing magnetic field caused by the current will tend to magnetize the iron core first in one direction and then in the other. However, as the alternating current reaches a peak and reverses, the magnetization of the iron core does not reverse instantly, but lags behind. This lag in magnetization of the iron causes an energy loss in an electromagnet or transformer. The energy loss appears as heat.

When the magnitude of the alternating current applied to a transformer or electromagnet for one cycle is plotted graphically against the magnetism of the iron core, a curve results which is called a hysteresis loop. The energy loss due to hysteresis is proportional to the area included by the hysteresis loop.

A hysteresis loop can be shown on the screen of an oscilloscope by using Gilley coils connected in a circuit as shown in Figure 8. The shape of the loop will vary with different magnetic materials used as a core for the Gilley coils. Since horizontal input connections have been made, the horizontal selector control on the oscilloscope must be set at horizontal input. Minor adjustment of the other controls may be necessary to get the proper appearance of the loop on the oscilloscope screen.

Many applications of electricity and electronics require direct current rather than alternating current which is generally more readily available. Direct current may be supplied by batteries, direct current

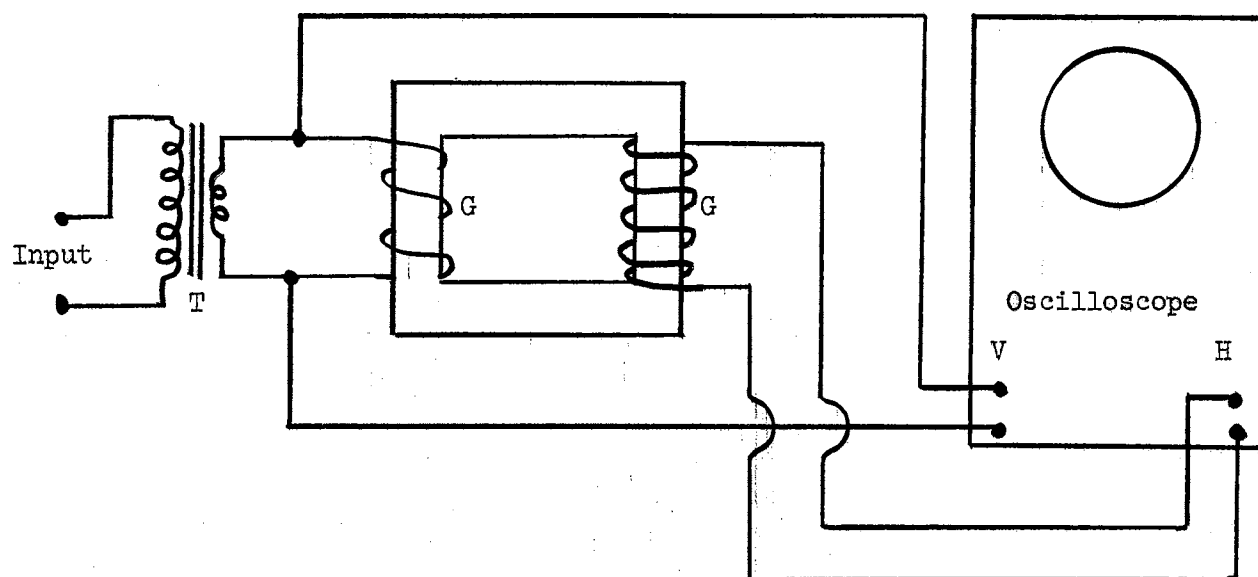


FIGURE 8

CIRCUIT CONNECTIONS FOR DEMONSTRATION OF A HYSTERESIS LOOP

T -- Stepp down transformer
 G -- Gilley coil
 V -- Vertical input
 H -- Horizontal input
 Input -- 110 volts A.C.

generators, or rectifiers. The rectifier is a device which will change A.C. to pulsating D.C. Discussion of applications of direct current to radio, television, and battery chargers may be useful in introducing rectifiers.

It may also be necessary to remind the students of the meaning of the sine wave curve as it appears on the oscilloscope screen. It must be remembered that the part of the curve above a horizontal axis on the screen represents current flow in one direction while that part of the curve below the line represents current flow in the opposite direction. If the alternating current is to be rectified to pulsating direct current, the rectifier must cause current to flow in only one direction. After rectification, the only part of the sine wave curve which will remain will be that which was above the horizontal mid-line or that which was below.

To show a visual account of rectification with the aid of the oscilloscope, any available rectifiers may be used. A double pole, double throw switch, or an electronic switch, may be used to switch conveniently from input to output of the rectifier in a manner similar to that described for the transformer circuit.

It may be more desirable to use breadboard circuit boards of home-made rectifiers to illustrate some of the various rectifiers and their associated filter circuits. Figure 9, 10, 11 and 12 show schematic diagrams of both half and full wave rectifiers utilizing the more modern selenium rectifier as well as the older vacuum tube method. In the tube

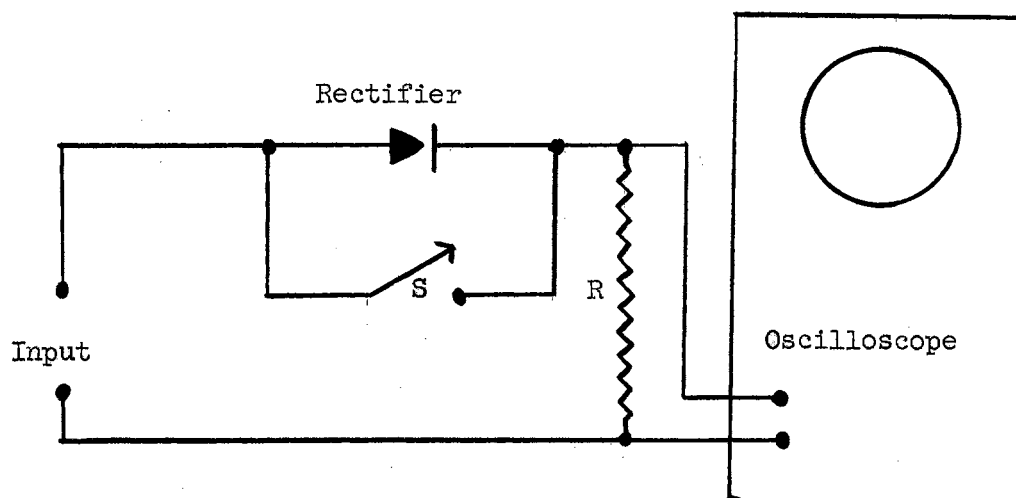


FIGURE 9

DIAGRAM SHOWING NECESSARY CONNECTIONS FOR A
HALF-WAVE SELENIUM RECTIFIER

R -- 25,000 ohm, 2 watt resistor
 S -- Single pole, single throw switch
 Input -- 110 volts A.C.
 Rectifier -- 65 ma. selenium rectifier
 Max. r.m.s. voltage: 130 v.

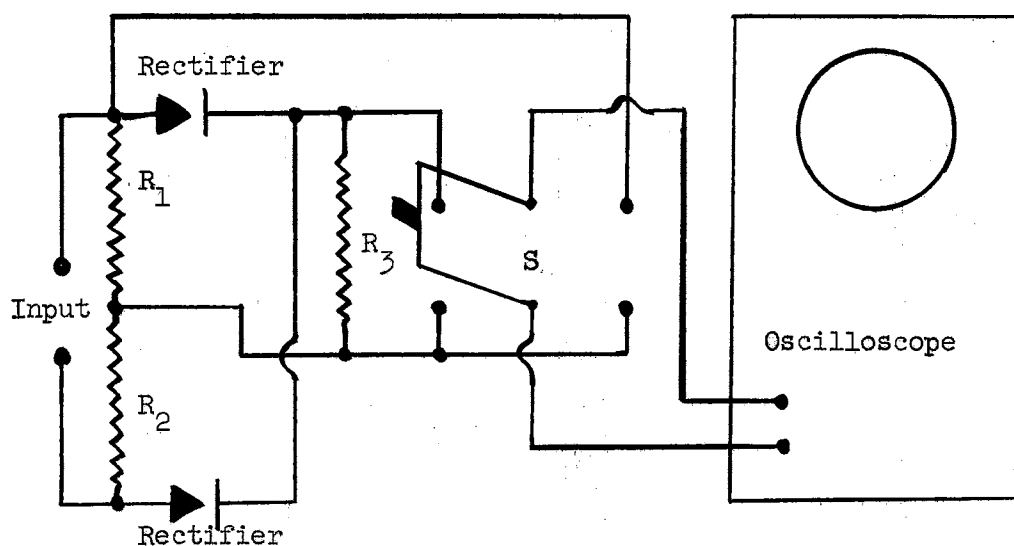


FIGURE 10

DIAGRAM SHOWING NECESSARY CONNECTIONS FOR A
FULL-WAVE SELENIUM RECTIFIER

S -- Double pole, double throw switch
 R_1, R_2 -- 5000 ohm, 2 watt resistor
 R_3 -- 20,000 ohm, 2 watt resistor
 Input -- 110 volts A.C.
 Rectifier -- 65 ma. selenium rectifier
 Max. r.m.s. voltage: 130 v.

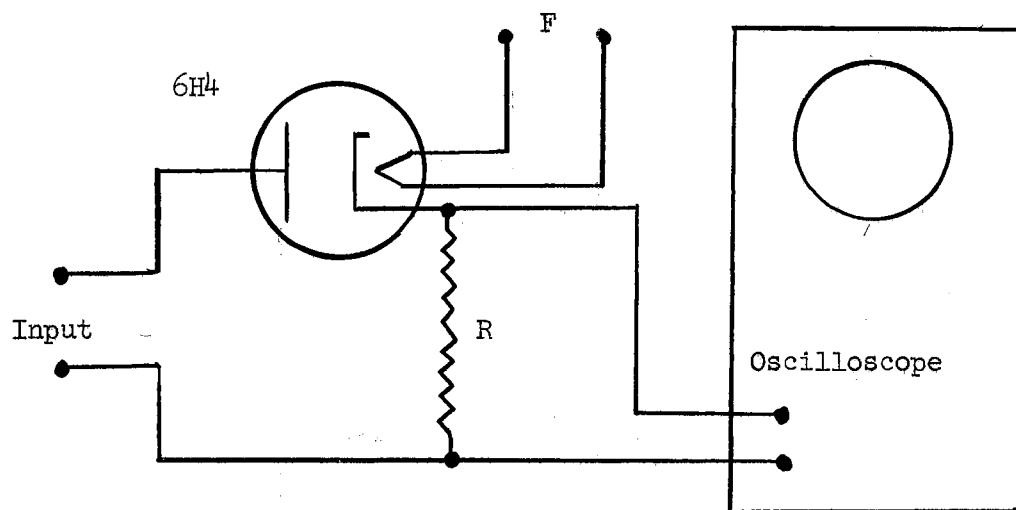


FIGURE 11

CIRCUIT DIAGRAM FOR A HALF-WAVE RECTIFIER
USING A VACUUM TUBE

R -- 20,000 ohm, 2 watt resistor

F -- Filament voltage 6.3 volts
A.C. or D.C.

Input -- 110 volts A.C.

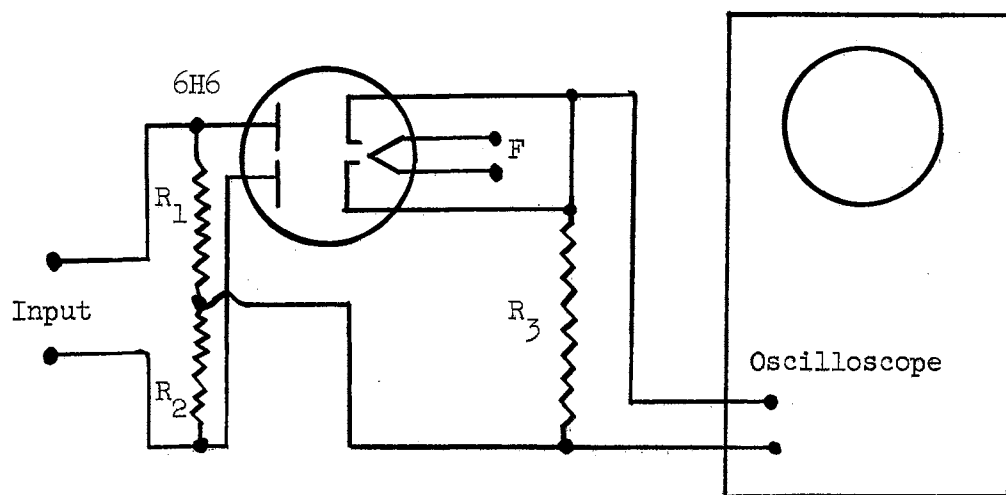


FIGURE 12

CIRCUIT DIAGRAM FOR A FULL-WAVE RECTIFIER
USING A VACUUM TUBE

R_1, R_2 -- 5000 ohm, 2 watt resistors

R_3 -- 20,000 ohm, 2 watt resistor

F -- Filament voltage 6.3 volts

A.C. or D.C.

Input -- 110 volts A.C.

circuits regular tubes normally used in rectifier circuits have been employed. However, any tube that has the correct number of plates can be used. In tubes where no cathode exists, cathode connections can be made to one of the tube filament connections. The presence of grids does not affect use for demonstration purposes. Even discarded but usable receiving tubes may be used with success. Of course, for tubes other than those specified in the circuits, circuit alternations may be necessary to prevent damage to the tube or other components and to insure proper performance of the circuit.

Without filter circuits after rectification, the direct current is of a pulsating nature as can readily be seen by the patterns on the oscilloscope. In electronic applications this is generally undesirable. For example, voltage variation on the plates of amplifier tubes cause hum as can be readily demonstrated by removal of the filter condensers from any amplifier or radio set. This same hum effect can be shown on the oscilloscope by connecting leads from the vertical input terminals of the oscilloscope to the center volume control terminal and ground on any A.C. - D.C. radio set.

After the need for filter circuits has been shown, demonstrations with various filter circuits may be shown with the aid of the oscilloscope. Although many different types of filter circuits may be found in electronic handbooks, only two basic types are in use today. The choke input filter employs an inductance in series with one side of the rectifier output. A condenser across the rectifier output leads is typical of the condenser

input filter, the other basic type. Other filter circuits differ only by the addition of more condensers and inductors to attain better filtering.

Again, breadboard circuit boards prove useful in showing various filter circuits. Figure 13 is a schematic diagram of a condenser input filter circuit which can also be used as a choke input filter. More elaborate modifications for even greater filtering would consist of repeating the pattern of choke coil and condenser.

A basic use of the vacuum tube, other than for rectification as already discussed, is to amplify voltage. A schematic diagram of a Class A amplifier connected to an oscilloscope for study of amplification is shown in Figure 14. The necessary voltages for operating the tube in the circuit may be supplied by batteries as indicated in the diagram, or it may be more convenient to use a power supply which will furnish the proper voltages. Other tubes may be used in place of the 6P5, but a tube manual should be referred to in order to determine the voltage and current specifications of the tube actually used.

The frequency of the input voltage to the amplifier can vary over a wide range beginning at approximately ten cycles per second. A signal or audio generator may be used to furnish the input signal. Even a low voltage 60-cycle signal obtained from a step down transformer may be used. However, regardless of the frequency used, the magnitude of the input voltage must be considerably less than the negative grid bias voltage. If the grid becomes positive during any part of the voltage cycle, distortion of the amplified signal may result.

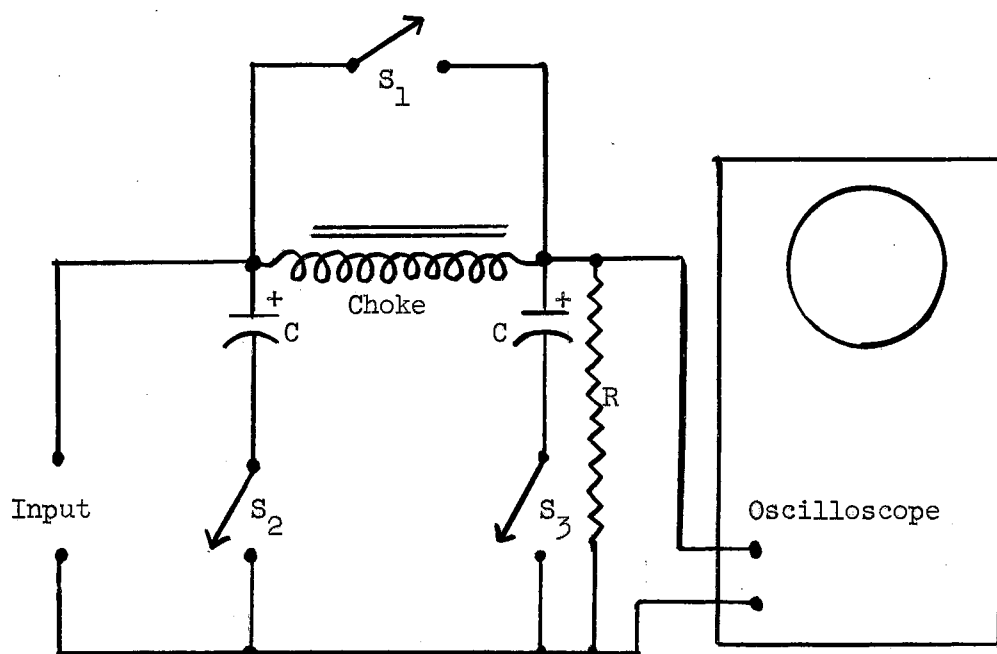


FIGURE 13

SCHEMATIC DIAGRAM OF A CONDENSER INPUT
FILTER CIRCUIT

C -- 20 mfd. dry electrolytic condensers
 R -- 20,000 ohm, 2 watt resistor
 S_1, S_2, S_3 -- Single pole, single throw switches
 Choke -- 20 hy. filter choke
 Input -- D.C. from rectifier such as in Figure
 9 or Figure 10

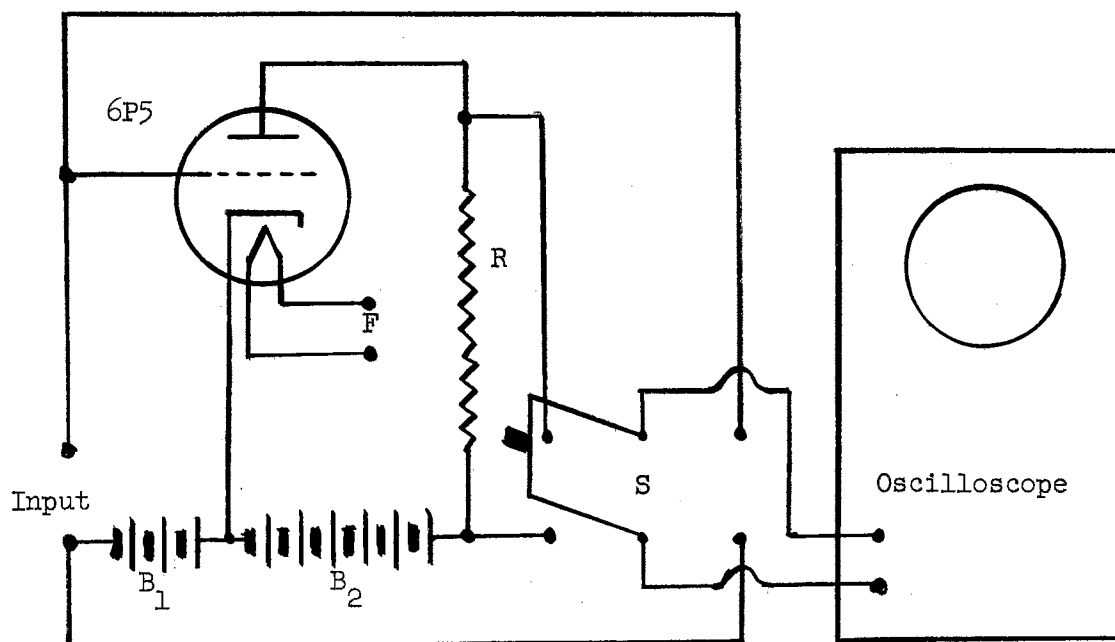


FIGURE 14

CIRCUIT CONNECTIONS FOR DEMONSTRATION
OF A VOLTAGE AMPLIFIER

R -- 20,000 ohm, 2 watt resistor
 B₁ -- 4 1/2 volt "C" battery
 B₂ -- 90 volt "B" battery
 F -- Filament voltage 6.3 volts A.C. or D.C.
 S -- Double pole, double throw switch
 Input -- 1 volt A.C. or signal generator
 voltage

Dampened oscillatory discharges produce interesting dampened waves often illustrated in texts dealing with radio. Such waves can be produced on the oscilloscope using radio frequencies. However, such patterns can also be produced at audio frequencies using a simple circuit described by Mack⁹ and shown in Figure 15. The middle Gilley coil is bucking the other two. Rapid adjustments by some switching means should be possible on the condenser pack so that the image may be adjusted to any desired decrement. Input must be ripple free full-wave rectified A.C. since any ripples present will be reproduced in the image of the dampened wave. Vertical input terminals of the oscilloscope may be connected across any one of the three coils. With each pulse of current a dampened wave should appear on the screen.

Electrical resonance and tuning is also discussed in conjunction with radio. Radio service manuals contain ample details for procedures of obtaining oscilloscope patterns of resonant and tuned circuits at radio frequencies. Mack¹⁰ describes one set of auxillary equipment that may be constructed to resonate at 60-cycles, and gives necessary instructions on how to demonstrate it with an oscilloscope. Most scientific supply houses now stock apparatus similar to that described by Mack.

The preceding demonstrations are some of the many possible in the study of electricity and electronics. Many variations may be used to fit a given situation. The total number of demonstrations possible are limited only by the ingenuity of the instructor.

⁹Mack, pp. 50-51.

¹⁰Ibid., pp. 47-50.

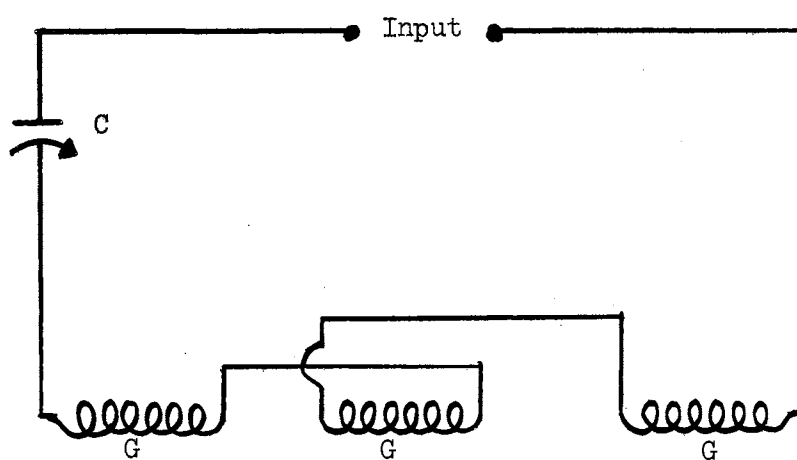


FIGURE 15

CIRCUIT DIAGRAM FOR PRODUCING DAMPENED
OSCILLATORY DISCHARGES

C -- Variable condenser 1-8 mfd.
G -- Gilley coil
Input -- Full-wave rectified A.C.

CHAPTER V

DEMONSTRATIONS WITH THE OSCILLOSCOPE IN SOUND

Because all sounds can be readily changed into electrical impulses through the use of a microphone, the oscilloscope can be used to study the nature of sound. However, the teacher should carefully explain to the student that sound waves are longitudinal; this fact can be emphasized by a demonstration with a mechanical model such as a coiled spring. This distinction of sound waves being longitudinal cannot be emphasized too strongly since, as Mack¹ points out, the student may become confused when the sound waves appear as transverse waves on the screen of the oscilloscope. If possible, a transitional demonstration with a vibrograph is recommended to show the student that longitudinal wave forms can be recorded and, for that matter, be interpreted and visually reproduced with greater ease when appearing as transverse wave patterns.

With most oscilloscopes, a crystal or dynamic microphone is most convenient since it may be connected directly to the vertical input and ground terminals of the oscilloscope. A carbon microphone will also work satisfactorily, however, but a microphone transformer with a battery

¹Mack, p. 55.

in the primary circuit is needed to couple the microphone to the cathode ray oscilloscope. A diagram showing the necessary connections when a carbon microphone is used is given in Figure 16.

On some oscilloscopes, the vertical gain may not be sufficient to give enough amplitude to the sound wave pattern appearing on the screen. In this event, an amplifier must be used to amplify the electrical impulses before they reach the oscilloscope. If a standard audio amplifier is not available, an easy method of obtaining the required amplification makes use of the final amplifier stage of a radio. By connecting one lead from the microphone to the center terminal of the volume control of the radio and the other lead to ground or chassis of the radio, sound at the microphone will be amplified and heard at the radio speaker. The volume control of the radio will also serve as a volume control for the amplifier. The radio should be tuned to a frequency where no station is heard to obtain minimum distortion of the sound at the microphone.

To observe the sound patterns from an amplifier on an oscilloscope, it is only necessary to connect two wires from the speaker terminals to the vertical input and ground terminal of the oscilloscope. Since the oscilloscope is essentially a voltmeter, it will give a visual account of the voltage fluctuations occurring at the speaker terminals and will not affect the sound amplification or reproduction by the speaker. Thus, the students can hear the amplified sounds and observe the sound patterns on the oscilloscope simultaneously.

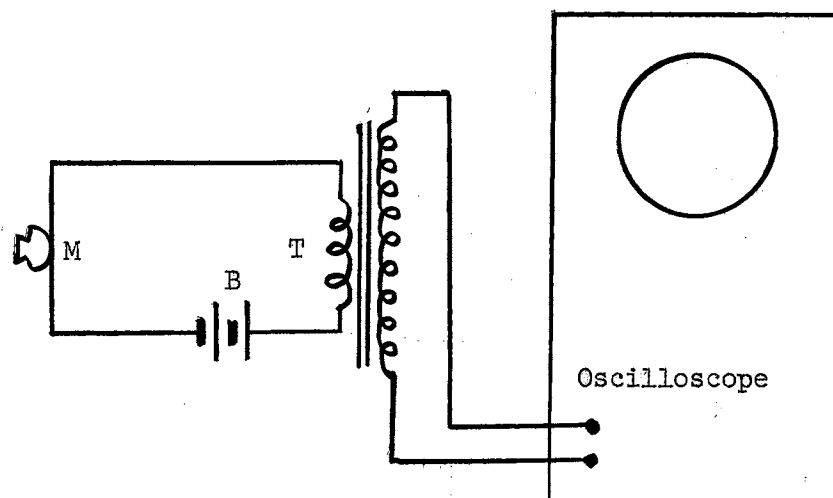


FIGURE 16

CIRCUIT DIAGRAM SHOWING NECESSARY CONNECTIONS
WHEN USING A CARBON MICROPHONE

M -- Carbon microphone
B -- Battery, 1 1/2 - 3 volts
T -- Audio transformer

Another method of observing sound waves from a radio or amplifier depends upon magnetic induction.² The ground of the oscilloscope is connected to ground or chassis or the radio or amplifier. The vertical input terminal of the oscilloscope is connected to a coil of wire which is merely slipped over the detector tube or appropriate tube found experimentally.

Probably the first sound wave patterns to be shown to the students should be the simpler patterns such as produced by tuning forks. It is first necessary to set the coarse frequency control of the oscilloscope as near the tuning fork frequency as possible and adjust the frequency vernier to the desired wave form while holding a tuning fork in front of the microphone. Normally, no adjustment of the frequency vernier is necessary to observe sound patterns of tuning forks which are harmonics of each other, but adjustment will be necessary when tuning forks which are not harmonics are to be shown.

When the proper adjustments have been made, the familiar sine wave will appear on the screen of the cathode ray tube. The instructor can effectively demonstrate change in frequency by using a second tuning fork which is a harmonic of the first. For example, if the wave form of a tuning fork of 256 vibrations per second, middle C, is shown on the screen and then a tuning fork of 512 vibrations, C above middle C, the

²E. B. Chrisman and R. Neal, "Cathode Ray Oscillograph Demonstrations in High School Physics," School Science and Mathematics, XLI, (June, 1941), 528-529.

student can observe the frequency doubling by counting the number of sine wave peaks which appear on the screen of the oscilloscope in each case.

Use of an amplifier and speaker is desirable since then the student will be able to hear clearly the higher pitch of the more rapidly vibrating tuning fork as well as the change in wave form observable on the screen.

The relationship between the intensity or loudness of the sound wave and amplitude of the wave pattern can be shown effectively also with the oscilloscope. If a tuning fork is struck hard and is then held in front of the microphone until the vibration dies down considerably, the oscilloscope will show a corresponding change in the vertical height of the sine wave appearing on the screen. The instructor should call the attention of the students to the fact that no variation in the number of sine wave peaks has occurred, but only a variation in the sine wave height or amplitude results. When using an amplifier, changes in the setting of the volume control will also be apparent on the oscilloscope.

Patterns of other sounds, such as the human voice, may be picked up by the microphone also. Because voice waves are fairly easy to project on the oscilloscope without special amplification, while tuning forks have low intensity patterns which are barely visible without special amplification, Gregory³ suggests a method of providing patterns of

³Brother H. Gregory, "Projecting Sound Waves and Beats on the Oscilloscope," The Science Teacher, XXIV, (December, 1957), 401.

suitable intensity without any external amplifier. The vertical input and ground terminals are connected to a pair of magnetic type earphones which can also act as microphones. One earphone is used directly as a microphone for voice pickup. The other earphone is used with tuning forks by removing the cover and diaphragm from the earphone. The vibrating tuning fork held near the small magnet in the earphones will induce a current of the same frequency as the sound wave and thus produce the desired wave form on the screen of the oscilloscope. Of course, this method is limited to steel tuning forks, since aluminum, the other common material, will not cause the magnetic field to fluctuate.

Many instructors may feel that the vibrations from most laboratory tuning forks are not of sufficient intensity or duration for many demonstrations. In this event, it is suggested that a bell lyre, found in most high school instrumental music departments, be borrowed to provide the necessary sound vibration sources. Added interest is created by the greater number of musical notes available than is generally possible with most high school laboratory collections of tuning forks.

Quality of sounds may be demonstrated with considerable interest when the students have the opportunity of observing their own voice patterns on the oscilloscope as well as the voice patterns of other students. As the microphone is passed from one student to another and a given sound is made by each student, the differences in tone quality as well as pitch and loudness of various voices can be readily observed. Students in glee clubs and choruses will be interested in differences in sound patterns as made by well-trained voices contrasted with sound patterns of untrained voices.

Other sources of sound for observation on the oscilloscope are nearly unlimited and depend largely upon the ingenuity of the teacher and students. Certainly a variety of musical instruments from the school band will add interest. Radio programs, phonograph records, and tape recordings all present many possibilities. With a tape recorder many unusual sounds and kinds of noise may be brought to the classroom conveniently. Variation in patterns of different kinds of noise is of interest in addition to the usual contrast shown between noise and musical sounds. An almost infinitely large source of pure musical notes is possible if an audio or signal generator is available.

Whenever two sounds are made which vary slightly in frequency, a phenomenon of interference occurs which is referred to as beats. Two tuning forks of the same initial frequency, one of which is altered by one or two cycles per second in frequency by the addition of a rider, or tiny piece of putty, on one of the prongs may be used to produce beats. Another method of altering the frequency of a tuning fork is by the use of a rubber band placed around the lower portion of the fork. When the two forks, differing slightly in frequency, are set vibrating and held near the microphone, the alternate reinforcing and canceling of the sound waves can be observed on the oscilloscope as changes in amplitude. If the difference in frequencies of the two forks is five or less cycles per second, beats can easily be heard on the speaker after amplification at the same time the pattern is being seen on the oscilloscope. Beats of more than five per second are difficult to hear, but they can still be observed on the oscilloscope.

If no amplifier is being used and the tuning forks are made of steel, the method using magnetic earphones suggested by Gregory⁴ may be used. Here both earphones would be used with covers and diaphragms removed. The use of two microphones may also offer the advantage of convenience.

If two audio generators are available, beats may be produced very conveniently connecting the generator outputs to the oscilloscope by way of the amplifier-speaker combination. Beats at any desired frequency and number may be obtained with considerable more ease than by the tuning fork method. If only one audio generator is available, satisfactory results may sometimes be obtained near the frequency of 60 cycles per second. In place of the second generator, a 60-cycle tone may be obtained from the regular household power supply. Most oscilloscopes have a one volt a.c. tap from which this 60-cycle source may be obtained. Audible results at this frequency are questionable depending largely on the capabilities of the audio amplifier at these low frequencies.

Another type of interference occurs when sound travels different distances in reaching the ear. This interference is often shown by rotating a vibrating tuning fork near the ear or by rotating the fork over a resonant air column. The phenomenon can also be shown on the oscilloscope by rotating the tuning fork near the microphone. In this manner, the entire class can observe the interference pattern as well as hear it over the speaker after amplification.

⁴Ibid., p. 401.

Resonant air columns, open and closed pipes may also be demonstrated with the aid of the oscilloscope. A microphone connected to the vertical input terminals of the oscilloscope need only be placed near the source of sound to produce the various patterns on the face of the cathode ray tube.

The topic of overtones and harmonics of a vibrating string usually receives some attention in a unit of sound. Grubbs⁵ suggests a very interesting experiment for demonstrating the harmonics of a vibrating string as well as the laws of vibrating strings. Figure 17 shows the necessary circuit connections as outlined by Grubbs. Figure 18 indicates the position of the antinodes where the magnets are placed over the vibrating wire to produce the specific wave forms.

With this apparatus up to the first 15 harmonics may be obtained depending upon the length of the string and size of the magnets. Adjustments in tension, length, and mass or diameters of the same material may be made thus showing the frequency change which results on the oscilloscope. In addition, it should be called to the attention of the students that they are observing a demonstration in which current is induced in a conductor as it cuts magnetic lines of force.

For demonstrations of sounds at very low frequencies, or to produce patterns below the lower audible frequency limit, a cathode ray oscilloscope may not be particularly suitable. The industrious instructor may

⁵R. C. Grubbs, "Demonstrations in High School Physics," School Science and Mathematics, XLVIII, (March, 1948), 199-201.

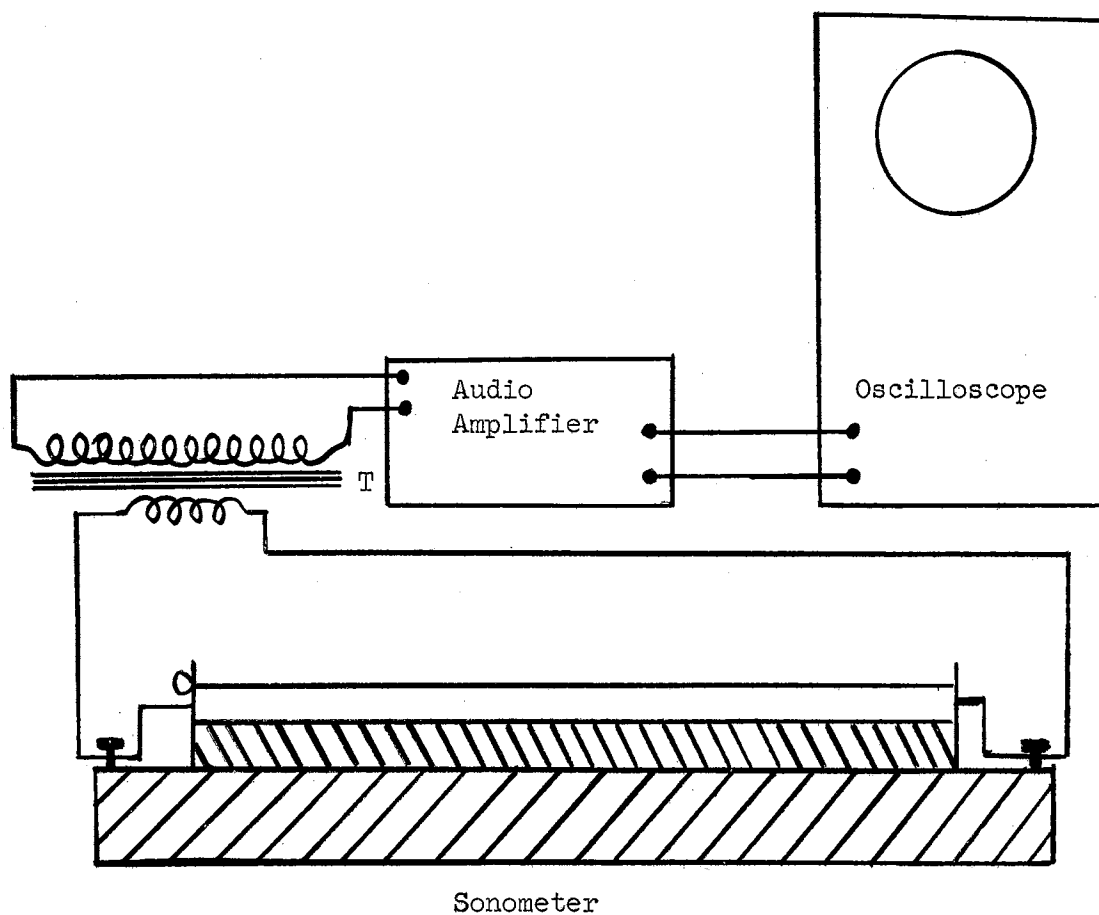


FIGURE 17

CIRCUIT CONNECTIONS FOR DEMONSTRATION OF WAVE FORMS
AND LAWS OF VIBRATING STRINGS

T -- 110-volt step down bell transformer

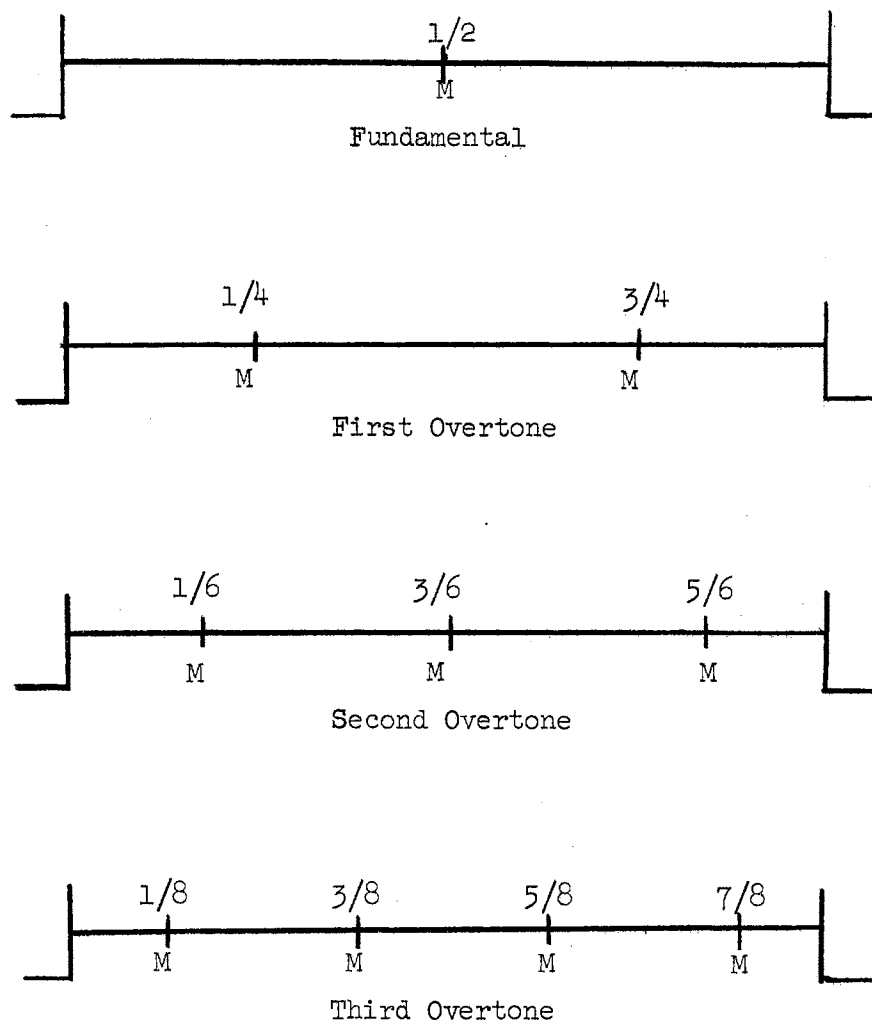


FIGURE 18

POSITIONS OF ANTINODES AND MAGNETS
FOR SONOMETER DEMONSTRATION

M -- Horseshoe magnet

wish to undertake the construction of an oscillograph as described by Hoecker and Asher.⁶ This apparatus may even be used to record the patterns produced by the human heart beating.

⁶F. E. Hoecker and A. G. Asher, "Unique Oscillograph Demonstration," American Journal of Physics, VIII, (February, 1940), 59-62.

CHAPTER VI

DEMONSTRATIONS WITH THE OSCILLOSCOPE IN ATOMIC PHYSICS

For the very advanced high school physics classes and the more ambitious instructor, demonstrations utilizing the oscilloscope may be undertaken in the field of atomic physics. However, most demonstrations are somewhat complex.

Perhaps one of the simpler demonstrations is an approximate method for measuring the mass of the electron with the aid of the oscilloscope as described by Kirkpatrick.¹ The procedure consists of removing the oscilloscope from its housing to avoid the magnetic shielding the case provides. The cathode ray tube is thus exposed to the inspection of the students and the manipulations of the demonstrator. The cathode ray tube should be oriented in an east-west line, and be free to rotate about its axis of symmetry. For this rotation, it will be necessary to loosen the tube socket clamp and any clamps that may hold the tube rigid. A small spot is focused on the screen and its position is recorded with an ink dot. The tube is then rotated a few degrees and the position of the spot which should be deflected by the earth's magnetic field, is recorded again. This process is repeated until the orbit of the spot is

¹P. Kirkpatrick, "Simple Determination of Electronic Mass," American Journal of Physics, XVII, (April, 1949), 320.

determined to be a circular loop of diameter d . It can then be shown that the electron mass, m in grams, is approximately given by

$$m = \frac{B^2 e L^4}{2 V d^2}$$

where B = strength of earth's magnetic field in gaussess,

e = electronic charge in emu or abcoulombs,

L = distance from anode to screen in centimeters,

V = accelerating potential in emu or abvolts, and

d = diameter of loop in centimeters.

Values of B and e may be taken from tables. The values of L and V may be measured or obtained from tube manufacturer's data. Results should deviate 15% or less from the accepted value for electron mass.

Electronic charge, velocity of the electron, and the determination of e/m may also be accomplished with the aid of the oscilloscope. Such demonstrations become increasingly complex, however. Many such demonstrations are described in issues of the American Journal of Physics and its predecessor, American Physics Teacher. Two such demonstrations, somewhat simpler than others described, have been written by Smyth and Curtiss² and by Weber and McGee.³

²H. D. Smyth and C. W. Curtiss, "Lecture Room Determination of the Velocity and e/m of the Electron in a Cathode Ray Oscillograph," American Physics Teacher, VI, (June, 1938), 158-160.

³A. H. Weber and J. F. McGee, "Specific Charge of the Electron by the Thompson Method with a Commercial Cathode Ray Oscillograph," American Physics Teacher, VII, (February, 1939), 62-64.

CHAPTER VII

ADDITIONAL EQUIPMENT

Applications and use of the oscilloscope in science teaching can often be made more effective by the addition to the high school science laboratory of an amplifier, loudspeaker, audio or signal generator, square-wave generator, and electronic switch. As with the oscilloscope, this additional equipment can be purchased in kit form, with the exception of the speaker, at a large saving over the cost of assembled instruments. The manufacturers of oscilloscope kits generally also have these other electronic kits available. Prices are generally under forty dollars.

The amplifier is useful to increase any low power signal so that a more effective trace is obtained on the screen of the oscilloscope, as well as to drive the loudspeaker in demonstrations with sound. Performance of the amplifier itself may be shown with the aid of the oscilloscope as suggested in Chapter IV.

The loudspeaker is useful in reproducing sounds at an audible level for classroom use while simultaneously seeing the oscilloscope pattern of the electrical fluctuations energizing the speaker. Any inexpensive replacement type speaker may be used, but speakers over five inches in diameter may prove to be more satisfactory since they generally produce better quality sound over wider frequency ranges.

The audio generator is a device which is designed to generate a low voltage, low power, alternating current in the audio range, with provisions for varying the frequency of the signal being generated. A signal generator is of the same general design as the audio generator except that the upper limit of the frequency range is in the radio range. Many types of generators are available and are designed for specific purposes. It is possible to obtain generators which can be varied in frequency from approximately twenty cycles per second to one million cycles per second. However, an audio generator with frequency range from twenty up to 20,000 cycles per second is adequate since this range includes the sounds audible to the human ear.

The audio or signal generator can be connected through an audio amplifier to the oscilloscope and the typical sine wave curve will appear on the screen. It may be used to supply the input voltage for the voltage amplifier as described in Chapter IV, where it will allow the amplifier to be tested over a range of frequencies. When used with an amplifier and speaker, the audio generator will serve to check individual students for the range of sound frequencies which they can hear. One or two generators are useful in producing beats in any desired combinations, and also for the productions of the signals to be fed to the oscilloscope to produce Lissajous figures.

The electronic switch is an instrument which makes high frequency, continuous switching between two points in a circuit possible. As an example, the electronic switch could be employed to switch between the

input and output terminals of an amplifier. If the output of the electronic switch is then connected to an oscilloscope, the sine wave input and output of the amplifier could be viewed simultaneously on the screen.

In more advanced work, especially in the study of phase shift caused by inductance or capacitance in alternating current circuits, the electronic switch is valuable in making it possible to observe the phase shift on the screen of the oscilloscope.

All of this additional equipment is rugged and dependable. They can be used by students in laboratory experiments as well as for classroom demonstrations.

CHAPTER VIII

SUMMARY

The cathode ray oscilloscope is an instrument which can be used effectively by the high school science teacher as a visual aid in classroom demonstrations. This report presents a number of basic circuits and instructions which can be used in conjunction with the oscilloscope and which will materially aid the science instructor in teaching some of the basic principles of electricity and sound.

In all cases, circuits have been kept as simple as possible in an attempt to keep the cost of setting up the demonstrations to a minimum. Most circuit components can be found easily even in a poorly equipped laboratory or can be readily obtained from discarded radio or television sets, from local radio or television repair shops, or from many wholesale electronic supply distributors.

Although the demonstrations presented here represent only a small part of the total number of possible demonstrations with an oscilloscope, the teacher should become sufficiently familiar with the operation of the oscilloscope to adapt it to use as an opportunity arises. The oscilloscope is not only versatile, but is rugged and not easily damaged regardless of how it may be connected into a circuit of reasonable voltage.

The oscilloscope can be used effectively in the laboratory as well as in the classroom for demonstration purposes. Many of the demonstrations listed in this study can be adapted for use in laboratory experiments. The student can learn to use the oscilloscope quickly and it will serve to increase student interest in experiments as well as to improve student understanding of basic principles in physics.

It is hoped that this report will help some teachers of high school physics to better understand the use of the oscilloscope and, in so doing, will result in the wider use of the cathode ray oscilloscope as a visual aid in teaching.

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Master of Science

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