# Student Manual

## INDUSTRIAL ELECTRONICS

COYNE
ELECTRICAL AND
RADIO-TELEVISION
SCHOOL
CHICAGO 12, ILLINOIS

16-7-30

Mon. - 630 800 Shop
Wed - All Shop
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# FOREWORD

This manual contains basic technical and practical information based on the curriculum outline for the Industrial Electronics Department of this school. The subject matter covered in this manual is necessary information that the student must learn in order to master the jobs that will be presented.

The purposes of this instructional manual are as follows:

1. To provide a guide for the student in his class and shop work.

2. To supply information in outline form to which the student may add supplemental notes in his own words as the different points are explained by instructors.

3. To serve as a reference both to the student in school and to the graduate after he enters the field.

Appreciation is extended to the Industrial Electronics personnel and to the entire faculty for developing the material for this manual.

B. W. Cooke,
President.

# INTRODUCTION

Electronics is the science which deals with electricity through vacuums and gases confined within tubes or tanks.

Industrial electronics is the branch of electronics dealing with the application of electronic tubes in manufacturing, assembling, processing, and many similar industrial or commercial applications.

In preparing the material for this manual the thought that was kept foremost in mind was to condense the explanation and to include only that material which would be of practical value to the ELECTRICIAN on the job or the beginner in this promising field of ELECTRONICS IN INDUSTRY.

## ACKNOWLEDGEMENTS

We wish to acknowledge and express our appreciation for the assistance and cooperation given by the following Companies in supplying data and illustrations for the preparation of this manual.

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T A B L E   O F   C O N T E N T S

# ELECTRONICS AS APPLIED TO UNITS OF MEASUREMENTS

## Objective

a. To become familiar with the correct terminology in industrial electronics, the basic electron theory, and the color code.

b. To learn to recognize the value of a resistor or a capacitor in industrial applications.

## References

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## Lesson Content

### A. Current and Electron Flow

The electrical field is going through a period of transition with regard to the direction taken by electricity as it moves through a conductor. Authorities agree, however, that as energy moves from point to point through a conductor, a charge of electricity actually moves within the conductor. This movement of electricity through a conductor is known either as current or as electron flow, either of which we can assume is correct. That is, electrons flowing result in current; so we may refer to electrons flowing, or the <u>result</u> of electrons in motion which is current.

In the early days before much thought was given to the electron as it is known today, the movement was always called current, and laws, rules, etc., were developed which assumed that the direction of current was from <u>positive</u> to <u>negative</u>.

Now, it is known that current is the result of electrons moving through the circuit from <u>negative</u> to <u>positive</u>. Since this disagrees with the earlier assumption students sometimes become confused, with the result that they may lose confidence in different authors who may present slightly different view points.

Actually it makes no difference which direction the electricity moves or whether we refer to the motion as current or electron flow; as long as we remember that electrons are negative and that they are attracted to a positive point. When tracing electrical circuits, however, arrows are often used and the arrow is usually given a direction which agrees for all circuits within a single diagram. It would make no difference which way the arrows point as long as all circuits are traced with the same theory in mind. In electronics, however, we find it much more convenient to trace the circuit in the direction of <u>electron travel</u>.

There are rules, such as the right and left hand rules for polarity, direction of current, etc., developed around the early theory which assumed that current flows from positive to negative. When these rules are applied to electron flow from negative to positive, they must be reversed. For example, the left hand could be used instead of the right hand.

When dealing with vacuum tubes, it is less confusing to follow the electron theory since the critical point is within the tube itself, where we deal mainly with electron movement from cathode (electron emitter) to anode (plate). So whether we use the term electron flow or current makes no difference when we are not necessarily establishing the direction taken by the electrons. As a matter of form, however, it is better to use the expression "current" and not "current flow". The word flow used with electron denotes electricity in motion, but the word "current" taken alone indicates the results of electrons in motion. The word "current" may be used as a noun or as an adjective while the term "electron flow" is used only as a noun.

E Examples - a. The current (n) generates heat in the resistor.

b. The direct current (a) generator is running hot.

c. The electron flow (n) moves in a direction from negative to positive.

In most cases common sense dictates the correct term to use, but since the term "electron flow" is more closely connected with direction of electron movement, we recommend using this term whenever possible. The two terms, however, should be understood because of the frequent use of both terms.

B. Basic Electron Theory

1. All matter exists in the form of a solid, liquid or gas and is made up of fundamental units called "molecules". A molecule may be defined as "the smallest portion of any substance which cannot be subdivided and keep the same chemical and physical properties".

2. There are as many kinds of molecules in the universe as there are different kinds of substances. The molecules in a solid are crowded very closely together and the attractive force between molecules makes it difficult to alter the shape of solids.

3. In a liquid the molecules are free to move from one point to another point within the liquid. One can put an arm easily in a bucket of water but not in a bucket of cement. The reason is that the molecular structures of the substances are different. The water molecule is freer than the cement molecule.

4. The movement of a gas molecule is still freer than the water molecule. In future lessons the gas molecule will be discussed in greater detail.

5. A molecule can be further subdivided, but the resulting particles are no longer called molecules. They are called ATOMS. One atom may be defined as "the smallest portion of matter obtainable by chemical separation".

6. The atom can be further subdivided into "protons" and "electrons". An electron is a minute particle of negative electricity. It makes no difference what type of atom the electron is associated with. All electrons are identical.

The proton is electrical in nature, just as the electron, but it consists of positive electricity.

7. The conclusion, therefore, is that all matter is merely different combinations of positive protons and negative electrons.

8. When referring to the electronic term resistance, it means the opposition a certain substance offers to the free movement of these electrons from one atom to another.

9. Electrons are moved from one atom to another by electro-motive force. EMF may be produced in three different ways:

   a. Chemical reaction

   b. Thermo-electric

   c. Electro-magnetic

   If two objects are charged differently; that is, if one has a deficiency of electrons (charged positive) and the other has an excess of electrons (charged negative) a potential difference will exist between them. This difference in potential (or charges of electrons) is measured by the electrical unit called the volt. It is not necessary to have unlike charges to have a difference in potential. For example; a difference of potential will exist when both charges are negative, providing one charge is more intense than the other. When speaking of larger voltages numerically, we mean that a greater difference of potential exists.

10. When a difference of potential is applied to a resistance unit, there will be a continuous drift of electrons from atom to atom and an electrical current will exist through the circuit. A current of one ampere represents about six million million million electrons flowing past a given point in one second.

11. Basic laws for electron theory

   a. Two negatively charged bodies repel each other, or two positively charged bodies will repel each other.

   b. Two oppositely charged bodies will attract each other.

   c. Within a conductor all positive charges are fixed in the nucleus of the atom and cannot move.

   d. 50% or more of the total number of electrons in an atom are contained in the orbits surrounding the nucleus. A large percentage of these electrons are "free to move".

   e. Current is a result of drift movement of "free electrons" in the direction of a more positive (less negative) potential.

   f. All electrons are identical.

12. Fig. 1 illustrates how electrons drift or flow through a conductor:

Due to the chemical reaction within the battery, a deficiency of electrons will uccur at point "B" which is marked positive, and an excess of electrons will exist at point "A" which is marked negative.

The basic law states that two oppositely charged bodies will attract each other. In Fig. 1, the negative free electron is a negatively charged body and point "B" of the battery is a positively charged body. These two oppositely charged bodies will attract each other.

The basic law states that current is a result of a drift movement of "free electrons". This drift movement, Fig. 1, may be explained in the following manner:

a. As the free electron of the atom located at the extreme right leaves its orbit, this atom will then have a deficiency of one electron and will tend to attract another electron in order to bring itself to its normal charge. A drift movement of free electrons will then take place from one atom to another as shown by the arrows.

b. All electrons are identical and these electrons will drift or flow from the negative side of the battery, through the wire, to the positive side of the battery through the internal structure of the battery from positive (plus) to negative (minus), and back to the starting point. The chemical action within the battery overcomes the attraction between unlike charges and - draws the electrons from the positive terminal and also forces them through the battery to the negative terminals.

C. The RMA (Radio Manufacturers Association) Color Code Chart for Resistors and Basic Three-dot Capacitors.

| COLOR | 1st DOT or Stripe A | 2nd DOT or Stripe B | 3rd DOT (Multiplier) or Stripe C | 4th Stripe TOLERANCE CODE (resistors) D |
|---|---|---|---|---|
| BLACK | - | 0 | 1 | GOLD . . . . 5% |
| BROWN | 1 | 1 | 10 | SILVER . . .10% |
| RED | 2 | 2 | 100 | NO COLOR . .20% |
| ORANGE | 3 | 3 | 1000 | |
| YELLOW | 4 | 4 | 10000 | |
| GREEN | 5 | 5 | 100000 | |
| BLUE | 6 | 6 | 1000000 | |
| PURPLE(violet) | 7 | 7 | 10000000 | |
| GREY | 8 | 8 | 100000000 | |
| WHITE | 9 | 9 | 1000000000 | |
| GOLD | - | - | Divided by 10 | |
| SILVER | - | - | Divided by 100 | |

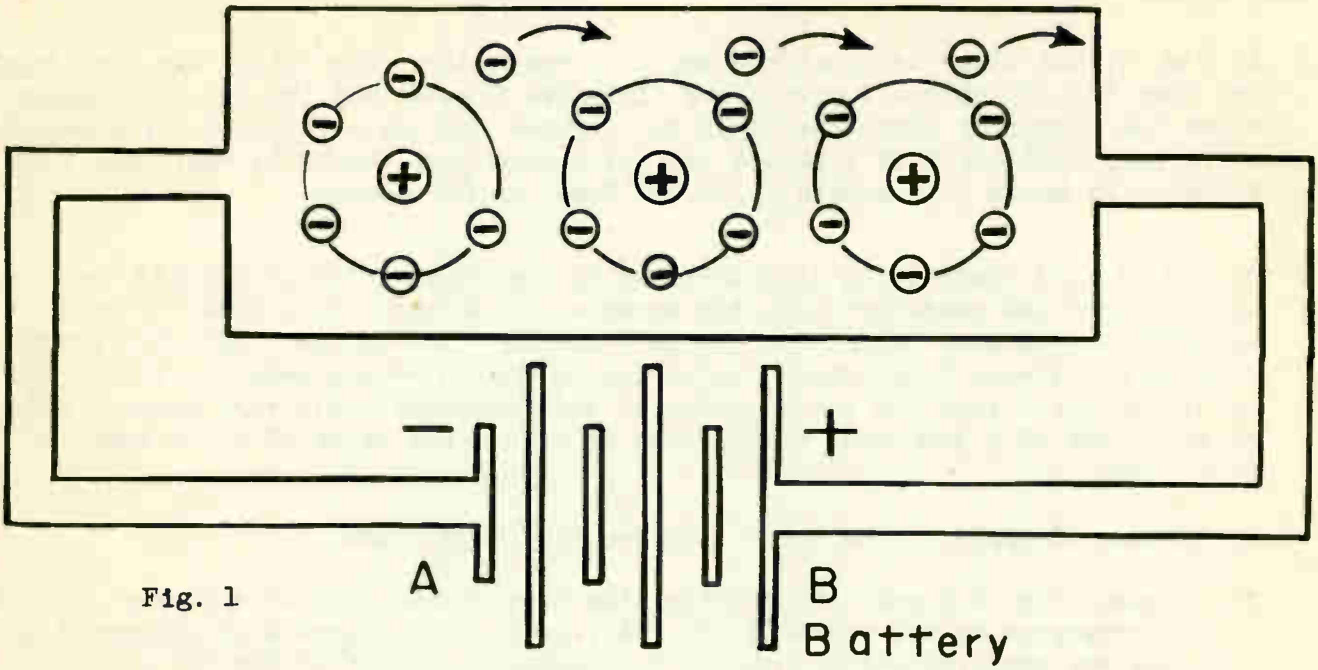



Fig. 1

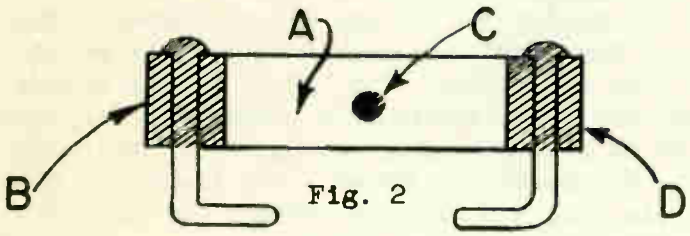



Fig. 2

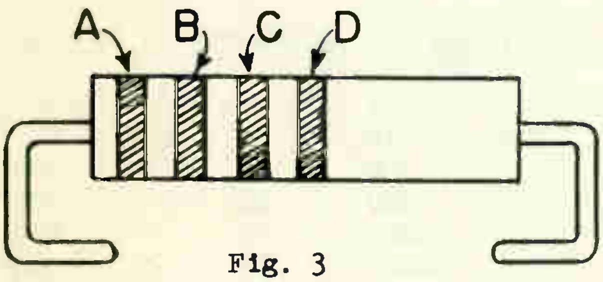



Fig. 3

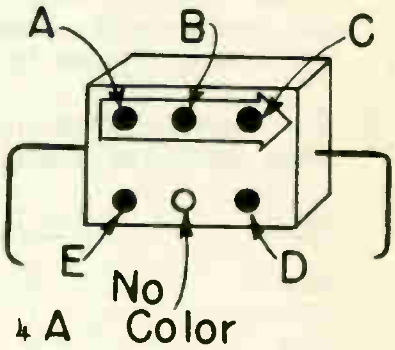



Fig. 4 A

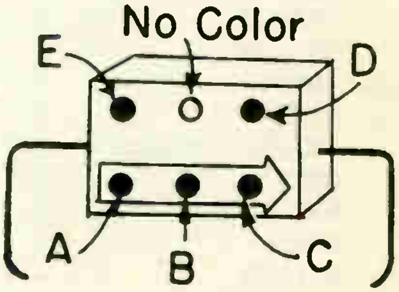



Fig. 4 B

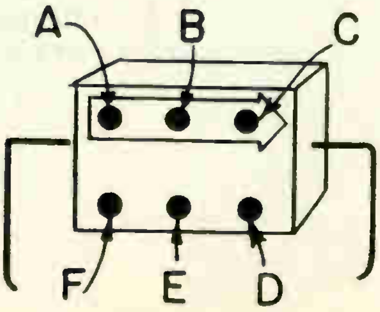



Fig. 5

D. Two Different Methods of Applying the Color Code to Resistors.

1. In Fig. 2, the color designations apply to body color, tip color, and dot color. The body and tip colors indicate the first two figures and the dot color determines the number by which the first two figures must be multiplied. For example, a red body resistor with a violet tip and a green dot, would be red: Red - 2; violet - 7; green - 5; equals 2,700,000 Ohms, or 2.7 megohms.

2. In Fig. 3, the ohmic value is determined by the application of colored radial stripes upon the resistor unit. For example, a resistor color coded in this manner (1st stripe - GREEN, 2nd stripe - ORANGE - 3rd stripe - RED, 4th stripe SILVER) would read 5,300 ohms. Referring to the tolerance code, by 4th stripe should indicate that the actual value of this resistor would vary between plus or minus 10% of 5,300 Ohms, or it would be within the value of 4,770 ohms to 5,830 ohms.

E. Three Systems of Applying the Color Code for Mica Capacitors.

1. One System, Fig. 4-A and 4-B, incorporates three basic dots of different colors which correspond to the standard RMA color code. The sequence of colored dots indicate the capacity value in MICRO-MICROFARADS. The first dot "A" of the capacitor is the first number and the second dot "B" is the second number. The third dot "C" indicates the multiplier. The first two numbers times the multiplier determines the total capacity of the capacitor. Dot "D" is the tolerance and "E" the voltage rating of the capacitor. For example, a .00025 mmf. capacitor (250 mmf) rated with a tolerance of 3% and a voltage rating of 500 volts would be color coded as follows: Red - 2; Green - 5; Brown - 10; (multiply by 10) Orange - 3%; Green - 500 volts; Tolerance and voltage ratings for all capacitors is listed in the following paragraph No. 2.

2. The second system incorporates six dots of different colors. The R.M.A. color code chart for these capacitors is as follows:

| COLOR | 1st DOT | 2nd DOT | 3rd DOT | MULTIPLIER | TOLERANCE | VOLTAGE |
|---|---|---|---|---|---|---|
| BLACK | 0 | 0 | 0 | 1 | - | |
| BROWN | 1 | 1 | 1 | 10 | 1% | 100V |
| RED | 2 | 2 | 2 | 100 | 2% | 200V |
| ORANGE | 3 | 3 | 3 | 1000 | 3% | 300V |
| YELLOW | 4 | 4 | 4 | 10000 | 4% | 400V |
| GREEN | 5 | 5 | 5 | 100000 | 5% | 500V |
| BLUE | 6 | 6 | 6 | 1000000 | 6% | 600V |
| PURPLE(violet) | 7 | 7 | 7 | 10000000 | 7% | 700V |
| GREY | 8 | 8 | 8 | 100000000 | 8% | 800V |
| WHITE | 9 | 9 | 9 | 1000000000 | 9% | 900V |
| GOLD | - | - | - | Divided by 10 | 5% | 1000V |
| SILVER | - | - | - | Divided by 100 | 10% | 2000V |
| NO COLOR | - | - | - | - | 20% | 500V |

The color code designates the capacity of the capacitor in micro-microfarads. Fig. 5 illustrates the method of applying the above R.M.A. color code chart.

The color code is read in a clock-wise manner starting with the first colored dot "A" and ending with the last colored dot "F". The first three dots "A", "B", "C", indicate the first three significant figures. The significant figures multiplied by the figure representing the multiplier color determines the total capacity of the capacitor. The fifth and sixth colored dots represent the tolerance and voltage ratings respectively. For example, a capacitor rated at 250 micro-microfarads with a tolerance of 2% and a voltage rating of 600 volts would be color coded in the following manner: red - green - black - black - red - blue.

3. The third system is the six dot color code, American Standard Association (ASA) for mica and ceramic capacitors. The ASA color code chart for these capacitors follows:

| COLOR | 1st DOT A | 2nd DOT B | 3rd DOT C | 4th DOT D | 5th DOT E | 6th DOT F |
|---|---|---|---|---|---|---|
| BLACK | 0 | 0 | 0 | none | 20% | No specified qualities |
| BROWN | - | 1 | 1 | 0 | 0 | Specified "Q" |
| RED | - | 2 | 2 | 00 | 2% | Temperature coefficient plus or minus 200 parts/million/C° |
| ORANGE | - | 3 | 3 | 000 | - | Temp. coefficient plus or minus 100 parts/million C° |
| YELLOW | - | 4 | 4 | - | - | Temp. coefficient 0 to plus 100 parts/million/C° |
| GREEN | - | 5 | 5 | - | - | Temp. coefficient 0 to plus 50 parts/million/C° |
| BLUE | - | 6 | 6 | - | - | Temp. coefficient - to minus 50 parts/million/C° |
| VIOLET | - | 7 | 7 | - | - | |
| GREY | - | 8 | 8 | - | - | |
| WHITE | - | 9 | 9 | | | |
| GOLD | - | - | - | Divided by 10 | 5% | |
| SILVER | - | - | - | Divided by 100 | 10% | |

NOTE: When the ASA standard is applied to molded paper capacitors, the first dot is silver as is the fifth dot. A mica capacitor is designated by the fifth dot being black. The sixth dot indicates operating temperature range; brown, from minus 67 to 167 degrees; and black, from minus 67 to plus 185 degrees.

Fig. 5 illustrates the method of applying the above ASA color code chart. A .00012 mf. (120 micro-microfarads) capacitor is marked to indicate its value as follows; black (0), brown (1), red (2), and brown (one additional zero). The fifth dot indicates the capacitance tolerance in percentage of rated capacitance. The sixth dot introduces a new factor, denotes characteristics of design involving Q factors, temperature coefficients, and production test requirements.


F. Summary Questions

1. Electrons flow through a resistor from right to left. Which end of the resistor is positive? Why?

2. Why is a reference point used when describing the potential at a point in a circuit?

3. What is the smallest subdivision of any material substance that can exist separately and maintain its physical and chemical identity?

4. Do good conductors have more free electrons than poor conductors?

5. Arrange these voltages in sequence from the highest positive to the maximum negative; plus 75 volts, zero volts, minus 15 volts, plus 13 volts, minus 2 volts, minus 75 volts, plus 2 volts.

# CORRECT SOLDERING TECHNIQUE

## Objective

To become proficient in the care and use of electric soldering irons.

## References:

## Lesson Content

### A. Soldering

When a metal is heated by a soldering iron, the surface of the metal combines with the oxygen of the air and forms an oxide film on the surface of the metal. Oxide film on the metal will prevent the soldering of another metal to it. The application of the correct flux will prevent the metals from becoming oxidized. The temperature of the metals being joined together must be such that it will melt the solder freely.

There are two classes of flux, corrosive and non-corrosive. Rosin is a noncorrosive flux and is most commonly used in electrical work. It is available in powdered, liquid, or paste form.

Liquid rosin is made by dissolving rosin in alcohol until the rosin is about the consistency of varnish. Rosin paste is made by mixing rosin with tallow. The rosin core solder is supplied in the form of a wire with a core of rosin flux extending through it. This arrangement does away with the necessity of having two separate articles, i.e., solder and flux.

Rosin becomes disintegrated by heat. Its active life is limited by the length of time and the amount of temperature to which it is subjected in the soldering operation. When using rosin core solder, remember the rosin must come in actual contact with the joint to be soldered. It will then be able to dissolve the oxide film from the surface to be soldered.

Fluxes generally used for various metals are as follows:

| METAL | FLUX |
|---|---|
| Brass, copper, tin | Rosin |
| Iron, steel | Borax of Sal-Ammoniac |
| Lead | Tallow, rosin, and stearine |
| Galvanized iron | Zinc chloride |
| Zinc | Zinc chloride |
| Aluminum | Special solder is now available which makes the use of a flux unnecessary. |

### B. Soldering Iron Use and Abuse

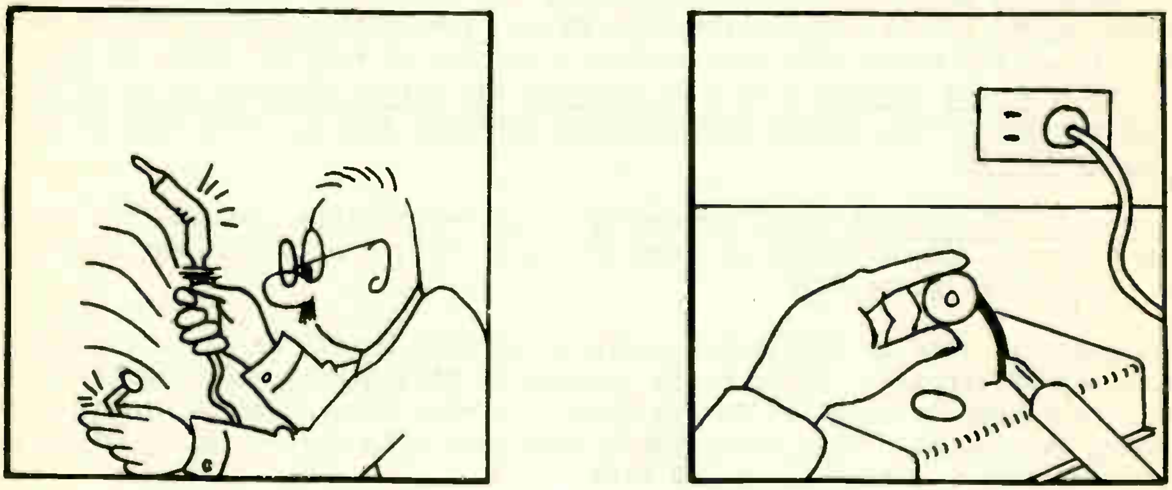
1. Handle your soldering iron with care. It is not built for hammering in nails. It should be used only for soldering, Fig. 1.

2. When your soldering iron is not in use, wrap the cord neatly around the handle of the soldering iron. Avoid unnecessary damage caused by pulling, jerking, or twisting the cord, Fig. 2.

3. Retin the iron occasionally. Dirt and metallic oxides are poor conductors of heat. When the tip becomes dirty or oxidized, clean the working face with a wire brush, Fig. 3. Do not file or grind a tip after it has been tinned.

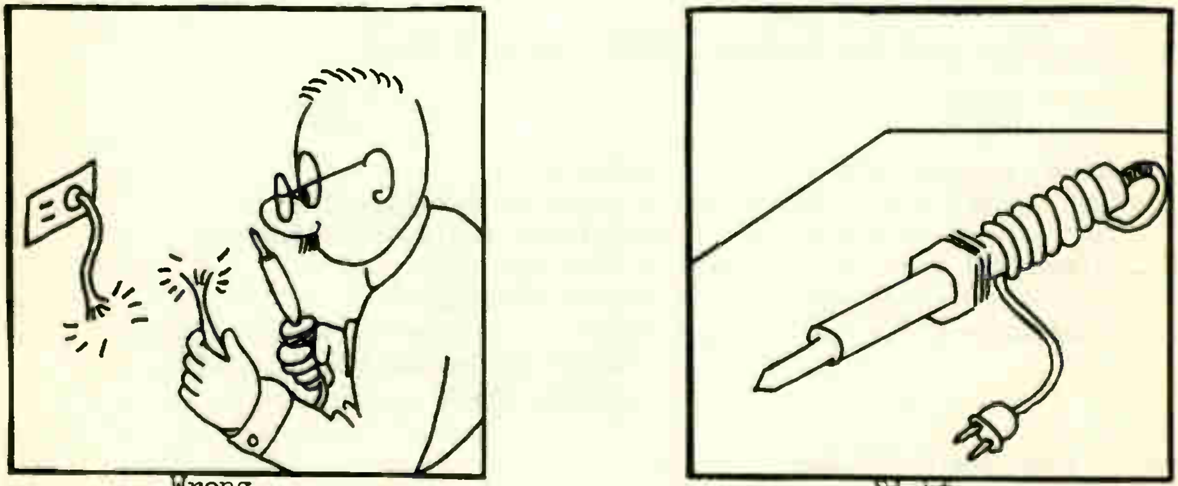
4. To retin the copper apply flux to the working face only, then hold the core solder against the tip until the solder melts, Fig. 4. Do not dip the entire tip into the soldering flux for this will cause the tip to corrode and thus shorten its useful life considerably.

5. Unless a heat control stand is used, disconnect the soldering iron, if it is not to be used within 15 minutes, Fig. 5. Do not allow the iron to remain connected for a long time without being used, for the iron will likely overheat and cause the tip to corrode faster than if the iron were disconnected.



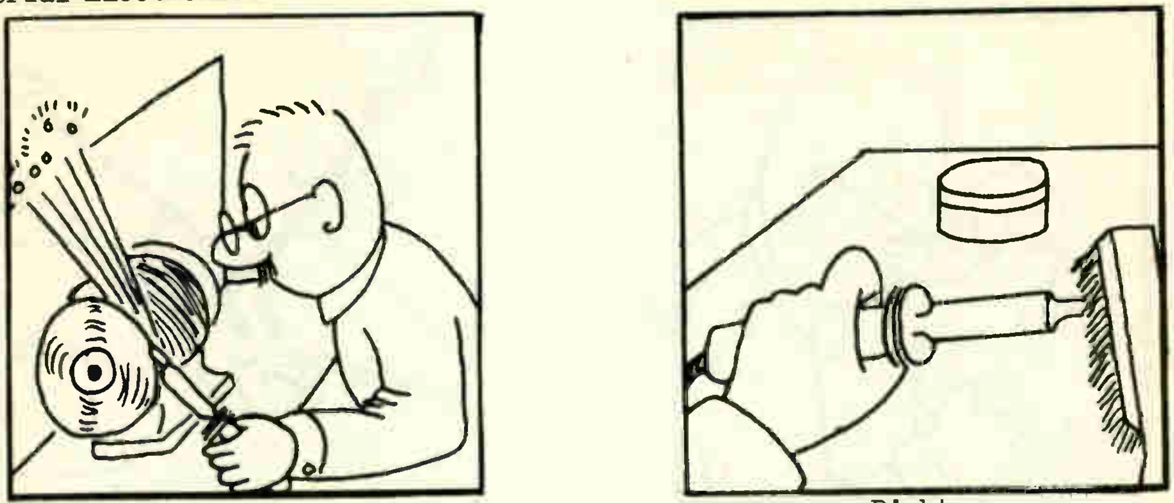
Wrong Right

Fig. 1 Handle the soldering iron with care. It should be used only for soldering.



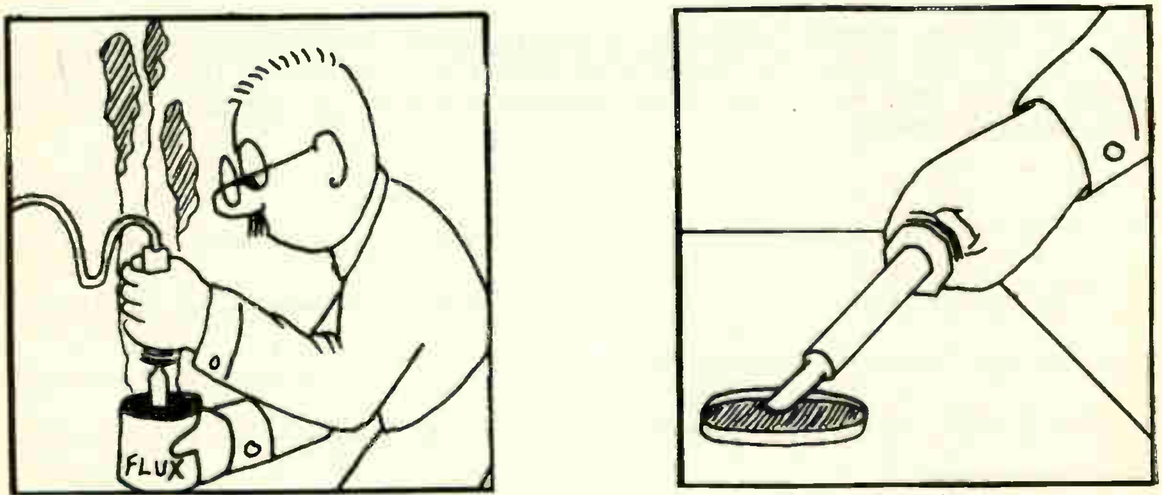
Wrong Right

Fig. 2 Avoid damage to the soldering iron cord.



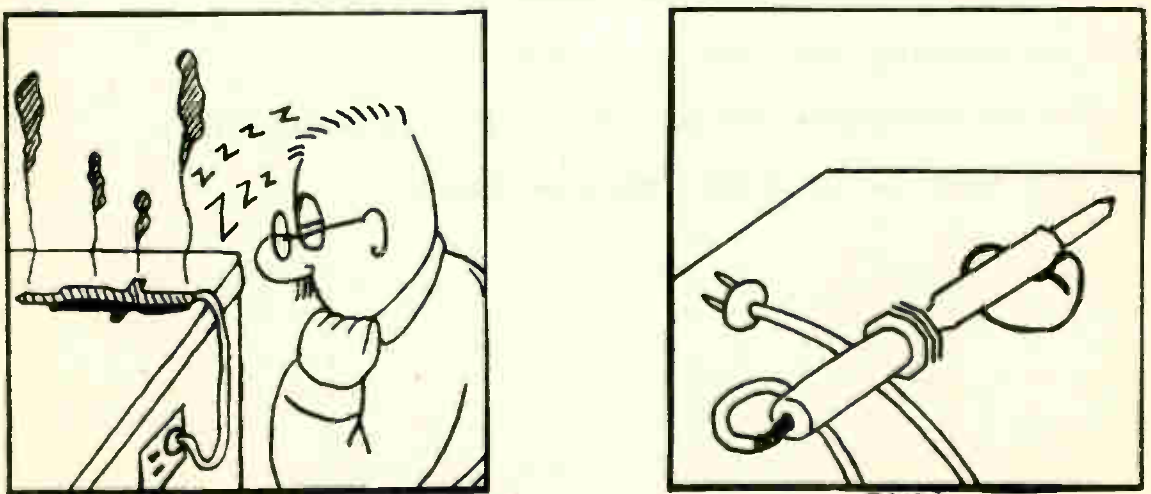
Wrong Right

Fig. 3 Do not grind the iron after tinning. Use a wire brush



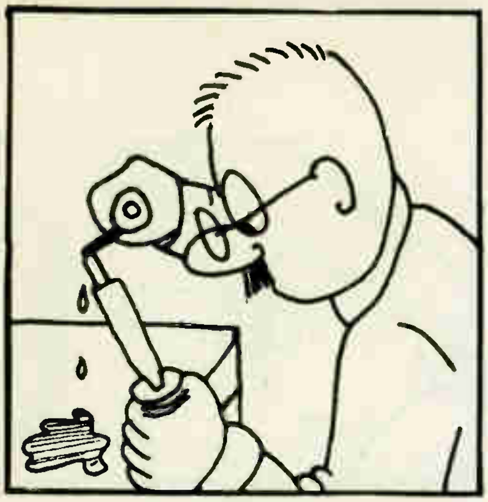

Wrong Right

Fig. 4 Do not dip the entire soldering iron tip in the flux container.

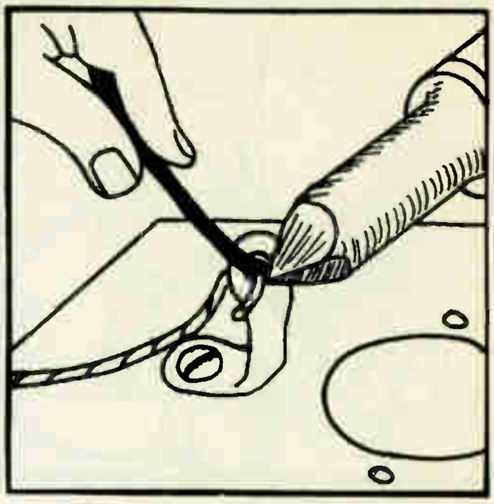


Wrong Right

Fig. 5 Do not leave the iron connected to the power when the iron is not in use.



Wrong



Right

Fig. 6 Do not apply solder directly to the iron. Apply the iron to the part being soldered.

6. When soldering, always apply the soldering iron to the part being soldered, Fig. 6. Do not apply the rosin core solder to the tip of the iron because the rosin, which acts as a flux, will evaporate before it can make contact with the part being soldered.

C. Summary Questions

1. Explain, what causes oxide to form on heated metals.
2. How do oxides interfere with the process of soldering?
3. What is soldering flux? Why is it used?
4. What is the most convenient form of flux for electronic work?
5. Why must soldering irons and coppers be tinned?

# USE OF THE ELECTRONIC VOLT-OHMMETER

## Objective

To become familiar with the proper use of the vacuum tube volt-ohmmeter.

## References:

## Lesson Content

### A. General

It is difficult to measure potentials in grid circuits and plate circuits with any of the general types of voltmeters used, especially when the circuits are carrying signal currents as in normal operation. The principle reason is insufficient resistance in the usual voltmeters for use in grid and plate circuits whose own resistances are high and in which the currents are small.

The electronic voltmeter used in Industrial Electronics is designed to overcome most of the difficulties encountered with other types. This instrument has a very high input resistance for both direct and alternating potential measurements.

### B. Rules for Meter Use

The rules of good laboratory practice, as regards meters, apply to the use of the vacuum tube volt-ohmmeter. The progressive technician in electronics will make these rules a part of his consciousness. The following rules are of importance.

1. In order to prevent damage to the meter when checking voltages of unknown values, observe habitually the custom of switching the instrument first to its HIGHEST VOLTAGE RANGE before touching the test prods to the circuit under test. This applies to all a-c and d-c measurements. The meter then may be switched, step by step, to each successively lower range until an accurate reading is obtained.

2. For best accuracy when making the final reading use the voltage scale in which deflection is obtained near the upper end of the scale.

3. Be cautious of a high voltage circuit. Circuits with more than 100 volts are dangerous. Get familiar with the electronic circuit operation before taking any test with the meter.

4. When checking high d-c voltages, keep the COMMON terminal of the meter connected to ground (B minus) terminal of the circuit under test. This keeps the instrument case and panel at ground potential and protects the individual from electric shocks.

5. Be sure that all power has been switched off in the circuit under test before using the ohmmeter ranges for checking circuit components or continuity of wiring.

C. Description of the Industrial Electronics Vacuum Tube Volt-Ohmmeter.

The Industrial Electronic vacuum tube volt-ohmmeter is designed to measure d-c and a-c voltages and resistances over an extremely wide range.

As a d-c or a-c voltage measuring device, its range of operation is from .05 to 1,000 volts. Its input resistance (11 megohms) is constant at all d-c ranges. Thus the sensitivity on the three volt d-c scale is 3,666,666 ohms per volt. The meter will measure d-c voltages which are positive or negative with respect to ground without switching leads. It will not interfere with the operation of any circuit or element across which it may be connected.

It is not necessary to re-set the zero adjustment when changing voltage ranges except for the three volt a-c range. All d-c voltage measurements, regardless of polarity, can be made with the common lead connected to the chassis or ground by simply turning the polarity reversing switch.

During a-c voltage measurements, with the selector switch in a-c position, the instrument is completely isolated from the line and all a-c voltages up to 1,000 volts can be measured. The sensitivity on the three volt a-c range is 2,000,000 ohms per volt. The input circuit is such that the meter is protected should a d-c voltage be accidently measured with the a-c prod while the selector is in the a-c volts position and the common lead connected to the chassis ground.

The ohmmeter covers ranges from 0.2 ohm to 1,000 megohms and generally does not require resetting of the zero ohms adjustment when changing ranges.

D. General Operation

Fig. 1 is a full size view of the vacuum tube volt-ohmmeter used in this department. Reference to this drawing should be made as discussion of operation is explained.

Before plugging in the a-c power cord, adjust the mechanical zero on the meter face for correct setting. Plug the power cord into an appropriate source and allow the unit to warm up for about five minutes.

With the "Selector Switch" on "DC plus" position and the "Range Switch" on "3 volt" position, set the meter to zero with the "Zero Adjust" knob. Then check variation of meter zero at all voltage settings of "Range" and "Selector" switches. The zero set holds for all scales except the three volt scale which requires a slight readjustment.

There are four scales on the meter. The top scale indicates "OHMS" only. The second scale (0-30 above line) and the third scale (0-10 below line) indicates all a-c and d-c voltages. The proper multiplier must be kept in mind when using these scales. The fourth scale is used for measurements of the gain or loss of power, voltage or current in a circuit.

# VACUUM TUBE VOLT-OHMMETER

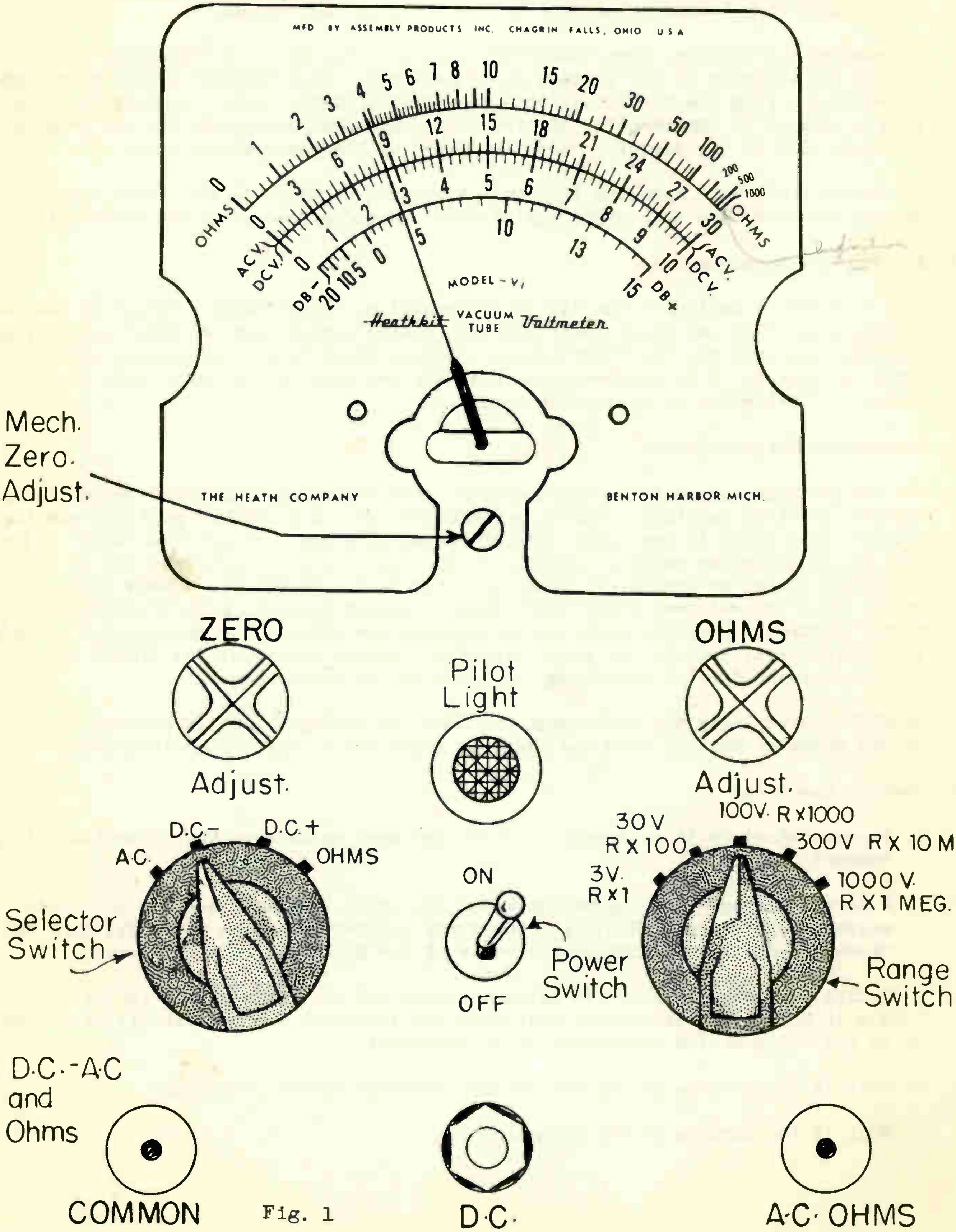



Fig. 1

E. D-C Voltage Measurements

When measuring high voltages, a safe practice is to have both prods securely connected into the circuit under test before applying the voltage.

To measure d-c voltage, turn "SELECTOR" switch to "DC plus" or "DC minus" according to the polarity of the voltage to be measured. Turn "RANGE" switch to the desired range. Plug the black lead into the (black) common jack. Connect the black lead to ground or common point of circuit to be tested and touch the d-c prod to the high side of the circuit. Read the meter on the appropriate scale.

The black probe with shielded lead and phone-plug contains in the probe a one megohm resistor. Use this probe and shielded lead for measuring d-c volts only.

F. A-C Voltage Measurements

Turn "SELECTOR" switch to the "AC VOLTS" position. Turn "RANGE" switch to the desired range. Plug the black lead into the (black) common jack on front panel. Plug the red lead into the "AC VOLTS" jack. Connect black lead to ground or common point of circuit to be measured and touch the red prod to the other side of the circuit. Read meter on appropriate scale.

G Resistance Measurements.

To use the ohmmeter, set the "ZERO ADJUST" knob while the "SELECTOR" switch is on the d-c positive position. Turn the "SELECTOR" switch to "OHMS" position and the pointer will swing to the right side of the meter scale. Adjust the "OHMS" adjust knob until the meter point is exactly on the heavy line at the right end of the 10V meter scale at number 10. Plug the black lead into (Black) COMMON jack on the panel. Plug the red lead into "OHMS" jack. Connect leads to ends of resistance to be measured. Read the meter on the appropriate scale. For measurement of very low resistances, connect the leads directly together and reset the "ZERO" adjust knob to correct for the resistance of leads before measurement.

CAUTION: Never leave the instrument on "OHMS" as this may greatly shorten the life of the ohmmeter battery when the ohmmeter leads touch together accidentally.

H. Summary Questions

1. On what range is it necessary to reset the zero adjustment when changing voltage ranges?

2. A direct voltage is being measured and the range switch is set for 300 volts maximum full scale deflection. The meter pointer indicates four divisions and three sub-divisions. What is the value of the potential being measured?

3. A high resistance circuit is being measured and the range switch is set for R x 10 M. The meter pointer indicates ten divisions and two sub-divisions. What is the value of the resistance being measured?

4. What is the purpose of the DC- and DC+ selector switch positions?

5. What is the purpose of the DB scale?

# HIGH VOLTAGE ELECTRONIC POWER SUPPLIES

## Objective

1. To learn the fundamental theory of transformer action.
2. To learn the theory of electronic kenotron tubes and their use in industrial applications.
3. To learn the analysis of electrical rectifier circuits used in electronic industries.

## References

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## Lesson Content

### A. Power Transformer

A power transformer is an electrical device for coupling or transferring alternating energy from one circuit to another with no change in frequency. Its chief use, from the standpoint of power supply work, is to change a given value of voltage to values desired for specific application. To accomplish this, it employs a primary winding which, when connected to a source of supply, develops a magnetic field. This magnetic field cuts the conductors of a secondary winding to induce a voltage.

A core of soft iron laminations is used to provide a path of low reluctance which enables the electron flow in the primary winding to develop a flux of high density, and increases the energy transfer by increasing the number of lines of force, Fig. 1.

When a voltage is developed in the secondary winding, and electrons are delivered to a load, a part of the power is used in overcoming the resistance of the winding itself and is therefore not available at the load. This is compensated for by increasing the number of turns in the secondary winding by a factor of approximately 3%. The power used by the electron flow through the resistance of the winding develops heat in the windings themselves and is called the "copper loss".

Fig. 3, illustrates a "center-tapped" transformer. The voltages at the ends of the secondary winding become alternately 50 volts positive and 50 volts negative with reference to the center tap. The center tap is connected approximately midway in the number of turns in the winding. This will cause its potential always to remain midway between the potentials at the ends of the winding.

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### B. Fundamentals of the Kenotron Tube

The kenotron is a high-vacuum thermionic tube. It consists of two electrodes, the plate (also referred to as the anode of the tube) and the cathode. These two electrodes are properly spaced within an evacuated envelope. When the cathode is heated to a certain temperature, electrons will be emitted from its surface. These electrons, being negative, will be attracted toward the plate (or anode) when the plate is at a positive potential with respect to the cathode.

The cathode is the only emitter of the tube, therefore, the flow of electrons in a Kenotron tube takes place in one direction only. For this reason the Kenotron tube is particularly useful in rectifier circuits for industrial electronic applications.

Kenotrons have no rotating parts and are quiet in operation. They occupy a small amount of space and are light in weight considering the amount of power which they are rated to handle. When very high voltages are to be rectified, kenotron tubes possess advantages over gas tubes, due to the high degree of vacuum within the tube envelope which results in practically perfect insulation on the inverse cycle when the plate is negative.

C. General Classes of Kenotron Tubes

1. Radiation cooled kenotron (usually of the glass envelope type).

2. Water-cooled kenotron (with plate cooled externally by water circulation through a water jacket which surrounds this electrode).

D. Applications of Kenotron Tubes in Electronic Industry

1. Air filters

Kenotrons supply the high voltages necessary to filter the air by electrical precipitation. The air is ionized and the positively charged dust particles adhere to plates negatively charged by the kenotrons. Fig. 4 illustrates the basic operation of an electronic air filter unit.

2. Cable testing

A Kenotron tube supplies high voltages for testing the insulation of cables. Fig. 5 illustrates a schematic diagram for a high voltage cable tester.

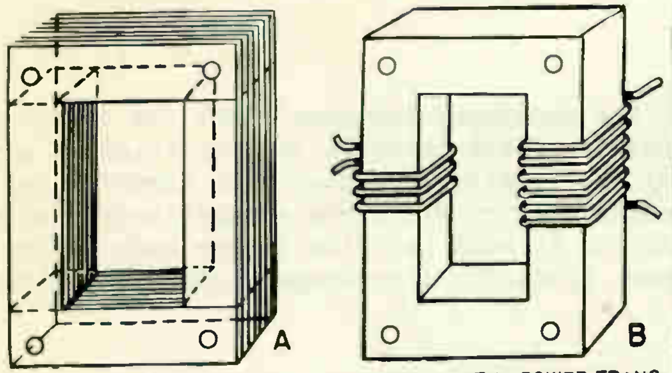



Fig. 1 ■ THE CORE FOR A LARGE POWER TRANSFORMER (GENERAL ELECTRIC)

THE CORE OF THE POWER TRANSFORMER WITH THE COILS OR WINDINGS IN PLACE AND THE CONNECTION LEADS ATTACHED. G.E.

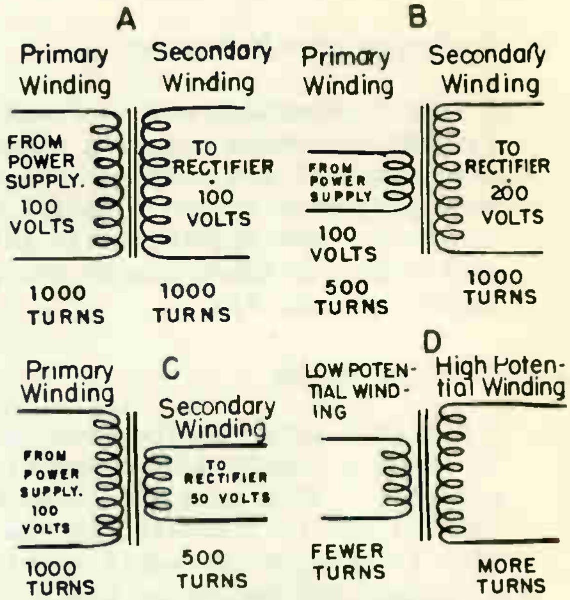
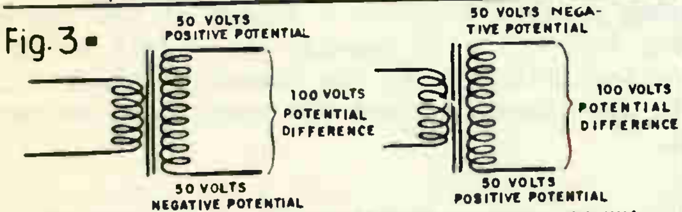



Fig. 2 ■ THE RELATION BETWEEN PRIMARY AND SECONDARY TURNS AND PRIMARY AND SECONDARY POTENTIAL DIFFERENCES OF TRANSFORMERS WITHOUT A LOAD.

Fig. 3 ■




THE CENTER TAP REMAINS AT A CONSTANT POTENTIAL, MIDWAY BETWEEN THE ALTERNATING POTENTIALS AT THE TWO ENDS OF THE WINDING

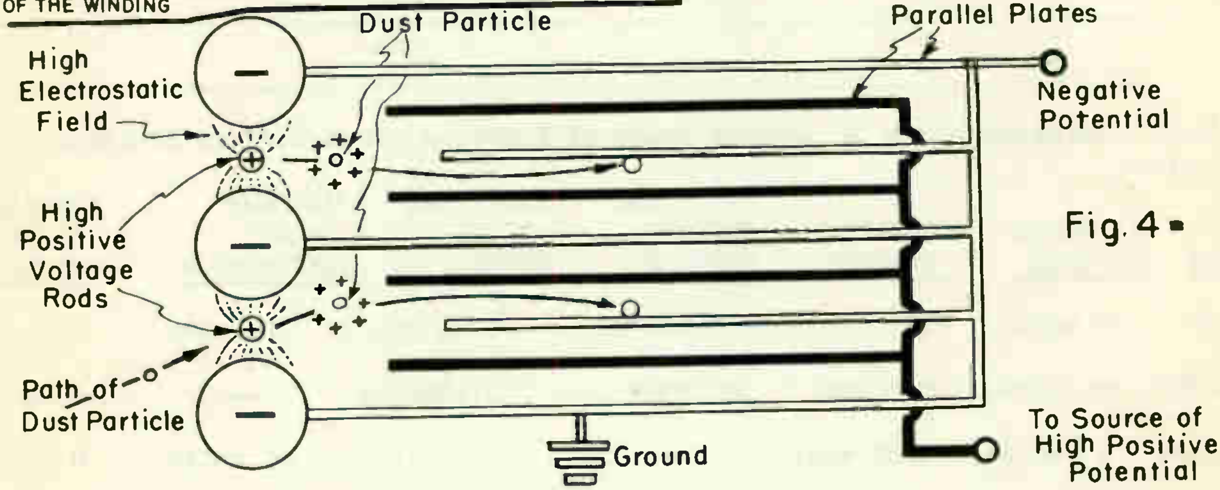
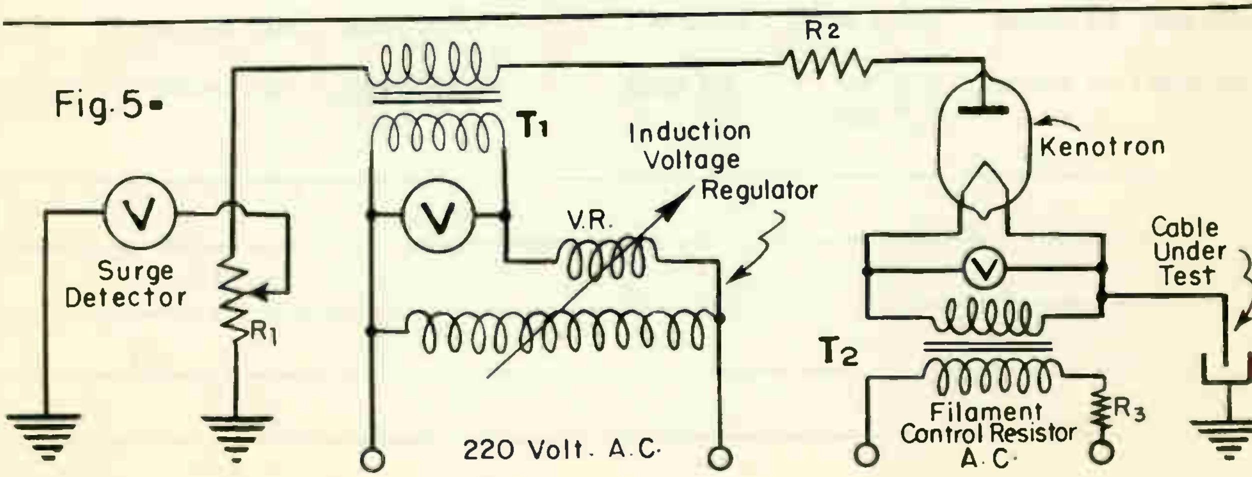



Fig. 4 ■

Fig. 5 ■



3. Kenotron tubes are also used for X-ray and other electro-physical and electro-chemical apparatus requiring high direct voltages at moderate current.

4. Sandpaper manufacturing

   A very interesting use is found in the sandpaper industry. Here the kenotron is used to create a strong electrostatic field in which the particles of abrasive material are charged by a very high positive voltage. The abrasive is then projected toward adhesive coated paper spread above a negatively charged platform. The electrostatic attraction is such that the larger ends of the particles are drawn toward the paper, producing a sandpaper with all the sharp points upward, Fig. 6.

5. Paint spraying

   A kenotron tube is also used in paint spray machines where each droplet of spray is given a charge and the metal being painted is given a charge of the opposite polarity. With such a machine every drop of paint reaches the object being painted and is traveling at its greatest velocity at the moment of arrival. No free floating paint would remain in the atmosphere and the spray room becomes a cleaner and healthier place, Fig. 7.

E. General Characteristics of Several Types of Kenotron Tubes Used in Electronic Industries.

| G.E. TYPE | FILAMENT VOLTAGE | FILAMENT CURRENT | MAX. PEAK INVERSE VOLTAGE | MAX. PEAK PLATE CURRENT | MAXIMUM PLATE DISSIPATION | AVERAGE PLATE CURRENT |
|---|---|---|---|---|---|---|
| KC-4 | 20 volts | 24.5 amp. | 150,000V. | 0.75 amp. | 750 watts | ---- |
| FP-85A | 10 volts | 5.0 amp. | 20,000V | 0.100 amp. | ---- | 0.020 amp. |
| FP-400 | 4 volts | 2.25 amp. | ---- | ---- | 15 watts | 0.025 amp. |
| GL-411 | 10 volts | 14.5 amp. | 100,000V | 0.300 amp. | 500 watts | ---- |
| GL-8020 | 5 volts | 5.5 to 6.5 amp. | 40,000V | 0.750 amp. | 75 watts | 0.100 amp. |

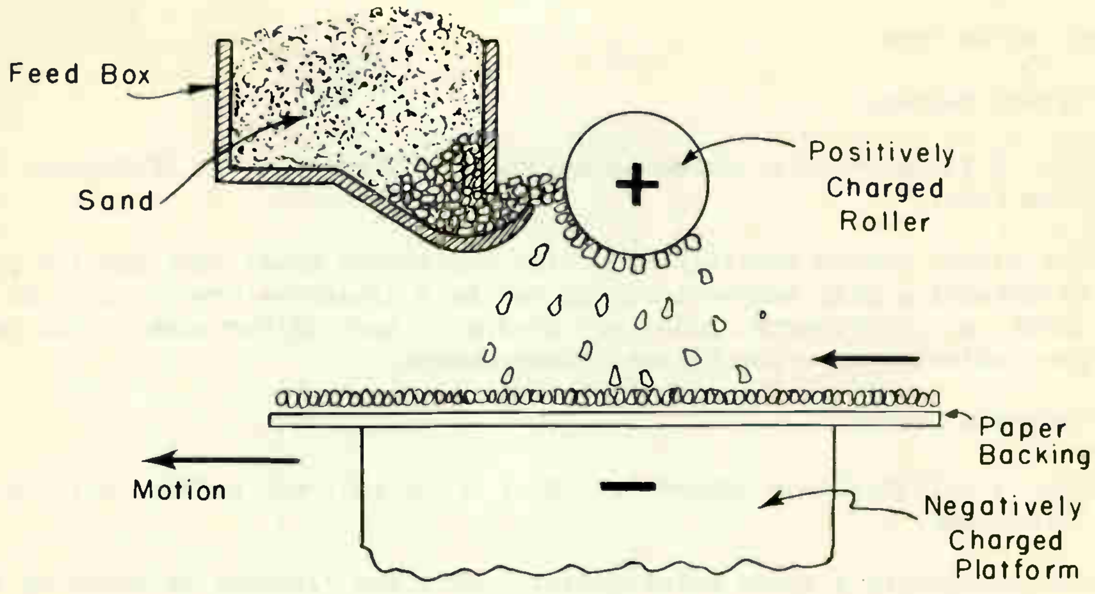



Fig. 6

GENERAL ELECTRIC

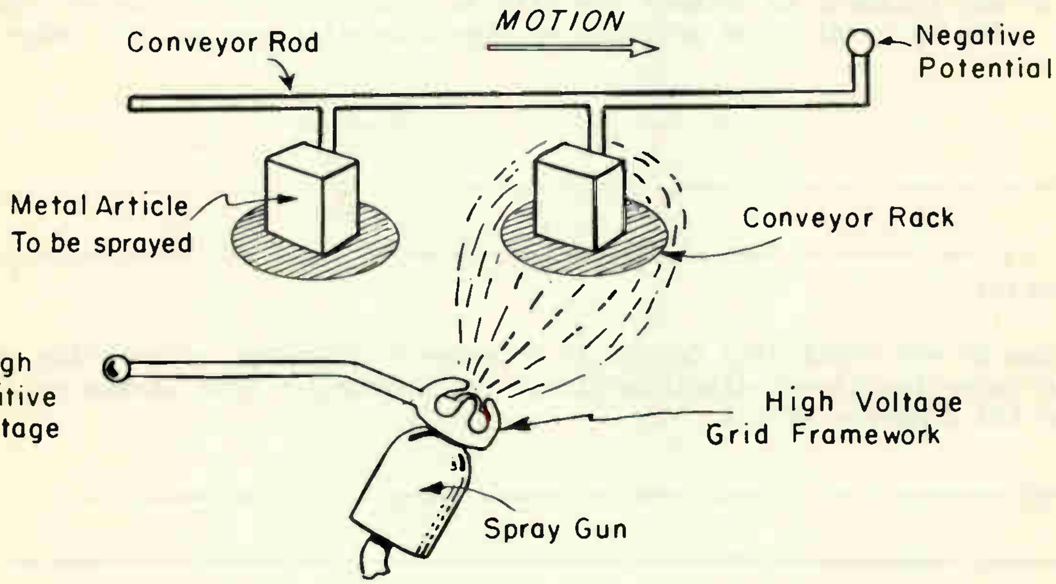



Fig. 7

GENERAL ELECTRIC

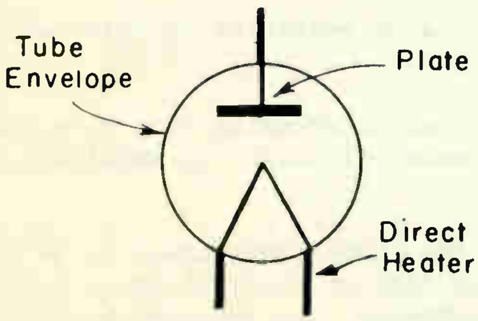



Fig. 8

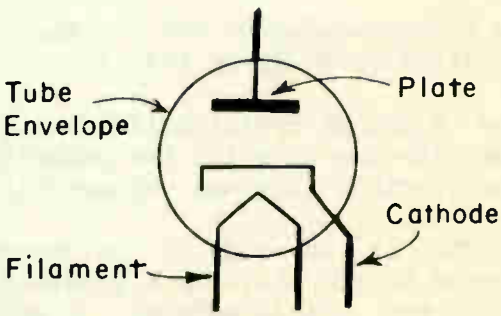



Fig. 9

F. Types of Heaters

1. Direct heater.

Fig. 8 illustrates a schematic symbol of a direct heater (filament) type kenotron tube.

The direct heater consists of a high resistance metal that has the property of withstanding high temperature and can emit electrons freely. In some kenotron tubes, alkaline earth oxides are used as a coating for wire filaments to permit free emission at a low filament temperature.

2. Indirect heater

Fig. 9 illustrates a schematic symbol of an indirect heater (cathode) type kenotron tube.

The cathode is a round metal cylinder with the filament extended up through the center, Fig. 10. The cathode is heated by the filament which is insulated from the cathode sleeve. The cathode is the only emitting element. The function of the filament is to heat the cathode. The cathode is coated with an earth oxide to permit free emission of electrons at a low cathode temperature.

G. The Rectifier

The purpose of any rectifying device is to convert or change alternating electron flow into pulsating direct electron flow. The electronic tube serves as a power rectifier and converts AC into DC.

H. Half-wave Rectification

An understanding of how a simple single phase half-wave rectifier operates may be obtained by studying Fig. 13.

The object of rectification is to transform a typical alternating sine wave voltage into one in which the polarity is always the same, although the amplitude of the electron flow and voltage may vary continually.

In Fig. 13, one side of the secondary winding of the power transformer $T_1$ is connected to the plate of a kenotron tube. The other side of the winding is connected to the cathode emitter. A small filament transformer, $T_2$, provides means of heating the cathode emitter of the tube.

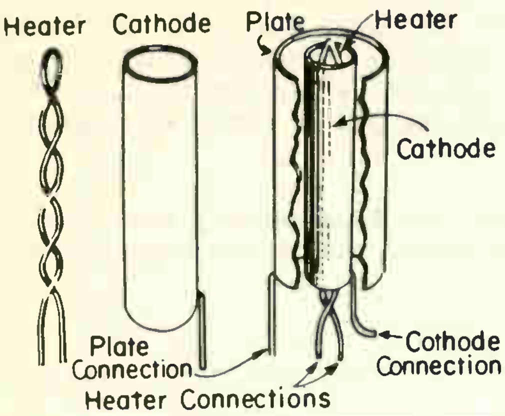



Fig. 10

The Construction of a Rectifier having a Heater-Cathode

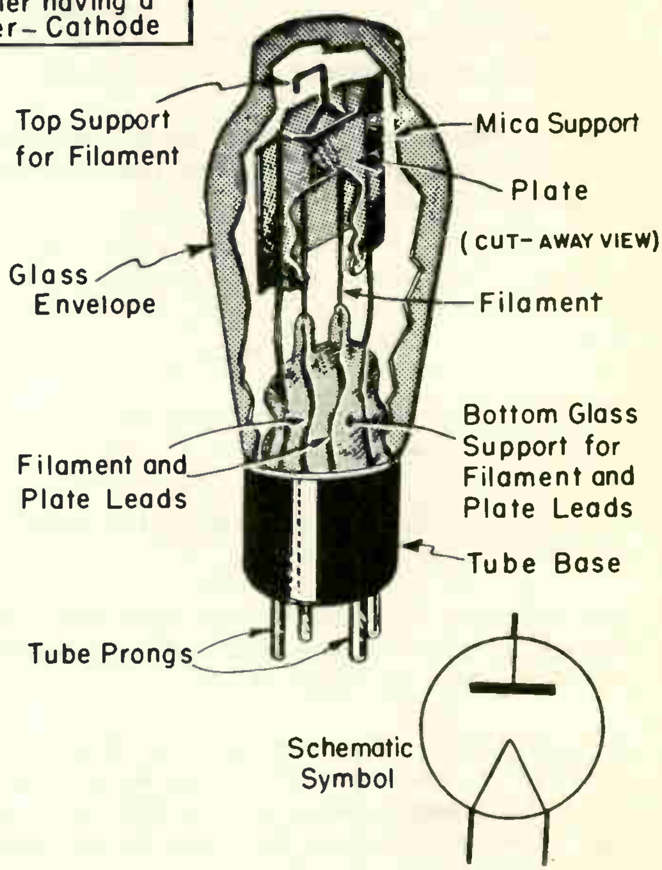



Fig. 11 Cut-away View of a Kenotron

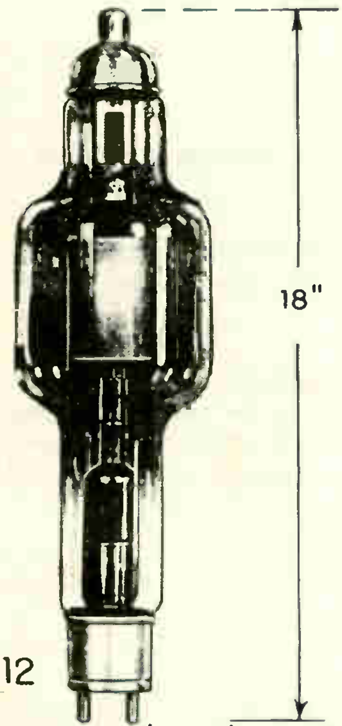



Fig. 12

A Kenotron Rectifier which will operate at electrical pressures as high as 100,000 volts

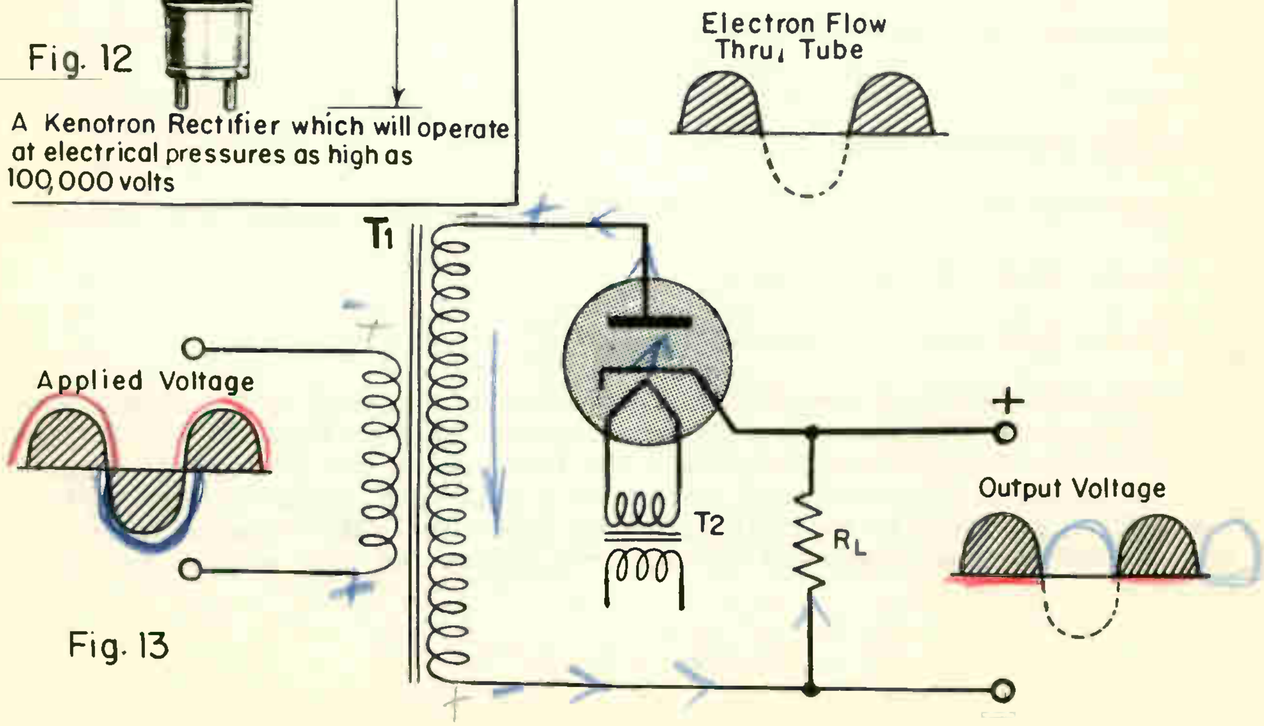



Fig. 13

Remember that electrons flow through the tube only when the plate is positive with respect to the emitter. During the period when the upper end of $T_1$ is positive electrons flow through the load $R_L$. When the polarity reverses, electrons cannot pass through the tube and consequently no electrons flow through the load $R_L$. Only one-half of each input cycle is useful in furnishing power. This arrangement is known as single-phase half-wave rectification.

The average direct voltage developed across the load is generally less than half the alternating voltage when the kenotron is operated within its normal electron flow capacity.

I. Full-wave Rectification

In order to utilize the remaining half of the wave, a system known as full-wave rectification is used.

The diagrams in this lesson show various types of rectifier circuits in which high vacuum kenotron tubes are used. The output wave-forms are correspondingly drawn for each type of circuit.

By tracing the electron path on Fig. 14A for one complete cycle of input, it can readily be seen that both halves of the alternating cycle are being rectified and the output wave shape across the load is as shown. NOTE: the polarity of the voltage developed across the load $R_L$ is such that the filament end is always positive with respect to the transformer end.

J. Rectifier Characteristics.

Two important characteristics in connection with a high vacuum rectifier are:

1. Maximum peak inverse voltage

2. Maximum peak plate electron flow

Tube characteristics of several kenotron tubes were listed in the former contents of this lesson. The numerals under the caption "Maximum Peak Inverse Voltage" is the potential in volts applied across the tube during the alternation while the tube is idle. The inverse peak voltage in a full-wave rectifier such as built in the I.E. shop, actually is 1.414 times the effective (RMS) value of the secondary transformer voltages, less the voltage drop across the tube section that is conducting.

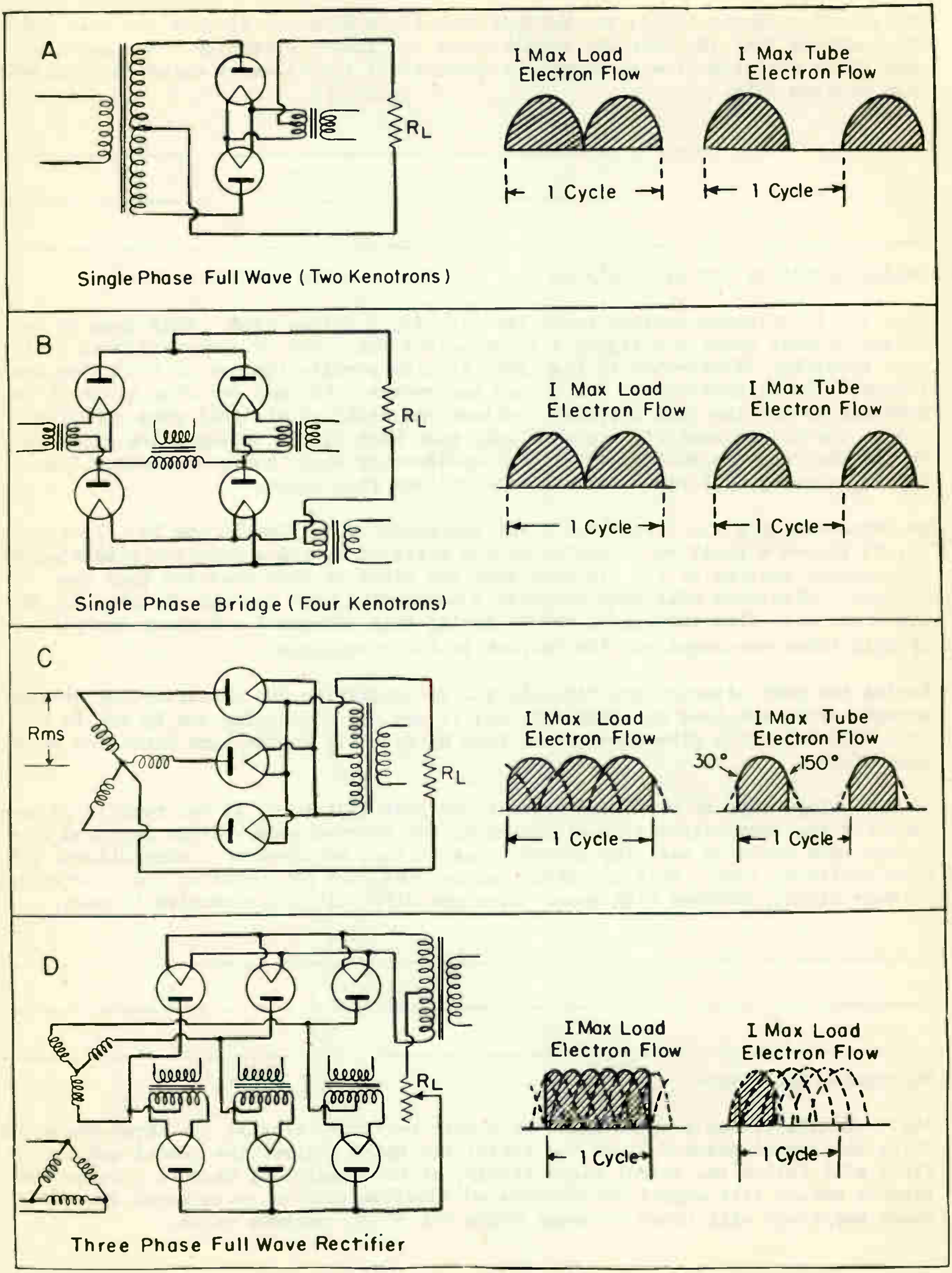

A
R_L
I Max Load Electron Flow
I Max Tube Electron Flow
1 Cycle
1 Cycle
Single Phase Full Wave (Two Kenotrons)
B
R_L
I Max Load Electron Flow
I Max Tube Electron Flow
1 Cycle
1 Cycle
Single Phase Bridge (Four Kenotrons)
C
Rms
R_L
I Max Load Electron Flow
I Max Tube Electron Flow
30°
150°
1 Cycle
1 Cycle
D
R_L
I Max Load Electron Flow
I Max Load Electron Flow
1 Cycle
1 Cycle
Three Phase Full Wave Rectifier

Figure 14.

The second characteristic, the Maximum Peak Plate Electron Flow is the safe value of electrons that the tube can handle under continuous operation. The maximum peak plate electron flow is generally governed by the filament emission permissible with a given tube.

## K. Bridge Rectifier Circuit Analysis

Fig. 14B illustrates another rectifier circuit, a bridge type. This type of rectifier circuit permits a higher voltage output than that of a conventional full-wave rectifier illustrated in Fig. 14A. It also permits the use of a simpler transformer. The elimination of the center tap reduces its cost and size since it is possible to use the full secondary voltage and still obtain full wave rectification. The bridge rectifier is used only when high direct voltages are required. Due to the fact the voltage will vary considerably when the load electron flow varies, this type of rectifier has poor voltage regulation.

To understand how the bridge rectifier operates, study Fig. 15 and 16. In Fig. 15, T1 places a positive potential on the plate of $V_2$ and a negative potential on the cathode emitter of $V_3$. In each tube the plate is more positive than the cathode. Electrons will then complete a conducting path through the load $R_L$. No electrons will flow through $V_1$ and $V_4$ during this alternation because the plates of both tubes are negative with respect to their cathodes.

During the next alternation, Fig. 16, all potentials in the rectifier are reversed except across the load $R_L$. Tubes $V_1$ and $V_4$ are now conducting and $V_2$ and $V_3$ are idle. The electron flow through the load $R_L$ is still in the same direction as it was before.

In the bridge type of rectifier circuit, as just explained, it can readily be seen that for the same output voltage across $R_L$ the inverse peak voltage required of a bridge tube would be half the inverse peak voltage required of a conventional full-wave rectifier tube. This advantage reduces the cost of operation and construction to some extent, because high rated tubes are difficult and expensive to make.

## L. Multiphase Rectifiers

Fig. 14C| illustrates a three-phase half-wave rectifier circuit. In three-phase circuits the second phase follows the first, the third follows the second and the first will follow the third, respectively, at 120 electrical degrees. These continuous phases will supply unidirectional electron flow to an external circuit whose amplitude will never decrease below 50% of its maximum value.

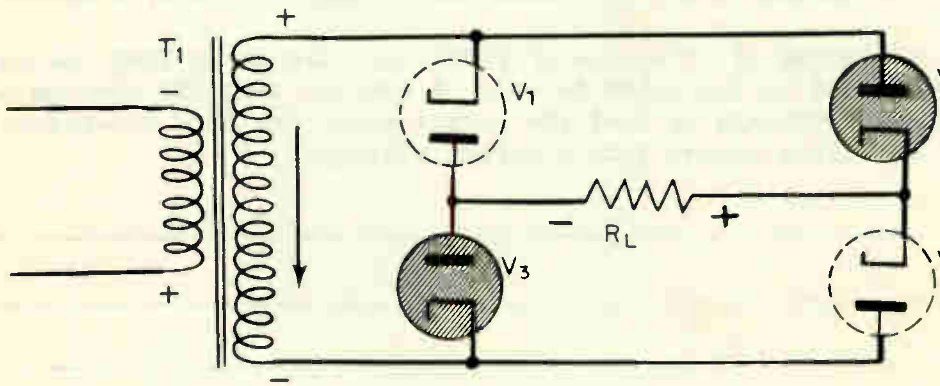



Fig. 15 V2 and V3 conducting during the first alternation

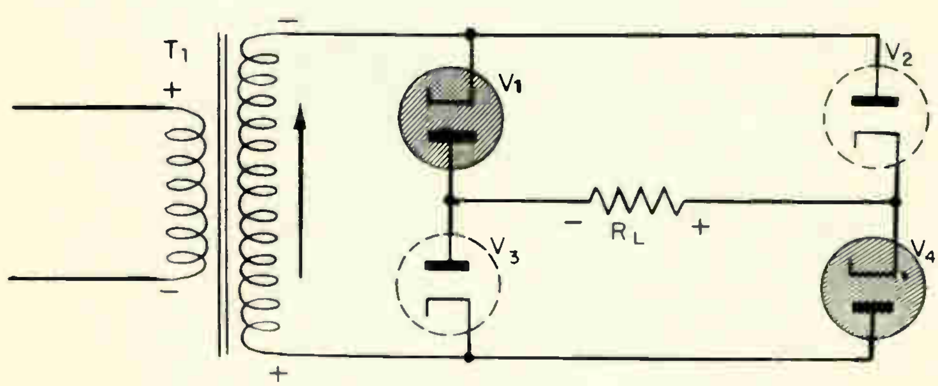



Fig. 16 V1 and V4 conducting during the second alternation.

The theory of operation is the same for any half-wave rectifier with the exception of the application of the plate voltages on the kenotron tubes in their regular phase relations and the shape of the output waves. Each tube passes electrons one-third of the time, and the effect on the output electron flow is to give three pulses of direct electron flow for each three-phase cycle of alternating potential.

Fig 14D illustrates a full-wave three-phase rectifier circuit. This type of rectifier is very efficient. Approximately 95% of the transformer secondary voltage peaks are available at the output of the rectifier. The voltage output of the rectifier gives more than a voltage doubling effect due to the delta-star system of transformer connection which increases the voltage output by a factor of 1.73.

One principal advantage of this type of rectifier circuit is that the maximum inverse voltage applied to the tubes is only 5% greater than the average output voltage. Another advantage is that the output wave form is a six-phase ripple which is easy to filter almost into a direct voltage.

M. Summary Questions

1. Explain briefly what causes a space charge within a kenotron tube?

2. What is meant by the "peak inverse rating" of a Kenotron Tube?

3. What advantages do multiphase rectifiers have over half-wave rectifiers?

   greater P.D.C.

4. What advantages does a bridge rectifier have over a conventional full-wave rectifier?

FILTERING METHODS - VOLTAGE DIVIDERS

Objective

To become familiar with the purpose and principles of operation of filter circuits and voltage dividers.

References

Lesson Content

A. Filter Circuits

In many industrial electronic devices a high smooth direct voltage is required. The circuits shown thus far produce only a high pulsating direct voltage. In order to obtain a smooth direct voltage from a rectifier, a filter circuit must be used.

Generally speaking, a filter is a device for separating things of different characteristics from each other. Mechanical filters are commonly used to separate sand from stones, a coffee strainer separates the coffee grounds from the liquid, etc. Similarily, when a circuit contains a flow of electrons of several frequencies, or direct and alternating currents, electrical filters may be used to separate these currents.

The action of electrical filters for rectifiers generally depends upon the following main principles of a-c circuits.

1. An inductor (inductance) offers much less resistance or opposition to the passage of DC and low frequency AC than it offers to high frequency electron flow.

2. A capacitor (capacitance) offers much less resistance or opposition to the passage of high frequency energy than to low frequency energy and stops or blocks the flow of DC altogether.

By proper arrangement of capacitors and inductors any desired electrical filtering action may be obtained.

The wave-form illustrated in Fig. 1 represents the voltage obtained from a full-wave rectifier circuit. The average voltage across the load $R_L$ is shown as the line which divides the wave shape so that area A equals area B..

B. Types of Filter Circuits

1. Capacitor filter

Illustration of Fig. 2A shows the output of a full-wave rectifier. Fig. 2B illustrates a simple capacitor filter circuit. Capacitor "C" is charged to the peak voltage of the rectifier within a few cycles. When the rectifier output drops to zero the voltage across the capacitor does not fall immediately but is discharged through the load $R_L$ during the time the rectifier is not supplying energy.

The voltage across the capacitor decreases at a very slow rate, when a large capacitor is used. After the capacitor has been charged.the rectifier does not begin to pass electrons until the output voltage of the rectifier exceeds the voltage across the capacitor. Fig. 2C illustrates how electrons begin to flow in the rectifier when the rectifier output reaches a voltage equal to the capacitor voltage. This occurs at the same time, "X", when the voltage has a magnitude of $E_1$. Electrons continue to flow in the rectifier until slightly after the peak of the half-sine wave, at time "Y". At this time the sine wave voltage is falling faster than the capacitor can discharge. A short pulse of electron flow which begins at "X" and ends at "Y" is supplied therefore to the capacitor by the power supply.

The simple capacitor filter is used only with rectifiers which do not have to supply a large flow of electrons through the load. If the resistance of the load was small and a large flow of electrons was drawn by the load, the average direct voltage would decrease considerably.

2. Inductance filter

Fig. 3B illustrates a simple inductance filter. The wave-forms of Fig. 3A represent the output from a full-wave rectifier.

When an inductance is added in series with the load resistor, the electron flow is modified as shown by the solid curves of Fig. 3 C. The modification takes place because the inductance tends to prevent the electron flow from building up or dying down. If the inductance were large enough, the electron flow would become nearly constant. This type of filter circuit permits a larger drain of electrons without a serious change of output voltage.

3. Pi filter

Fig. 4A illustrates a "pi" type filter using capacitors and an inductor. (This is termed a "Pi" type filter because of its resemblance to the Greek letter "Pi"). When a capacitor precedes the inductor, the circuit is termed as a "capacitor input"Pi"filter.

4. Choke input filter

Fig. 4B illustrates a choke input filter circuit. In these two types of filter circuits the capacitors handle the function of storing and releasing energy while the inductors simultaneously tend to prevent changes in the magnitude of the electron flow. The result of these two actions is to remove the ripple voltage from the rectifier output and to produce a voltage with a nearly constant magnitude. In the circuit of Fig. 4A the capacitor $C_1$ has infinite opposition to direct voltage but very low opposition to the ripple voltage so that most of the ripple voltage is by-passed by $C_1$. The remaining ripple voltage at "A" encounters a very high opposition in the inductor $L_1$.

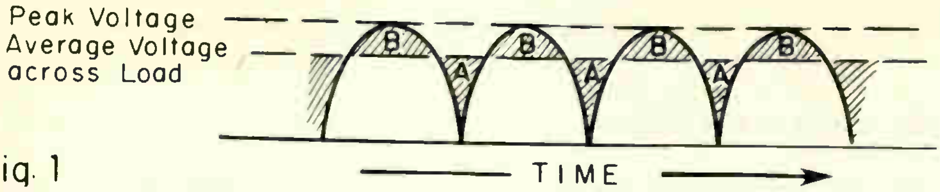



Fig. 1

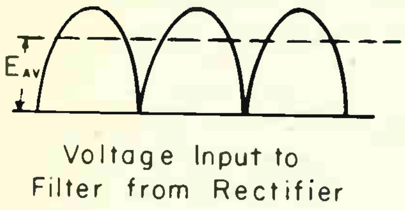



Fig. 2A

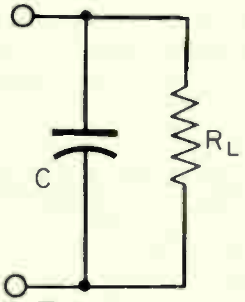



Fig. 2B

Fig. 2C

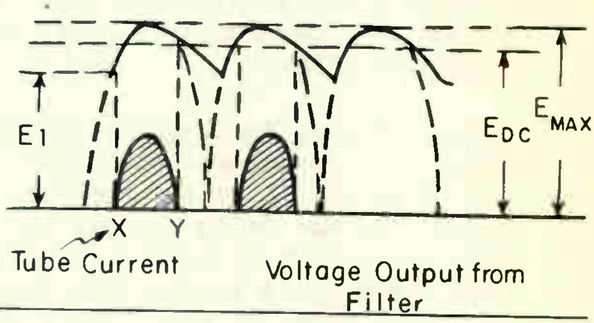
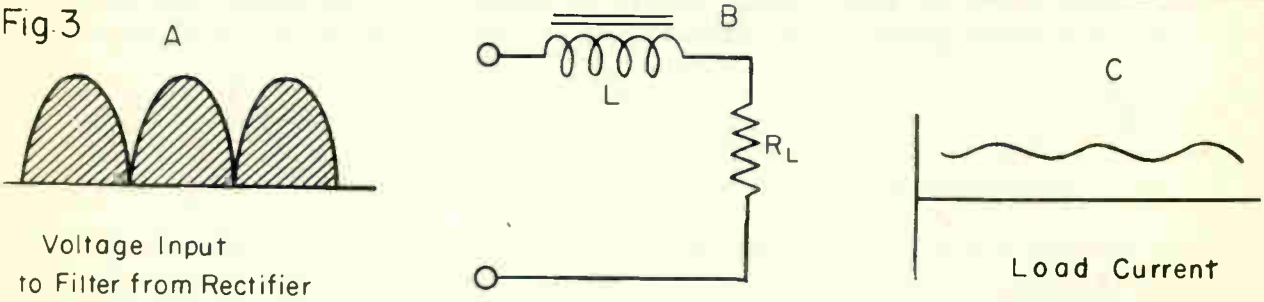



Fig. 3



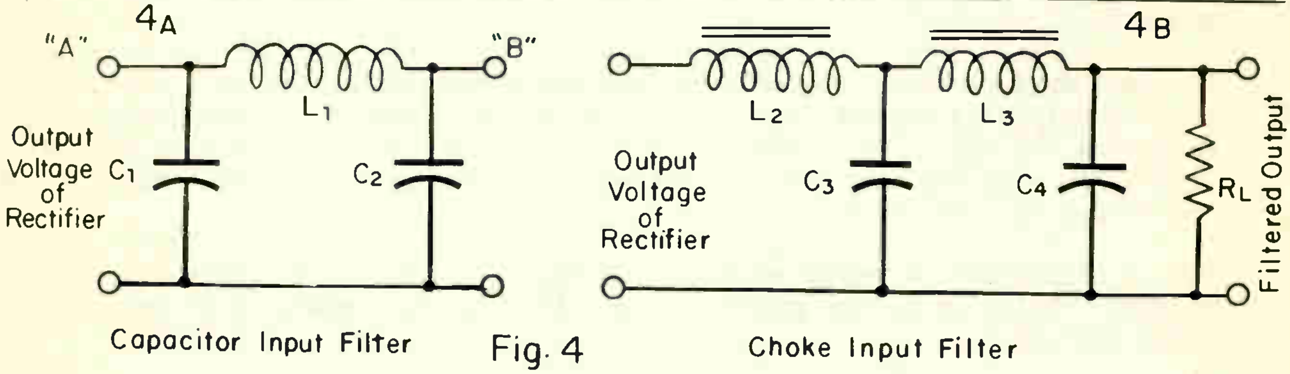




Fig. 4

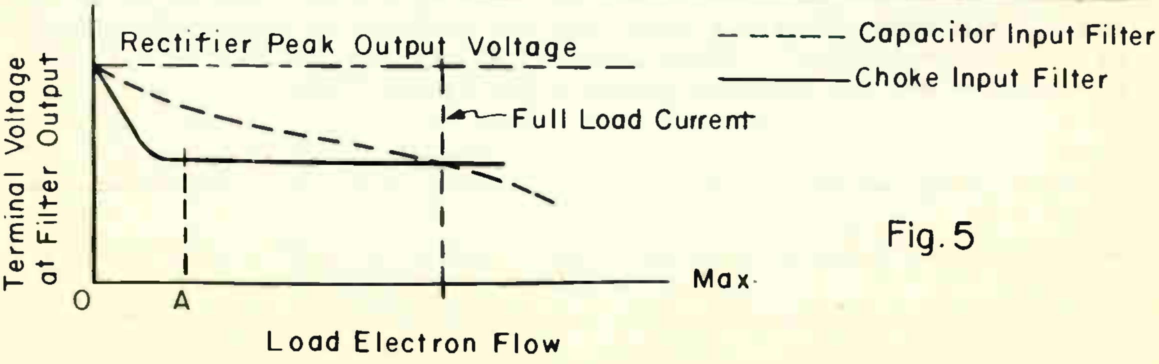



Fig. 5

What little ripple voltage passes from point A to B is largely by-passed to ground by capacitor $C_2$. A similar analysis may be used for the circuit of Fig. 4B.

5. Capacitor vs. choke input filter

Effect of load on terminal voltage of capac'tor input filter - As the load $R_L$ is increased, the terminal voltage decreases, because the electron flow through the load prevents the capacitor from retaining its charge. The capacitor input filter is undersirable for applications which require a large electron flow because the peak electron flow that must pass through the rectifier tubes, to charge the input capacitor $C_1$, may damage the tubes or require the use of large expensive tubes.

Effect of load on terminal voltage of choke input filter - with no electrons flowing through the load, capacitor $C_3$, (Fig. 4B) is charged to the peak voltage. However, if only a small flow of electrons is drawn through the load, the output voltage falls sharply to some lower value such as point A in Fig. 5. This sharp drop in voltage occurs because the inductance of $L_2$ prevents a surge from charging $C_3$ to the peak voltage, as happened to $C_1$, Fig. 4A. As the load increases there is very little change in output voltage except for the voltage drop that takes place in the resistance of the two choke coils $L_2$ and $L_3$.

C Voltage Dividers

1. General

The name of a resistor connected across the output terminals of a rectifier power supply will depend upon its principle use. Fig. 6 illustrates how two resistors, $R_1$ and $R_2$ are used to bleed off the charge on the filter capacitors $C_1$ and $C_2$, when the rectifier is turned off. Resistors used for this purpose are called "Bleeder Resistors".

Fig. 7 illustrates a resistor connected across a filter circuit to improve the voltage regulation of the power supply. This type of resistor is called a "Load Resistor".

If terminals are connected to the resistor at various points to provide a variety of voltages which are less than the terminal voltage, the resistor is called a "Voltage Divider". Figs. 8 and 9 illustrate the basic principle of a voltage divider and how various voltages may be obtained.

Fig. 6

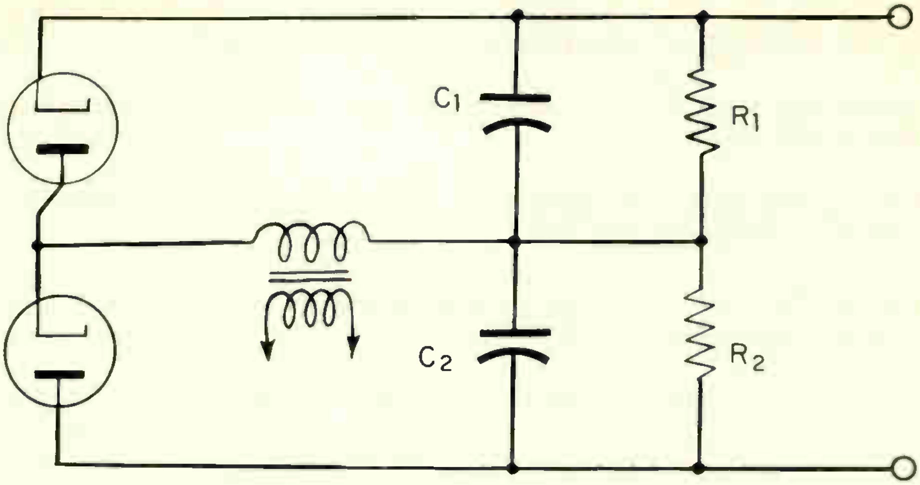
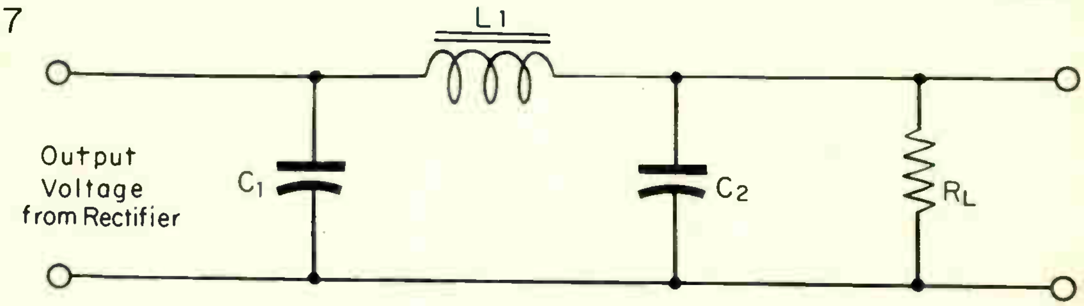



Fig. 7



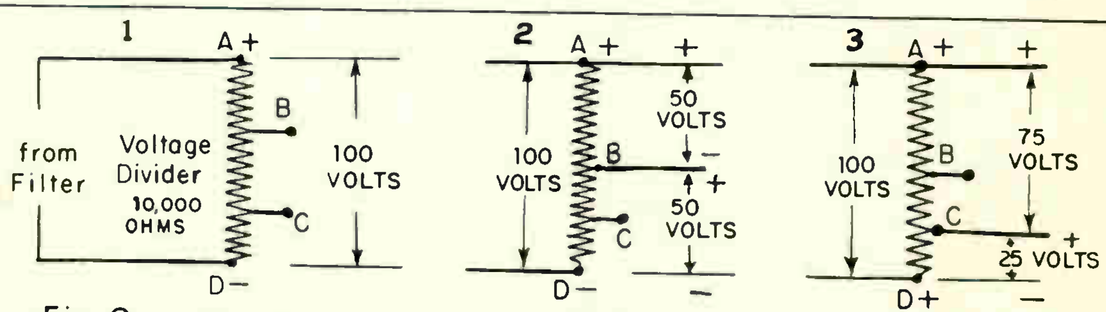




Fig. 8 • The Basic Principle of a Voltage Divider without a Load

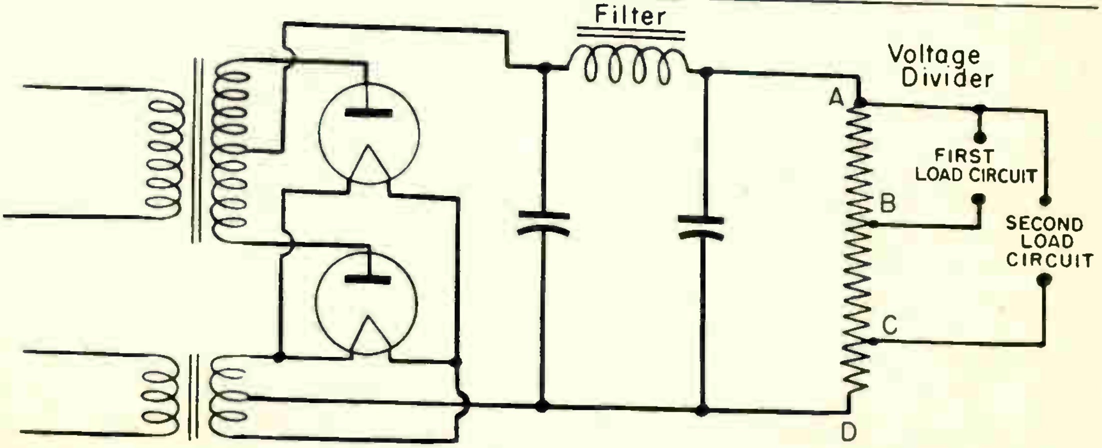



Fig. 9 • A Voltage Divider between the Rectifier Filter and the Load Circuits

D. Summary Questions

1. Define the meaning of the electrical term "Filter" change PDC to pure D.C

2. Does capacitor $C_1$ in Fig. 7 charge to the "peak" or "average" voltage applied from the rectifier.

3. Explain briefly how the capacitors in a "Pi" filter circuit discharge during the time the rectifier is not supplying energy.

4. What causes the voltage from a choke input filter circuit to drop considerably when a small load current is drawn.

5. Explain the difference between a voltage divider and a [redacted]. Bleeder

# CAPACITOR TESTING

## Objective

To become familiar with the theory and maintenance of capacitors used in industry.

## Reference

## Lesson Content

### A. General

In almost every electronic control device, capacitors are used to make the circuit function properly. Listed below are the various types of capacitors.

1. Paper capacitor.
2. Mica capacitor
3. Vacuum capacitor
4. Electrolytic capacitor
5. Air capacitor

Capacitors are used in industrial applications where their particular characteristics result in the greatest benefit to the user. Fig. 1 illustrates the use of four capacitors as grid-blocking capacitors in a 1200 watt electronic heater for dielectric heating. In this circuit the B plus voltage is grounded in order to minimize hazard to the operator.

Capacity is the property of two electrical conductors, separated by an insulating material called the dielectric to receive and retain electrical charges.

### B. Capacitor Construction

A device, called a capacitor, consisting of two metal plates separated by a dielectric will receive a charge of electricity and retain it until it is released.

The dielectric material used in capacitors may be any sort of electrical insulator, but usually it is paper, mica, glass, air, or oil; or in the case of electrolytic capacitors, an oxide film. The selection of the dielectric for industrial use depends upon many factors, such as the difference in potential that will exist between the plates, space limitations, etc.

An electrolytic capacitor consists of two electrodes, usually lead and aluminum, immersed in an electrolyte. The electrolyte constitutes one plate of the capacitor. Aluminum is used as the second electrode. The lead element provides means to make a connection with the electrolyte. The dielectric in an electrolytic capacitor is an oxide film which surrounds the aluminum electrode.

The capacity of an electrolytic capacitor depends upon the area of the plates, the thickness of the oxide layer, and the materials composing the plates. The thickness of the oxide layer is determined by the value of the voltage that is impressed across the capacitor during the process of "forming". Fig. 2 illustrates the basic construction of a dry electrolytic capacitor.

C. Unit of Capacity

The capacity of a capacitor is measured in farads. One farad is the capacitance in which a potential difference of one volt will produce a change represented by one coulomb more electrons on the negative side of the dielectric than on the positive side. A micro-farad is one millionth (.000001) of a farad. A micro-microfarad is mone millionth (.000001) of a micro-farad. An electrostatic unit, another term applied to the charge on the plates of a capacitor, is 1.1124 micro-microfarads.

D. Methods of Connecting Capacitors

In many industrial applications, capacitors are connected in series or parallel with each other to produce the proper amount of capacity in the circuit.

1. Capacitors in series.

   Connecting capacitors in series decreases the amount of capacity in the circuit. In fact, the total capacity in a circuit containing capacitors in series will always be less than that of the capacitor having the least capacity.

   The formula to determine the total capacity of capacitors connected in series is the counterpart of that for resistance connected in parallel, thus:

$$C = \frac{1}{1/C_1 + 1/C_2 + 1/C_3 \text{ etc.}}$$

   If more than one capacitor having the same capacity are connected in series, the total capacity will equal the capacity of one capacitor divided by the number of capacitors in the circuit.

2. Capacitors connected in parallel.

   Connecting capacitors in parallel produces the same effect as increasing the number of plates. Therefore, the total capacity is the sum of the capacities. The formula is as follows: C equals C1 plus C2 plus C3 plus C4 etc.

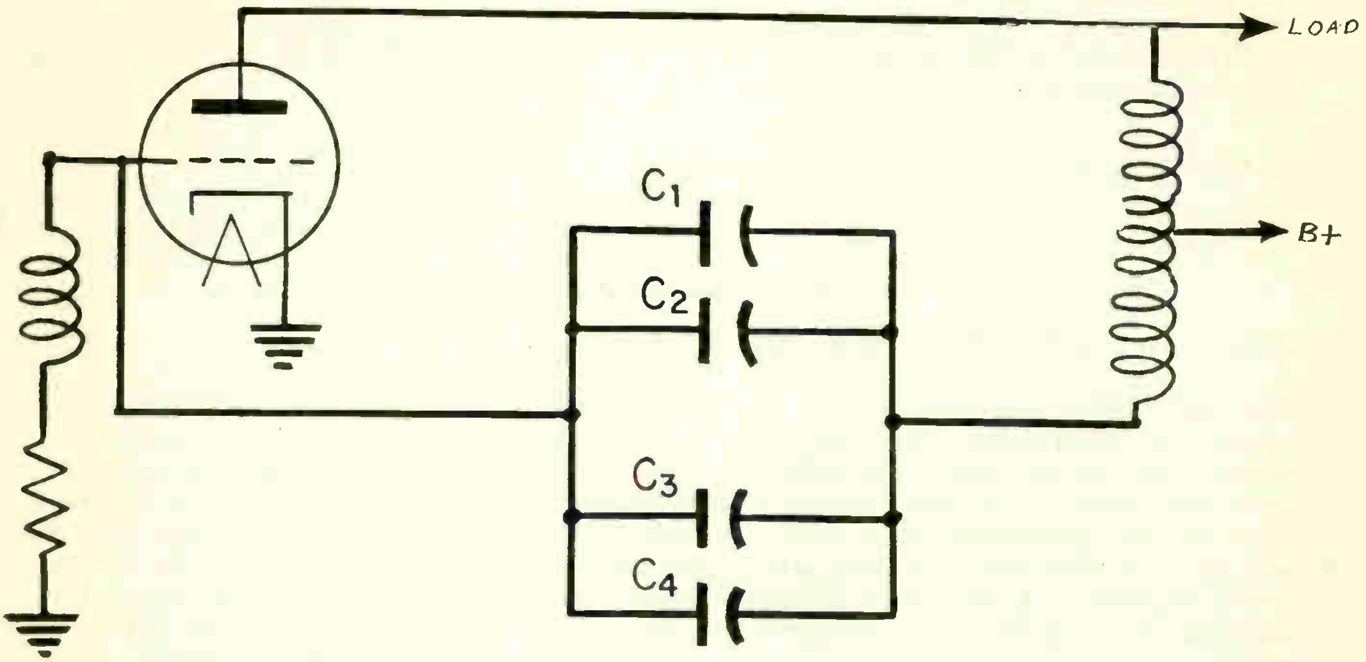



Fig. 1 • Electronic Heater Circuit

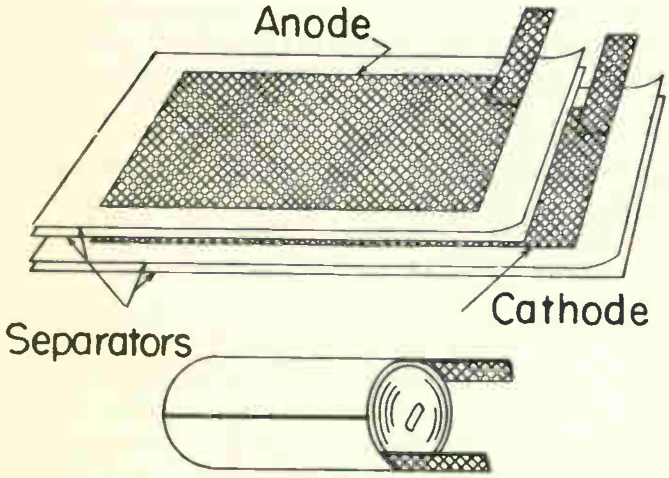



Fig. 2 • Capacitor Cartridge Construction

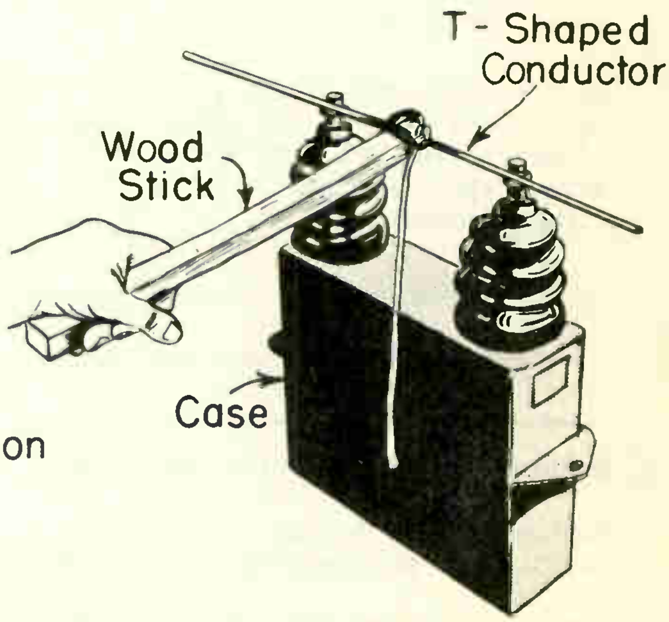



Fig. 3 • Discharging a Capacitor

3. Capacitors in series - parallel.

When capacitors are connected in series-parallel, the capacities of the parallel combinations are determined first and then the equivalent values are calculated in accordance with the formula given for series connections.

E. Testing Filter and By-Pass Capacitors.

Filter and by-pass capacitors used in many electronic devices may be tested for breakdown by several methods. One of the simplest is to disconnect the capacitor from the circuit and apply approximately 200 volts DC to its terminals through a neon test lamp. The test lamp will glow once during the charge time of the capacitor. If the capacitor has a short circuit between its plates, no charge will be stored by them and the neon lamp will glow continuously. (Refer to Job #4 in the I.E. Department). A capacitor of small capacity may also be tested by means of connecting it in series with an earphone and applying a low potential to this combination. A "click" will be heard in the earphone as the capacitor charges.

Another method of testing a capacitor is by applying an audio signal through the capacitor. A pair of earphones will detect this audible signal if the capacitor is not open.

An electrolytic capacitor may be tested by connecting it directly to a source of direct voltage and measuring the electron leakage through it by means of a milliammeter. Care should be taken to connect the capacitor to the line terminals having the correct polarity. To prevent the burning out of the milliammeter, the capacitor should first be tested with an ohmmeter for a possible "short" between the capacitor plates.

Electrolytic capacitors produced by different manufacturers differ as to the leakage. Some idea of the value to be expected may be obtained from two typical capcitors tested with 400 volts DC. For a 10 mfd. capacitor the leakage should not exceed about 2.5 milliamperes. For a 4 mf. capacitor, it should not exceed about 1.0 millamperes.

F. Testing Large Industrial Capacitors.

For capacitors installed in industrial plants more caution must be exercised in testing and maintaining these units.

Because of their size and extremely high internal resistance these capacitors may retain a charge for days after they are disconnected from the circuit, providing

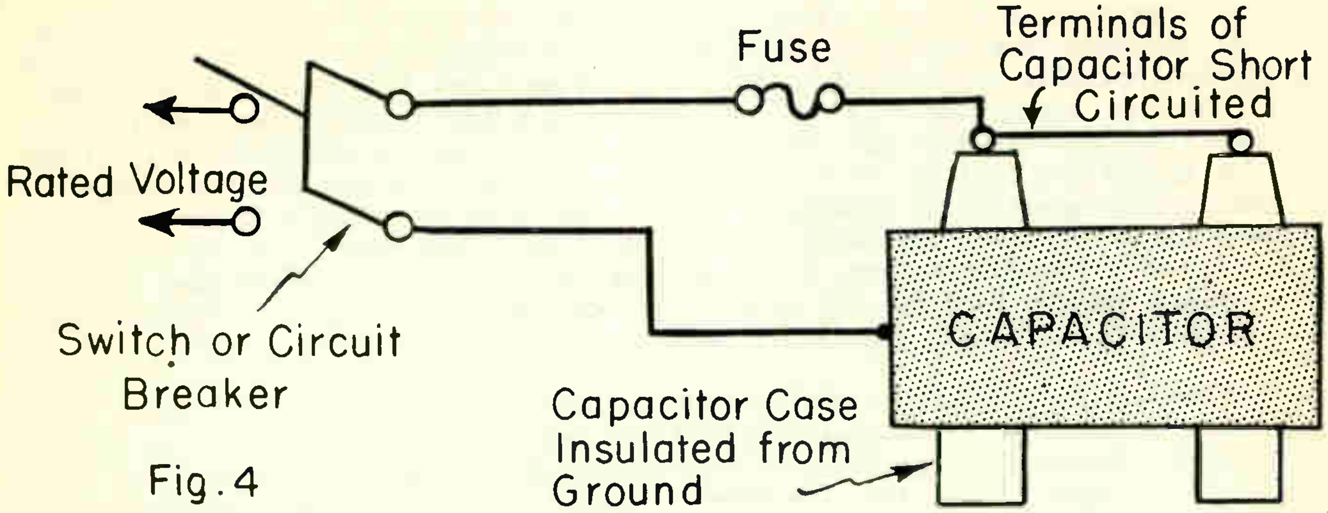



Fig. 4

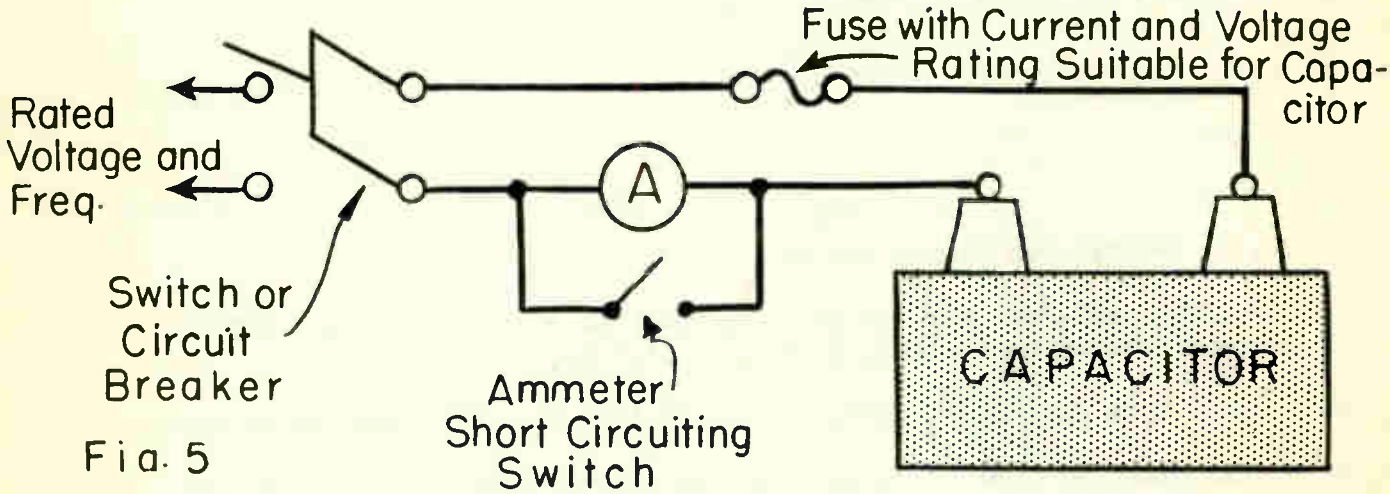



Fig. 5

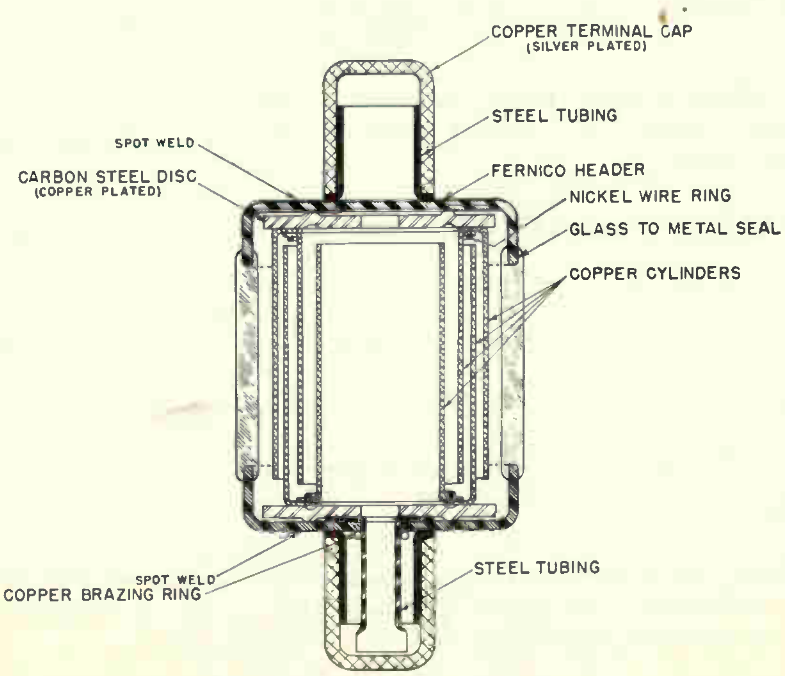



Fig. 6 GL-IL38

no discharge path is present. Therefore, before touching any terminal or bus connection the capacitor should be disconnected from the circuit and then discharged by short-circuiting the terminals, and at the same time, temporarily ground them to the case of supporting rack. A "T" shaped conductor insulated by a stick of wood provides a convenient and safe means of discharging the capacitor unit, Fig. 3. One method for testing the insulation between the terminals and the case of an industrial capacitor is shown in Fig. 4. The rated 60 cycle voltage is applied between the short-circuited terminals and the case of the capacitor. A flow of electrons of a few milliamperes is normal when a capacitance of less than .002 mf. exists between terminal and case. A blown fuse or a tripped circuit breaker would indicate a fault in the insulation.

Another method for capacitor testing is shown in Fig. 5. This circuit shows a method for a terminal to terminal voltage test and for measurement of capacitance at a rated voltage and frequency. If the voltage is not readily variable and if full-rated voltage is applied, the ammeter should be protected by a short-circuiting switch. After it has been established that no short circuit exists, this switch should be opened to read the rate of electron flow.

G. Points to be Observed During the Test.

1. Excessive over-load that would cause the blowing of a fuse or tripping of a circuit breaker indicates a short circuited capacitor.

2. Absence of a flow of electrons indicates that the capacitor has an open circuit.

3. Normal electron flow indicates that the capacitor is in good condition. Normal electron flow equals $\dfrac{6.28 \times \text{frequency} \times \text{mf.} \times \text{rated voltage}}{1,000,000}$

4. Electron flow above normal indicates that a series section in the capacitor is short-circuited. Capacitors rated 1500 volts and above usually include two or more series sections.

5. Electron flow below normal indicates that a portion of the capacitor is open circuited.

H. Vacuum Capacitors

The vacuum capacitor is a high voltage, small size vacuum-dielectric capacitor designed for use on DC, AC, or radio frequencies. Fig. 6 illustrates a cross sectional view of a vacuum capacitor rated at 7,500 volts.

Some of the more important advantages of a vacuum capacitor are listed below:

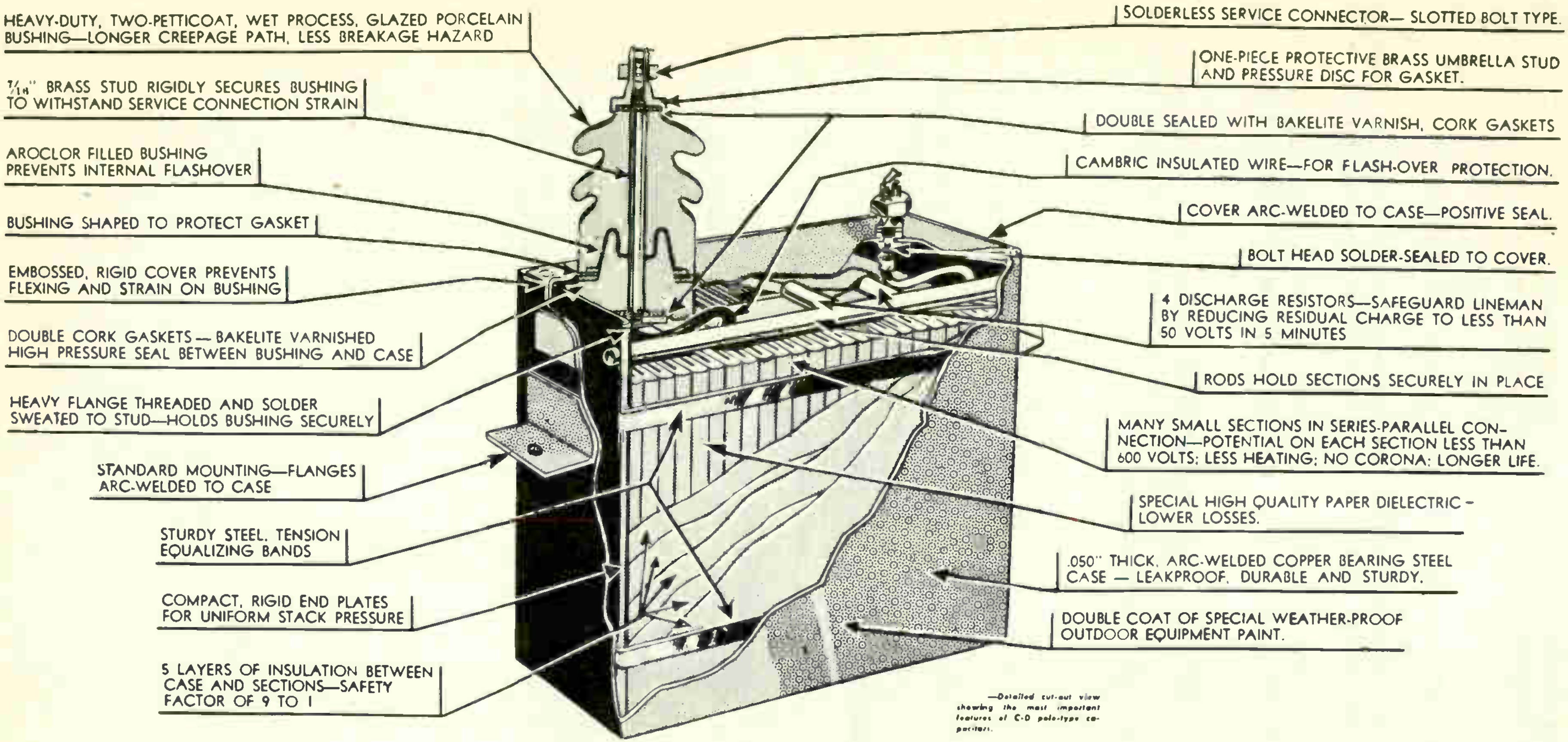



Fig. 7 - A detailed cut-out view showing the important features of a C-D Pole-Type CAPACITOR. Capacitors such as this contribute to industry its use in scientific, industrial, filter and power - factor, improvement, carrier current coupling and trap applications.

1. Vacuum capacitors are comparatively loss-free, since there are no losses in the vacuum dielectric and because the total capacitance is lumped in a very small area.

2. Dust and other foreign matter have no effect on vacuum capacitors.

3. Internal voltage break-down is constant and is independent of altitude, temperature, humidity and other factors because of the vacuum construction.

4. A vacuum capacitor does not depend upon a solid dielectric for its voltage insulation. Therefore, there is no dielectric to puncture if over-voltages are accidentally applied.

Vacuum capacitors range from approximately five micro-microfarads to 100 micro-microfarads. These capacitors are mostly used in high frequency circuits such as industrial diathermy and electronic heating equipment.

I. Summary Questions

1. What purpose does the dielectric serve inside of a capacitor? Its an insulator & a charger as well

2. Name six various types of capacitors used in industry. paper, mica, Vacuum Electrolytic, Air + Pyranol

3. Six 3 mf. capacitors must be connected in such a manner so that a total capacity of $5\frac{1}{2}$ mf., is available. Draw a sketch showing the connections.

4. Three 2 mf. capacitors rated at 200 volts each must be connected so as to withstand a voltage of 600 volts. Draw a sketch showing connections.

5. The capacitance of an industrial capacitor is being measured at rated voltage and frequency. What would be the normal electron flow of a 100 mf. capacitor rated at 2000 volts and a frequency of 60 cycles? Show all work.

Distance shows the governed Voltage between Plates!

# GAS RECTIFIER TUBES

## Objective

To become familiar with gas rectifier tubes (Phanotrons) and their applications.

## References

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## Lesson Content

A. The Phanatron Tube

A phanotron is a thermionic gas filled rectifier tube. This type of tube is a more efficient rectifier than the high-vacuum tube because of the constant low voltage drop in the tube during normal operating conditions.

Phanotrons are designed to be used as rectifiers in many types of electronic applications where it is desired to supply d-c power for other electronic tubes.

Gas filled rectifier tubes of the general style illustrated in Fig. 1 are designed for such uses as battery charging in automobile service stations. These tubes contain gas at relatively high pressure which lowers the maximum permissible peak inverse potential between 275 and 300 volts. Average electron flow rates are from 2 to 15 amperes and the maximum peak rates are from 6 to nearly 50 amperes.

In a high vacuum tube, the space charge around the cathode resists the flow of electrons from cathode to plate. This space charge causes the internal resistance of the tube to increase and is undesirable in applications where greater rates of electron flow are required.

This obstacle, however, is overcome by the injection of an inert gas within the tube envelope. The gas used may be one of the inert gases such as argon, zenon, helium, or mercury. When mercury is used it is injected into the tube under a very low pressure.

Before an explanation of how the space charge is reduced by injecting a gas into the tube enevelope, a few basic facts should be understood.

1. An "ion" is an electrically unbalanced atom.

2. There are two types of ions which can be released by electronic bombardment.

   a. A positive ion.
   b. A negative ion.

3. A positive ion is an atom which has lost one or more electrons due to bombardment.

4. A negative ion is an atom which has gained one or more electrons.

Both positive and negative ions may be created by the electronic bombardment of gas atoms. In order to fully understand how the space charge is reduced within a gas rectifier tube by ionization, the positive ion effect will be discussed.

The action of the cathode in a gas filled or high vacuum tube is basically the same. Electrons given off by the heated cathode speed toward the plate when a high positive potential is applied to this plate, thus forming an undirectional flow of electrons.

The presence of a gas or mercury-vapor within a tube neutralizes the electron space charge in the following manner:

When an electron leaves the cathode and gains speed on its way toward the plate it collides with an atom of gas. As a result of such a collision, an electron is knocked loose from the orbit of this gas atom and two electrons thus speed on their way toward the plate. The atom which lost one electron now becomes a "positive ion" and finds itself charged positive. This positive ion now tends to move toward the negative space charge existing around the cathode so as to attract an electron and become a neutral atom of gas once more. In normal operation of a phanotron tube there are enough positive ions released to practically neutralize the entire negative space charge surrounding the cathode.

The high voltage drop existing in a vacuum rectifier tube is due to the effect of the space charge which has to be overcome by the plate potential in order to have electron flow. In a phanotron tube the space charge voltage drop is reduced to approximately 15 to 20 volts and it remains approximately at this value regardless of load. By increasing the load the number of collisions increases which in turn causes greater neutralizing action in the space charge, thereby causing the voltage drop to remain practically constant, Fig. 2.

In using phanotron tubes, the following precautions must be taken into consideration:

1. The maximum peak electron flow must never be exceeded due to the danger of cathode disintegration. This is due to bombardment of the cathode by the positive gas ions.

2. The maximum inverse peak voltage should never be exceeded due to the danger of flash back within the tube. The gas or mercury vapor furnishes an excellent (reverse) path for electron flow.

3. The cathode of mercury vapor types must be brought up to operating temperature before the plate voltage is applied. This is necessary in order to build up a sufficient space charge around the cathode to protect it against bombardment of positive gas ions. The heating time may vary from about thirty seconds to as much as five minutes, depending upon the characteristic and size of the tube.

4. A phanotron should be kept out of magnetic fields. Such fields have the effect of distorting the gas atom orbits and making certain directions of motion easier than others.

5. In operation, a mercury vapor tube must be maintained at proper temperature because, as the temperature of a mercury vapor tube is raised, more of the liquid mercury evaporates into vapor and with more vapor the pressure becomes greater inside the tube. As the tube is cooled some of the vapor condenses and the pressure inside the tube becomes lower. Between 70 and 180 degrees Fahrenheit

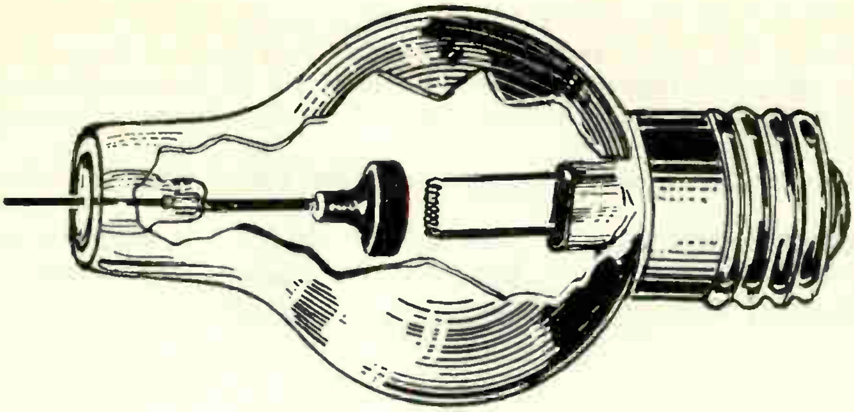


Fig. 1. A Rectigon Gas-filled Rectifier Tube. (CUT-AWAY VIEW)

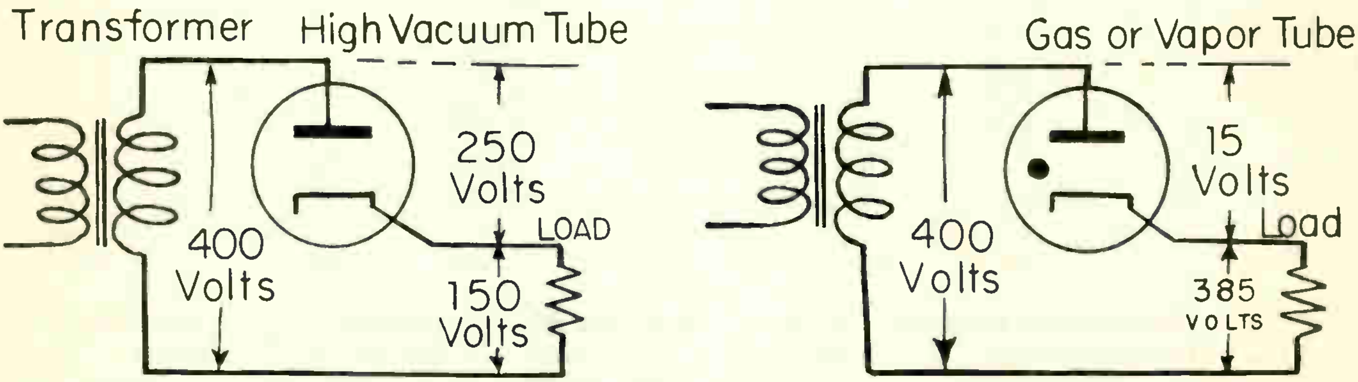



Fig. 2

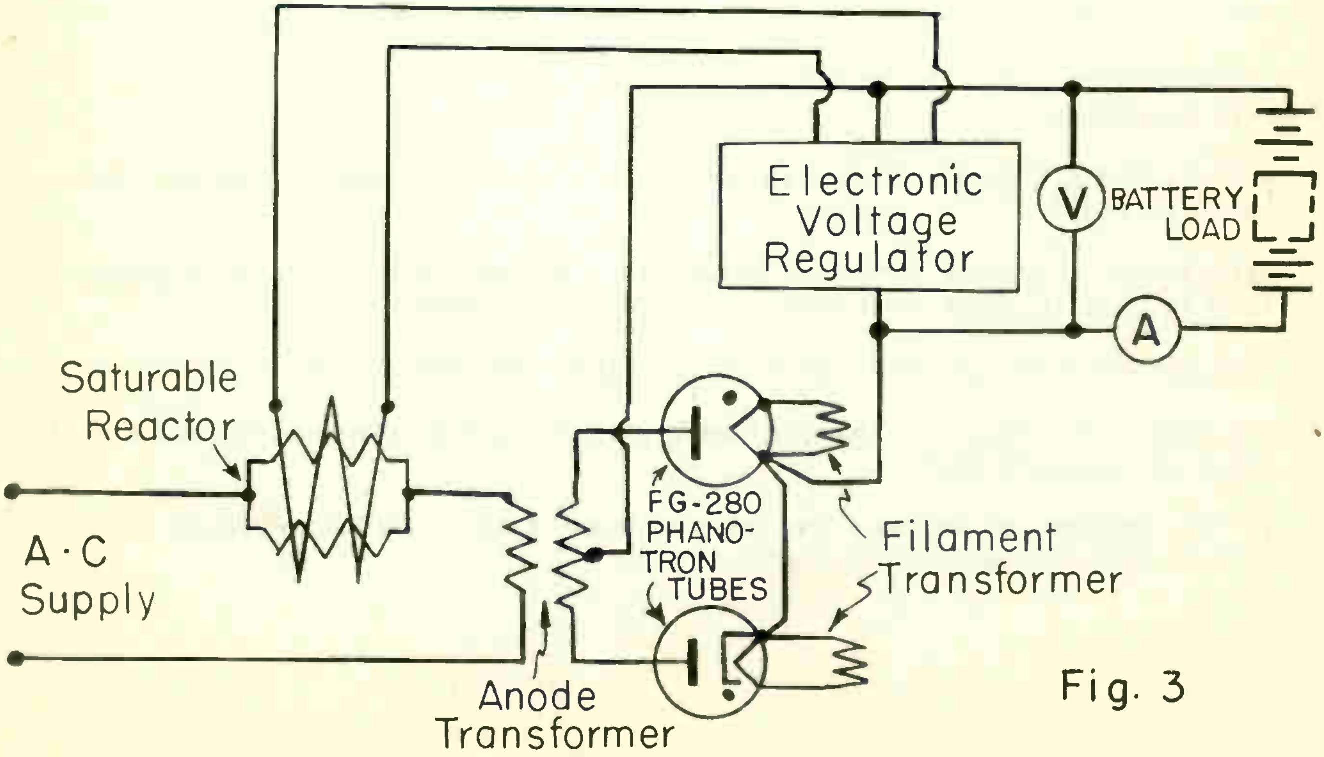



Fig. 3

the "vapor pressure" of mercury increases from about 20 millionths to about 1800 millionths of one pound per square inch. To maintain satisfactory operating pressures, mercury vapor tubes are maintained at temperatures from about 20 to 55 degrees Centigrade, which is from 68 to 130 degrees Fahrenheit.

Characteristics of representative phanotron tubes used in industry:

| TUBE TYPE | FILAMENT VOLTAGE | FILAMENT CURRENT (Amperes) | HEATING TIME (seconds) | TUBE VOLTAGE DROP (average) | PEAK PLATE VOLTAGE | PEAK PLATE CURRENT (amperes) | AVE. PLATE CURRENT (amperes) |
|---|---|---|---|---|---|---|---|
| GL-575A | 5 | 10 | 30 | 10 | 15,000 | 6 | 1.5 |
| GL-673 | 5 | 10 | 30 | 10 | 15,000 | 6 | 1.5 |
| GL-857B | 5 | 30 | 60 | 12 | 22,000 | 20 | 10.0 |
| GL-866 | 2.5 | 5 | 30 | 15 | 10,000 | 1 | .25 |
| GL-866A | 2.5 | 5 | 30 | 15 | 10,000 | 1 | .25 |
| GL-869B | 5 | 18 | 60 | 15 | 20,000 | 15 | 5.0 |
| GL-872 | 5 | 7.5 | 30 | 10 | 5,000 | 5 | 1.25 |
| GL-872A | 5 | 7.5 | 30 | 10 | 5,000 | 5 | 1.25 |
| GL-8008 | 5 | 7.5 | 30 | 10 | 10,000 | 5 | 1.25 |
| FG-32 | 5 | 4.5 | 300 | 12 | 1,000 | 15 | 2.5 |
| FG-104 | 5 | 10 | 300 | 15 | 3,000 | 40 | 4.0 |
| FG-166 | 2.5 | 100 | 120 | 9 | 1,500 | 75 | 20.0 |
| FG-190 | 2.5 | 12 | 5 | 8 | 175 | 5 | 1.25 |
| FG-280 | 5 | 10 | 300 | 15 | 2,000 | 40 | 6.4 |

Fig. 3 illustrates a typical circuit where two FG-280 phanotron tubes are used in a battery charger. The tubes supply d-c power for the battery charging equipment. Various types of phanotron tubes may be used. For circuit design refer to the tube rating chart.

B. Summary Questions

1. What is the difference in electrical characteristics between a negative and a positive ion?

2. Explain why a greater potential can be obtained across a load when a phanotron tube is used in place of a high vacuum rectifier tube?

3. What precautions must be observed when using phanotron tubes?

4. Why must the cathode of a mercury vapor filled tube be pre-heated before applying a plate potential?

5. If the temperature around a gas mercury vapor tube is increased, what effect will it have on the rate of electron flow?

# RC TIME CONSTANTS

## Objective

To become familiar with the basic theory of series and parallel RC timing circuits.

## References

## Lesson Content

A General

In a fundamental timing circuit, a series or parallel combination of capacitance and resistance is placed across a potential difference. The voltage across the capacitor will keep on changing until the electron flow through the resistor becomes zero. This lesson will be devoted to studying such timing action.

B. Series Timing Circuit Analysis

1. Charging the capacitor.

Fig. 1 illustrates the basic series RC time constant circuit which consists of a resistor and capacitor connected in series and across a voltage source.

Upon closing switch S in Fig. 1, the positive side of the battery will attract electrons from the bottom plate of capacitor C Electrons from the negative side of the battery will travel through resistor "R" and create a voltage drop, "Er", across it. This voltage drop prevents the full battery voltage from being immediately applied to the capacitor plates.

As the capacitor charges, fewer electrons per second pass through the resistor and the voltage drop, "Er", across the resistor diminishes, thereby allowing a greater voltage, "Ec", to be applied to the capacitor. When the maximum number of electrons (determined by the capacitance of the capacitor have been taken from the bottom plate and transferred to the top capacitor plate there is no further voltage drop across the resistor and the full battery voltage is applied across the capacitor. The time required for this whole operation depends upon the resistance of R and the capacitance of C.

2. Effect of R on charging time.

When R is increased, the voltage drop "Er", is larger for a given electron flow and less voltage is applied to the capacitor than previously at any given time after the switch S is closed. When R is smaller, the voltage drop is less for a given electron flow and the capacitor charges more quickly.

3. Effect of C on charging time.

When C is increased, more electrons will be displaced from each capacitor plate. This will cause an increased voltage drop, "Er", across the resistor and full capacitor charge will be delayed. When C is decreased, fewer electrons will flow and full capacitor charge will occur more quickly.

C. Resistor-Capacitor Factors

Time delay of charging due to resistance is easy to understand if the following well known facts are remembered.

1. A charge on a capacitor consists of a surplus and a deficiency of electrons in some definite quantity.

2. Quantities of electrons are measured in coulombs. The mathematical formula is Q equals CE.

3. Coulombs per second are measured by the unit "ampere". For a smaller charge upon a capacitor fewer amperes are needed. The mathematical formula is $I=Q/T$.

4. From Ohm's Law, amperes are equal to volts divided by ohms, or amperes are inversely proportional to ohms of resistance.

Formulas for 2 and 3 above apply when: Q equals coulombs
C equals capacitance in farads
E equals volts
I equals amperes
T equals time in seconds.

Studying the four factors listed, it can readily be seen that to have fewer amperes and a slower charge in a timing circuit, more ohms of resistance are needed.

D. Time Constant

The time required for the capacitor in series with a resistor to reach a voltage equal to 63.2% of the charging voltage, or to discharge the capacitor to 36.8% of its final voltage is called the time constant of the capacitor-resistor combination.

The mathematics required to calculate the "time constant" is extremely simple.

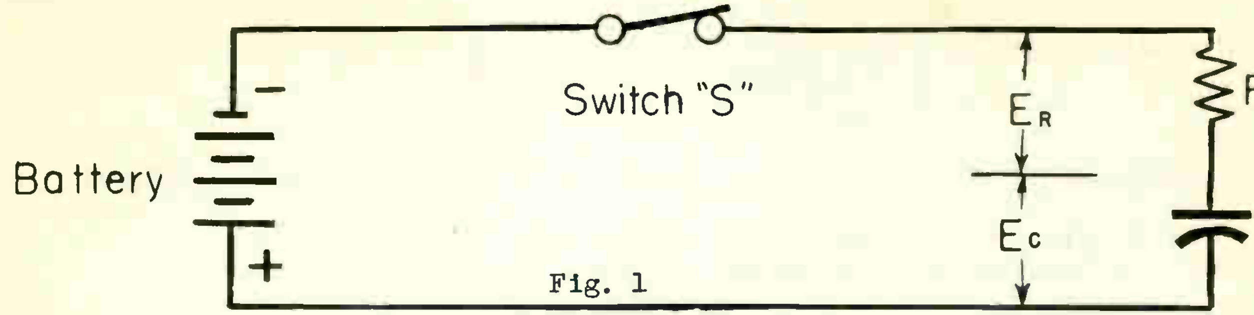



Fig. 1

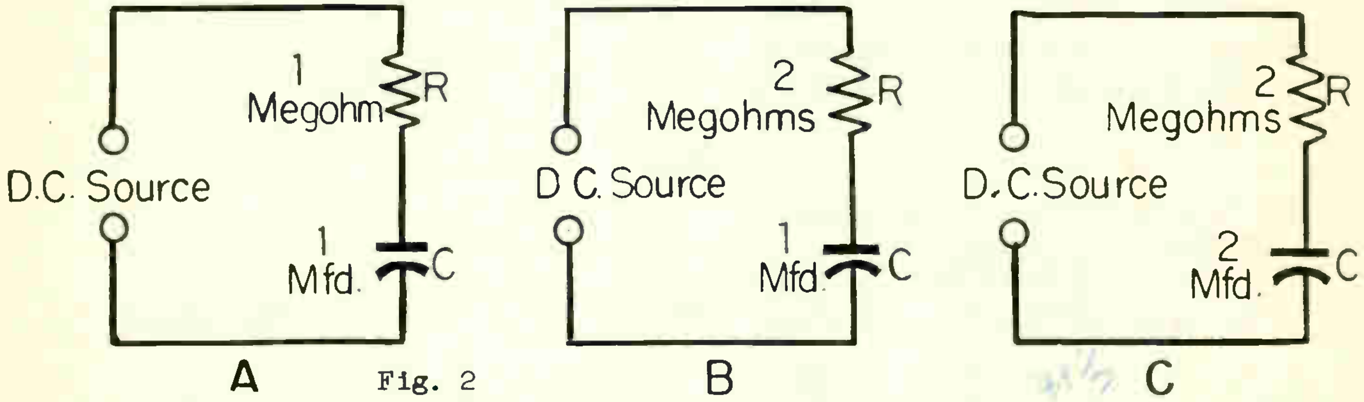



Fig. 2

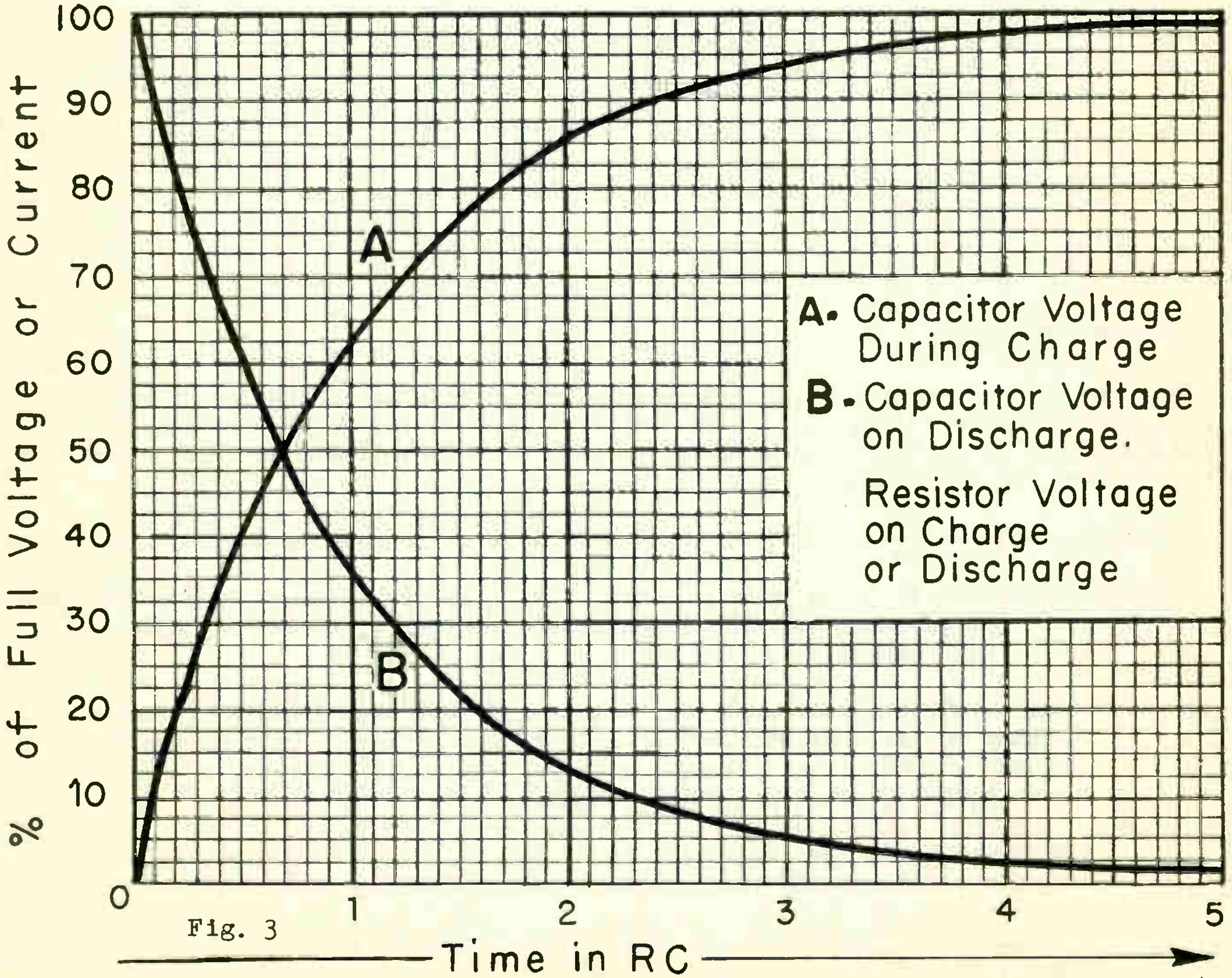



Fig. 3

The formula is: T=RC  T=time
R=resistance
C=capacitance

Some useful relations often used in calculating time constant are as follows:

R (ohms) x C (farads) equals T (seconds)
R (megohms) x C (microfarads) equals T (seconds)
R (ohms) x C (microfarads) equals T (micro-seconds)
R (megohm) x C (micro-microfarads) equals T (micro seconds)

Below is a table illustrating various percent of voltages existing upon a capacitor and resistor in a series RC circuit as illustrated in Fig. 2.

SERIES

| END OF TIME CONSTANT | Elapsed time period (seconds) Fig.A (RC=1) | Fig.B (RC=2) | Fig.C (RC=4) | TOTAL CAPACITOR VOLTAGE % | VOLTAGE GAINED BY CAPACITOR % | VOLTAGE ACROSS RESISTOR % |
|---|---|---|---|---|---|---|
| 0 | 0 Sec. | 0 Sec. | 0 Sec. | 0.00 | 0.00 | 100.00 |
| 1 | 1 " | 2 " | 4 " | 63.20 | 63.20 | 36.80 |
| 2 | 2 " | 4 " | 8 " | 86.50 | 23.30 | 13.50 |
| 3 | 3 " | 6 " | 12 " | 95.00 | 8.50 | 5.00 |
| 4 | 4 " | 8 " | 16 " | 98.20 | 3.20 | 1.80 |
| 5 | 5 " | 10 " | 20 " | 99.30 | 1.10 | .70 |

E. Time Constant Chart

Fig. 3 is a time constant chart. This is an accurate graph of the voltage rise or fall across the capacitor and across the resistor in a series RC circuit. The voltage scale is graduated in terms of percent of full voltages so that the curves may be used for any voltage.

The following illustrative problem shows how these curves may be used.

EXAMPLE: A circuit is to be made in which a capacitor must charge to one-half of the charging voltage in .001 seconds. The resistor must be 30,000 ohms. What size capacitor is needed?

Curve "A" is first consulted to determine the part of an RC (time) necessary to give one-half or 50% of the full voltage. Time necessary equals 0.7 RC. If 0.7 RC must equal .001 seconds, then one complete RC must equal .001/0.7 or .00143 seconds.

If T equals RC, or .00143 equals 30,000 x C, then C equals T/R, or C equals .00143/30,000 equals .0000000476 farads, or .0476 micro-farads.

In an actual circuit a .05 micro-farad capacitor would be used unless great precision was absolutely necessary.

BL
BR
RED
OR
Yell

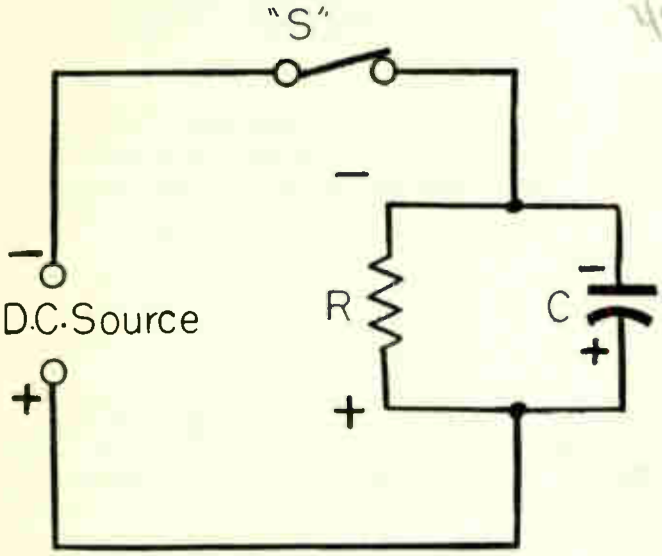



Fig. 4A

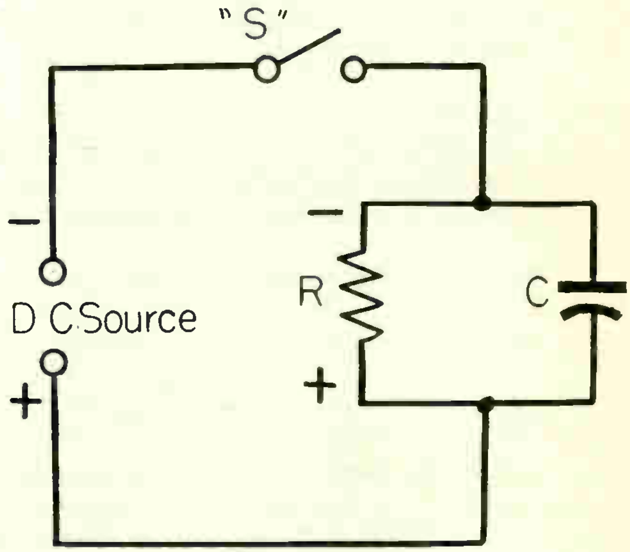



Fig. 4B

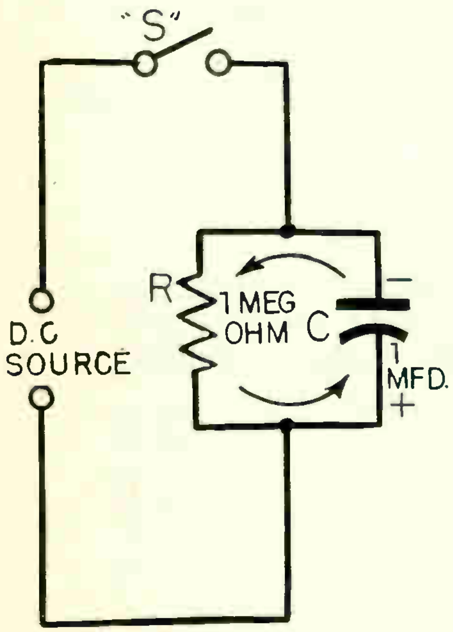



Fig. 5A

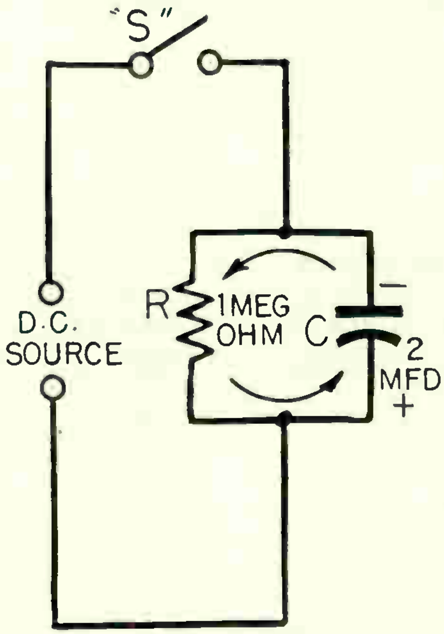



Fig. 5B

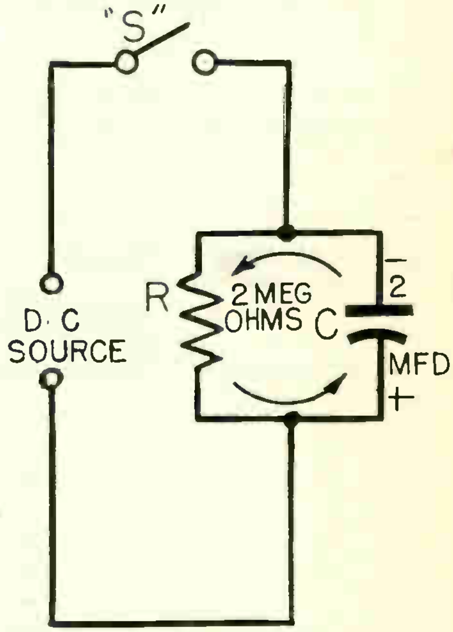



Fig. 5C

F. Parallel Timing Circuit Analysis

In Fig. 4A a capacitor and resistor are connected in parallel and across a source of voltage. It can be seen that no time constant exists the instant switch S is closed in a parallel RC circuit. The capacitor is instantaneously charged to the same voltage as that of the source and the voltage across the resistor is the same as that of the source.

In Fig. 4B, switch S is opened. A time constant exists now. Capacitor C discharges through resistor R. The time delay in seconds becomes directly proportional to the resistance multiplied by the capacitance. The time period which the capacitor voltage will decrease will depend on:

1. The capacitance of the capacitor.

2. The resistance of the resistor.

Example: If 10 volts is the applied voltage Fig. 4A, the charge on the capacitor one time constant after the switch S is opened (Fig. 4B) will be 3.68 volts. If 100 volts is applied to the same capacitor, the charge upon the capacitor one time constant after the switch is opened will be 36.8 volts. Regardless of what the applied voltage may be, the voltage across the capacitor in a parallel RC circuit one time constant later, after switch S is opened, will always drop 63.2% of the voltage applied to the capacitor. During each succeeding time constant of an RC parallel circuit the capacitor will decrease 63.2% of the remaining applied voltage.

Below is a table illustrating various percent of voltages existing upon a capacitor and a resistor in a parallel RC circuit as illustrated in Fig. 5.

PARALLEL

| END OF TIME CONSTANT | Elapsed time period (seconds) Fig. A (RC=1) | Fig. B (RC=2) | Fig. C (RC=4) | TOTAL CAPACITOR VOLTAGE % | VOLTAGE LOST BY CAPACITOR % | VOLTAGE ACROSS RESISTOR % |
|---|---|---|---|---|---|---|
| 0 | 0 Sec. | 0 Sec. | 0 Sec. | 100.00 | 0.00 | 100.00 |
| 1 | 1 " | 2 " | 4 " | 36.80 | 63.20 | 36.80 |
| 2 | 2 " | 4 " | 8 " | 13.50 | 86.50 | 13.50 |
| 3 | 3 " | 6 " | 12 " | 5.00 | 95.00 | 5.00 |
| 4 | 4 " | 8 " | 16 " | 1.80 | 98.20 | 1.80 |
| 5 | 5 " | 10 " | 20 " | .70 | 99.30 | .70 |

The capacitor in a series RC circuit will never assume a full charge, nor will the capacitor in a parallel RC circuit ever fully discharge. The voltages across the capacitors, however, will either get so near to full charge, or decrease to such a small value, that the difference cannot be measured. Therefore, at the end of the fifth time constant the capacitor is considered either fully charged or discharged.

G. Summary Questions

1. A capacitor in series with a four megohm resistor obtains 95% of its full charge voltage in six seconds. What is the value of the capacitor?

2. Fifty volts are applied across a capacitor and resistor in series. What voltage exists across the resistor in 0.7 RC time constant?

3. 100 volts are applied across a 1 mf., capacitor and resistor in series. What voltage exists across the capacitor in 1.2 time constant, if the product of RC is 1.2 micro-seconds? What is the value of the resistor?

4. A .001 mf. capacitor discharges through a 2 megohm resistor. How many micro-seconds will it take for the capacitor to lose 70% of its full initial charge?

5. The battery potential in Fig. 1 is reversed so that the negative terminal is connected to one plate of capacitor C. What percent of voltage will now exist across C after one time constant?

# ELECTRONIC TRIGGER TIMING CIRCUITS

## Objective

To become familiar with cold cathode tubes and the fundamental theory of electronic trigger timing.

## References

## Lesson Content

### A. General

In many common electrical circuits, electronic trigger timing devices are used to operate, at some definite time after a signal is given, such units as transmitters, fence controllers, electronic welders, light blinkers, stapling machines, and almost all types of electronic oscillators. Electronic control plays an increasingly important role in our every day life. An electronic control circuit can replace the mechanical delay relay usually at a much lower cost and can be controlled accurately over a wide range.

An electronic trigger circuit is a control circuit whose output is used to start an action in another circuit or device. The resultant action continues for a time under its own control and then it stops of its own accord.

In an electronic trigger circuit, a cold cathode glow tube usually serves the purpose of an electronic switch. Electronic action may be delayed from a small fraction of a second to many minutes by simple RC circuits.

### B. Cold Cathode Tubes

The tube symbols shown in Fig. 1 illustrate cold cathode types of tubes. Gas filled tubes such as $V_1$ and $V_2$, in the circuit of Fig. 5 do not depend upon thermionic emission, but do depend upon a great enough difference of potential between the plate and cathode to start ionization and maintain an electron flow between these two electrodes. This type of tube is called a "cold cathode glow tube".

Glow tubes contain a gas of either argon, helium, neon or xenon. The purpose of injecting a gas within the tube envelope is to obtain greater rates of electron flow. Symbols for tubes containing gas have a dot placed within the circle to distinguish these tubes from high vacuum tubes.

Electron emission is possible from a cold cathode tube due to two principal factors.

a. Ionization of the gas injected within the tube.
b. The high potential gradient existing near the surface of the cathode.

C. Ionization

The atoms of gas within the tube envelope contain quantities of positive and negative electricity in the form of a positive nucleus and negative electrons.

In any such gas filled tube envelope some of the gas atoms are unstable and have lost one or more electrons. These electrons are floating in the space within the tube envelope and are called "free electrons".

When a positive potential is applied to the plate of this type of tube these few free electrons will be attracted toward the positive plate at a high velocity.

The electrons will then collide with neutral gas atoms with sufficient force to dislodge one or more electrons off the atom. These additional electrons will collide with more neutral gas atoms. The atom is then called a "positive ion" or just "ion" because it has lost some of its negative electrons.

Fig. 2A illustrates how one electron is about to collide with a neutral gas atom. In Fig. 2B one electron has been knocked off the atom and the two electrons proceed toward the positive plate. In Fig. 2C the positive ion may be attracted toward the mass of negative electrons which may form near the cathode if the positive potential is not great enough to attract all the electrons toward the plate. In Fig. 2D the positive ion recombines with enough negative electrons to again make the ion a neutral gas atom. Thus the quantity of negative electrons not attracted toward the plate are absorbed by the positive ions.

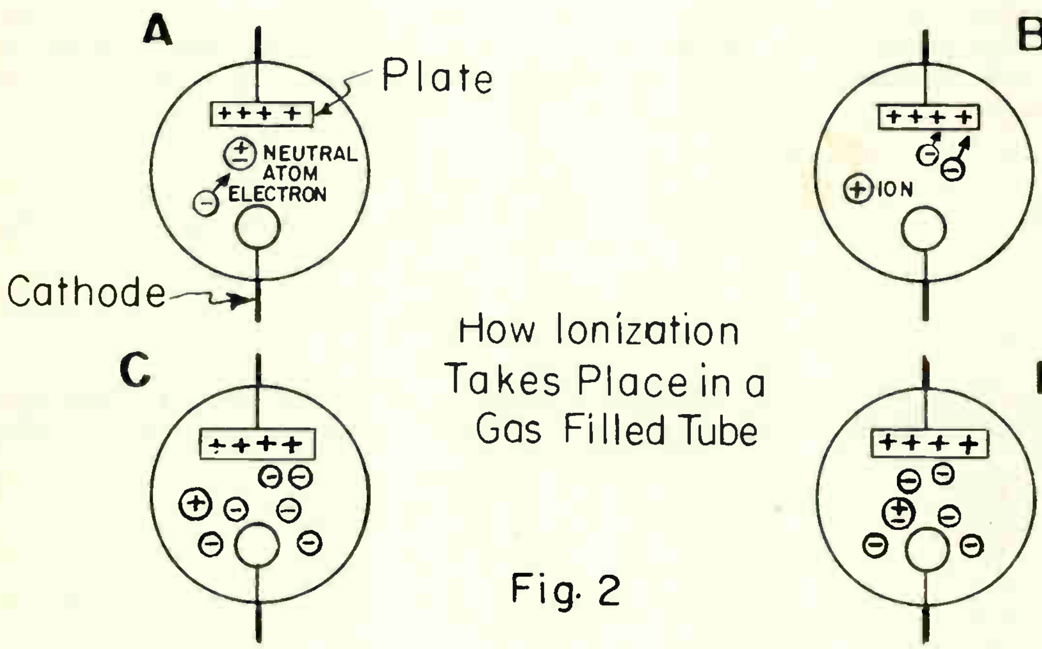
The previous retarding effect of electrons hovering near the cathode, now all but completely removed, will cause a high potential gradient to exist near the surface of the cold cathode.

D. Potential Gradient

Figs. 3A and 3B illustrate the second principal reason why electron emission is possible from a cold cathode in a gas filled tube while such emission would be difficult to produce in a vacuum tube. Both graphs represent a tube in which the plate is 0.20 inch from the cathode and in which there is a potential difference of 100 volts between plate and cathode.

With the vacuum type of tube there is a nearly uniform drop of potential from plate to cathode. Referring to Fig. 3A, the chart illustrates that half way between the plate and cathode the potential has fallen to a little less than 40 volts. This "potential gradient" or "slope" is about the same all the way from plate to cathode.


Fig. 1




How Ionization Takes Place in a Gas Filled Tube

Fig. 2

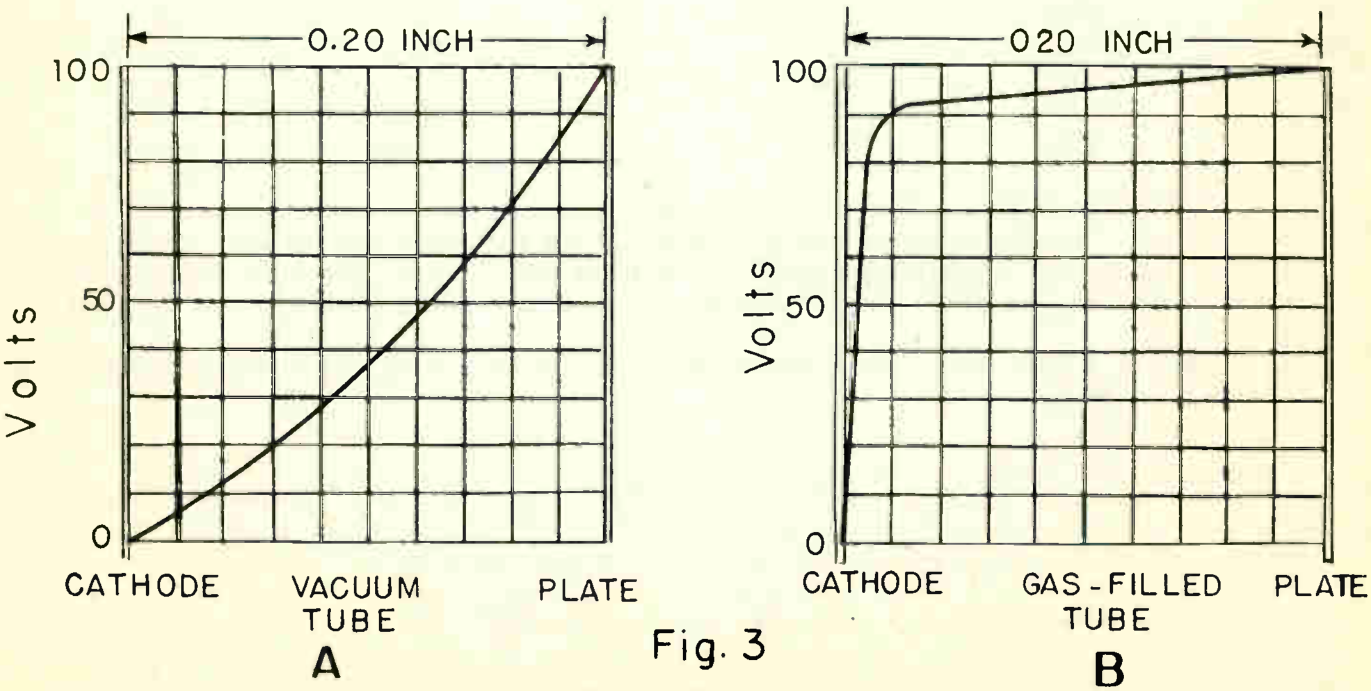



Fig. 3

In the gas filled tube there is but a little drop of potential until the surface of the cathode is reached. Referring to Fig. 3B note at 0.02 inch from the cathode in a gas filled tube a potential gradient of 90 volts exists. In the last 0.01 inch an exceedingly greater drop of potential exists per unit of distance. The result is that in the cold cathode gas filled tube the very high potential close to the cathode surface, after ionization occurs, actually pulls electrons out of the cold cathode. Most cathodes in a glow tube are coated with a material which has the property of giving off electrons with comparative ease.

In a cold cathode glow tube there is a luminous glow over part or all of the cathode surface. Hence this type of tube is called a "glow tube". If the electron flow through the tube is allowed to exceed a certain value, the ion bombardment of the cathode surface becomes so severe as to form a bright spot on the cathode surface.

This bombardment will raise the temperature of this spot to a point at which thermionic emission occurs. The heating due to this arc discharge materially shortens the life of the cathode in comparison with operation only with a glow discharge.

E. Glow Tube Characteristics

| TUBE TYPE | MIN. DC PLATE SUPPLY VOLTAGE | DC OPERATING CURRENT MAX. (Ma.) | MIN. | DC STARTING VOLTAGE | DC OPERATING VOLTAGE DROP |
|---|---|---|---|---|---|
| VR-75 | 105 | 40 | 5 | 100 | 75 |
| VR-90 | 125 | 30 | 10 | 110 | 90 |
| VR-105 | 133 | 40 | 5 | 115 | 105 |
| VR-150 | 185 | 40 | 5 | 160 | 150 |
| GL-874 | 125 | 50 | 10 | 125 | 90 |
| BA | 350 | 350 | -- | --- | -- |
| BH | 350 | 125 | -- | --- | 90 |
| BR | 350 | 50 | -- | --- | -- |
| 1003/0Z4A | 310 | 110 | -- | --- | -- |
| 0Z4 | 300 | 75 | 30 | 300 | 25 |
| 0Z3 | 350 | 85 | -- | --- | -- |

Most VR type glow tubes are provided with a jumper wire connected internally. This wire is usually employed as a switch and is wired in series with the primary of the transformer supplying power to the glow tube. When the tube is removed from the socket the power supply circuit is automatically shut off.

Fig. 4 shows a full wave rectifier circuit in which a cold cathode rectifier glow tube may be used.

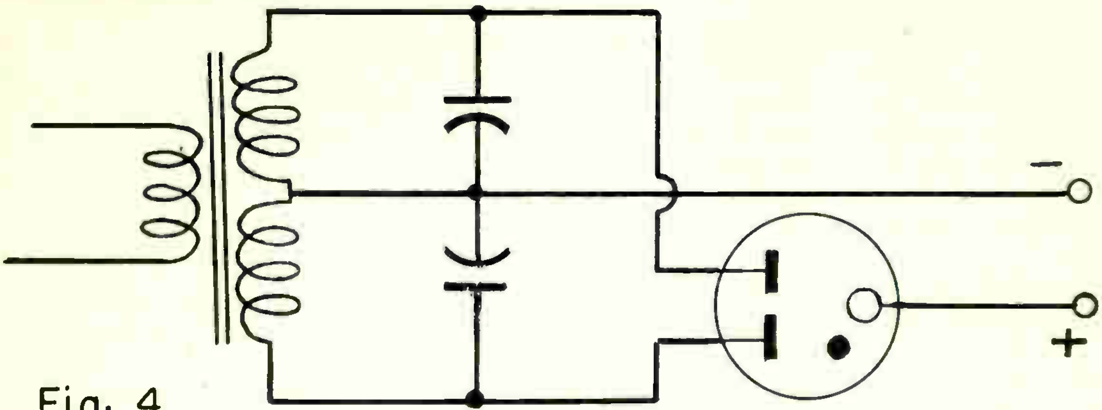



Fig. 4

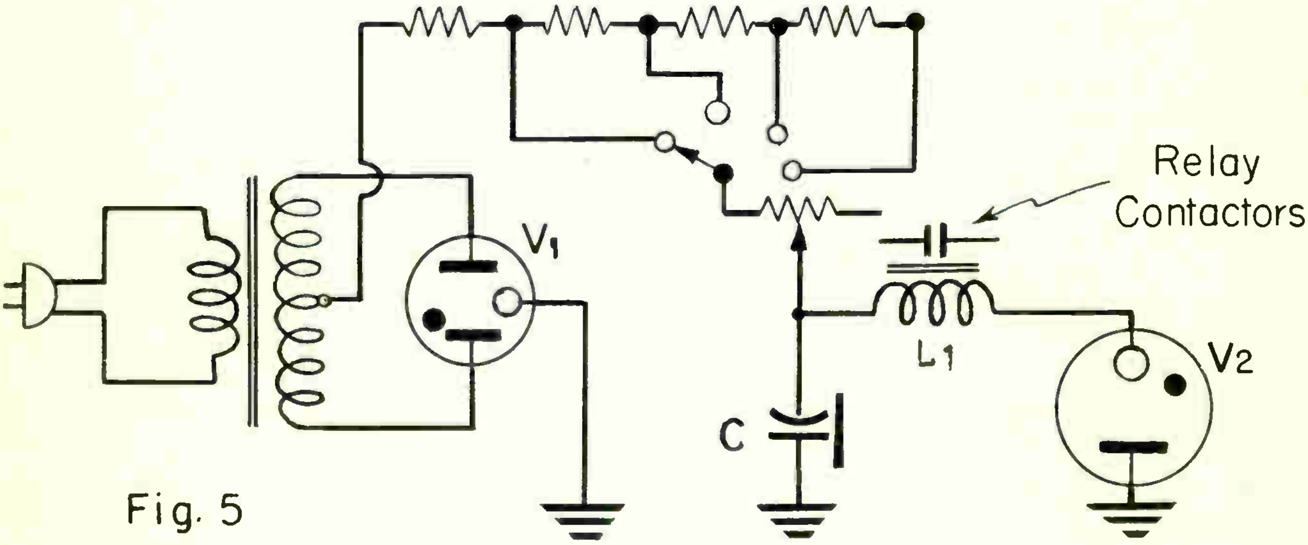



Fig. 5

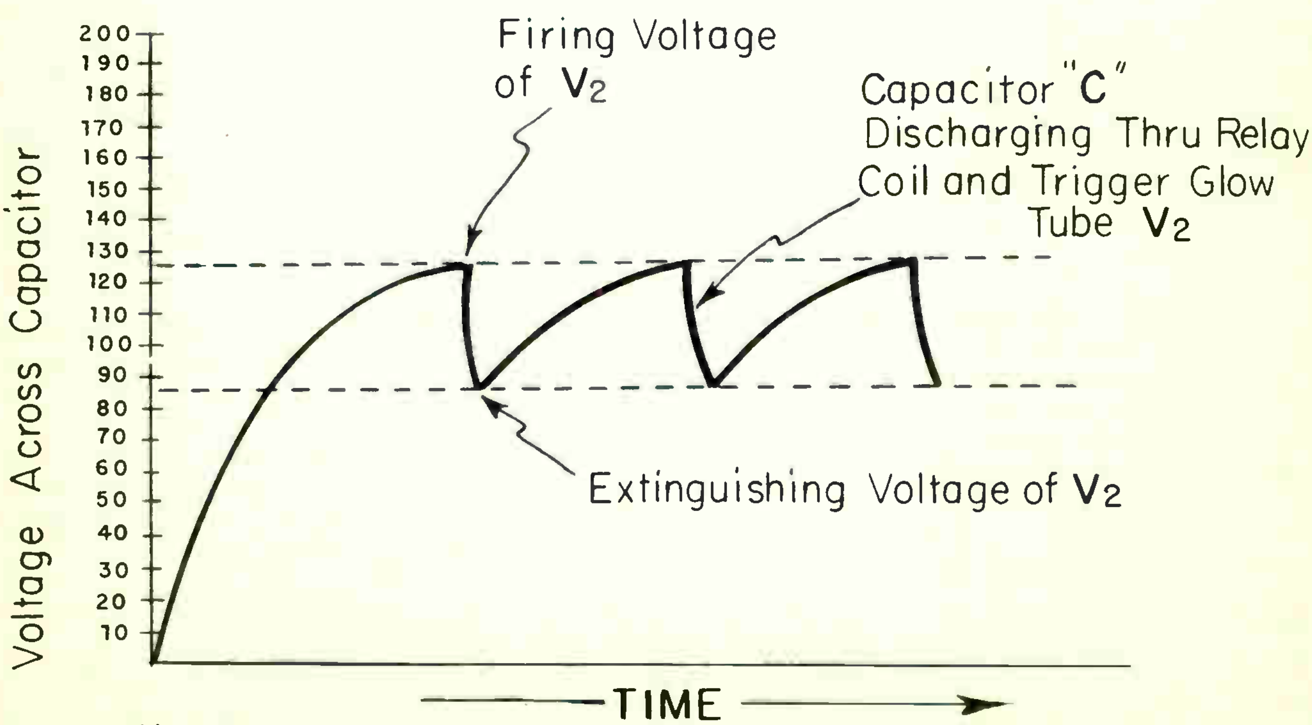



Fig. 6

F. Trigger Circuit Analysis and Application

Fig. 5 illustrates a basic trigger type time delay circuit. This circuit is useful in industrial applications where it is desirable to obtain operation of a circuit with an impulse of short duration.

The basic circuit operation is as follows:

1. A cold cathode gas rectifier tube V1 is used in a full wave rectifier circuit to produce a pulsating direct electron flow to charge capacitor C.

2. When the voltage across capacitor C builds up to the starting voltage of the gas tube V2 it will begin to conduct, since the capacitor voltage is applied across V2. The discharge current of the capacitor along with the rectifier electron flow will pass through the relay and V2 almost instantaneously. The relay will then be energized.

3. When the voltage across the capacitor drops to the extinguishing voltage of V2 the tube will cease to conduct almost instantaneously, thus preventing electron flow through the relay coil. This will cause capacitor C to again begin to charge, thereby repeating the cycle.

4. The length of the time delay will depend upon how rapidly capacitor "C" will reach the starting voltage of V2. When more resistance is added in series with capacitor C, the capacitor will charge at a slower rate since the electron flow will be reduced. Therefore, by changing the amount of resistance in series with the capacitor, it is possible to change the length of the time interval between successive relay actions. Fig. 6 illustrates the voltage wave pattern existing across capacitor C.

Fig. 7 illustrates the schematic diagram of an electric fence controller. Practically all fence control circuits involve the basic principles of a trigger time delay circuit.

In this circuit a rectified voltage obtained by V1 is applied to capacitor C through the series resistor R. The time rate at which C charges is determined by resistor R. When capacitor "C" builds up a charge equal to the breakdown potential of V2, it will discharge through the primary of transformer, T2, by the path of V2. The surge of electrons through this primary winding builds up a relatively high secondary voltage which is in turn applied to the fence. V3 is a neon indicator lamp, used for the purpose of indicating visually whether the circuit is in operation.

The rate of discharge of capacitor C varies inversely with the value of resistor R The greater the value of R will cause capacitor C to discharge through V2 and the primary of T1 less frequently per minute. Precautions must be taken according to the Underwriters Laboratories as to the "OFF PERIOD". Successive shock impulses should not be less than 0.90 seconds. Since the value of resistor "R" determines the number of shock impulses the circuit will deliver, precautions should be taken so that its value is not too small. Generally a 2 megohm resistor used in the circuit of Fig. 7 will produce approximately 30 shock impulses per minute which is equivalent to an "OFF PERIOD" of 2 seconds.

The practical operating principle of the electric fence is to keep cattle in a confined area. The psychological effect on the animal after receiving several

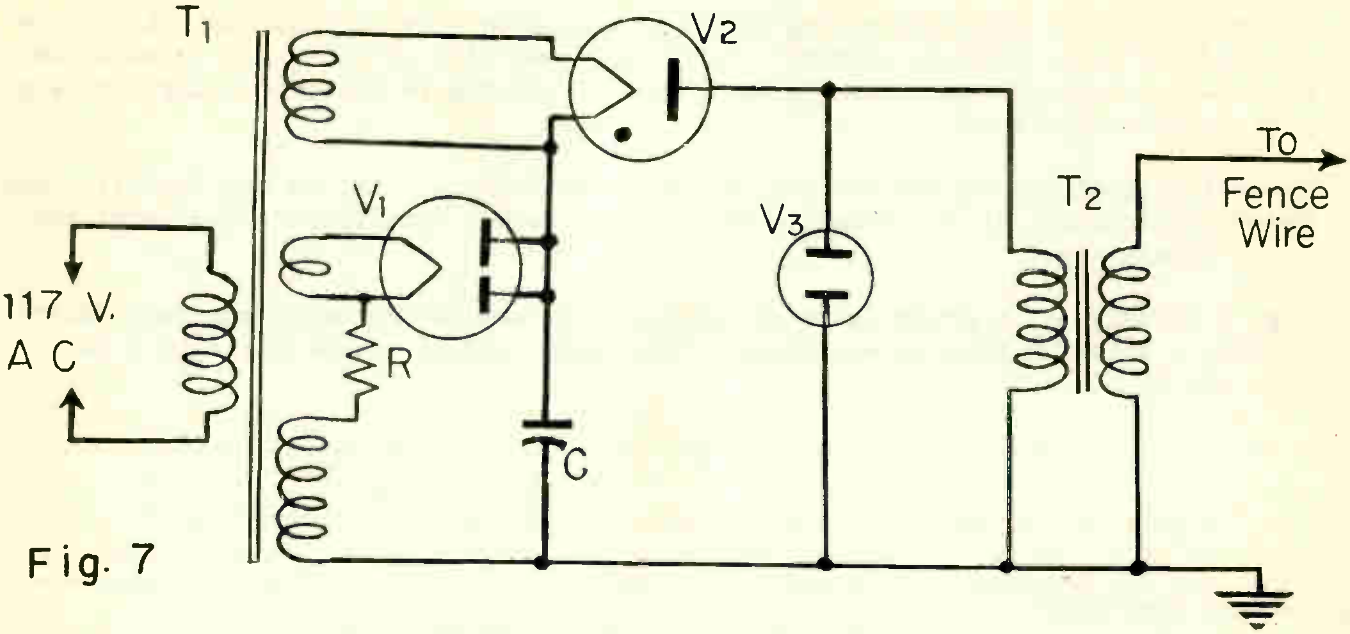

T1
V2
V1
117 V.
A C
R
C
V3
T2
To
Fence
Wire

Fig. 7

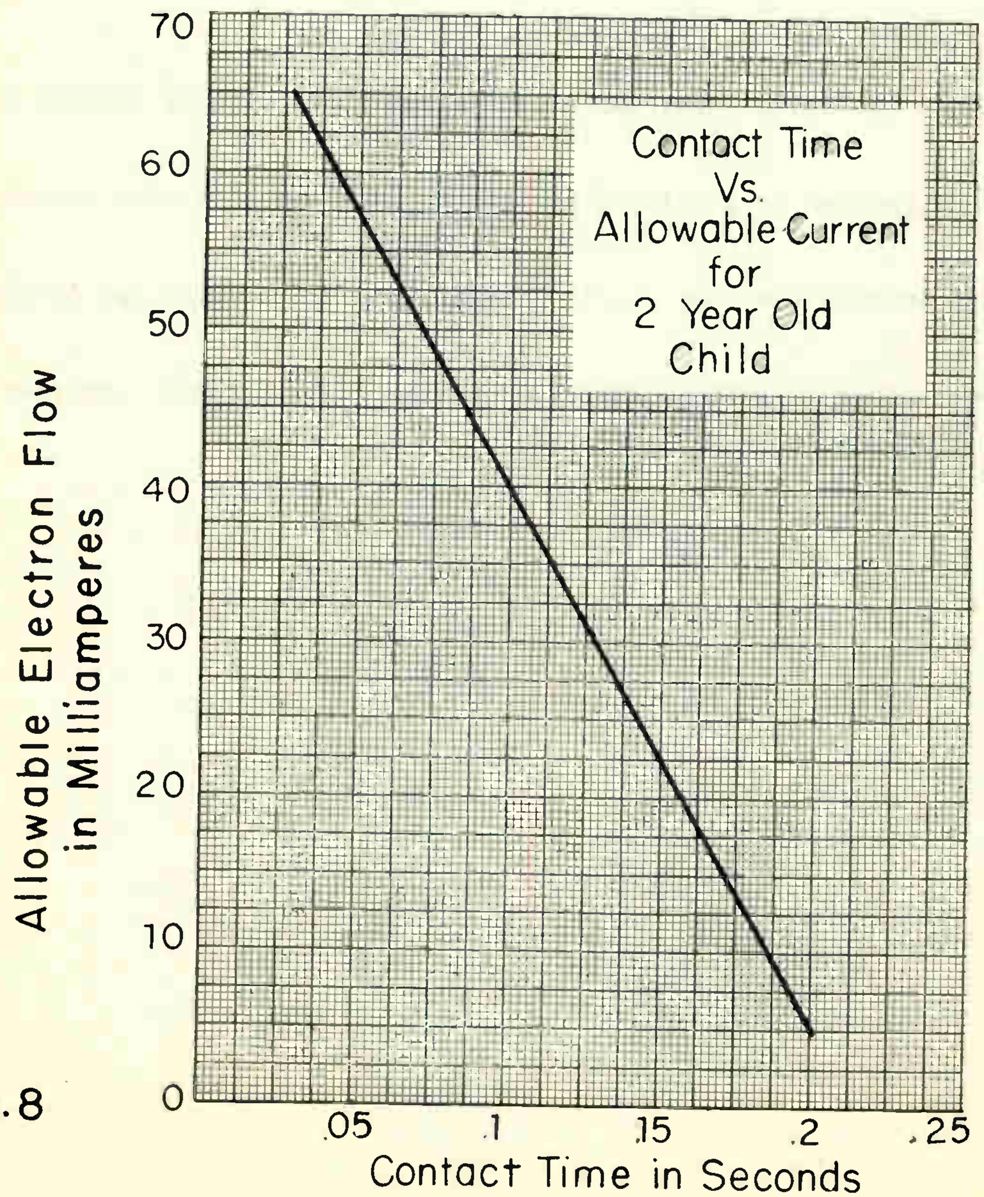

Contact Time
Vs.
Allowable Current
for
2 Year Old
Child
Allowable Electron Flow
in Milliamperes
70
60
50
40
30
20
10
0
.05
.1
.15
.2
.25
Contact Time in Seconds

Fig. 8

electrical shocks when attempting to cross the fence wire is such that it will be inclined to avoid further contact. Since only one wire is necessary to make the fence, the electric fence has the advantage of being more economical and portable than an ordinary fence.

Several communities forbid the use of fence controllers. Before any installations are actually made, it is advisable to investigate and carefully follow local and state regulations.

Fig. 8 illustrates a graph in which the Underwriters Laboratories consider their allowable electron flow versus contact time relationship on the basis of a two year old child.

G. Summary Questions

1. What is a "glow tube"? On what principle does it operate?

2. What causes a small "potential gradient" to exist near the cathode surface of a vacuum tube?

3. For what reason or reasons is gas injected into an envelope of a cold cathode tube?

4. Electron emission is possible from a cold cathode tube due to what two principal factors?

5. Name several uses, other than those listed, for electronic trigger circuits?

# PLIOTRONS

## Objective

To become familiar with the fundamental theory of pliotrons and their applications

## References

## Lesson Content

### A. General

A pliotron tube is a high vacuum type thermionic tube in which there are one or more control electrodes or grids.

The one or more grids in a pliotron tube makes possible for it to:

1. Control electron flow
2. Amplify
3. Change frequencies.

Fig. 1 illustrates the various schematic symbols of pliotron tubes which have different construction and characteristics.

The triode pliotron is practically a simple two element kenotron with a third element, the grid, added to it. The grid consists of fine parallel wires supported on two sides by insulated supports. The grid is usually placed closer to the emitting element than to the plate and therefore has an important controlling effect on the output of the tube, Fig. 2.

### B. Fields Around an Electron

It is well to remember that every electron is a negatively charged unit which produces an elementary electrostatic field. This electrostatic field is represented as radial spokes around the electron. As the electron drifts from one atom to another in a conductor or travels through space in a vacuum tube this electrostatic field will always move as a unit with its associated charge, Fig. 3. An electromagnetic field exists when the electron is in motion.

## C. Grid Potential

In a previous lesson it was illustrated how a steady direct electron flow was obtained through the plate circuit of a kenotron tube as soon as the heater circuit caused the cathode to emit electrons. This electron flow was in one direction only. Fig. 4 illustrates a circuit wherein a B battery is connected with a relay coil and with the plate of a kenotron tube in a manner so that a positive potential is on the plate at all times. This constant positive potential upon the plate will cause the electron flow to have only a certain predetermined value. The only means of de-energizing the relay would be by opening the switch.

Before studying what control the grid element will have upon the electron flow through a tube, it is well to review a few fundamental principles.

Fig. 5A illustrates the schematic symbol of a battery. Whether points "B" and A are connected or disconnected, this battery potential will exist due to chemical reaction taking place within the battery itself. In Fig. 5B, a resistor, R. is connected to the negative side of the battery. The potential across points A and C would be the same as across points A and B. There is no complete path for the electrons to flow from point B to point A because of an open circuit.

In Fig. 5C the grid element of a pliotron tube is connected to point C and the cathode to point A of the basic circuit shown in Fig. 5B. The negative potential at point C is still the same as at point B If the difference of potential of the battery were three volts, the grid, point C, would be negative three volts, -3V, with reference to the cathode, point A This negative potential upon the grid will cause electrostatic lines of force to exist around the grid mesh wires within the tube. These electrostatic lines of force should not be confused with the "electromagnetic lines of force, which travel through the iron core of a magnet or through the air core of a solenoid. Electrostatic lines of force are different in that they avoid the interior of the conductor being charged. In the vacuum tube the charge is distributed exclusively over the surface of the grid mesh wires.

## D. Grid Construction

The grid is generally wound in a spiral form upon two insulator supports within the tube. The effect the grid has upon controlling the electron flow from cathode to plate is determined by:

a. The spacing of the grid mesh wires within the tube.

b. The distance existing between the grid and cathode elements within the tube.

c. The negative potential applied to the grid externally.

d. The positive potential applied to the plate of the tube externally.

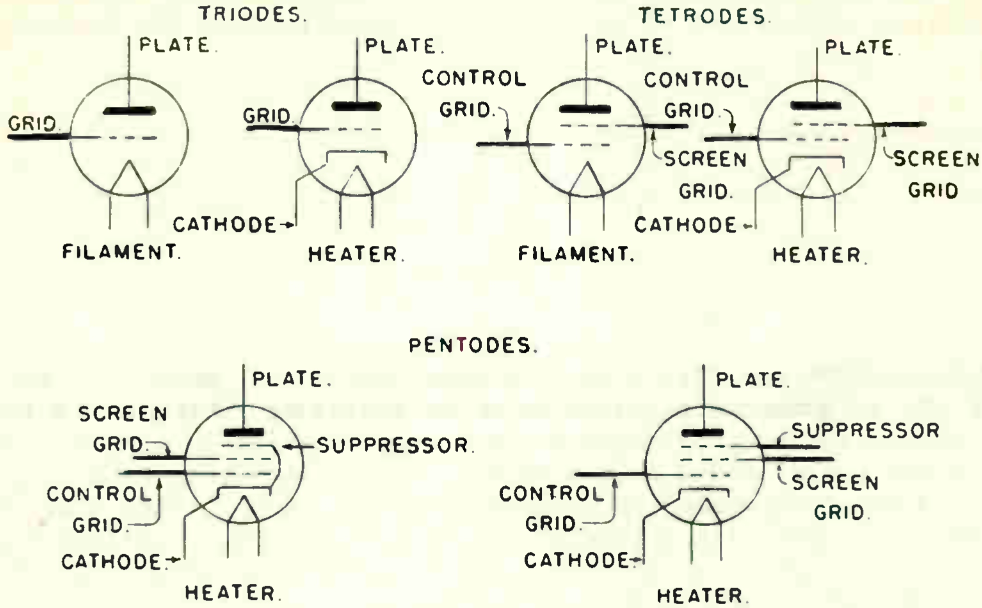



Fig. 1

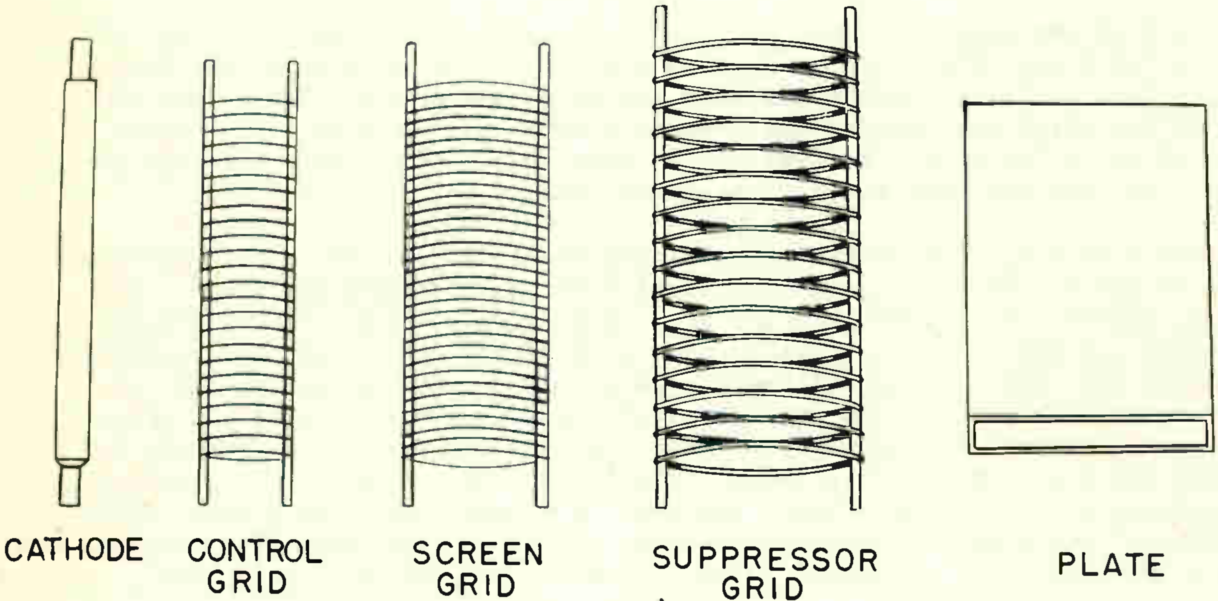



Fig. 2

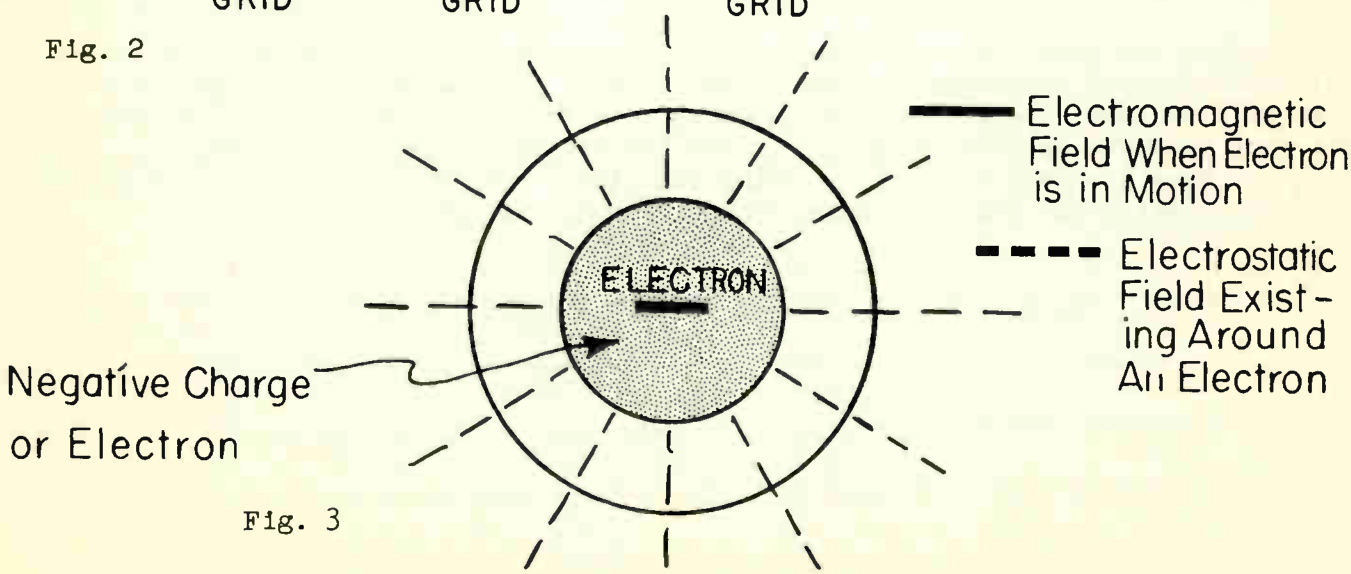



Fig. 3

The first two factors are determined by the tube manufacturer. The third and fourth factors are determined by the technician constructing the electronic equipment.

E. Grid Control of Electron Flow.

By imposing a negative electric potential upon the grid of a vacuum tube, the free electrons of the grid mesh wires will be moved partially from their original orbit in the same manner as in the dielectric of a capacitor being charged. The resultant electrostatic field of two free electrons moving partially from their orbit will cause a force of repulsion from one another laterally. This will cause the free electrons with their electrostatic fields to move outwardly toward the surface of the grid mesh wire and produce a similar repelling effect upon an electron traveling through space towards the grid. Fig. 6.

The strength of the electrostatic field is determined by the number of unit charges within a given area. Fig. 7 shows a cross sectional view of a grid and the electrostatic lines of force existing between the grid mesh wires. The closer the spacing of the wires the greater the repulsion upon the electron. The larger the charge applied to the grid, the greater the repulsion. The closer the grid is mounted to the cathode, the greater the repulsion.

The grid of a tube is mounted between the cathode and the plate. The electrons will try to proceed on their normal straight line paths toward the plate. The electrons, however, will come into the zone of influence of the electrostatic fields which are built upon and around each wire of the grid conductor element. These fields are negative and will repel the electrons emitted by the cathode. Some electrons will get through the spiral of the grid and arrive at the plate of the tube. However, as the electrostatic field on the grid is increased, by increasing the negative potential upon the grid with reference to the cathode, more electrons will be repelled and less electrons will reach the plate. Hence, there will be less electron flow from cathode to plate. The negative potential applied to the grid with reference to the cathode is called the "grid bias".

By varying the negative bias upon the grid, the negative electrostatic fields are either decreased or increased, and either more or less electrons will get through the grid to reach the plate. The electrostatic field on a grid can be increased to such strength as to completely cut off the electron flow from cathode to plate. A means then has been obtained by which the pliotron tube acts as an electronic switch or valve and can turn the electron flow on and off.

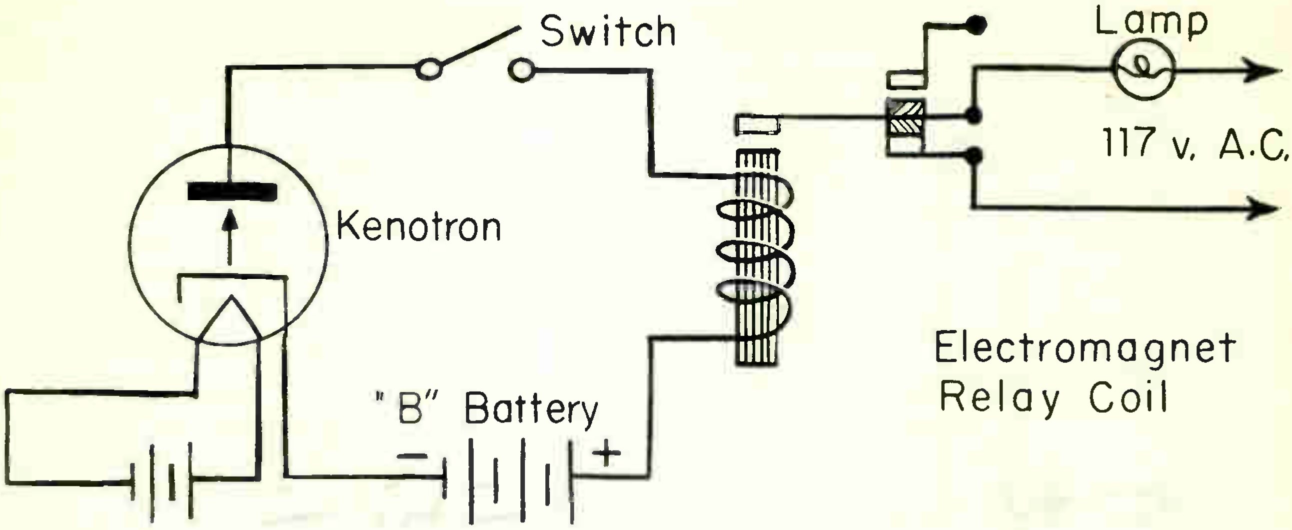



Fig. 4

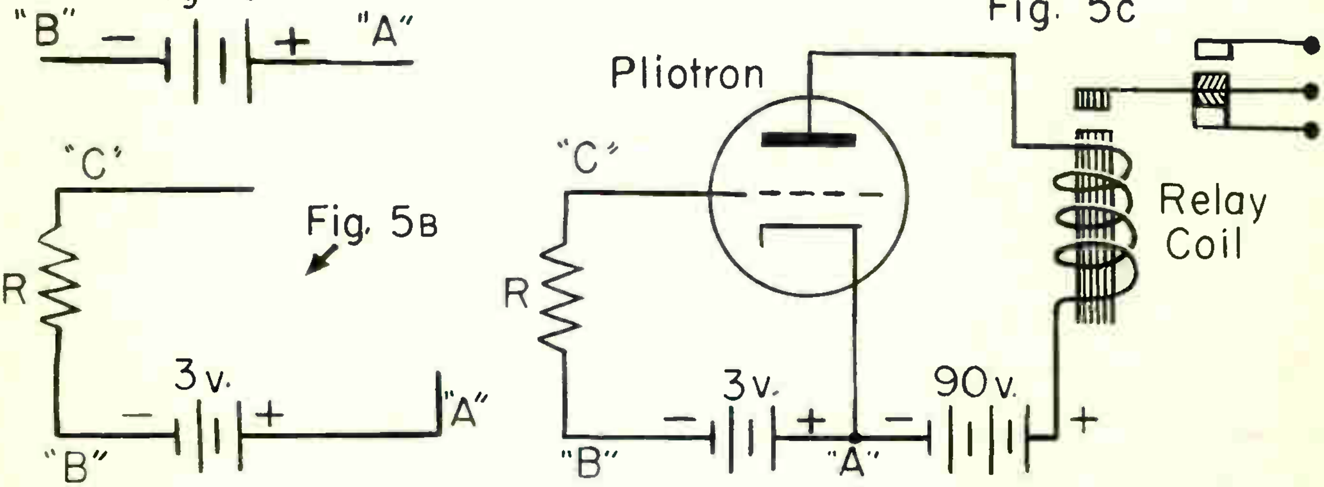



Fig. 5A

Fig. 5B

Fig. 5C

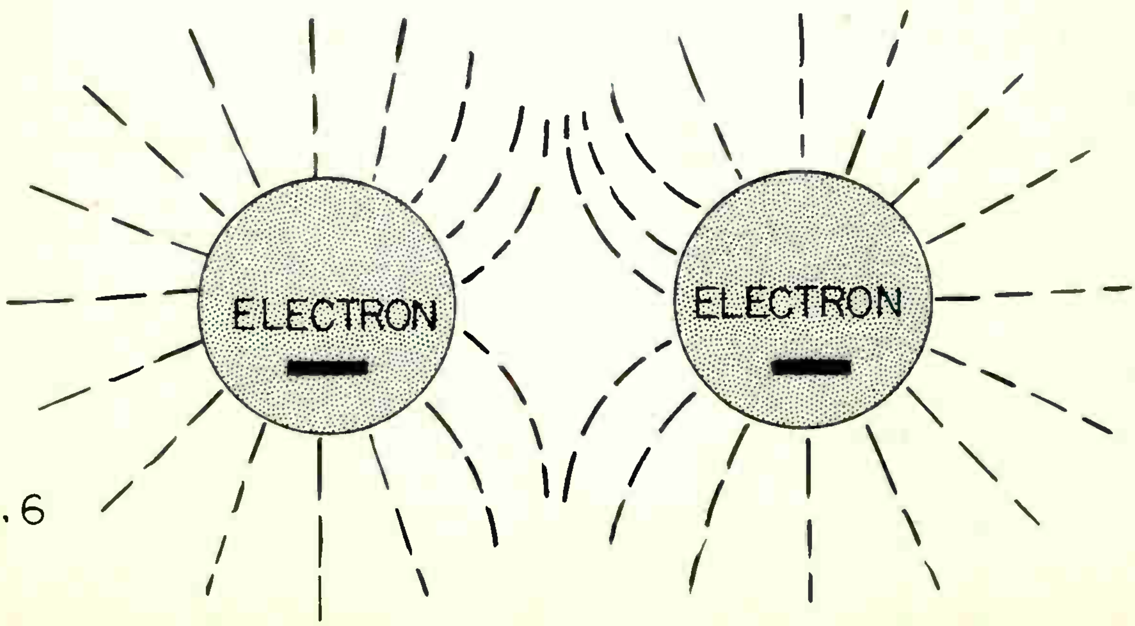



Fig. 6

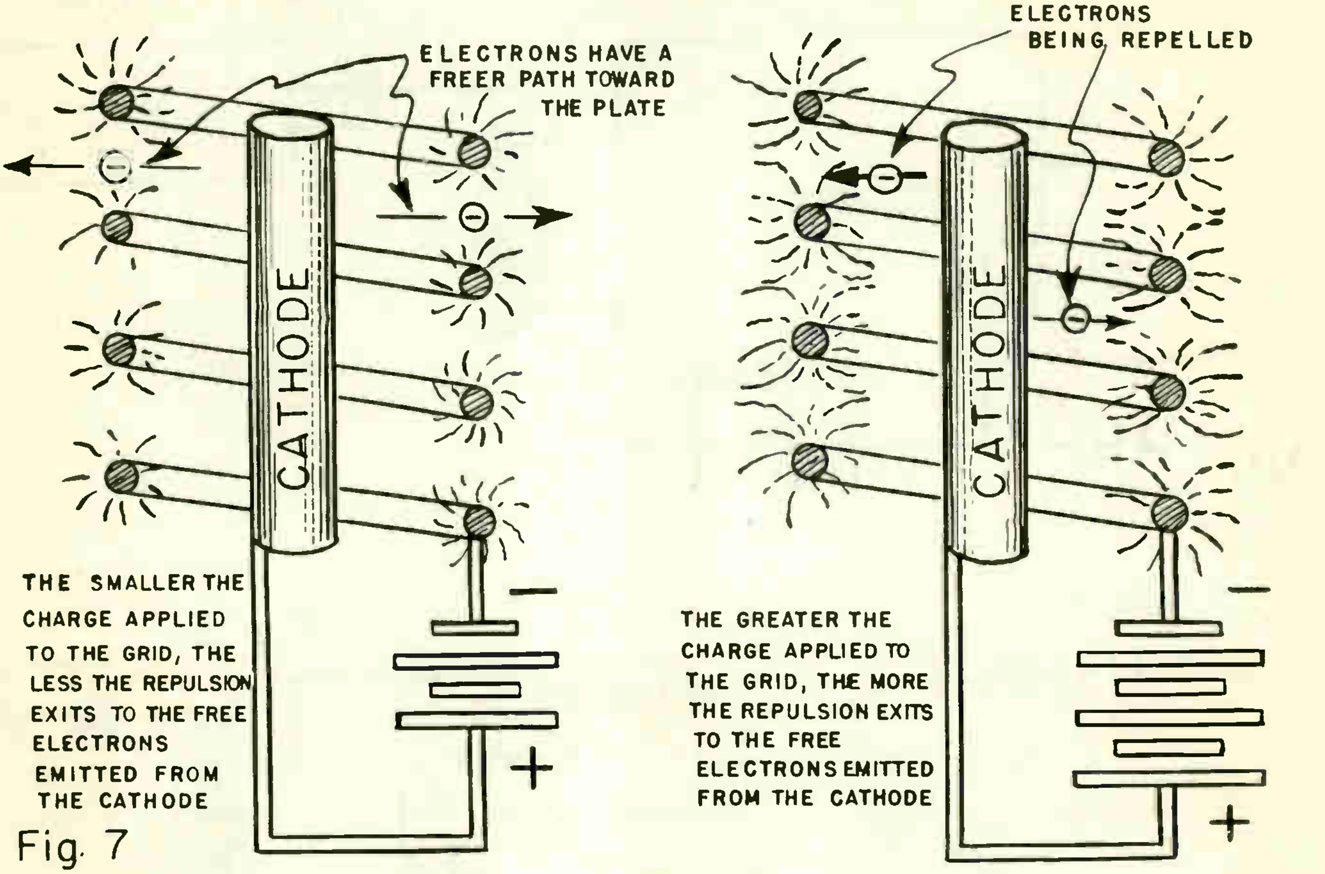
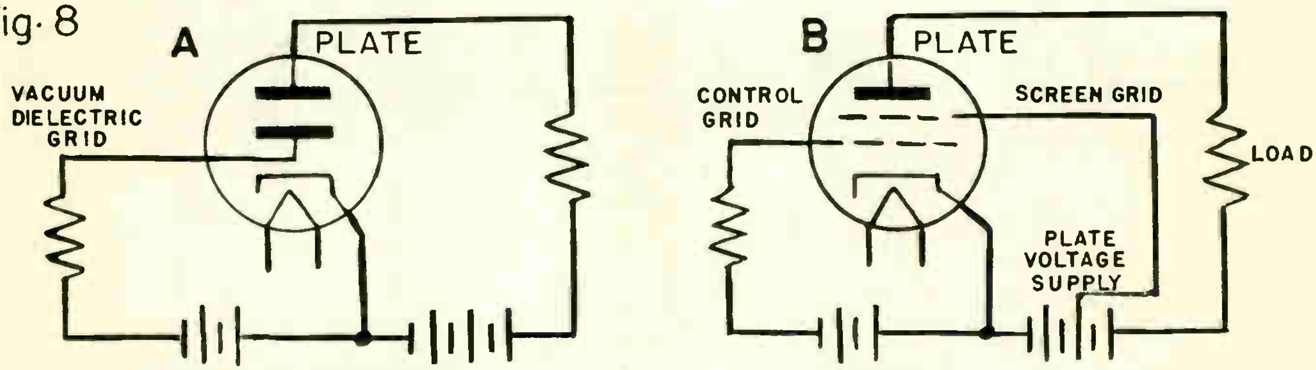



Fig. 7

Fig. 8



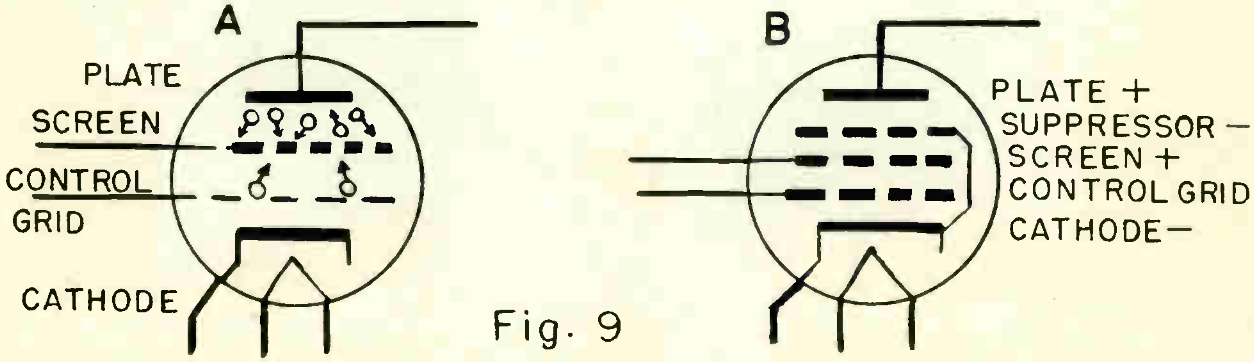




Fig. 9

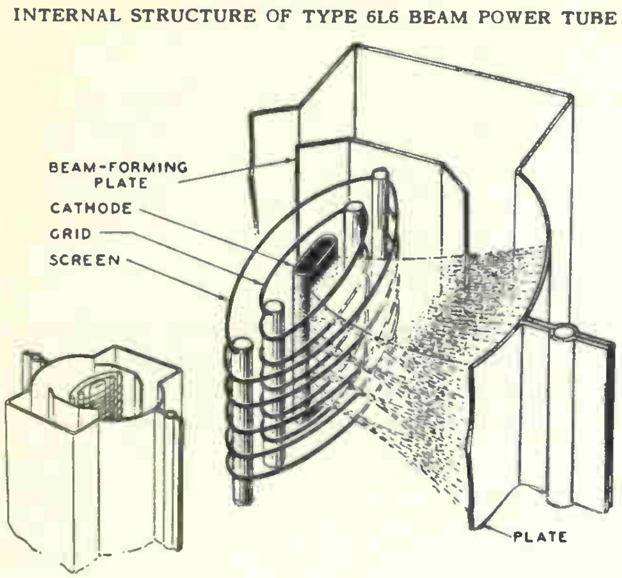



Fig. 10

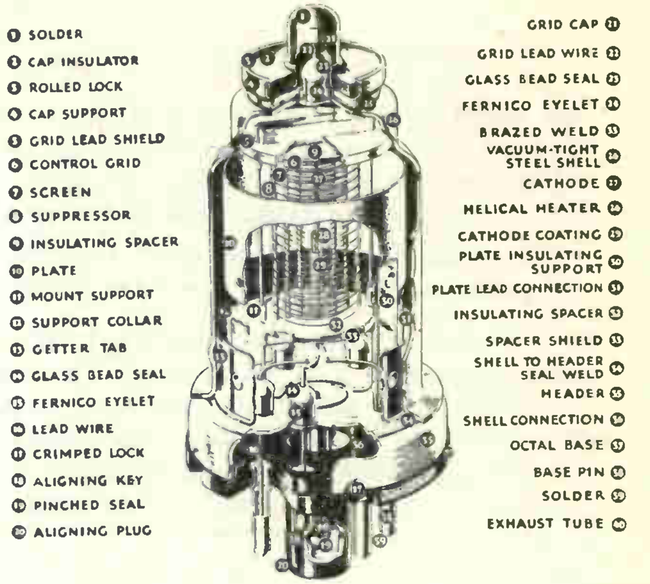



Fig. 11

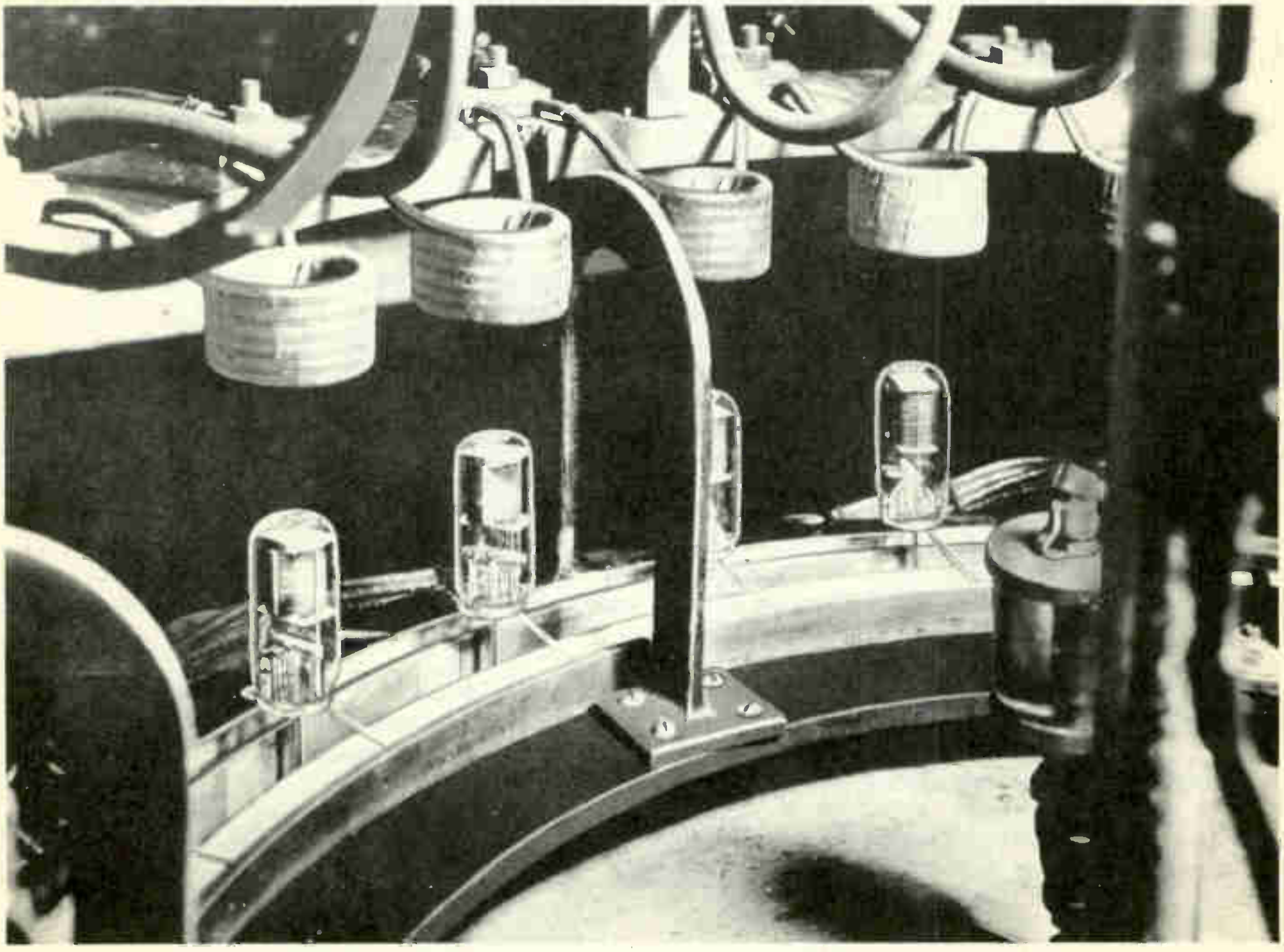


Fig. 12 Use of High Frequency to Minimize Gasses in Tube Envelopes.

F. Inter-electrode Capacity

The space between the grid, plate, and cathode of a triode pliotron serves as a dielectric and each electrode acts as one plate of a small capacitor. These capacitances are known as inter-electrode capacitances and exist between grid and plate grid and cathode, and plate and cathode. The grid-plate capacitance produces undesireable coupling between the external input grid circuit and the external output plate circuit when the tube is used as an amplifier, Fig. 8.

The tetrode pliotron is designed to reduce the errect of the grid-plate inter-electrode capacity. An additional electrode, called the screen grid, is mounted between the grid and plate and acts as an electrostatic shield thus reducing the grid-to-plate capacitance. The addition of this extra electrode is desirable also in that it makes the plate electron flow practically independent of plate voltage due to the fact that the screen is operated at a positive potential with reference to the cathode and therefore attracts electrons from the cathode. These electrons pass through the mesh wire of which the screen grid is constructed and are attracted to the plate. Hence, the screen grid supplies an electrostatic force which attracts electrons emitted from the cathode to the plate. It is this electrical property which makes it possible to obtain much higher amplification with a tetrode pliotron than a triode pliotron.

G. Secondary Emission

In all pliotron tubes, electrons striking the plate may dislodge other electrons from the plate electrode. Emission caused by bombardment of the plate by electrons emitted from the cathode is called "secondary emission". Fig. 9.

In screen grid tubes the positive potential on the screen grid offers a strong attraction to these secondary electrons. Because this effect lowers the plate electron flow, a fifth electrode was placed within the tube between the screen and the plate. This fifth electrode is known as the "suppressor grid". The suppressor grid is operated at a negative potential with respect to the plate and retards the secondary electrons and diverts them back to the plate. This type of pliotron is referred to as a "pentode" meaning five electrodes. The suppressor grid makes possible higher power output and higher voltage at moderate values of plate voltage.

Another type of tetrode or pentode is a beam power tube. A beam power tube employs beam forming plates at a cathode potential to prevent stray electrons from the plate from returning to the screen. Fig. 10 illustrates the structure of a beam power tube employing space charge suppression.

Fig. 11 illustrates a cut-away view of a typical metal pliotron pentode used in various trigger and time control circuits.


Fig. 13


Fig. 14

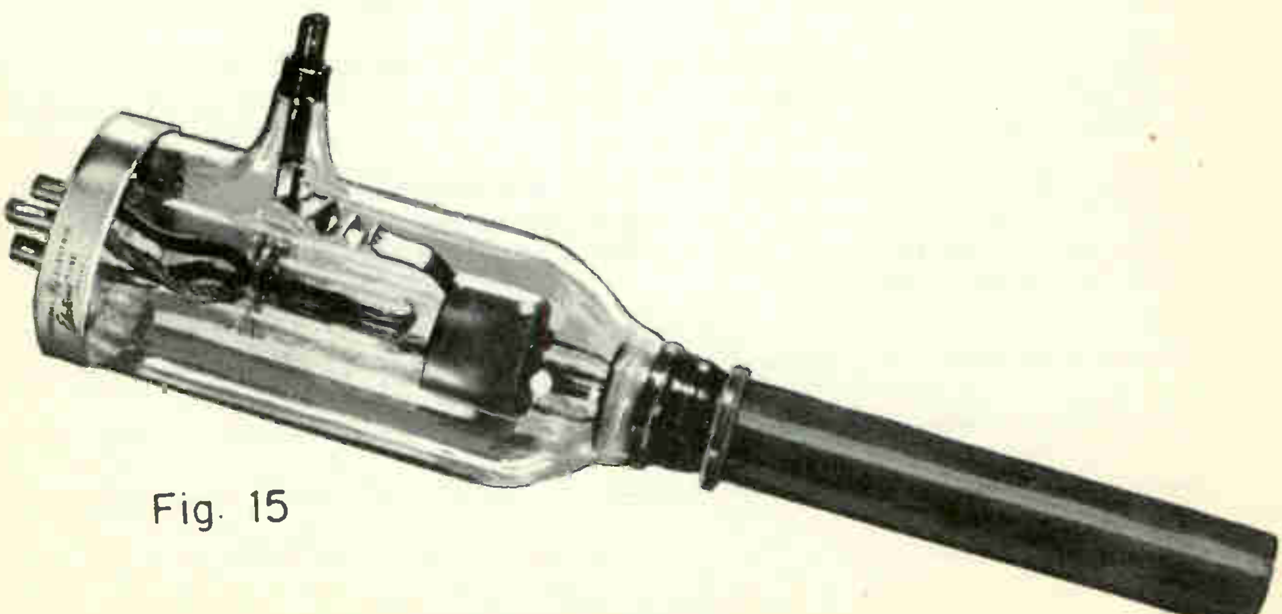


Fig. 15

H. Tube Construction

After the tube envelope is sealed to the glass support of the tube elements it is necessary that the space within the tube envelope be void of all traces of gas. (Air is considered a gas, also.) Fig. 12 illustrates the process of pumping the air out of the tube enclosure. The electrodes of the tube are heated by surrounding the tube with an induction heater coil through which there is a high frequency electron flow. The high frequency magnetic field of the coil induces voltages in the electrodes within the tube, thereby causing eddy currents that heat the metal. The heat drives the gasses out of the metal electrodes.

Any remaining traces of gas within the tube are eliminated by means of a "getter". Magnesium and Batalum, commonly known metals, are used as "getters". The getter is mounted inside the tube and is discharged by the high frequency coil. This high frequency explodes the getter and seals the remaining traces of gas tightly against the side of the glass or metal envelope which causes the silvery coating on the inside of the tube envelope.

I. Three General Classes of Pliotrons

1. Radiation-cooled pliotrons, usually of the glass envelope type.

2. Forced air-cooled pliotrons, which usually have a radiator to aid in dissipating heat. Such tubes are cooled by an air flow directed against the radiator.

3. Water-cooled pliotrons, in which the plate is cooled directly by a flow of water.

   Fig. 13 illustrates a PJ-7 radiation-cooled pliotron. Fig. 14 illustrates forced air-cooled pliotron, GL8002-R (note the fins around the plate which help dissipate the heat.) Fig. 15 illustrates a water-cooled pliotron, GL-892.

Pliotron tubes are used extensively in induction heating and diathermy circuits. Fig. 16 illustrates the typical application of a pliotron tube in an inductotherm unit with surgical attachment.

Pliotrons are useful in most applications requiring the generation or amplification of audio or high frequency voltages. Pliotrons are also used for many applications which require accurate measurement of small signal voltages and amplification for control purposes.

J. Pliotron Characteristics

| TYPE | NO. OF ELECTRODES | FILAMENT VOLTS | FILAMENT AMPS. | DC PLATE VOLTAGE | CURRENT | DC GRID VOLTAGE |
|---|---|---|---|---|---|---|
| PJ-7 | 3 | 4.5 | 1.1 | 350 | 2.8 Ma. | -6 |
| PJ-8 | 3 | 4.5 | 1.1 | 350 | 9.0 " | -30 |
| PJ-21 | 3 | 4.5 | 1.1 | 350 | 19.5 " | -83 |
| GL-207 | 3 | 22.0 | 51.0 | 12500 | 400.0 " | -575 |
| FP-265 | 3 | 10.0 | 5.2 | 1500 | 200.0 " | -400 |
| FP-285 | 3 | 10.0 | 3.25 | 1250 | 200.0 " | -200 |
| GL-592 | 3 | 10.5 | 5.3 | 3000 | 50.0 " | -500 |
| GL-807 | 5 | 6.3 | 0.9 | 750 | 60.0 " | - 35 |
| GL-810 | 3 | 10.0 | 4.5 | 2250 | 70.0 " | - 60 |
| GL833-A | 3 | 10.0 | 10.0 | 4000 | 150.0" " | -120 |
| GL-862-A | 3 | 33.0 | 207.0 | 20000 | 5 Amps. | -3000 |
| GL-880 | 3 | 12.6 | 320.0 | 10000 | 3 " | -1200 |
| GL-889R-A | 3 | 11.0 | 125.0 | 7500 | .9 " | - 300 |
| GL-891 | 3 | 11.0 | 60.0 | 12500 | .4 " | -1450 |
| GL-891-R | 3 | 11.0 | 60.0 | 10000 | 2.0 " | -3000 |
| GL-892-R | 3 | 11.0 | 60.0 | 12500 | 2. " | -3000 |
| GL-893-A | 3 | 10.0 | 61.0 | 20000 | 4. " | -3000 |
| GL-895 | 3 | 19.0 | 138.0 | 17000 | 9. " | -3000 |
| GL-8002 | 3 | 16.0 | 38.0 | 3500 | 1. " | - 500 |

K. Summary Questions

1. Explain briefly how the control grid has an effect upon the plate electron flow in a pliotron.

2. Do the electrons have to be in motion in order to produce an electrostatic field? Why?

3. What causes the space charge between grid and cathode of a pliotron tube?

4. What element was mounted between grid and plate to reduce the grid plate interelectrode capacity?

5. What purpose do the "beam power plates" serve in a beam power tube?

6. What causes the silvery coating on the inside of a tube envelope?

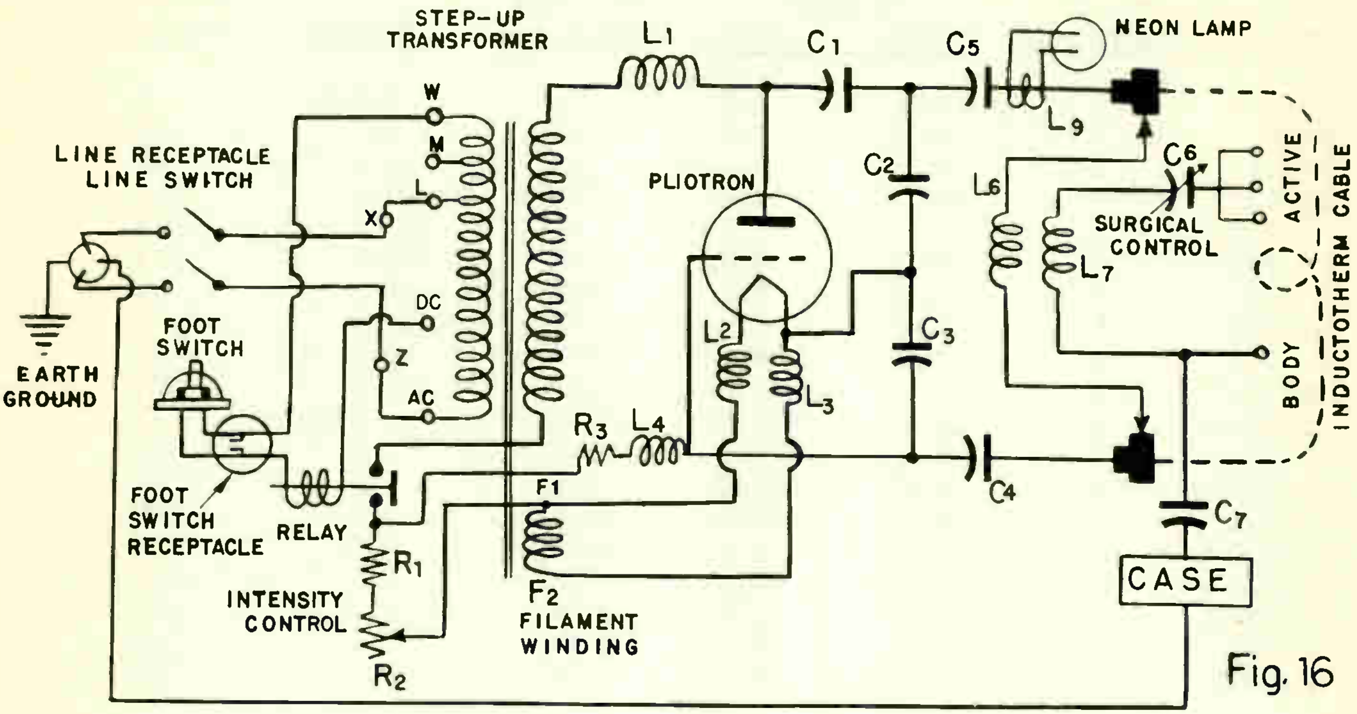



Fig. 16

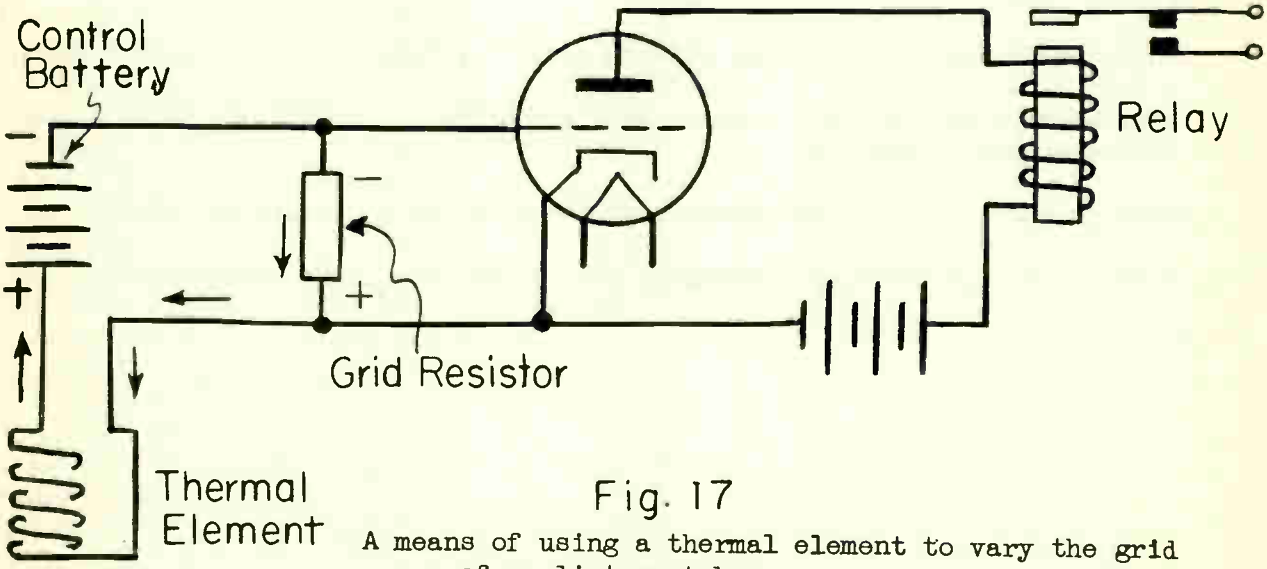



Fig. 17
A means of using a thermal element to vary the grid of a pliotron tube.

# VARIABLE TIME DELAY CIRCUITS

## Objective

To become familiar with the fundamental theory, applications and advantages of electronic timing.

## References

## Lesson Content

### A. General

An electronic pliotron tube together with a resistor-capacitor timing circuit can form a combination capable of automatically timing almost any process. The simplicity of the electronic circuit and the absence of all moving parts, except for a small control relay, makes the electronic timer ideal for many applications. Listed are just several of many typical applications where electronic time delay circuits are used:

a. Molding machines
b. Conveyor control
c. Photographic timing
d. Traffic signals
e. Riveter control
f. Laboratory tests
g. Resistance welders.

### B. Series RC Time Delay Circuit Analysis

Fig. 1 illustrates the basic principles of how a series capacitor-resistor time delay circuit can be connected into the grid circuit of an electronic tube and produce a time delay.

The basic circuit operation is as follows:

With the switch S open, capacitor C charges through resistor R. The polarity of the charge is such, that the grid of V1 becomes highly negative and cuts off all electron flow in the V1 plate circuit. With no electron flow in the plate circuit, the relay coil is de-energized and the contacts are open. The equivalent circuit with switch S open is shown in Fig. 2.

Upon closing switch S , capacitor C discharges through the switch instantaneously. The grid then is at the same potential as the cathode of V1. This resultant zero potential upon the grid causes the tube V1 to conduct and energize the relay in its plate circuit. Fig. 3 illustrates the equivalent circuit with switch closed. The time delay action takes place when switch S is opened again. The short across the capacitor is removed and the grid to ground potential required to make the tube react as an open circuit is delayed, due to the time required for the capacitor to charge in the resistor-capacitor circuit.

C. Parallel RC Time Delay Circuit Analysis

Fig. 4 shows the circuit of a time delay that is used for general purpose in industry. A parallel resistor-capacitor circuit is connected to the control grid of a pliotron tube.

The circuit operation is as follows: Assuming switch SW. 1 open and point A negative and point B positive, during one alternation of the a-c source across the secondary winding of transformer T1, the electron flow at one instant would be through the following points:- A, C, B, A. Resistors R2 and R3 have a voltage drop with such polarities as to make point "C" positive with respect to cathode of tube V1. Note that this positive potential is applied to the plate of C1 opposite to the one connected to the grid of V1, and will induce an attracting force for electrons to the C1 capacitor plate connected to the control grid.

In the same half cycle, electrons will travel from point A through R4, from cathode to grid, then through R1 and the lower portion of R2 to point B. A direct electron flow by the method of "grid rectification" has taken place. The effective resistance between cathode and control grid during "grid rectification" is approximately 1,000 ohms. An equivalent circuit just described is shown in Fig. 5.

Due to the low resistance of the charge circuit, capacitor C1 is charged almost instantaneously negative upon the capacitor plate connected to the control grid. At this stage the effective resistance, between the cathode and grid electrodes, becomes infinite because the control grid cannot attract any more electrons emitted by the cathode. With the grid of V1 highly negative, no electrons are permitted to flow from cathode to plate. Relay L1 is de-energized.

During the next half-cycle with point A positive and point B negative, the negative grid of tube V1 prevents any reverse flow of electrons. C1 does lose a small part of its charging voltage by discharging through R1 but the amount is so small it may be considered negligible.

Upon closing switch 1, the cathode connects with the lower side of T1 (point B) and by-passes the cathode-grid circuit so that capacitor C1 receives no further charge. <u>It is at this instant when the time delay begins</u>. Now C1 begins to discharge through R1 so the grid potential becomes less and less negative. After a certain delay the grid potential becomes so close to the cathode potential that tube V1 begins to conduct. The electron flow increases to the amount required to energize the relay coil in the plate circuit. An equivalent circuit is shown in Fig. 6.

Capacitor C2 is a "smoothing capacitor" to prevent the relay from de-energizing during the half cycles when there is no electron flow through the tube.

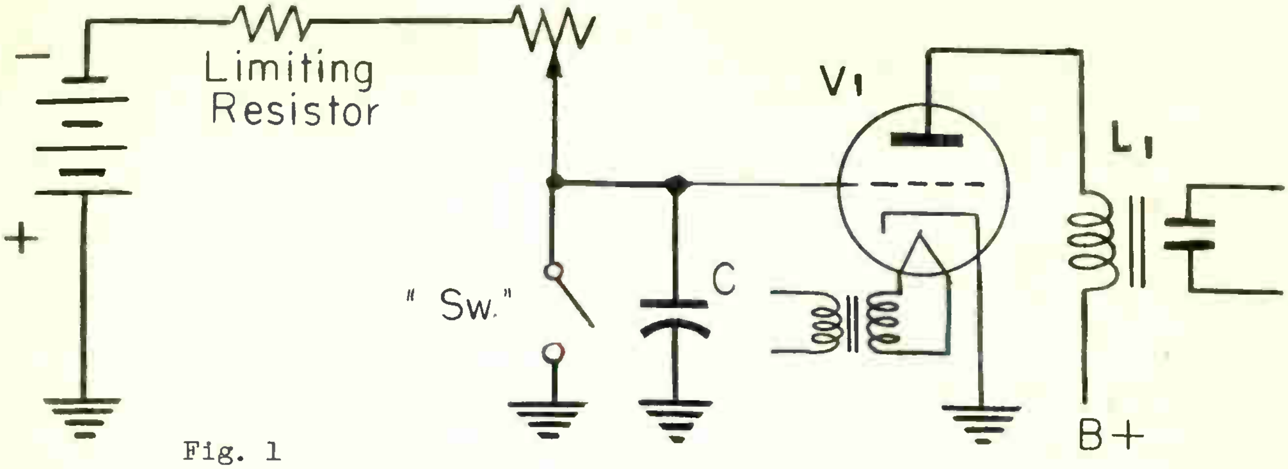



Fig. 1

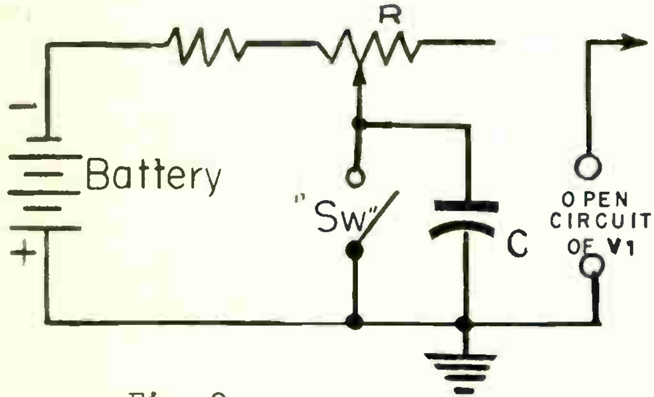



Fig. 2

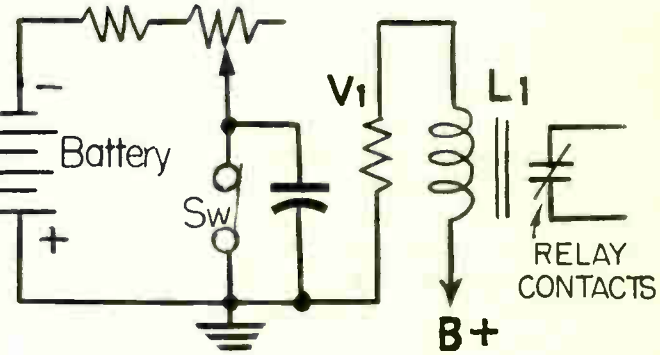



Fig. 3

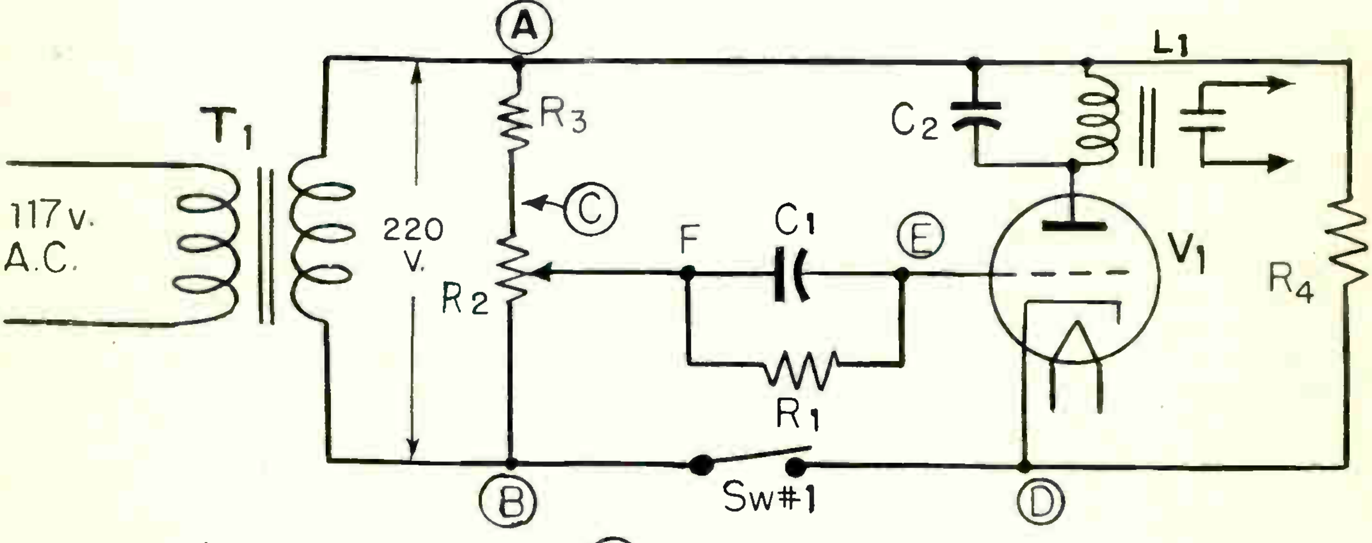



Fig. 4

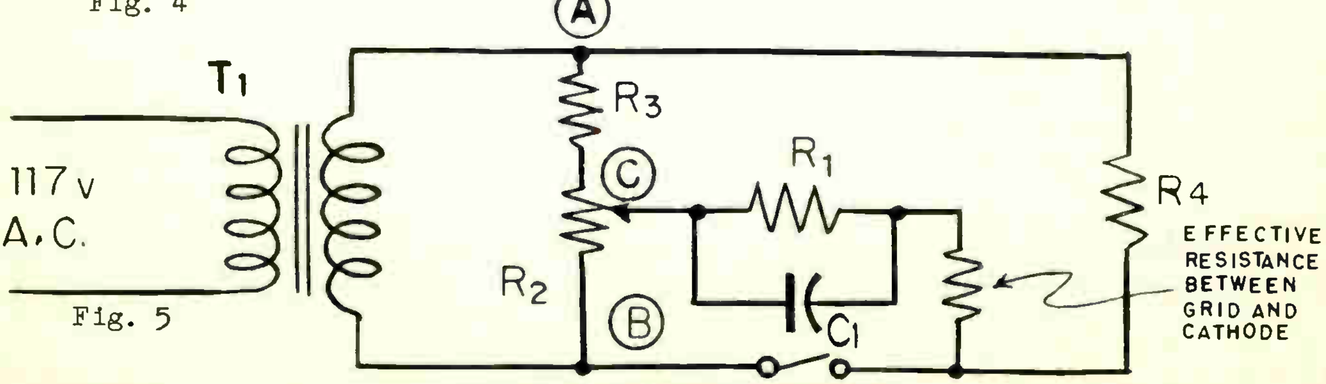



Fig. 5

The length of time delay may be varied by adjusting R2. For a long time delay circuit action, the rotating contact arm is adjusted so that it touches point B. The equivalent circuit shown in Fig. 7A illustrates the approximate voltages appearing across C1. Fig. 7B illustrates the approximate voltages appearing across C1 during a shorter time delay action with contact arm of R2 connected to point C.

It must be remembered that C1 will charge to the peak potential existing across R1 which in Fig. 7B is 1.4x115 which equals 160 volts. In Fig. 7A, 1.4x200 equals 280 volts.

The actual time delay in seconds of a timing circuit such as in Fig. 4 is not necessarily dependent only upon the resistor-capacitor circuit connected to the grid, but also upon the grid potential at which electron flow in the plate circuit operates the relay. The amount of voltage applied across C1 is determined by the positioning of the variable contact arm of R2.

The greater the charge upon capacitor C1, the longer the time the grid of tube V1 will remain negative enough to prevent electron flow from cathode to plate.

The smaller the charge upon capacitor C1, the shorter the time the grid of V1 will remain negative, thus permitting the tube to conduct sooner.

Various electronic tubes have different characteristics and consideration must be given at what value of negative grid voltage will the tube conduct and permit the electron flow to energize the relay in the plate circuit.

## D. Linear Time Delay Circuit Analysis

For some control purposes it is often necessary to turn electrical equipment on and off after a DEFINITE PRECISE TIME INTERVAL. The circuit in Fig. 4 using a parallel resistor-capacitor circuit connected to the grid does not fulfill this requirement. The capacitor discharges through the resistance non-linearally. Fig. 8 shows the logarithmic curve obtained when a capacitor discharges through a pure resistance. The shaded portion illustrates the critical area where precision time control is difficult to obtain.

To obtain precision time control, the effective resistance of a vacuum tube between the cathode and plate elements is used. Fig. 9 illustrates this type of circuit and the linear time discharge curve obtained.

The basic circuit operation is as follows:

1. The adjustment of the time range is provided by a variable resistance control R1. By setting this control at any desired point in this range the required time interval may be obtained by closing switch SW. 1 momentarily.

2. Assuming point A negative at one instant of the alternating input voltage and switch 1 open, the electrons will flow from point A through tube V2, through

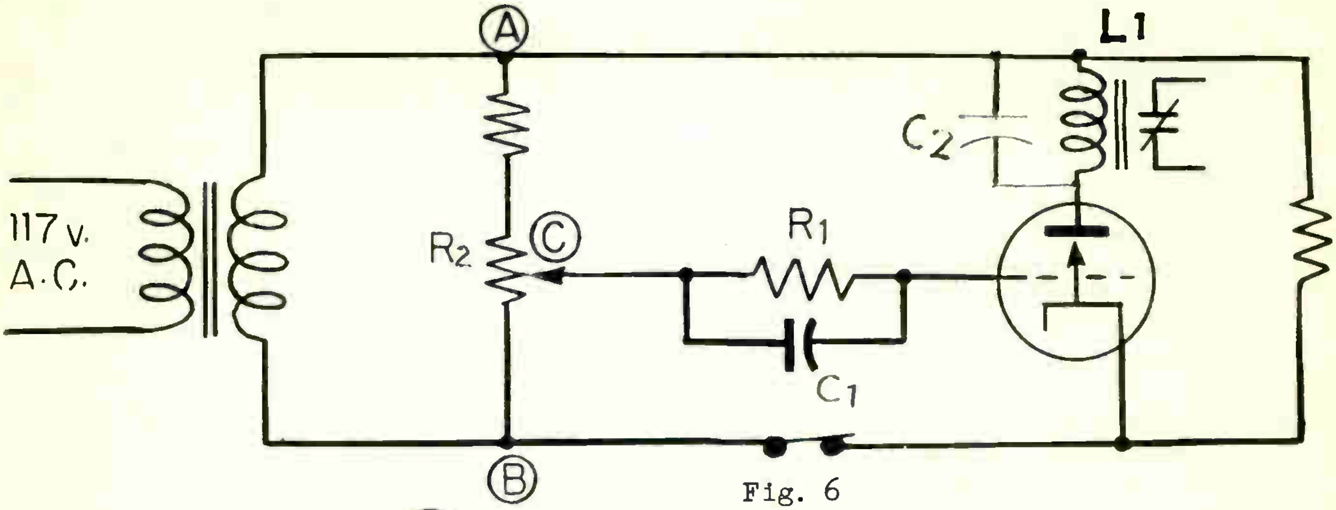



Fig. 6

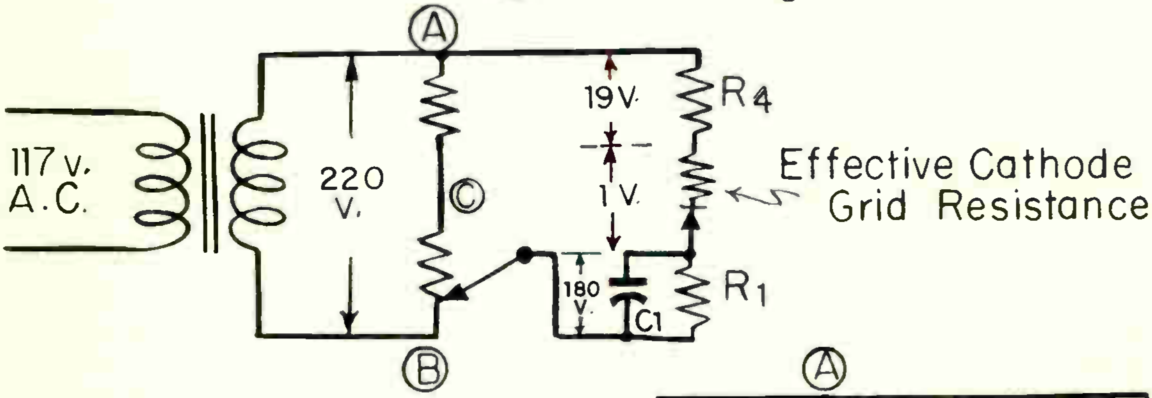



Fig. 7A

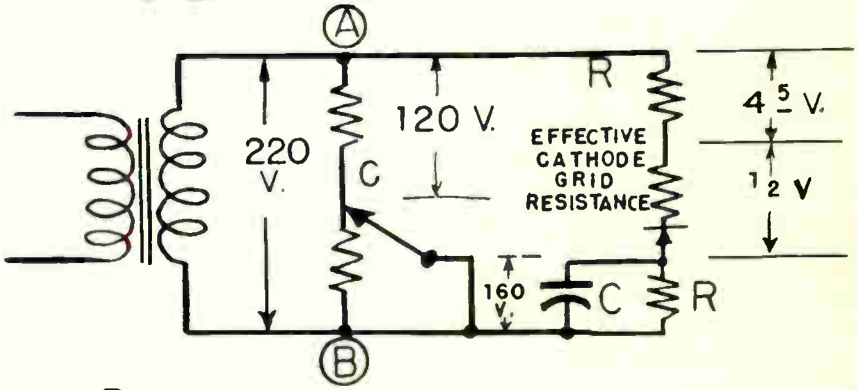
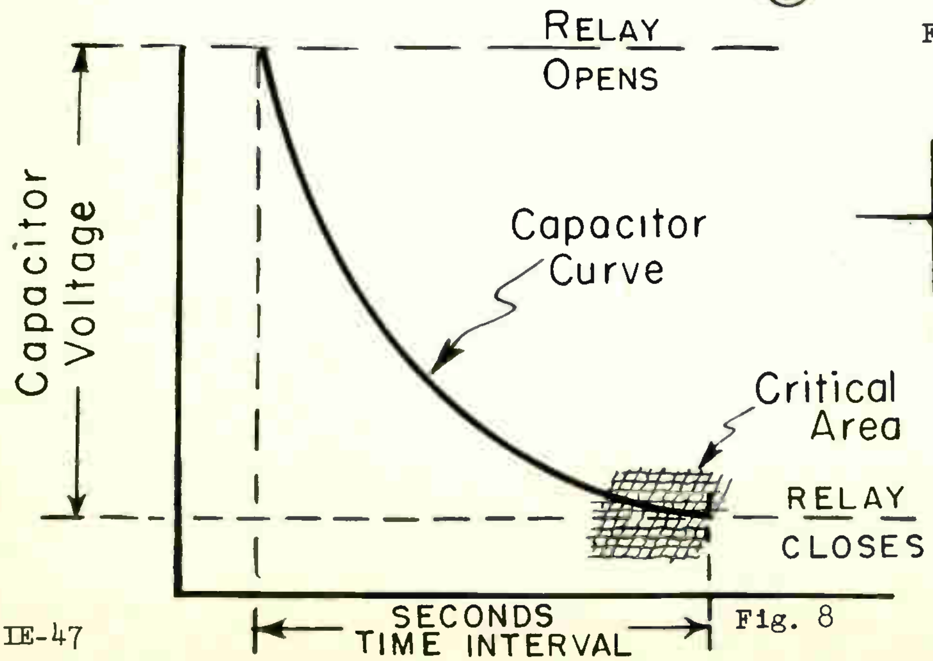



Fig. 7B



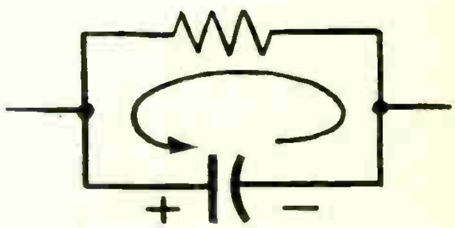




Fig. 8

the relay coil to capacitor C2 and to the other side of the a-c line, point G Instantaneously point G will connect to the cathode of tube V1 and no voltage is applied to the load. The equivalent circuit first described is shown in Fig. 10.

3. Capacitor C2 charges with an abundance of electrons on the plate side of tube V2. On the other half of the alternation of alternating voltage when point G is negative, the plate of V2 is negative with respect to its cathode and tube V2 does not conduct. Capacitor C2 then sends its stored up energy through the relay coil which provides a steadier electron flow through the coil and prevents it from chattering. The equivalent circuit is shown in Fig. 11.

4. Upon closing switch 1 momentarily and assuming at one instant point A of the alternating input voltage positive and point G negative, the electron flow is from point G through relay contacts V1, SW1, R2, to capacitor C1 and completes the circuit at point A The equivalent circuit is shown in Fig. 12.

5. The charge across capacitor C1 imposes a negative potential upon the grid of tube V2 with respect to the cathode. This negative potential is great enough to stop all electron flow through V2. With V2 not conducting, the relay coil de-energizes and the moving contact arm of the relay makes connection with the normally closed contact. The load is now directly connected across the 117 volt a-c source voltage. The equivalent circuit is shown in Fig. 13.

6. With relay L1 de-energized, the time delay action begins. Capacitor C1 starts to discharge through the variable resistor R1 and tube V3, which places a negative potential on the grid of tube V3. This causes the effective plate resistance of tube V3 to increase, dependent upon the value of discharge current. As capacitor C1 discharges, the negative voltage controlling the 6V6 tube is reduced to a point where sufficient electrons flow through the 6V6 tube again and cause the relay to energize and disconnect the voltage across the lead, Fig. 14.

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E. Summary Questions

1. What advantages has the linear time delay circuit over the circuit shown in Fig. 4?

2. What is the purpose of R3 in Fig. 4?

3. In Fig. 7A is the time delay longer or shorter? Why?

4. What is the purpose of V1 in Fig. 9? Can a switch be used in place of this tube?

5. Is the capacitor in series or in parallel with R1 and V3 when it is discharging? Refer to Fig. 9.

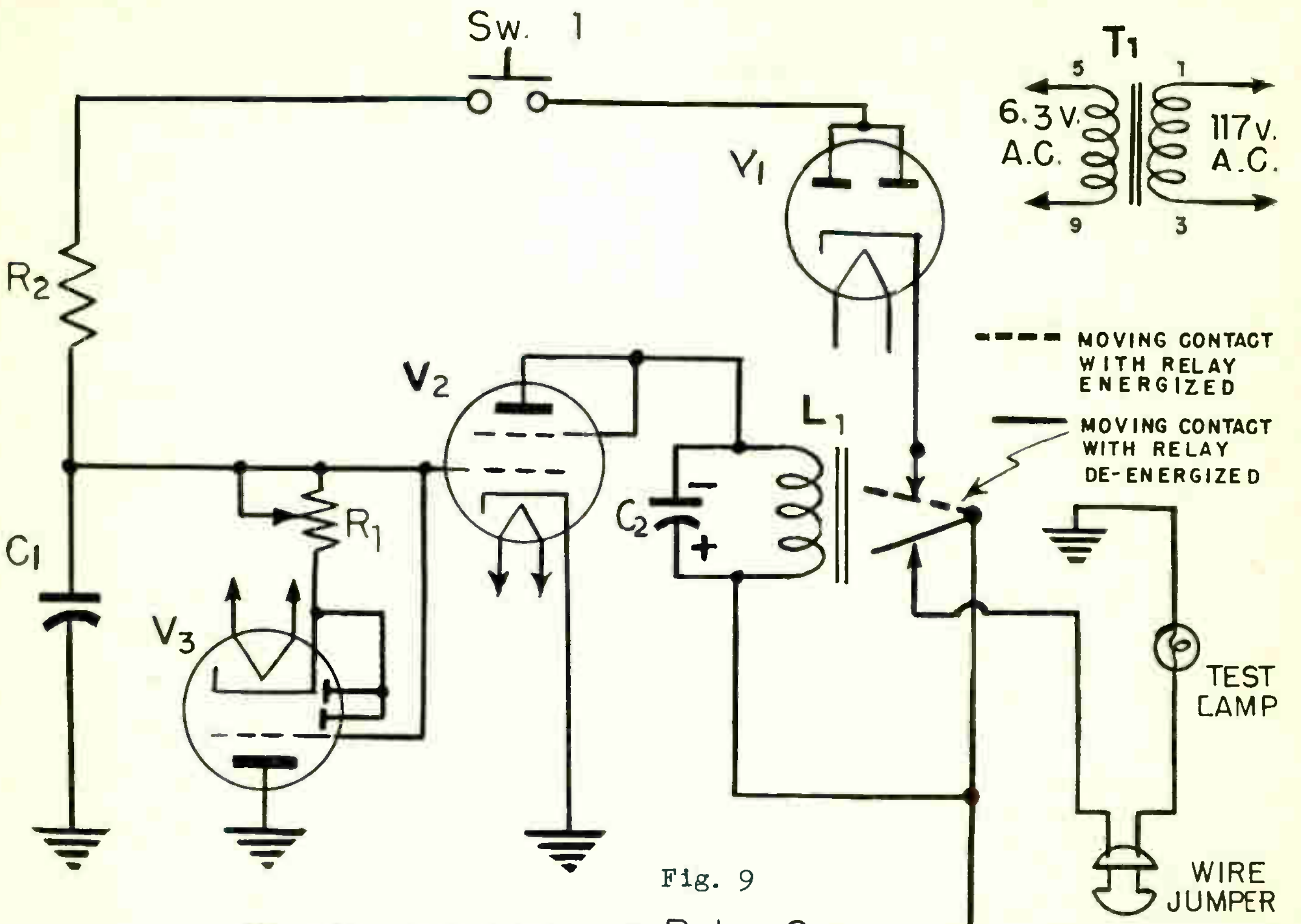



Fig. 9

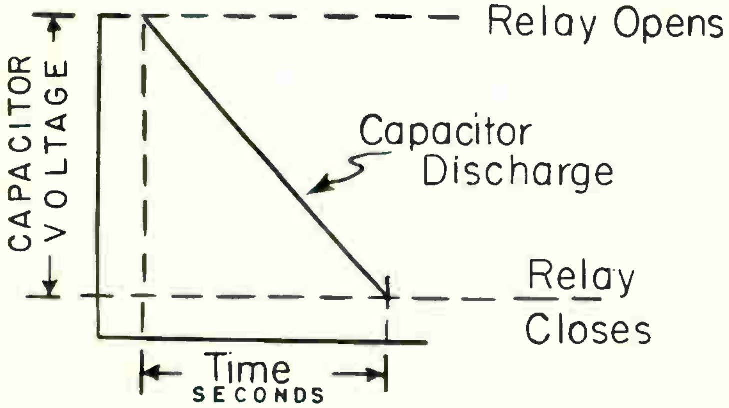



Fig. 9

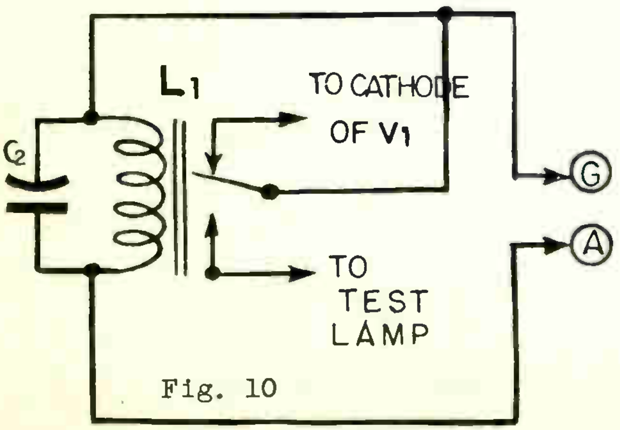



Fig. 10

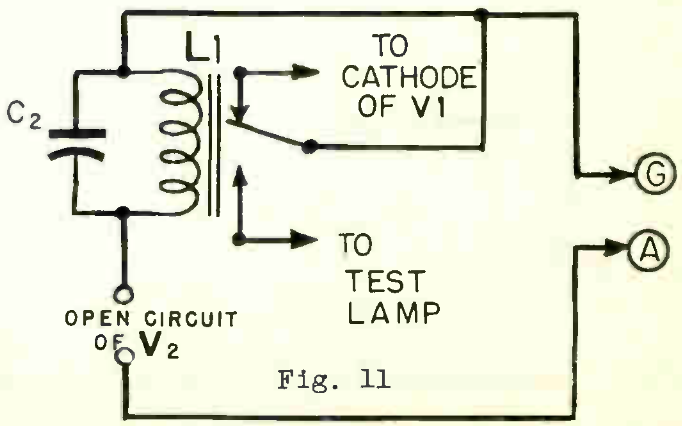



Fig. 11

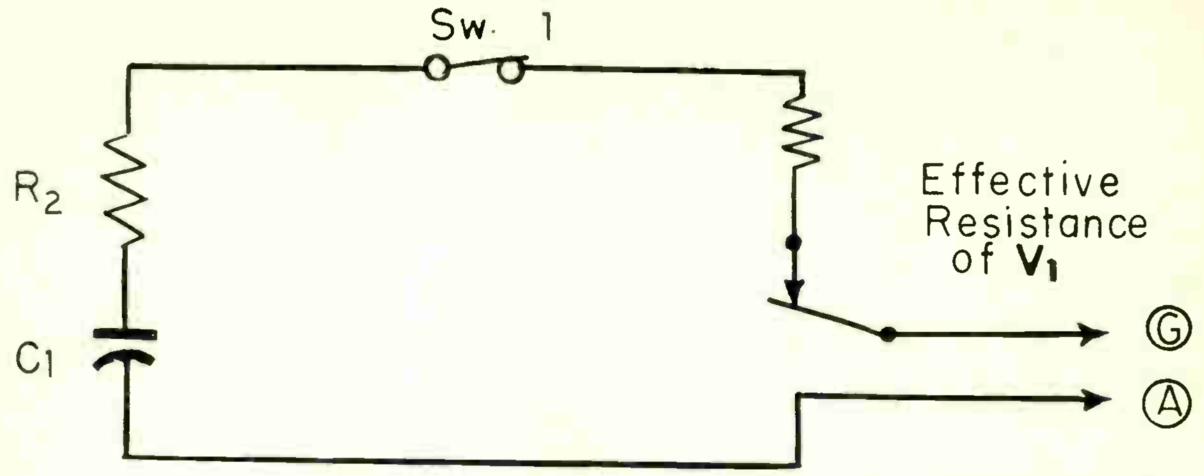



Fig. 12

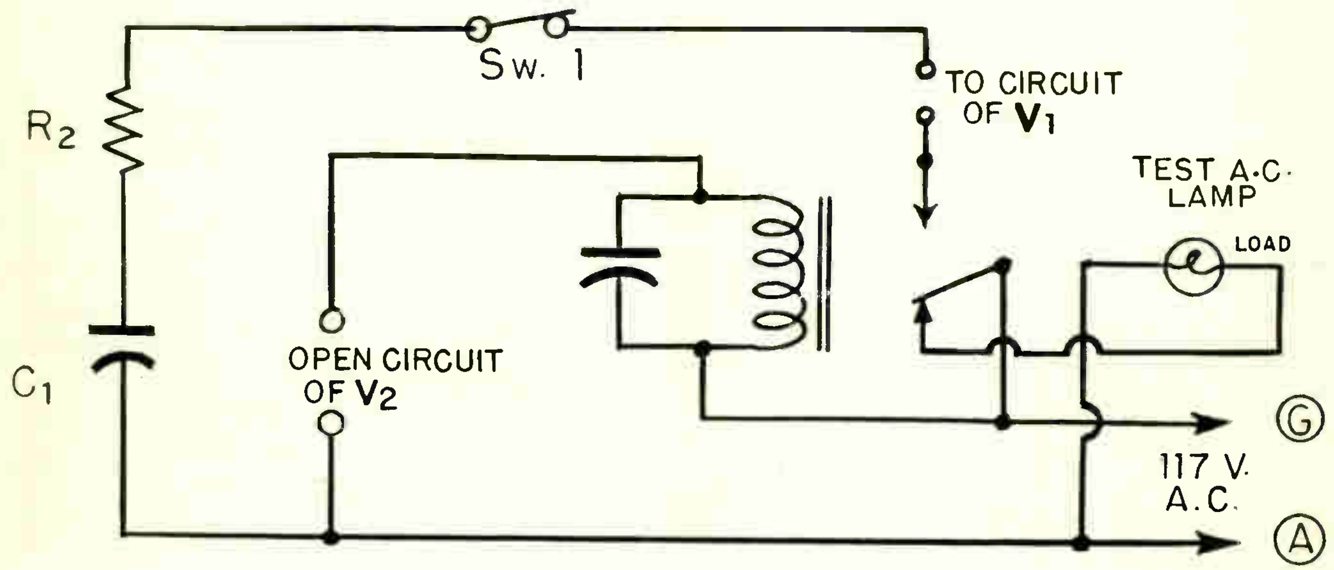



Fig. 13

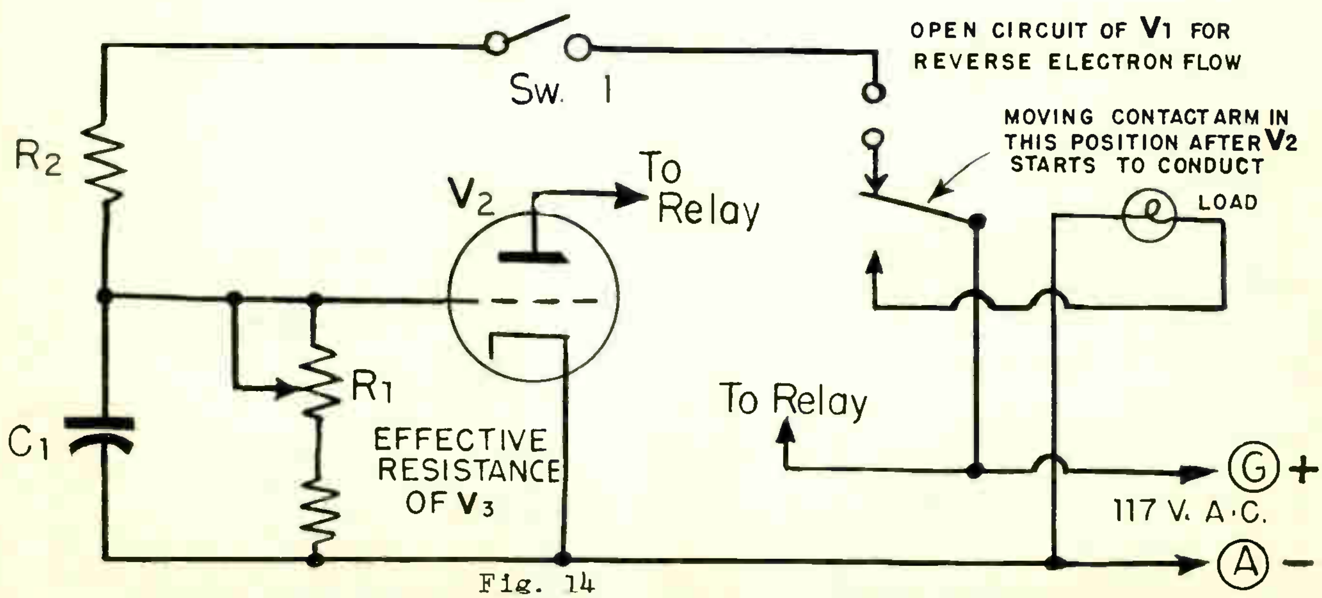
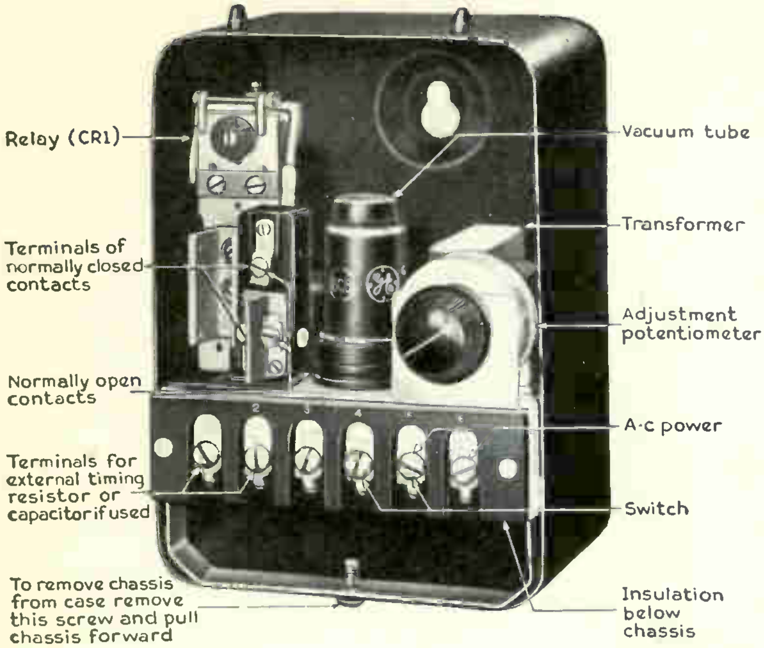
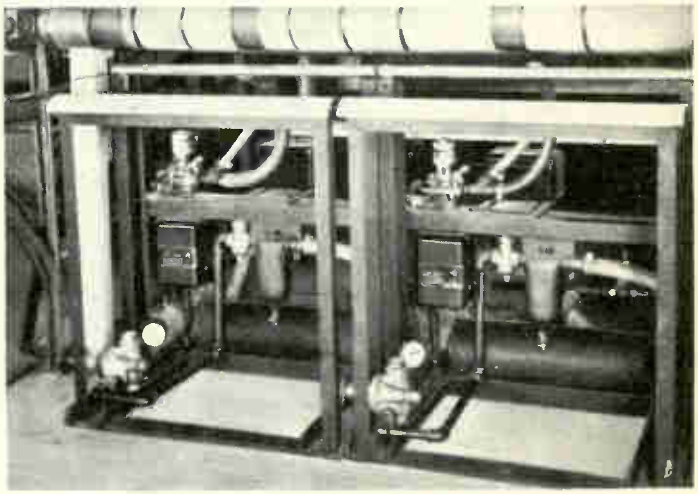
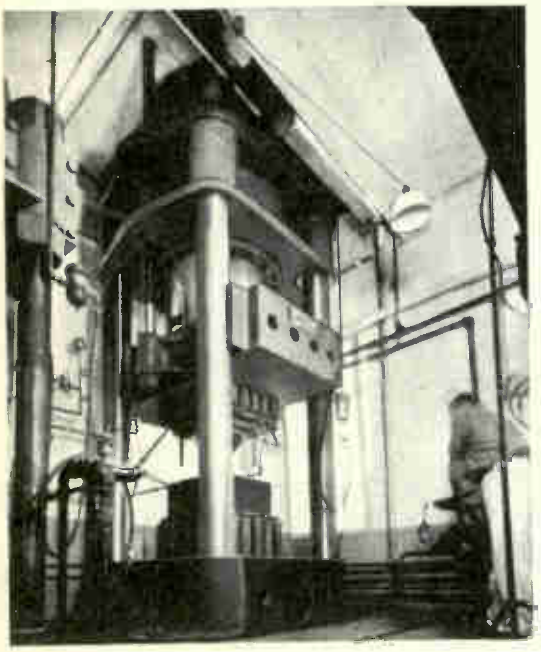



Fig. 14


Relay (CR1)
Terminals of normally closed contacts
Normally open contacts
Terminals for external timing resistor or capacitor if used
To remove chassis from case remove this screw and pull chassis forward
Vacuum tube
Transformer
Adjustment potentiometer
A-c power
Switch
Insulation below chassis





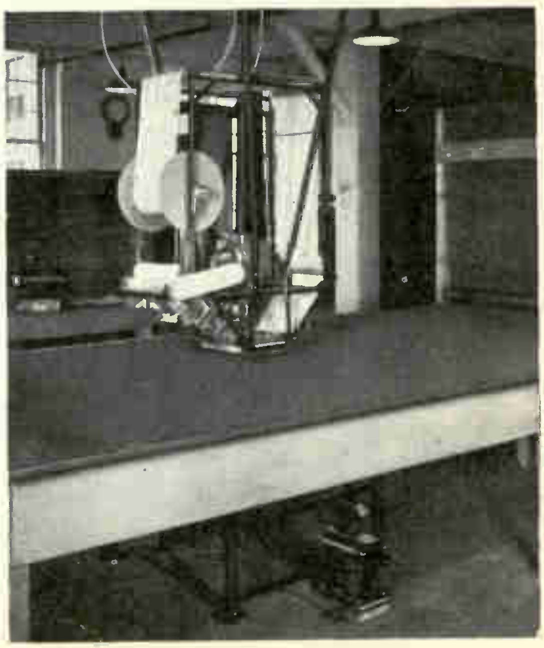


Fig. 15

# THYRATRONS

## Objective

To become familiar with thyratron tube theory and construction.

## References

## Lesson Content

### A. General

A thyratron is a thermionic gas tube in which one or more electrodes control the starting of the electron flow.

Thyratrons are used in many industrial applications. The list below gives only a few of the wide field of applications.

1. Controlling high temperatures.
2. Illumination control circuits.
3. Motor control circuits.
4. Welding Controls.
5. Inverters (DC to AC)
6. Time Delay circuits
7. Power supplies
8. Photoelectric controls

Fig. 1 illustrates the construction of the RCA-2050 or 2051 thyratron tube. The construction of the thyratron is similar to that of the phanotron, however in the thyratron one or more grids are placed between the cathode and plate which greatly increases the usefulness of the tube.

Symbols for thyratrons are shown in Fig. 2 for the type of tube having separate cathode and heater electrodes, for the type in which a filament serves as the heated electron emitter, and also the symbol for the shield grid type of thyratron shown in Fig. 1. The shield grid permits the control grid to have a greater sensitive reaction when a bias voltage is applied to it. Due to its physical construction the shield grid also protects the control grid from the heat of the cathode. With the shield grid at zero potential with reference to the cathode the tube characteristic is as a triode thyratron. If a positive potential were applied to the shield grid, with reference to cathode, the tube characteristic would change and a more negative control grid potential would be needed to prevent electron flow through the tube. Applying a negative potential to the shield grid causes the thyratron to become a positive control tube in which plate electron flow does not occur until a positive potential is applied to the control grid, with reference to the cathode. The dot in these thyratron tube symbols indicates that the tubes contain either a gas, a vapor or both.

B. Grid Action in a Thyratron

It has been learned in previous lessons that by means of a potential applied to the grid of a vacuum tube, normally negative, it is possible to control the plate electron flow. With thyratron tubes it is also possible to control the electron flow through the tube by means of a grid, but the degree of control is more limited than with vacuum tubes. In thyratron tubes the grid can control the electron flow only to the extent of starting it. Once this flow commences the only way to stop electron flow through the tube is to stop ionization of the gas within the tube.

Fig. 3 illustrates how and when the grid controls electron flow through the thyratron tube.

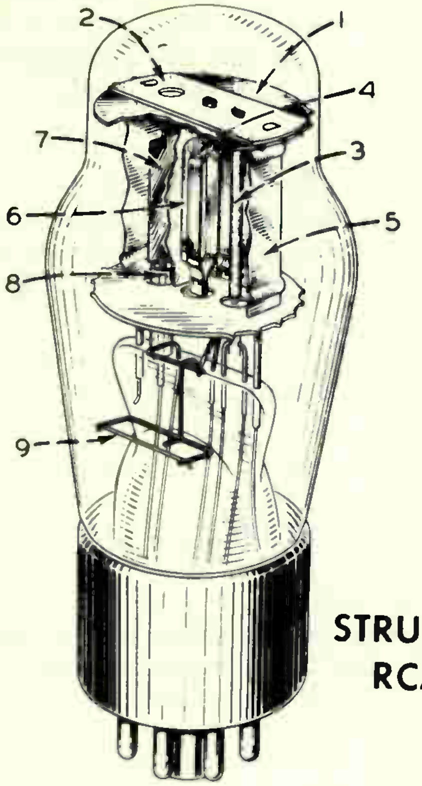
In Fig. 3A the plate is highly positive with reference to the cathode, while the grid is much more negative than the cathode. The manner of making the plate positive and the grid negative, with reference to the cathode, can be done with a voltage divider or in various other ways.

Heating of the cathode causes quantities of electrons to be emitted from its surface. The positive potential upon the plate tends to attract these electrons, but the strongly negative electrostatic field around the grid repels the electrons. The negative grid has a greater effect upon the electrons than the positive plate, because the grid is between the plate and cathode and much closer to the electron emitter than the plate. Because the grid exerts a greater electrostatic effect for a given potential, electrons are prevented from flowing from the cathode to the plate. There is no electron flow through the thyratron or the circuit to which it is connected.

In Fig. 3B, while the plate is still strongly positive with reference to the cathode, the grid has been made less negative with reference to the cathode. Making the grid less negative permits the attractive force of the positive plate to partially overcome the repelling force of the grid on the negative electrons. Some electrons then travel through the openings of the grid and toward the positive plate.

The space within the thyratron is filled with atoms of gas or vapor. Negative electrons in motion strike these atoms of gas or vapor and many of the collisions result in knocking a negative electron out of an atom or molecule. This action causes IONIZATION, just as in the gas or vapor filled phanotron tubes. After ionization of the gas, the voltage drop between plate and cathode remains approximately 15 volts regardless of the electron flow through the tube.

Atoms of gas which have lost one or more of their negative electrons become POSITIVE IONS as shown in Fig. 3C. The positive ions are then attracted to the space charge consisting of negative electrons around the cathode surface. These ions neutralize the negative space charge just as in the phanotron tube. With practically all the negative space charge neutralized, due to ionization, there is an increased flow of electrons from the cathode to the plate of the thyratron tube. Therefore a limiting resistance MUST ALWAYS BE INSERTED IN THE PLATE CIRCUIT of a gas filled tube to prevent the tube from destroying itself as a result of excessive electron flow.




**1** SHIELDING MICA
**2** INSULATING MICA
**3** CATHODE
**4** CONTROL GRID
**5** SHIELD GRID
**6** SHIELD-GRID APERTURE
**7** ANODE
**8** GLASS SLEEVE
**9** GETTER

Fig. 1

**STRUCTURE OF GAS-TETRODES RCA-2050 AND RCA-2051**

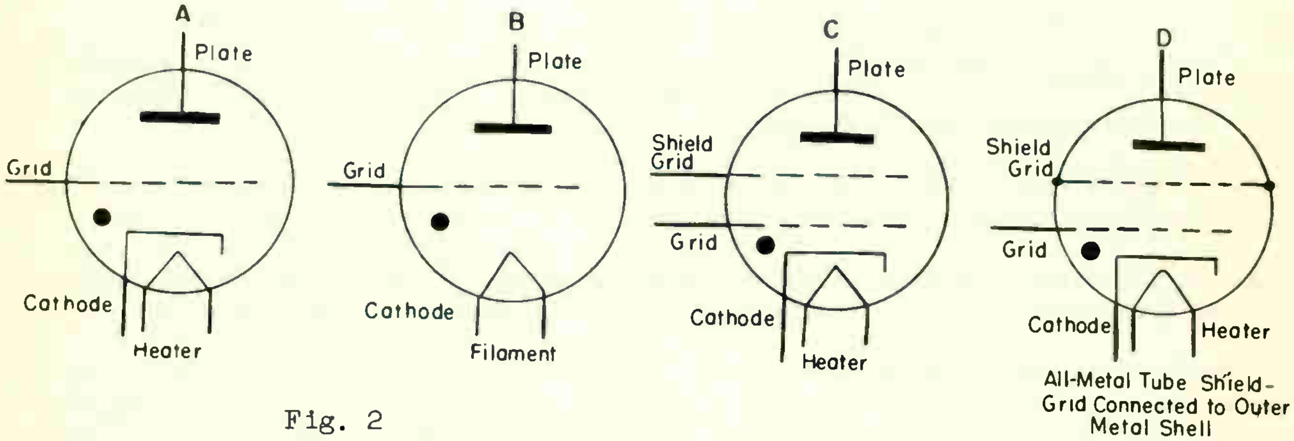



Fig. 2

ALL GLASS THYRATRON TUBES

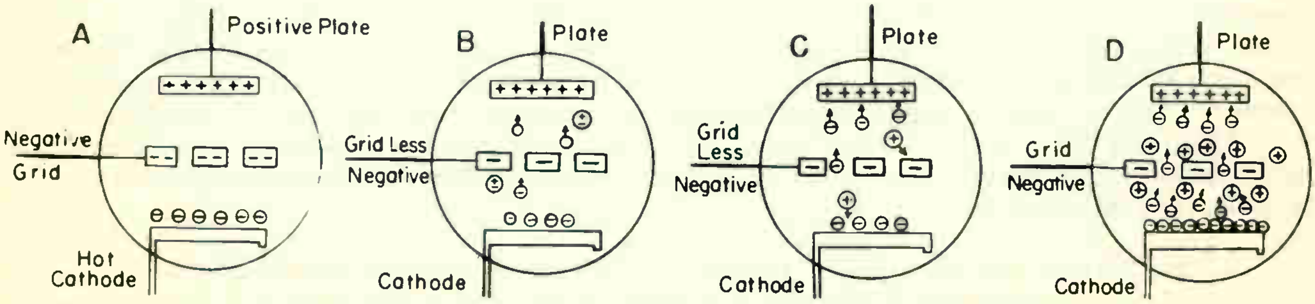



Fig. 3

The positive ions are also attracted to the negative grid. The negative electrostatic field upon the grid causes an attracting force for the positive ions. This causes a sheath of positive ions to collect around the grid and prevent the negative electrostatic field on the grid from having any appreciable effect in repelling negative electrons, Fig. 3D.

If the grid were now made more negative with reference to the cathode, it would no longer have any effect on the rate of electron flow through the tube, inasmuch as a greater number of positive ions would be attracted toward the grid and thus continue to neutralize its controlling effect on negative electrons traveling from cathode to plate.

C. Critical Grid Potential

Various types of thyratron tubes have various characteristics in that the tubes differ in construction, type of gas within the tube envelope, etc. These factors change the electrical characteristic of the thyratron tube.

For every value of plate voltage applied to a thyratron tube, a corresponding value of grid voltage is determined by the tube manufacturers and engineers which just allows the thyratron tube to become conducting.

The value of grid voltage which will allow the thyratron tube to conduct at the value of plate voltage which is applied to the plate at that instant is called the CRITICAL POTENTIAL. The terms break-down potential and pick-up potential are also used by many manufacturers of tubes.

Fig. 4A illustrates the variation in grid bias necessary to permit the starting electron flow through a 2051 thyratron for various values of plate voltage.

Fig. 4B illustrates more clearly the value of grid voltage which permits this thyratron to conduct when an alternating voltage is applied to the plate of the tube.

If the 2051 thyratron were connected in a circuit as shown in Fig. 5 where an alternating potential of 350 volts is applied to the plate and a direct potential is applied to the grid, a simple method is obtained to control the rate of electron flow through the tube.

Referring to the characteristic curve B of Fig. 4A it can readily be seen if the grid were made negative 3.5 volts with reference to the cathode the thyratron tube would not conduct at any time. However, if the voltage divider in Fig. 5 were varied so that a negative potential of 2 volts were applied to the grid, the gas within the tube would ionize when the alternating plate potential would reach approximately 210 volts. The tube would then conduct for the remaining half of the positive alternation.

Fig. 6 illustrates the portion of positive half-cycles during which conduction or electron flow may take place through the thyratron tube connected in a circuit as in Fig. 5.

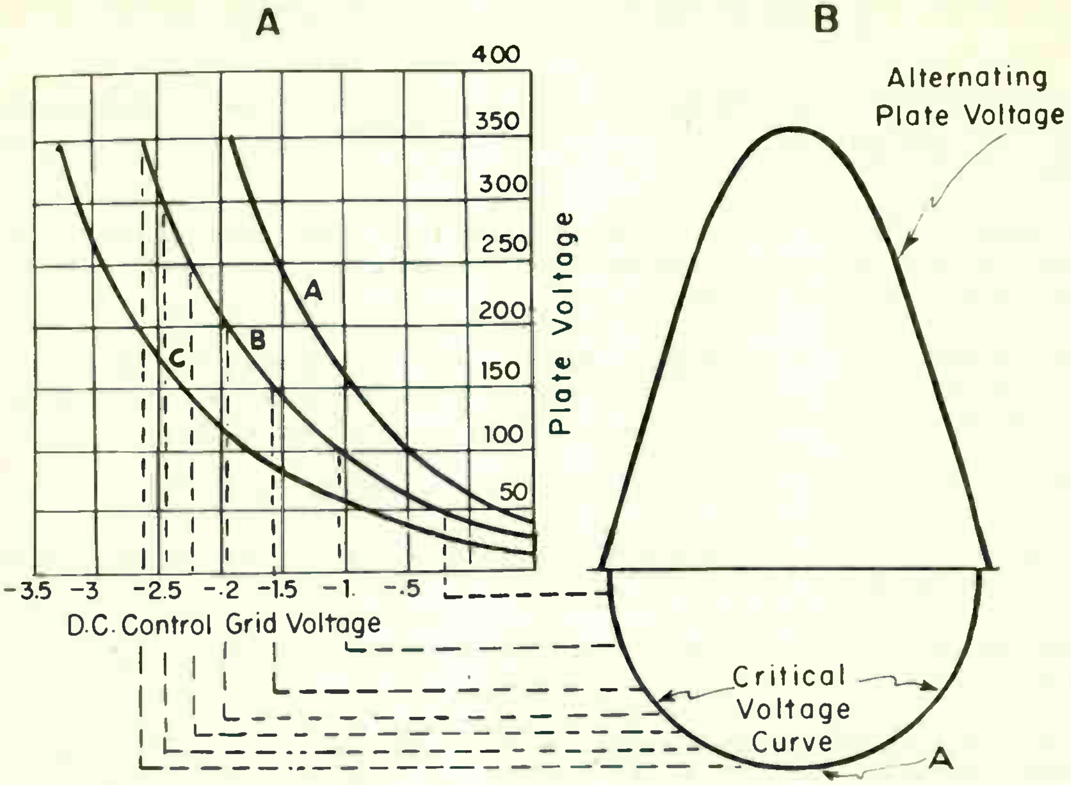



Fig. 4

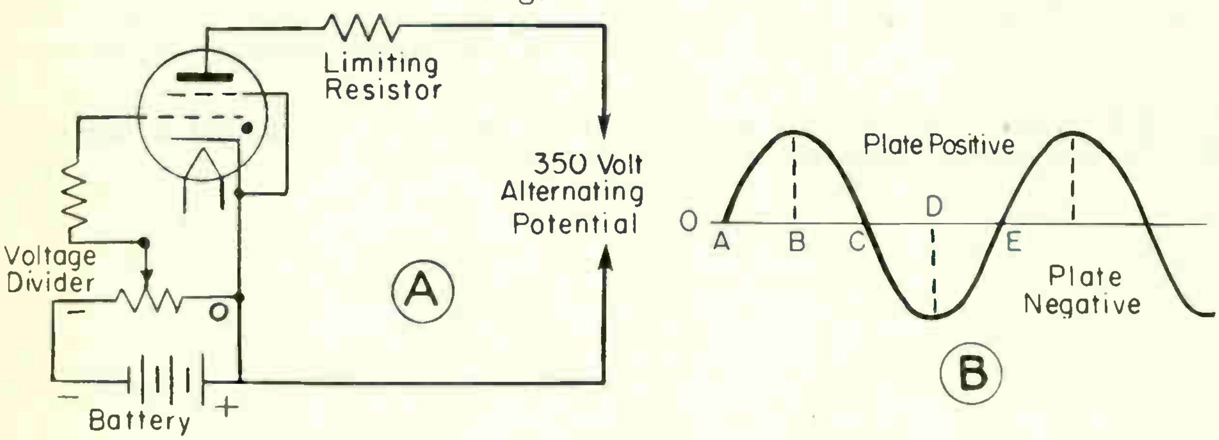



Fig. 5

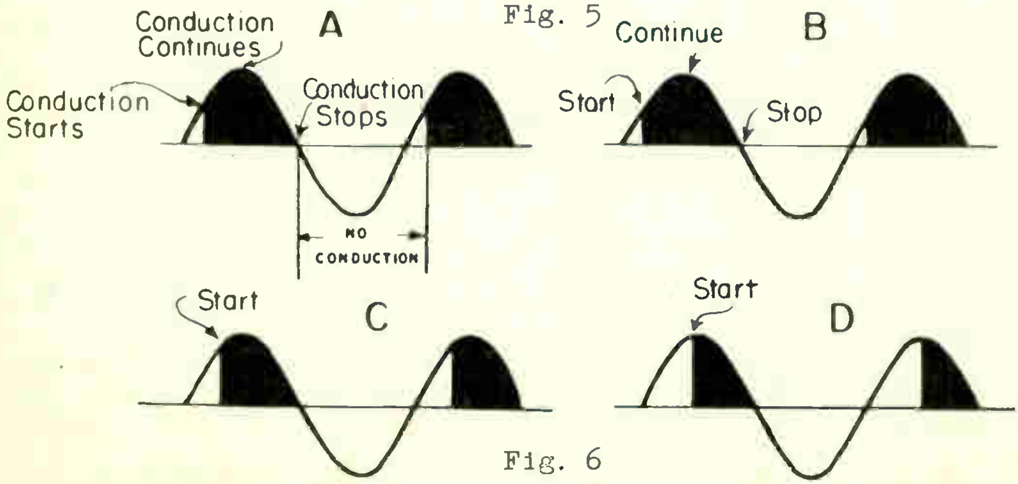



Fig. 6

As a summary for the study of thyratron tubes, the following factors should be considered.

1. The thyratron tube will permit electron flow from cathode to plate and will not conduct in the reverse direction unless the maximum peak inverse voltage rating of the tube is exceeded.

2. When there is electron flow through a thyratron, the ionizing potential drop across the tube becomes approximately 15 volts and is practically independent of the rate of electron flow.

3. The thyratron tube will permit maximum average plate electron flow whenever the potential of the plate is positive with reference to the cathode by an amount greater than the ionizing potential drop of the tube.

4. Electron flow through a thyratron tube can be started by:

   a. Varying the magnitude of the direct voltage applied to the grid carrying no alternating potential.

   b. Varying the phase relationship between the grid and plate voltage of the tube.

   c. Applying an alternating voltage, of the same frequency as that applied to the plate, to the grid and varying the amplitude of the grid potential.

   d. Super-imposing an alternating grid voltage on the direct grid voltage so that the critical voltage curve can be intersected by simply varying the d-c bias.

The various methods listed in 4D on how to start electron flow through a thyratron tube will be discussed in greater detail in future lessons.

Listed below are the various thyratrons available and their characteristics.

| TYPE NO. | NO. OF ELECTRODES | FILAMENT VOLTS | FILAMENT AMPS. | PLATE PEAK VOLTS INVERSE | PLATE PEAK AMP. | PLATE AVE. AMP. | STARTING GRID VOLTAGE |
|---|---|---|---|---|---|---|---|
| GL-2D21 | 4 | 6.3 | 0.6 | 1300 | 0.5 | 0.1 | -- |
| GL-3C23 | 3 | 2.5 | 7.0 | 1250 | 6.0 | 1.5 | neg. |
| GL-3C45 | 3 | 6.3 | 2.1 | 3000 | 35.0 | 0.045 | -- |
| FG-27-A | 3 | 5.0 | 4.5 | 1000 | 10.0 | 2.5 | neg. |
| FG-33 | 3 | 5.0 | 4.5 | 1000 | 15.0 | 2.5 | pos. |
| FG-41 | 3 | 5.0 | 20.0 | 10000 | 75.0 | 12.5 | neg. |
| FG-81-A | 3 | 2.5 | 5.0 | 500 | 2.0 | 0.5 | neg. |
| FG-97 | 4 | 2.5 | 5.0 | 1000 | 2.0 | 0.5 | var. |
| FG-98-A | 4 | 2.5 | 5.0 | 500 | 2.0 | 0.5 | neg. |
| FG-105 | 4 | 5.0 | 10.0 | 2500 | 40.0 | 6.4 | var. |
|  | 4 | 5.5* | 11.0 | 750 | 77.0 | 2.5 | var. |
|  |  | 5.5* | 10.0 | 10000 | 16.0 | 4.0 | var. |
| FG-154 | 4 | 5.0 | 7.0 | 500 | 10.0 | 2.5 | var. |
| FG-172 | 4 | 5.0 | 10.0 | 2000 | 40.0 | 6.4 | var. |
|  |  | 5.5* | 11.0 | 750 | 77.0 | 2.5 | var. |
| FG-178-A | 3 | 2.5 | 2.25 | 500 | 0.500 | 0.125 | neg. |
| GL-393-A | 3 | 2.5 | 7.0 | 1250 | 6.0 | 1.5 | neg. |
| GL-414 | 4 | 5.0 | 20.0 | 2000 | 100.0 | 12.5 | neg. |
| GL-502-A | 4 | 6.3 | 0.6 | 1300 | 0.500 | 0.100 | neg. |
| GL-546-A | 4 | 6.3 | 0.15 | 500 | 0.100 | 0.020 | neg. |
| GL-627 | 3 | 2.5 | 6.0 | 2500 | 2.5 | 0.64 | neg. |
| GL-672 | 4 | 5.0 | 6.0 | 1500 | 30.0 | 2.5 | neg. |
| GL-678 | 3 | 5.0 | 7.5 | 15000 | 6.0 | 1.6 | neg. |
| GL-884 | 3 | 6.3 | 0.6 | 350 | 0.300 | 0.075 | neg. |
| GL-885 | 3 | 2.5 | 1.4 | 350 | 0.300 | 0.0375 | neg. |
| GL-2050 | 4 | 6.3 | 0.6 | 1300 | 0.500 | 0.100 | neg. |
| GL-2051 | 4 | 6.3 | 0.6 | 700 | 0.375 | 0.075 | neg. |
| GL-5545 | 3 | 2.5 | 21.0 | 1500 | 80.0 | 6.4 | -- |
| GL-5557/F-17 | 3 | 2.5 | 5.0 | 5000 | 2.0 | 0.5 | neg. |
| GL-5559/F57 | 3 | 5.0 | 4.5 | 1000 | 15.0 | 2.5 | neg. |
| GL-5560/F95 | 4 | 5.0 | 4.5 | 1000 | 15.0 | 2.5 | var. |
|  |  | 5.5* | 4.0 | 1000 | 40.0 | 0.5 | var. |
| 1701 |  | 2.5 | 5.0 | 5000 | 2.0 | 0.5 |  |

*These ratings apply only when the tube is used in thyratron welding-control service.

D. Summary Questions

1. What purpose does the shield grid serve in a thyratron tube?

2. With the shield grid positive with reference to the cathode will the thyratron control grid require a greater or smaller negative grid potential to prevent electron flow?

3. Explain why the grid in a thyratron tube can control the plate electron flow only to extent of starting it?

4. What determines the "critical potential" of a thyratron tube?

5. State four means of controlling the electron flow through a thyratron tube.

# AMPLITUDE CONTROL OF THYRATRONS

## Objective

To become familiar with the fundamental theory of amplitude control circuits.

## References:

## Lesson Content

### A. General

Thyratrons are used in so many kinds of industrial and commercial control devices, that it would be impossible to list all of the various applications. However, when the operating principles of thyratrons and the general laws that govern electron flow in conductors, resistors, and other circuit elements are understood it is not difficult to determine from a circuit diagram the fundamental operation of the apparatus.

### B. Methods of Amplitude Control.

Amplitude control of a thyratron is accomplished by:

1. Varying the magnitude of a direct voltage applied to the grid with reference to the cathode.

2. Varying the amplitude of an alternating voltage applied to the grid with reference to the cathode.

3. Varying the magnitude of a superimposed alternating grid voltage on a direct grid voltage.

### C. Direct Potential on the Plate

A direct potential may be applied to the thyratron plate and conduction of the tube can be started by either of the methods stated under B above.

With a direct potential applied to the plate, once conduction begins, the grid completely loses control and the thyratron conducts continuously. The only means of extinguishing the flow is by opening the plate or cathode circuit of the tube or by reducing the plate voltage to such a low value that ionization of the gas within the tube ceases, Fig. 1.

When a direct voltage is applied to the plate of a thyratron, the circuit is said to have a lock-in feature since the plate potential must either be removed momentarily, reduced to a very low value, or an unusually high negative grid voltage of several hundred or thousand times its normal value must be applied in order to restore the tube to a non-conducting condition. This lock-in feature is undersireable in most applications and can be eliminated by applying an alternating potential, instead of a direct potential to the plate.

### D. Alternating Potential on the Plate and Direct Voltage on the Grid.

When an alternating voltage is applied to the plate, the grid regains control once each cycle so that by "firing" the thyratron at the same point in each cycle, the average electron flow may be easily controlled.

The magnitude of a direct voltage applied to the grid with reference to the cathode can be varied and thus control the average rate of electron flow through the thyratron.

The circuits shown in Fig. 2A, 2B, and 2C illustrate how the potential difference between grid and cathode is determined by the position of a contact arranged to slide along the resistor R of a voltage divider. The voltage divider resistor is connected across a 6 volt battery. The positive terminal of the battery should be connected to the cathode of the thyratron tube. An alternating potential is applied to the plate of the tube.

In Fig. 2A the slider is shown in a position which makes the grid 2 volts negative with reference to the cathode. Referring to Fig. 2A, the plate voltage which starts from a zero value would have to rise to a value "a" in order to overcome the negative grid bias and give enough velocity to the electrons to produce ionization of the gas within the tube.

The point on the grid-cathode potential curve, at which electron flow begins through a thyratron tube for a given plate potential, is known as the "critical grid voltage" and is indicated in Fig. 2 by point A, which is the point on the critical grid voltage curve at which electron flow begins through the tube for a value of plate potential as represented by "a". The tube will therefore conduct at that time and will continue to conduct until the plate voltage again reduces to zero.

In Fig. 2B the slider of the voltage divider was moved further toward the negative side of the battery. This new position of the slider makes the grid more negative with reference to the cathode. A greater potential now must be applied to the plate to overcome this grid potential. Fig. 2B illustrates how the average rate of electron flow becomes less, due to a greater negative potential applied to the grid.

In Fig. 2C the slider of the voltage divider was set so that the grid became 4 volts negative with reference to the cathode. The thyratron will now conduct for approximately one quarter cycle as shown in Fig. 2C.

From the illustrations shown, one can readily understand that while the plate potential is positive with reference to the cathode, the thyratron tube will conduct when the point of critical grid voltage is reached by the direct grid potential for whatever plate potential exists at that instant.

When the plate potential is negative with reference to the cathode, electron flow will stop because there is no force to attract electrons to the plate inside the tube. Just as ionization ceases, the grid is again able to control the starting of the following period of electron flow and ionization.

E. Alternating Potential for the Plate and Grid

In the preceding diagrams showing alternating potential applied to the plate cir-

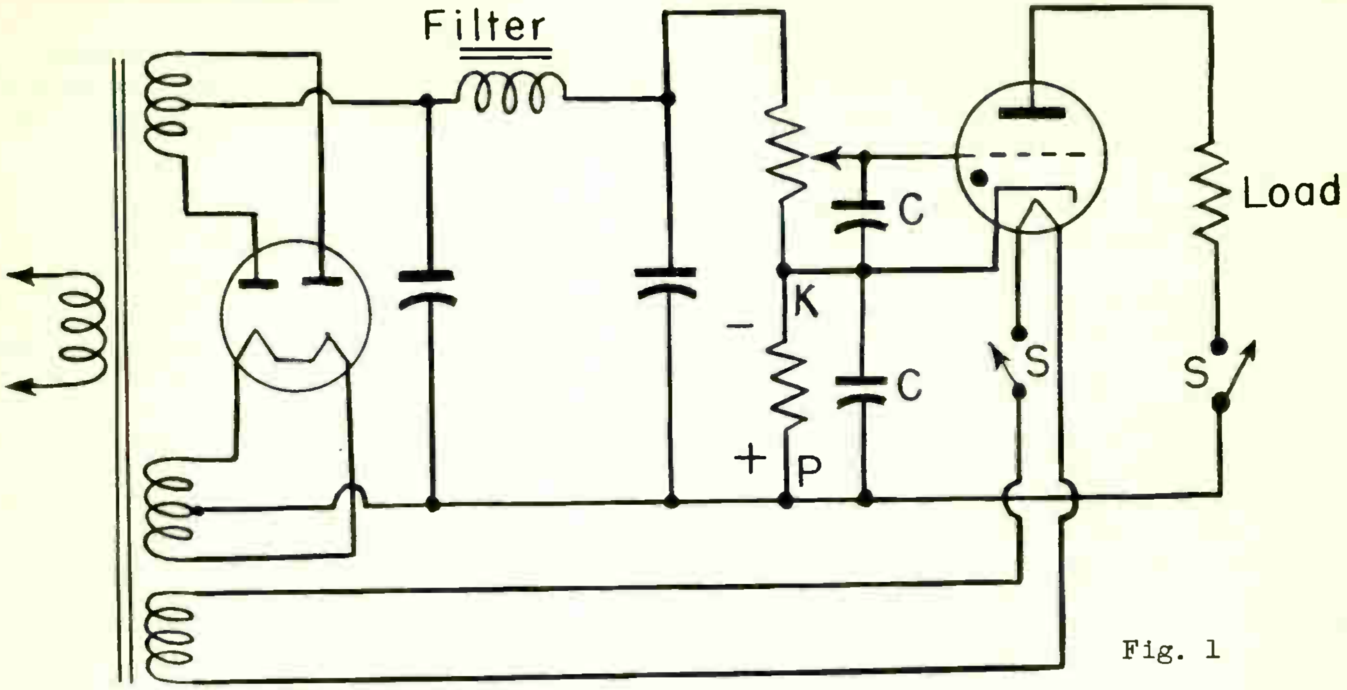



Fig. 1

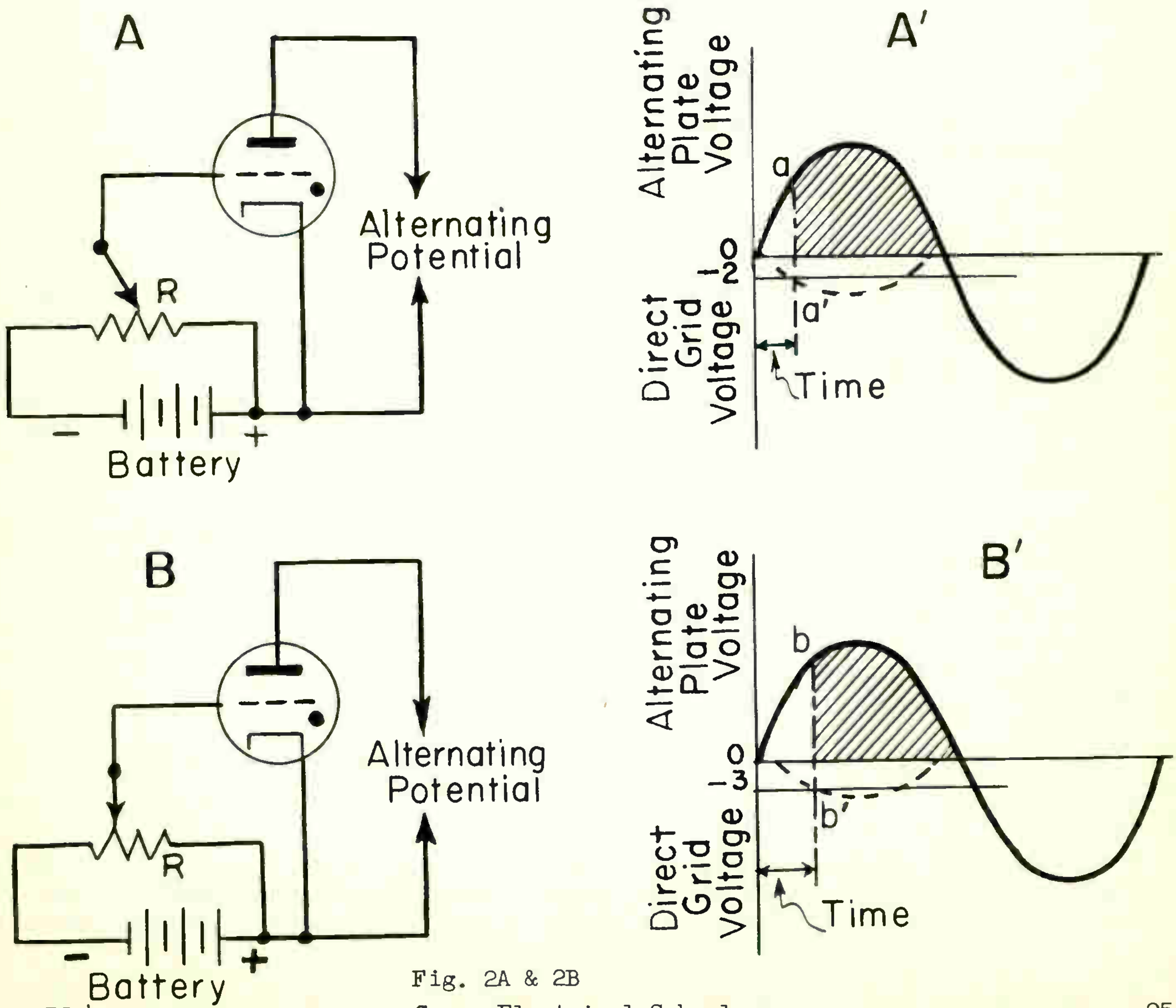



Fig. 2A & 2B

cuit of the thyratron, a direct potential from a battery was used for the grid circuit. It is also practical to use alternating potential for the grid as well as for the plate and to have variations of grid potentials that will vary the instant at which the tube breaks down and conducts.

If control of the thyratron is to be had with a varying grid potential, a grid potential must be obtained that is negative while the plate is positive.

Fig. 3 illustrates how a positive plate potential and a negative grid potential may be obtained at the same time. While one end of the transformer secondary winding is positive, the other end must be negative and when the first end becomes negative, the second will be positive. With the windings connected as shown in Fig. 3A, the grid will be negative with reference to the cathode while the plate is positive with reference to the cathode.

If the leads to the cathode and to the grid are reversed, the positive and negative ends would be reversed. This is indicated by Fig. 3B. Here it is necessary only to interchange the connections to the grid and cathode of the tube to make the grid negative while the plate is positive. To obtain an opposite potential for the grid and plate, requires only suitable connections of the transformer secondary to the tube circuit. If one method of connection does not give desired potential relations, reversing the connections of the secondary will do so.

To control the point at which the tube breaks down during the alternating cycle of plate potential a means of varying the amplitude of the grid potential must be obtained. One method of varying the amplitude of the alternating grid potential, while keeping it negative with reference to the cathode of the tube, is shown in Fig. 4.

In Fig. 4, the positive and negative signs on the ends of the transformer secondaries indicate which potentials occur together and show that the plate will be positive while the grid is negative. A potentiometer is connected across the grid winding of the transformer. It is apparent that with the potentiometer slider moved all the way up to the end marked zero (0) the grid of the tube will be at zero potential with reference to the cathode. As the slider is moved toward the end of the divider marked negative (-), more and more of the alternating potential from the transformer will appear across the grid and the tube cathode. When the plate is positive, moving the slider downward will make the grid more and more negative with reference to the cathode.

In Fig. 5 the change of plate potential with reference to the cathode during one cycle is shown by the full line curve. The changes of grid potential with reference to the cathode are shown by broken line curves for the same cycle. The grid is negative while the plate is positive and when the plate becomes negative, the grid becomes positive. As the slider of the voltage divider is moved away from the zero end and toward the negative end, the amplitude of the grid potential becomes greater and greater, as indicated by the successive curves, A, B, and C.

Fig. 6 illustrates how changing the amplitude of the grid potential causes the curve of the actual grid voltage to cross the curve of critical grid voltage at slightly different instants during the cycle.

The upper curve represents the plate potential applied to the thyratron tube. The lower curve drawn in a solid line is the curve of critical grid potential. The broken line curves at the lower part of Fig. 6 illustrate the negative grid poten-

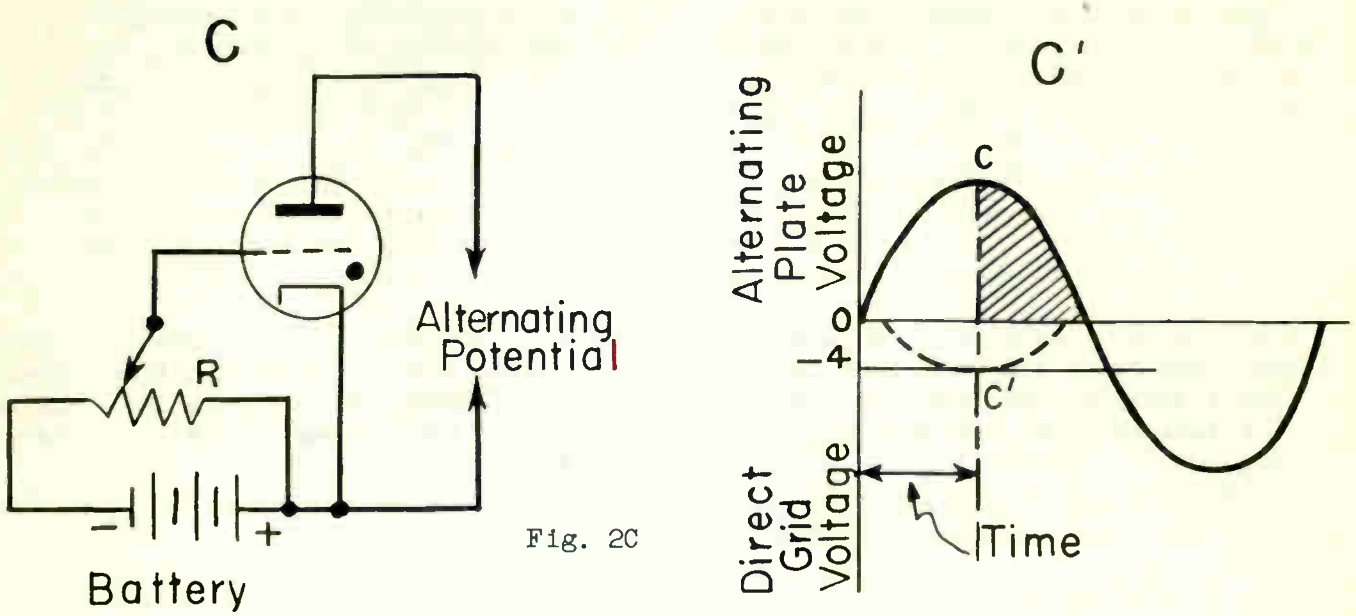



Fig. 2C

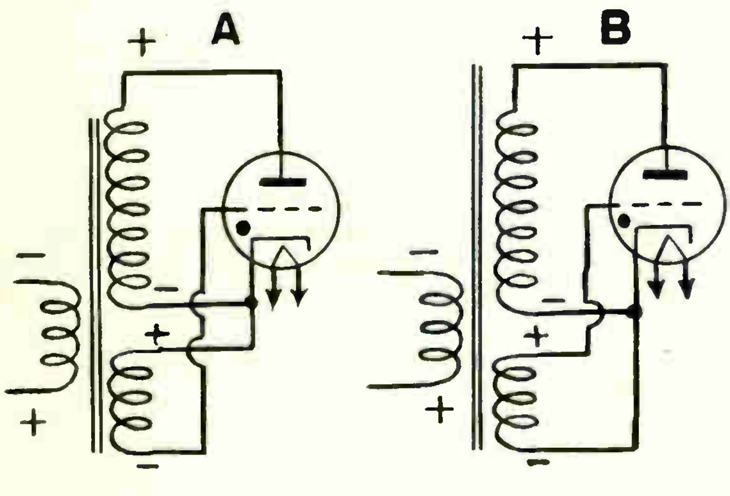



Fig. 3

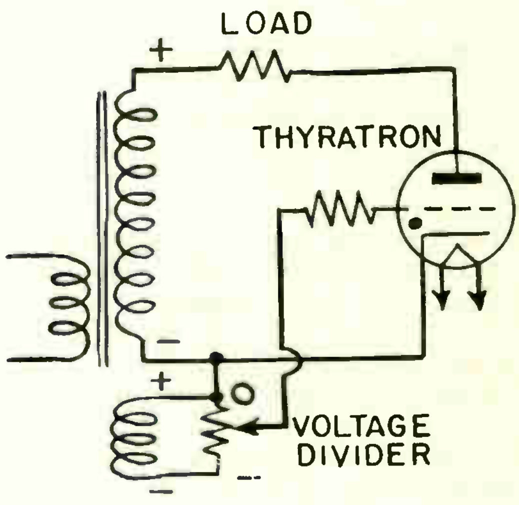



Fig. 4

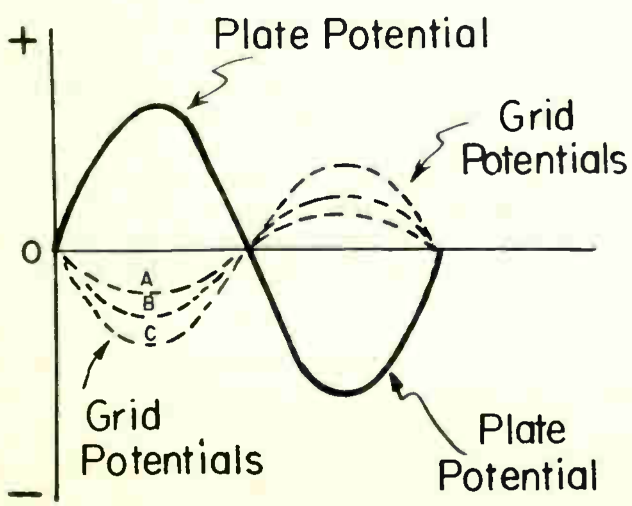



Fig. 5

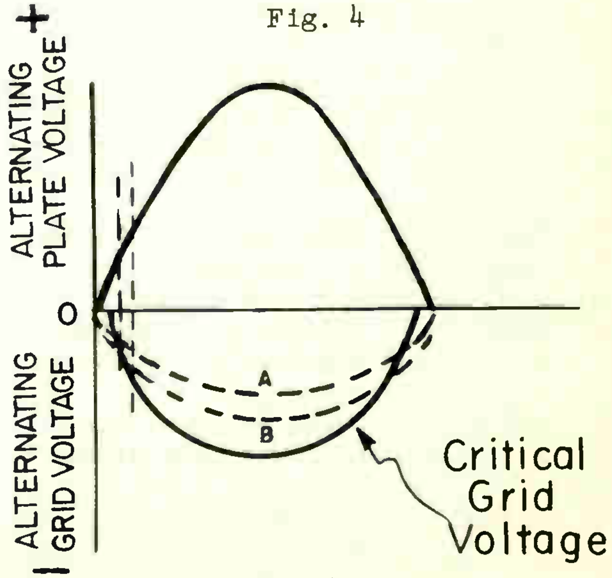



Fig. 6

tials of two amplitudes, such as might be produced by moving the slider on the voltage divider of Fig. 4. Curve A is for a potential having an amplitude of about 8.7 volts negative and curve B is for a potential having an amplitude of approximately 12.5 volts negative. Curve A crosses the critical grid potential curve at about 1.2 volt negative, so that the tube will break down at the point in the cycle where the plate potential rises to a value that corresponds to the critical grid potential of 1/2 volt. Curve B first crosses the critical potential curve at about one volt negative. With this grid potential or amplitude, the tube will break down at a very slightly different instant of time.

The type of control just explained is generally considered as an "on and off" control because of the fact that curves for actual grid potential (broken-line curves) have almost the same form as the curve for critical potential. A very small change of actual grid voltage will move the intersection of the curves a long way up or down, or will make a big change in the point during the cycle at which the tube breaks down and conducts. This control is critical and break-down at any particular point in the cycle would be difficult to obtain.

Fig. 7 illustrates a typical phototube circuit controlled by varying the amplitude of the grid to cathode potential.

## F. Alternating and Direct Potentials on the Grid.

Interesting possibilities can be obtained in starting the electron flow through a thyratron tube by applying an alternating and a direct voltage on the grid of the tube with an alternating potential applied to the plate.

Fig. 8 illustrates a basic circuit showing how a direct voltage may be combined with a continually varying alternating potential.

An alternating voltage of 6 volts is superimposed upon the direct voltage circuit consisting of a 12 volt battery and resistor R. The secondary transformer winding is connected in a manner so that the induced voltage is in phase with the primary voltage. The amount of direct voltage applied to the grid with reference to the cathode is controlled by moving the slider on resistor R. By moving the slider toward point B the direct grid potential becomes less and less negative with reference to the cathode. Moving the slider toward point C causes the direct grid potential to become more and more negative with reference to the cathode.

The 6 volt secondary alternating voltage is also applied to the grid with reference to the cathode and is superimposed upon the direct grid voltage. Fig. 10 illustrates the wave shapes which occur in the circuit shown in Fig. 8 as the direct grid voltage is progressively raised from a negative value well below the critical grid potential to a value above the potential.

In Fig. 9A there is no electron flow through the plate circuit at any time. This condition exists when the slider on resistor R of Fig. 8 is at point C.

In Fig. 9B the direct grid voltage is made less negative with reference to the cathode. This condition exists when the slider on resistor R of Fig. 8 is moved

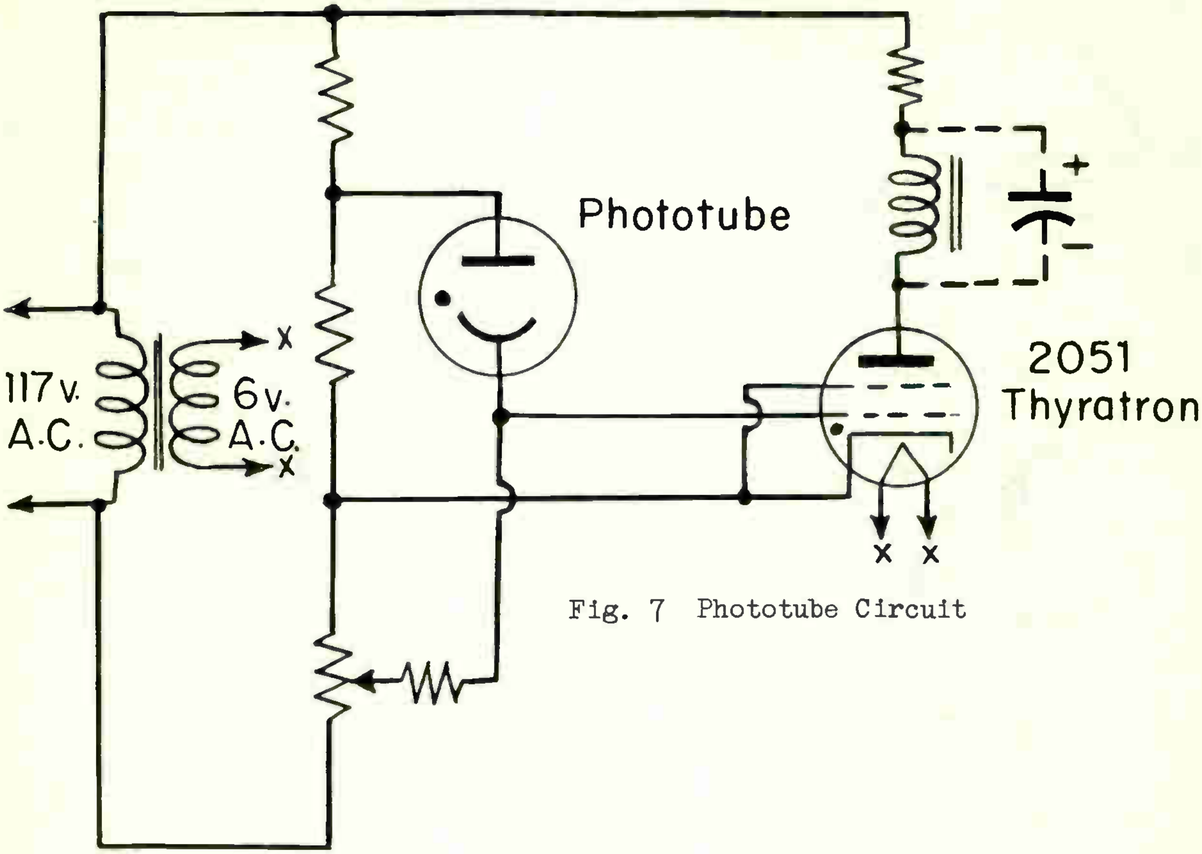



Fig. 7 Phototube Circuit

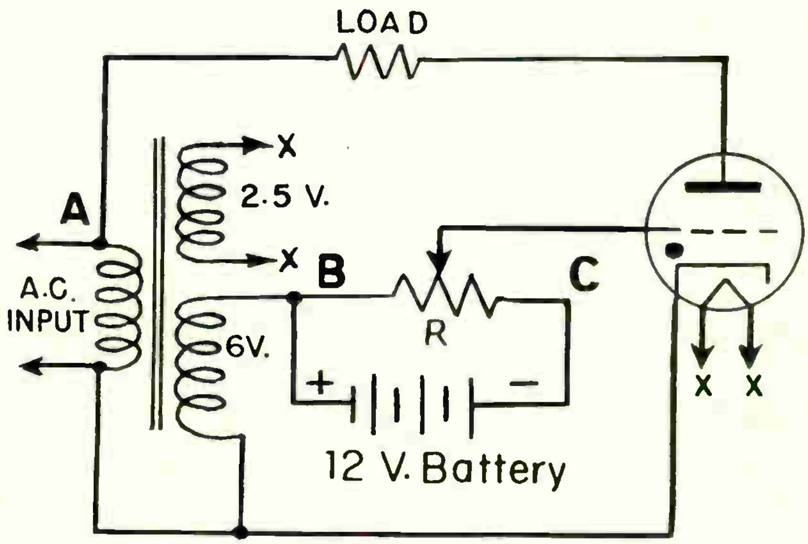
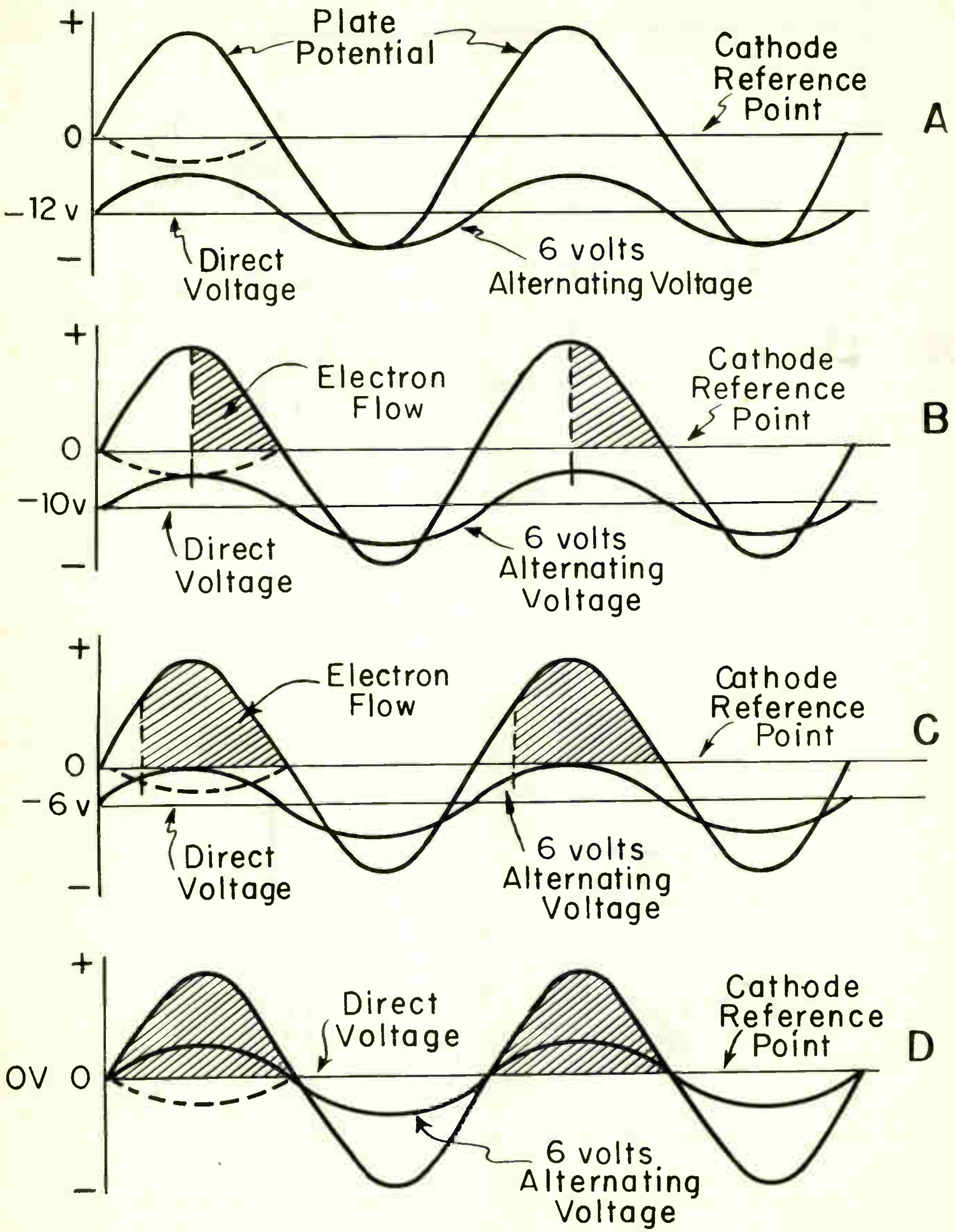



Fig. 8


+
Plate
Potential
Cathode
Reference
Point
A
0
-12 v
-
Direct
Voltage
6 volts
Alternating Voltage
+
Electron
Flow
Cathode
Reference
Point
B
0
-10v
-
Direct
Voltage
6 volts
Alternating
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Direct
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6 volts
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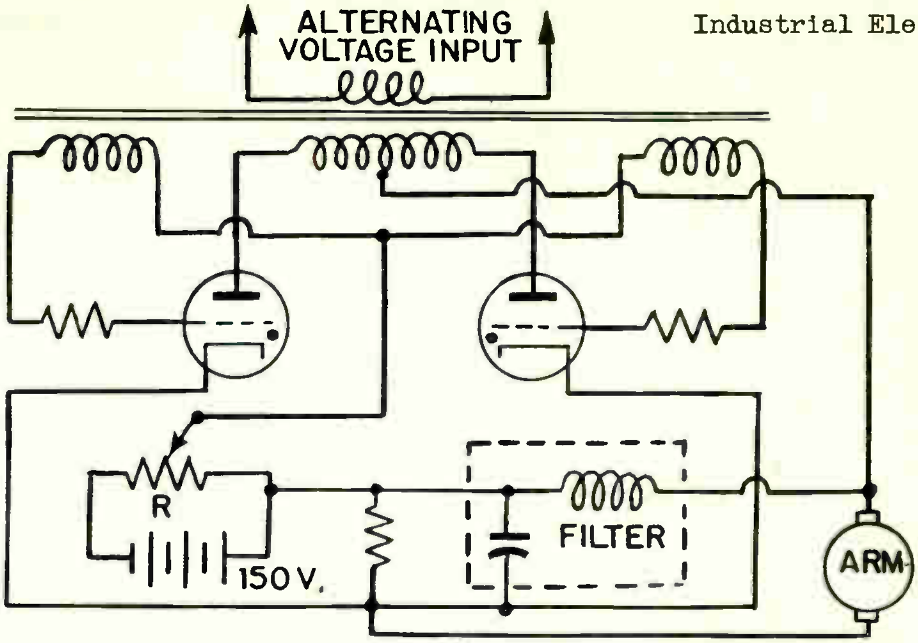
Fig. 9




towards point B. Making the direct grid voltage 2 volts less negative causes the 6 volt alternating voltage to become equal to the maximum critical voltage (bottom of the dotted curve) for the peak value of plate voltage. Plate electron flow will then occur during one-quarter of each cycle as indicated by the shaded area.

If the direct voltage on the grid is made still less negative, as in Fig 9C, then the plate electron flow will be turned on at an earlier time in the positive half-cycle and will continue until the plate voltage becomes zero.

For zero direct grid voltage, Fig 9D, plate electron flow occurs during the entire positive half cycle. It is apparent from Fig. 9 that changes of the direct grid potential will allow electron flow either during a complete positive half-cycle or during only half of the half-cycle. Electron flow cannot be reduced to periods less than quarter-cycles. In order to make the thyratron conduct for periods less than quarter cycles, a phase control circuit must be employed. Phase-shift control will be discussed in a later lesson.

Fig. 10 illustrates a circuit where a direct armature voltage is used to regulate the speed of a motor. The slider on resistor R selects the desired motor speed. If the slider were suddenly moved to the right, the position of the alternating grid-voltage curve could be raised and the resultant wave forms would change as from diagram B to diagram C of Fig. 9.

G. Summary Questions

1. Name three methods of starting electron flow in a thyratron.

2. With what type of control is it impossible to vary the thyratron plate electron flow by 90 electrical degrees?

3. Can the circuit in Fig. 8 control the electron flow through the thyratron for 180 electrical degrees? Why?

4. If the grid voltage is positive with reference to the plate voltage in the circuit of Fig. 4 can the starting time of the thyratron be controlled?

5. Why is it customary to apply an alternating potential to the plate of a thyratron rather than a direct potential?

# LIGHT SOURCES FOR PHOTOTUBE APPLICATIONS

## Objective

To become familiar with the theory of light systems as applied to photoelectric installations.

## References:

## Lesson Content

### A. General

A photoelectric system consists of a light sensitive photocell, an amplifier, relay, and a light source. Because a photocell depends upon a beam of light to produce a minute electrical current, a light source with an optical system is very important in order to obtain the maximum efficiency from any photoelectric system.

### B. Wave Length & Frequency

When waves of water move past the end of a pier, the waves are generally some distance apart. Fig. 1 illustrates one such wave at a distance of ten feet from another wave. The distance between these two waves is measured from the crest of one to the crest of the other. If one such wave passes point A during each second of time, the waves would then be traveling at a speed of ten feet per second. This wave is a sort of vibration in the water. The wavelength of this vibration would be ten feet, while its frequency would be one wave per second. If the wind changed so that the waves were only five feet apart, but traveled at the same speed of ten feet per second, twice as many waves must pass point A during each second, Fig. 2. The wavelength is now five feet and the frequency is two waves per second. Therefore as the wavelength decreased, the frequency increased, since the speed is unchanged.

Electromagnetic radiations travel through a conductor or through space in the same manner just explained. The speed of sound differs from the speed of light or electricity. At the present moment,primary interest is in the speed of light which travels at a speed of about 300,000,000 meters per second.

### C. Light and Color

The visible radiation called "light" is the band of frequencies that can be seen by the human eye. A light wave is shorter than one-millionth of a meter, so there are about 50,000 light waves to an inch. Each color of light has a different wave-length or frequency. Because wavelengths of light are so small, they are designated in; ANGSTROM UNITS or in MICRONS. One angstrom unit equals one ten-billionth of a meter. One micron equals 10,000 angstrom units. Fig. 3 illustrates a spectrum chart which indicates the wavelength and frequency of the various stages of the electronic spectrum.

Light is a form of energy which is emitted by and travels away from luminous bodies such as the sun and other various kinds of light sources. The flow of light energy is called the LUMINOUS FLUX. A light source may be thought of as emitting luminous flux which travels uniformly in all directions. The total quantity of luminous flux is measured in LUMENS. A large surface at a given distance from a light source will receive more luminous flux, or more lumens, than a smaller surface at the same distance, Fig. 4.

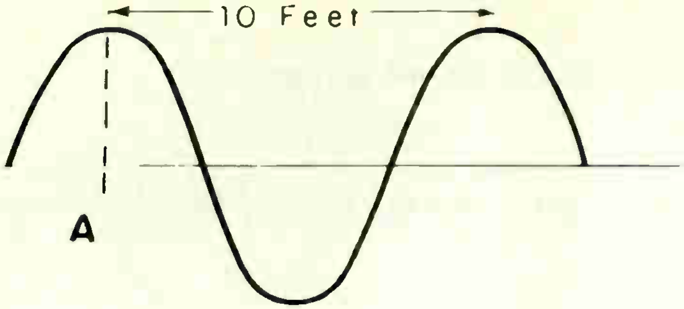



Fig. 1

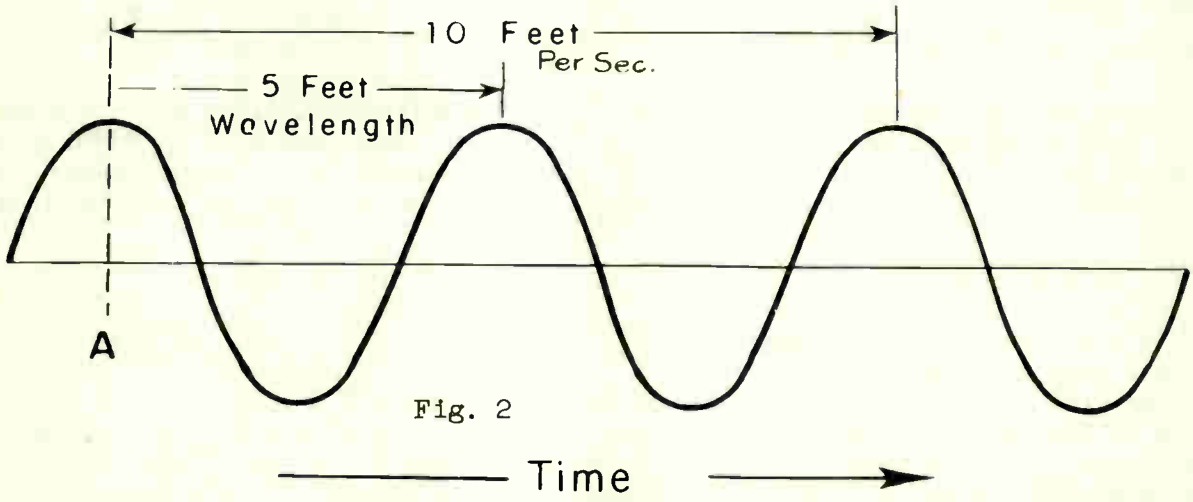



Fig. 2

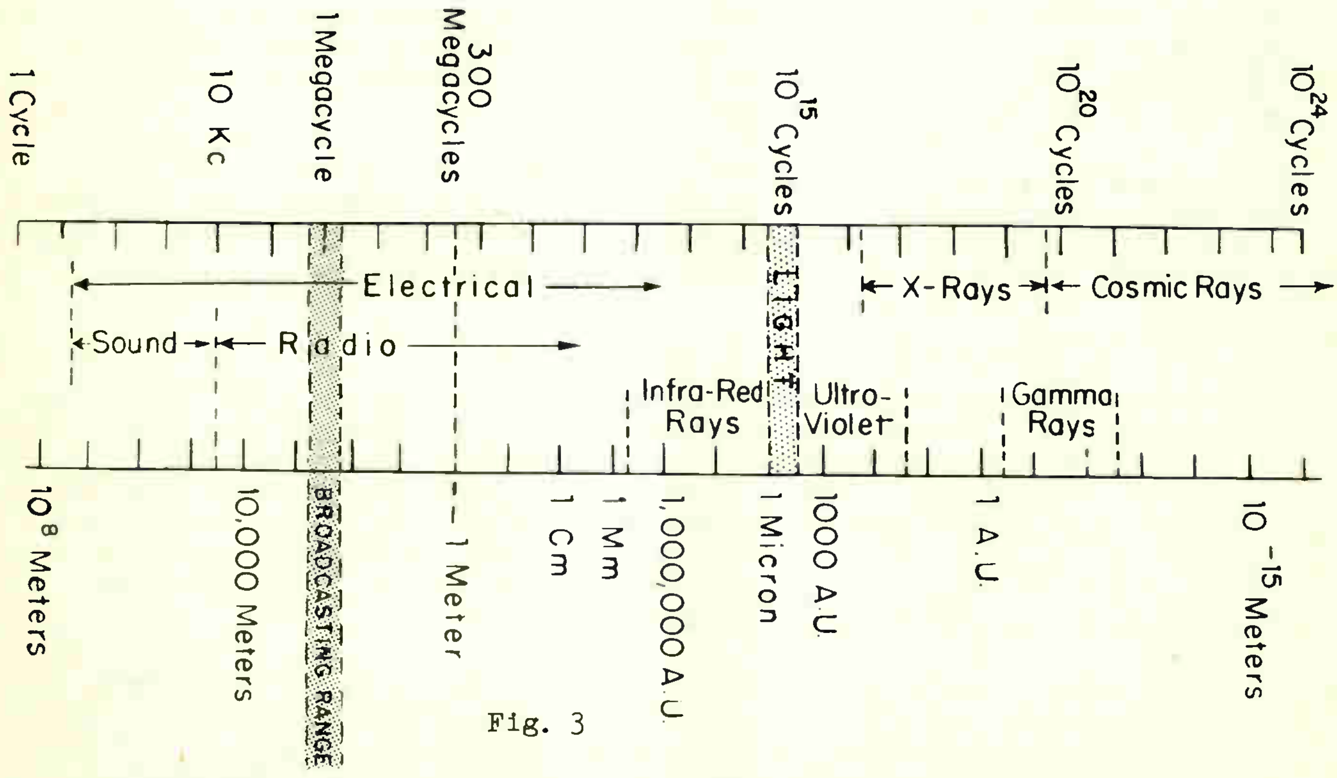



Fig. 3

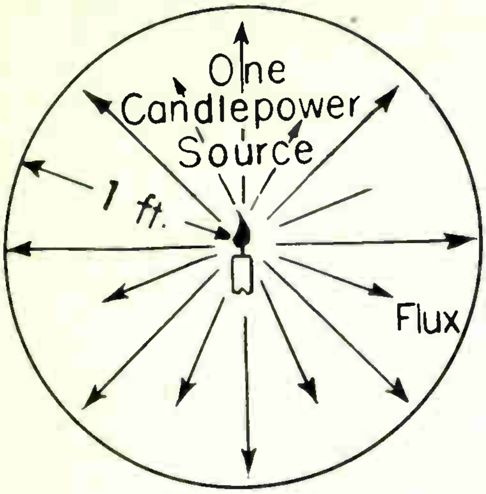



Fig. 4

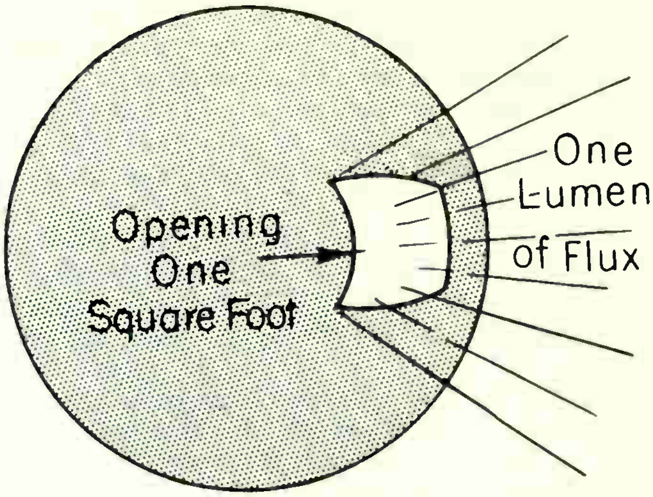



Fig. 5

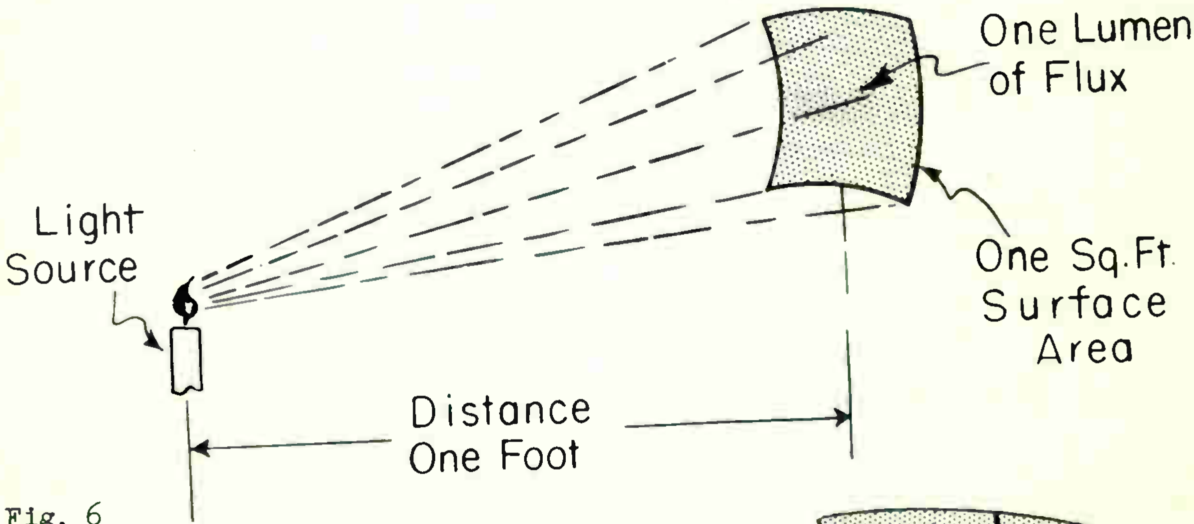



Fig. 6

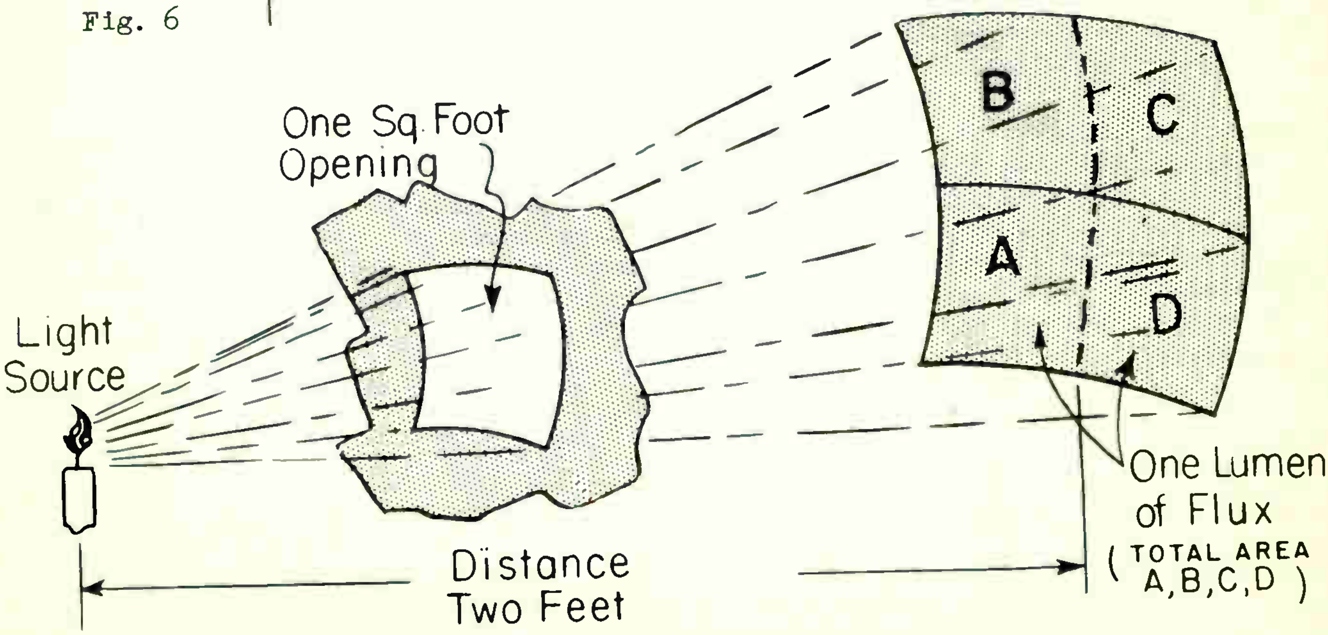



Fig. 7

The intensity of a light source is measured in CANDLEPOWER. One candlepower is the source of light from a standard candle. A source having an intensity of one candlepower emits a total luminous flux of 12.5664 lumens, or about 12.57 lumens on the total interior surface of the sphere. The reason is because the total interior area of a sphere of one foot radius is 12.57 square feet. Therefore, on each square foot there would be one lumen of flux.

If a square foot area were removed from the sphere as in Fig. 5, one lumen of flux would pass outwardly through this opening. This quantity of luminous flux would spread out thinner and thinner as it moved away from the opening, but no matter how thinly it would spread it still would be one lumen of flux.

The degree of lighting or illumination produced by a flux of one lumen on each square foot of surface within the interior of the sphere illustrated in Fig. 4, would be one foot candle. If one lumen of flux falls on the surface of Fig. 6, this surface being one foot from the light source and having an area of one square foot would have an illumination of one foot candle.

If the surface in Fig. 6 were considered to be an opening rather than a surface, one lumen of flux would pass through this opening. At a distance of two feet from the source the one lumen of flux would spread out to cover an area four times as great as the surface area in Fig. 6. One lumen of flux has actually spread over four times the area or one-fourth of a lumen exists on each surface area, lettered A, B, C and D of Fig. 7. This is an illumination of one-fourth footcandle upon the entire surface. Illumination in footcandles is equal to lumens per square foot.

Two following equations illustrate the relationship between footcandles, lumens, and the surface area covered.

1. $\text{FOOT CANDLES} = \dfrac{\text{lumens}}{\text{area in square feet}}$

2. LUMENS = Footcandles x area in square feet

Most light meters, such as those used in planning phototube installations, have scales marked in footcandles. If such a meter is situated in a position where a phototube is to be placed, and it registers a certain number of footcandles, it is really indicating the number of lumens per square foot.

Phototube cathodes and windows vary in area from about .02 to 2 square inches. By changing this size to square feet and multiplying it by the number of footcandles the meter indicates, the number of lumens of light flux which will reach the phototube cathode will be shown in Fig. 6 and 7, the two surface areas were respectively one and two feet away from the light source. The surface illuminations were one and one-fourth footcandles. The illumination of these two surfaces varied inversely as the squares of their distances from the light source. A formula then may be set up as follows.

$$\text{Intensity (varies as)} \ \frac{1}{(\text{Distance})^2}$$

The relative illumination of any two surfaces lighted by the same source therefore always vary inversely as the squares of the distances from the source.

Example: Two surfaces are situated, one at 12 inches and the other at 16 inches from a light source. The squares of 12 and 16 are 144 and 256. The inverse squares are 1/144 and 1/256 or .0069 and .0039, so the intensity

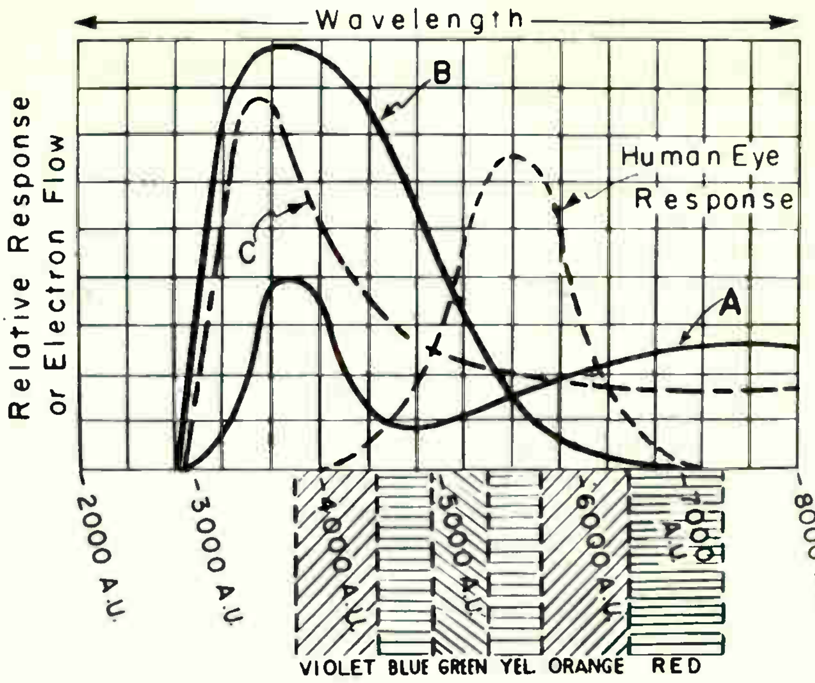

Wavelength
Relative Response or Electron Flow
B
C
A
Human Eye Response
2000 A.U.
3000 A.U.
4000 A.U.
5000 A.U.
6000 A.U.
7000 A.U.
8000 A.U.
VIOLET BLUE GREEN YEL. ORANGE RED

Fig. 8

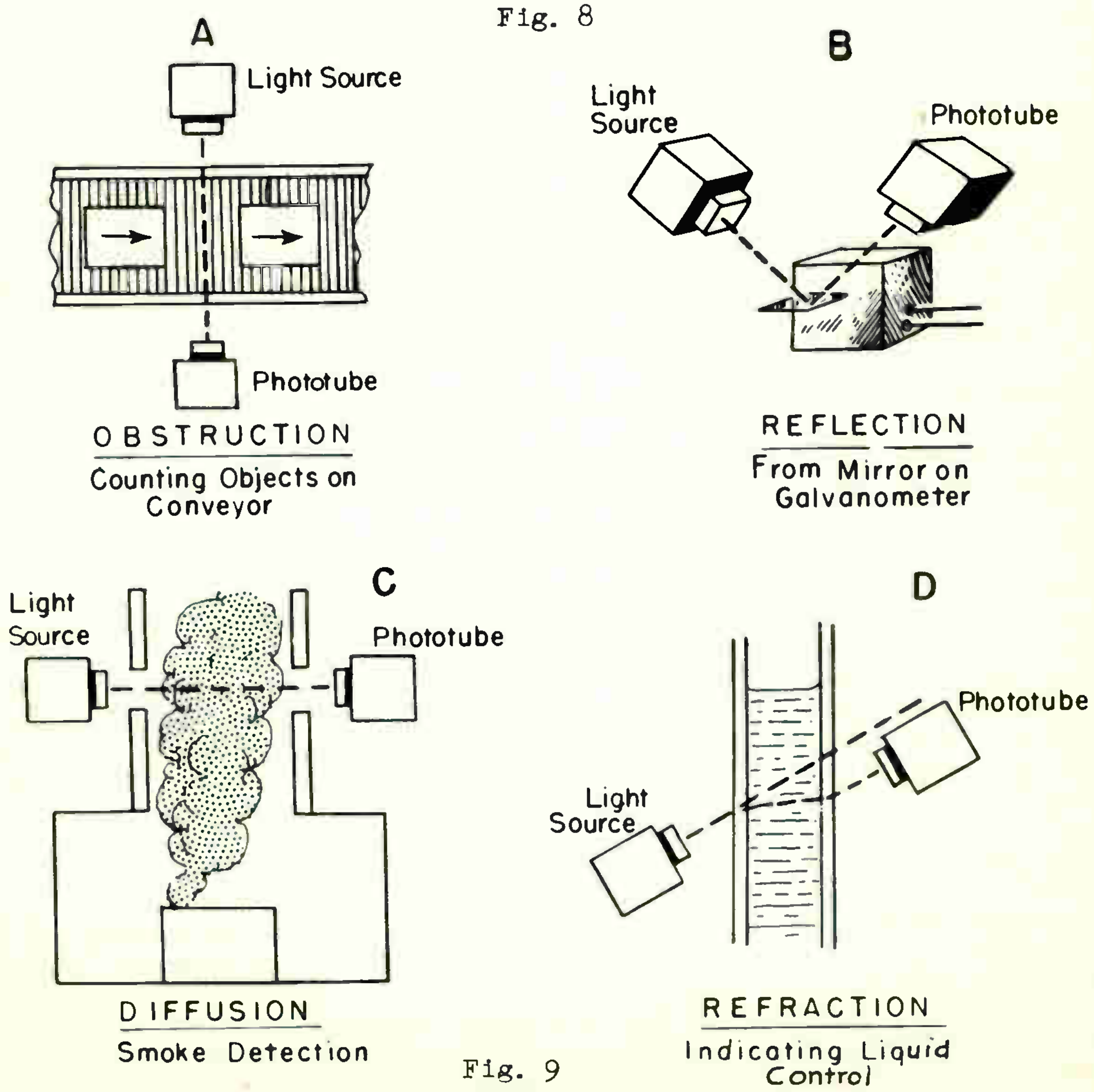

A
Light Source
Phototube
OBSTRUCTION
Counting Objects on Conveyor
B
Light Source
Phototube
REFLECTION
From Mirror on Galvanometer
C
Light Source
Phototube
DIFFUSION
Smoke Detection
D
Phototube
Light Source
REFRACTION
Indicating Liquid Control

Fig. 9

of illumination upon the surface at 12 inches would be 1.77 times as great as upon the one 16 inches away.

Since electron flow through a phototube is proportional to the light intensity upon the cathode, the proper illumination of this phototube cathode is an important factor in making a photoelectric device either operative or inoperative. Phototube electron flow also varies with the color of the light which strikes the cathode. Fig. 8 shows a chart which illustrates the response of various types of phototubes for equal energy of the different colors.

Referring to Fig. 8, note that color of light has a different wavelength or frequency. The wavelength of violet colored light is approximately 3800 to 4300 A.U. The human eye responds best to green or yellow light. The average human being cannot see or respond to a wavelength of light below 400 A.U. or above 7000 A.U. When the light rays of all the wavelengths between 400 and 7500 A.U. are mixed together in the right amount, the result is white light.

When light of different colors reaches a phototube, its cathode will emit different amounts of electrons. Curve A of Fig. 8 illustrates the amount of electron flow produced by various colors of light reaching a phototube whose cathode is responsive mostly to infra-red rays. Curves B and C of Fig. 8 illustrate how the cathode of phototubes coated with a different light sensitive material can be made responsive to different spectrums of light.

D. Practical Applications

For a definite application, the light intensity and the optical system must remain constant if the phototube response is to be constant. This means that the light source, lens mirror and phototube must not move with respect to each other and must be kept clean. Undesired fog, smoke, steam, or vapor must not pass through the light beam. The more light, within the rating of the phototube, which is available, the more reliable is the operation of the photoelectric equipment.

The change of light may be affected by:

1. Obstruction - counting opaque objects, limit switch, etc.
2. Reflection - operation from printed matter, sensitive gauges, etc.
3. Diffusion - by fog, smoke, turbidity, etc.
4. Refraction - control of liquid level, etc.

Fig. 9 illustrates the typical photoelectric applications just mentioned.

The most practical light source for photoelectric use has proved to be the lamp bulb used in automobile head-lights. These lamps contain a rugged concentrated filament, accurately spaced in the bulb. The bulbs are designed for a life of one or two hundred hours at six volts input. Transformers are used to reduce the usual alternating line voltage to the voltage required for the lamp.

E. Summary Questions

1. Are light wavelengths shorter or longer than radio frequency wavelengths?
2. A light has a wavelength of .001 micron. What is the wavelength in angstrom units?
3. Name four ways by which the change of light may be effected?
4. What unit of measurement is used to designate the intensity of light?
5. What unit of measurement is used to designate light flux?

# PHOTOCELLS

## Objective

To become familiar with the basic theory of the various types of photocells used in electronic industries.

## References

## Lesson Content

A. General

The photocell is the Seeing Eye of Electronics. Its ability to translate light into electric current makes it applicable to a wide variety of uses. It is to light what the microphone is to sound.

More than one type of cell is used as a pick-up for light signals. There are three types of photocells.

1. The photoconductive cell (Selenium resistance cell)
2. The photovoltaic cell (barrier layer group, usually composed of copper-oxide rectifier cell and selenium rectifier cell)
3. The photoemissive cell (tube types of emissive cell)

The following paragraphs will explain more in detail the construction and theory of the various types mentioned.

B. The Photoconductive Cell

Fig. 1 illustrates simplified breakdown view of a selenium photoconductive cell.

This type of cell is constructed as follows:

A conductive material is deposited on a piece of glass and a zigzag line is engraved across this material from one end of the glass to the other end. This engraved line separates the conductive coating and forms two electrodes. Crystalized selenium is then applied. This crystalized selenium connects the two electrodes and forms the selenium resistance cell. A protective coating is generally applied over the entire cell to protect it from various weather conditions and then the cell is enclosed in a protective casing usually made of bakelite to protect it against physical abuse.

Ordinarily, selenium has a resistance estimated at 4,500 million times that of copper and acts as an insulator. In order to use it for constructing a photoconductive cell it must be crystalized. The selenium is crystalized by controlled temperatures. The resistance of the selenium then lowers considerably and takes on the property of lowering its resistance when exposed to light.

Fig. 2 illustrates a basic curcuit of how light is used with a photoconductive cell to control a motor or any other type of device.

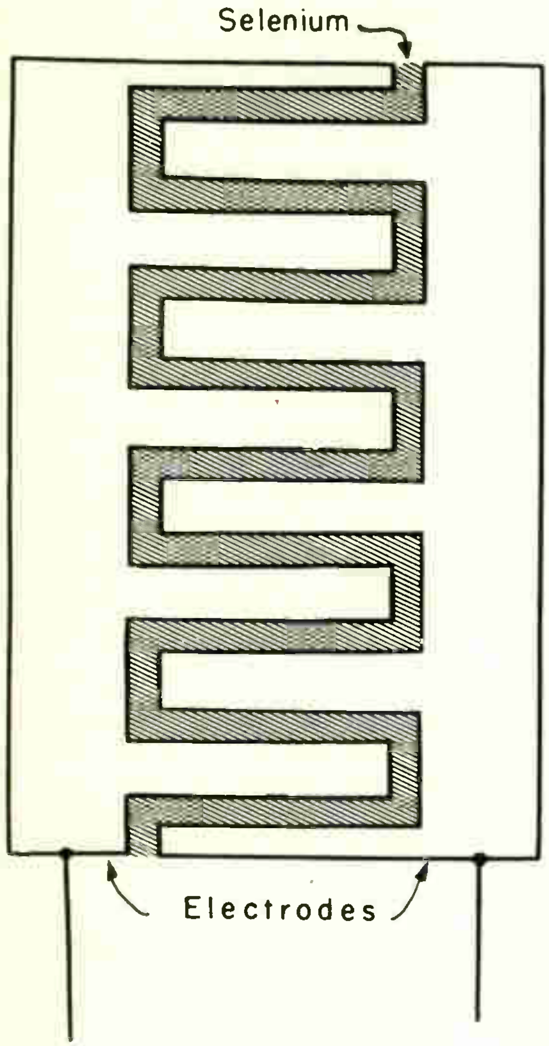



Fig. 1

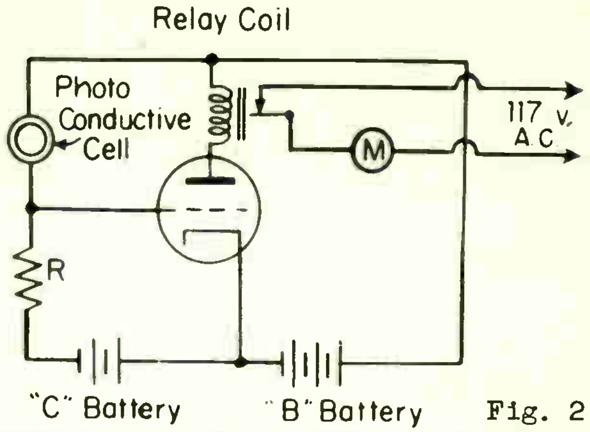



Fig. 2

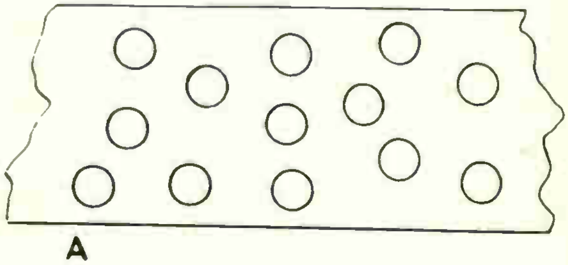



Fig. 3

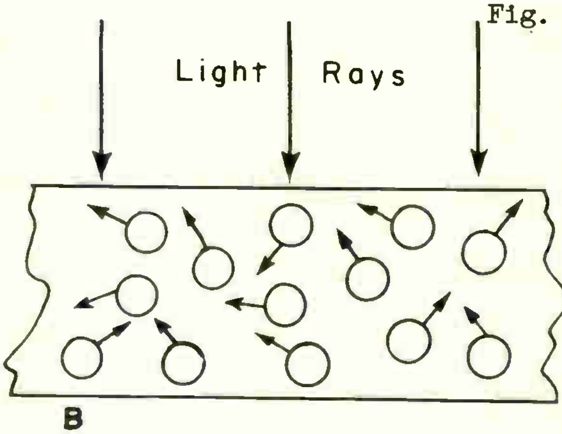



Fig. 4

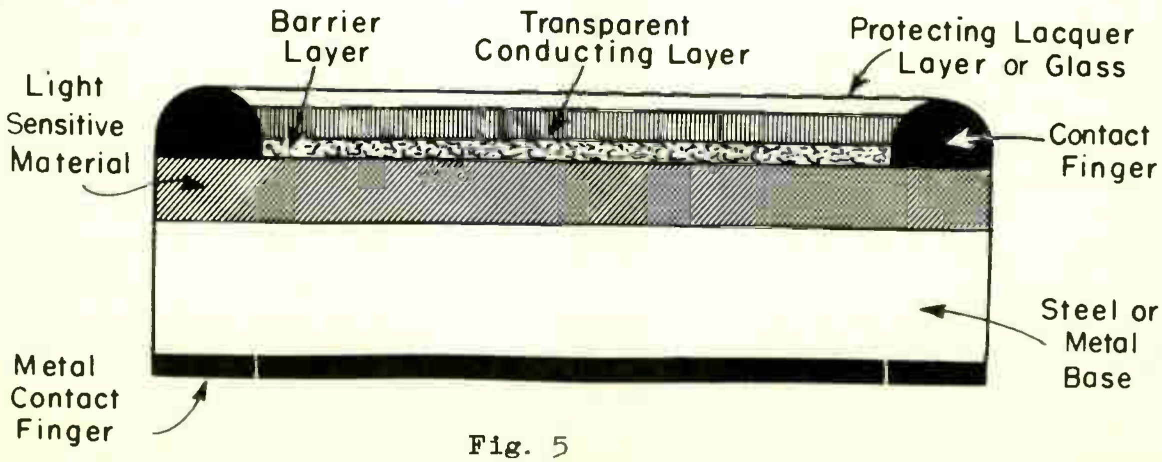



Fig. 5

The relay and the applied voltages used depend upon the tube characteristics of the pliotron. The value of resistor R is chosen so that when light reaches a certain intensity upon the conductive cell,enough electrons will flow through the photoconductive cell and resistor R, to cause the grid of pliotron tube to become less negative in respect to the cathode and allow plate electron flow through the tube. The electron flow through the tube passes through the relay coil and the relay becomes energized. The relay contacts serve the purpose of a single pole switch. Once these contacts close, the motor circuit is completed and the motor becomes energized.

When the photoconductive cell is exposed to light rays it decreases its resistance. The terms "light resistance" and "dark resistance" are used often by manufacturers of these cells. The approximate dark resistance of a photoconductive cell is about 40 million ohms. With the cell exposed to light, the light resistance varies according to the light intensity from one million to two million ohms. What occurs within the cell itself is illustrated in Figs. 3A and 3B.

Fig. 3A illustrates the cross-sectional view of the crystalized selenium with no light upon it. The small circles illustrate the atomic structure within this material when it is in total darkness. Fig. 3B illustrates the cross-sectional view of the crystalized selenium when exposed to light. The small arrows indicate that the atoms are in motion. The theory as to what happens within the cell itself when exposed to light is as follows.

Due to the ultra-high frequency of light waves, when light strikes the photoconductive cell it causes the atoms of the crystalized selenium to shift or move from their original positions. Because of this agitation of the atom structure of the selenium, an easier path is provided for electrons to drift from atom to atom.

C. The Photovoltaic Cell

When using a photoconductive type of cell,an external voltage source must be used to force electrons through the resistance of the cell, which varies according to light intensity.

A photovoltaic cell generates its own voltage. The greater the intensity of light upon the cell, the greater the potential which will be generated by the cell.

Fig. 4 illustrates a greatly enlarged cross sectional view of one of several photovoltaic cells produced by manufacturers. This type of cell is constructed by first depositing a light sensitive material upon a chemically treated piece of iron or steel. The light sensitive material is then coated with layers of secret composition of conducting metals. This composition contains certain alloys and precious metals including, at times, gold and platinum. The layers of this material are so thin that they are actually transparent although made of metal.

The photovoltaic type of cell is suitable for operating meters and super-sensitive relays without the use of any external source of voltage.

When light strikes the cell, electrons are given sufficient energy from this light to penetrate the thin barrier composition of conducting metals and thus builds up sufficient voltage across the cell to cause electrons to flow through an external circuit.

When using the photovoltaic type of cell in constructing a photo-exposure meter, the meter movement is connected to the cell as shown in Fig. 5.

Light striking the cell generates a voltage which causes electrons to flow through the small moving coil, to which is fixed the instrument magnet. Electrons passing through the moving coil set up a field which interacts with the magnetic field of the permanent magnet and causes the coil to turn in proportion to the intensity of the light.

The average photovoltaic cell generates approximately $3\frac{1}{2}$ micro-amperes for each footcandle of light intensity.

Fig. 6 illustrates the parts which make up a photovoltaic cell.

D. Photoemissive Cell

The mechanical and electrical arrangement of a cell of the modern photoemissive type is shown in Fig. 7. The plate generally consists of a metal rod or loop. The plate is shaped in this manner so that light may pass on its way to the cathode with very little obstruction from the surface area of the plate. The cathode consists of a metal plate formed as part of a cylinder. The inner surface of the cathode is generally coated with one of the light sensitive materials.

1. /Caesium
2. Rubidium
3. Potassium
4. Barium
5. Sodium
6. Strontium
7. Lithium
8. Calcium

When light reaches this sensitive material it will emit electrons much in the same way that a hot cathode surface emits electrons when heated.

Other phototubes are constructed with the light sensitive cathode material deposited on the inside of the glass bulb as illustrated in Fig. 8A and 8B. Light enters these types of phototubes through a clear glass area on one side of the glass bulb.

All common styles of phototubes have bases and base prongs which fit into sockets similar to those used for radio work. Since a phototube consists of only two electrodes, the cathode and plate, the extra base prongs are for additional support of the tube. There are two types of photoemissive tubes

1. Gas - the presence, of a small amount of inert gas in a phototube envelope increases the tube's sensitivity, or in other words, the gas increases the number of electrons passing through the phototube for a given amount of cathode illumination. The luminous sensitivity of a gas phototube is increased because free electrons moving from cathode to plate colide with gas atoms within the tube envelope. When such a collision occurs the electron disrupts the atom, and knocks an electron out of its orbit. The atom, minus one electron, becomes a POSITIVE ion. This disruption of the atom increases the electron flow through the tube because the dislodged electron is attracted toward the plate.

2. High vacuum - these types of phototubes have the air evacuated from their envelopes and therefore have a high internal resistance, more constant luminous

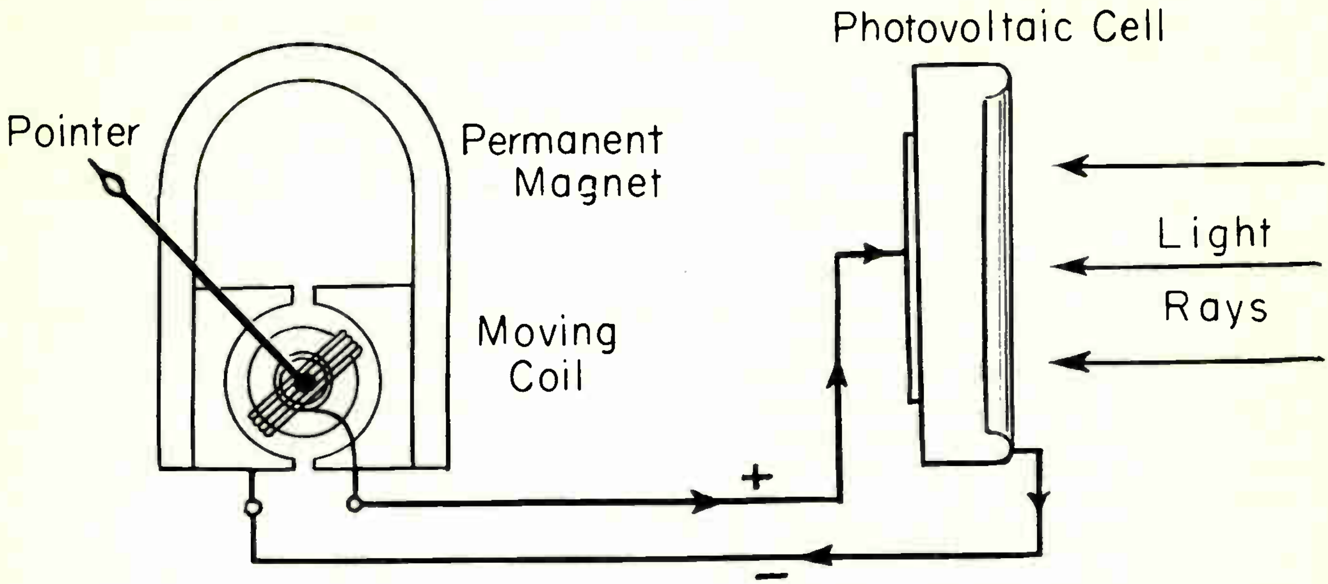



Fig. 5


WESTON PHOTRONIC PHOTOELECTRIC CELL AND ITS COMPONENT PARTS—MODEL 594

Fig. 6

sensitivity and are less likely to be damaged by accidental operation at higher than rated voltages.

Fig. 9 illustrates a chart which indicates the difference in luminous sensitivity existing between a gas and vacuum phototube. Both tube cathodes received one lumen of light. The curves plotted indicate the increases of electron flow in proportion with the increase of plate voltage.

Referring to the chart of Fig. 9, if the voltage or electron flow rating of a gas phototube is exceeded, a gas discharge may occur. This discharge can be identified by a faint blue glow within the tube envelope when in operation. Once this discharge is started it will continue independently of the illumination on the phototube. The plate voltage applied to a gas phototube as a rule should not exceed 90 volts. If a glow occurs, the plate voltage should be immediately disconnected in order to prevent permanent damage to the tube.

E. Color Frequency Response Ranges

The choice of phototube used depends upon its application in a circuit. The phototube can be used to distinguish various colors and the sensitivity of a phototube to certain colors will vary with the light sensitive material with which the cathode is coated.

The spectral sensitivity graphs of Fig. 10 illustrate the various color frequency response of various phototubes, having different cathode coatings.

F. Phototube Characteristics

The chart below lists a number of typical phototubes used in electronic circuits and their characteristics.

| TYPE NO. | GAS OR VACUUM | SPECTRAL RESPONSE RMA STANDARD | ANODE VOLTS | SENSITIVITY IN MICRO-AMPS PER LUMEN | MAXIMUM AMBIENT TEMPERATURE CENTIGRADE |
|---|---|---|---|---|---|
| GL-1P29/FG-401 | Gas | S3 | 90 | - | 100 |
| PJ-22 | Vacuum | S1 | 500 | 20 | 100 |
| FJ-405 | Vacuum | S6 | 200 | - | 50 |
| GL-441 | Vacuum | S4 | 250 | 45 | 50 |
| GL-868/PF-23 | Gas | S1 | 90 | 50 | 100 |
| GL-917 | Vacuum | S1 | 500 | 20 | 100 |
| GL-918 | Gas | S1 | 90 | 110 | 100 |
| GL-919 | Vacuum | S1 | 500 | 20 | 100 |
| GL-920 | Gas | S1 | 90 | 75 | 100 |
| GL-921 | Gas | S1 | 90 | 135 | 100 |
| GL-922 | Vacuum | S1 | 500 | 20 | 100 |
| GL-923 | Gas | S1 | 90 | 135 | 100 |
| GL-927 | Gas | S1 | 90 | 125 | 100 |
| GL-929 | Vacuum | S4 | 250 | 45 | 100 |
| GL-930 | Gas | S1 | 90 | 135 | 100 |
| GL-931-A | Vacuum | S4 | 1250 | 2.0 amperes | 50 |
| GL-935 | Vacuum | S4 | 250 | 30 | 50 |

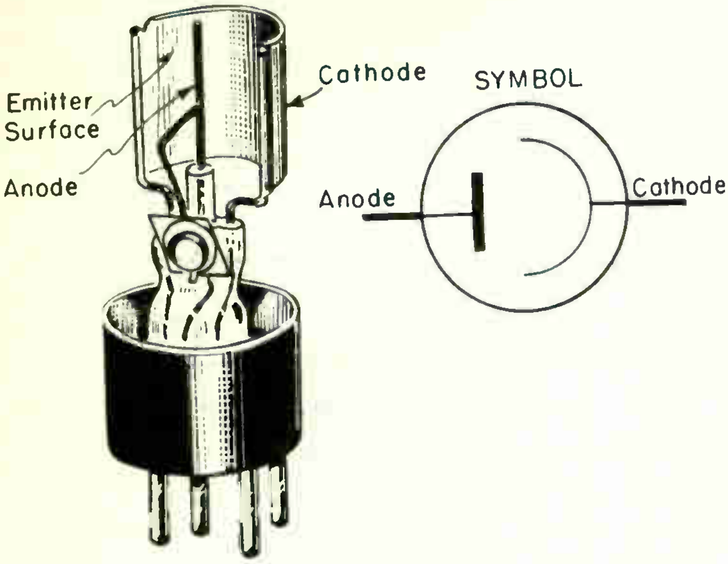



Fig. 7

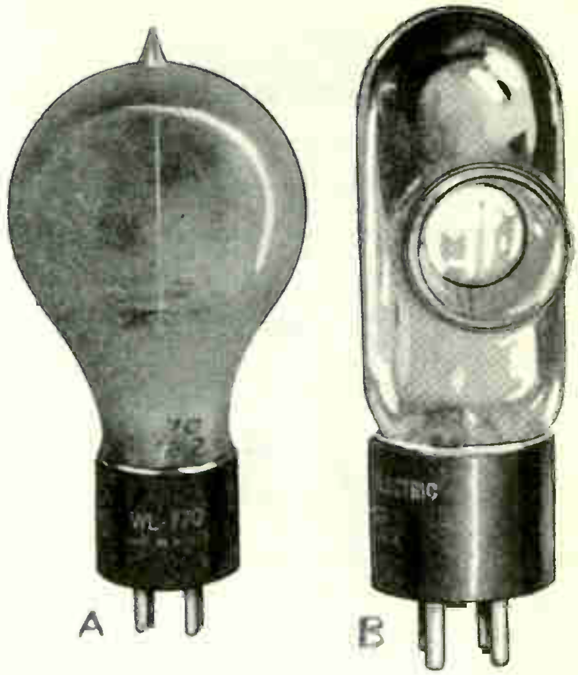



Fig. 8

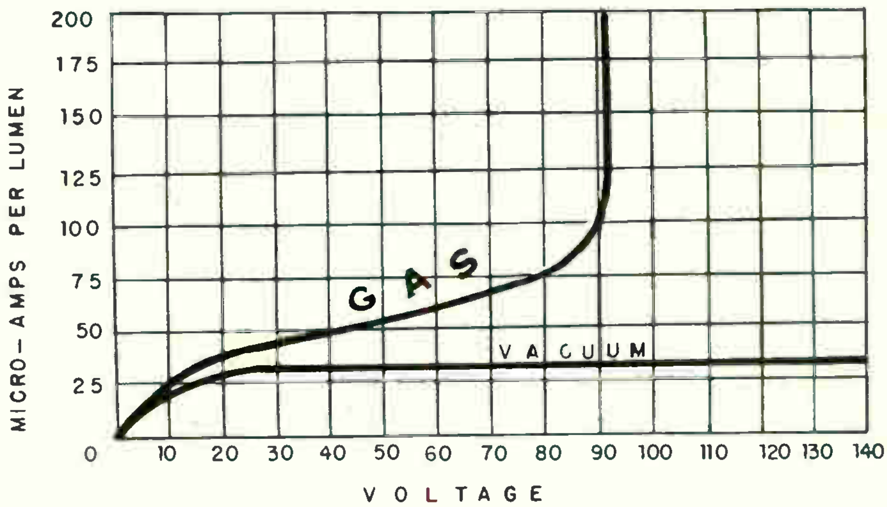



Fig. 9

G. Summary Questions

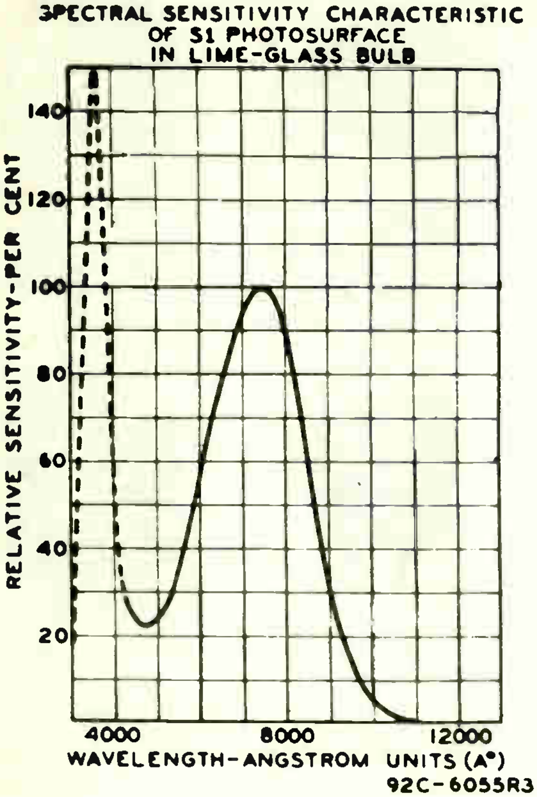
1. What type of photocell does not need an external source of voltage for operation?

2. Name three practical uses of a photovoltaic cell.

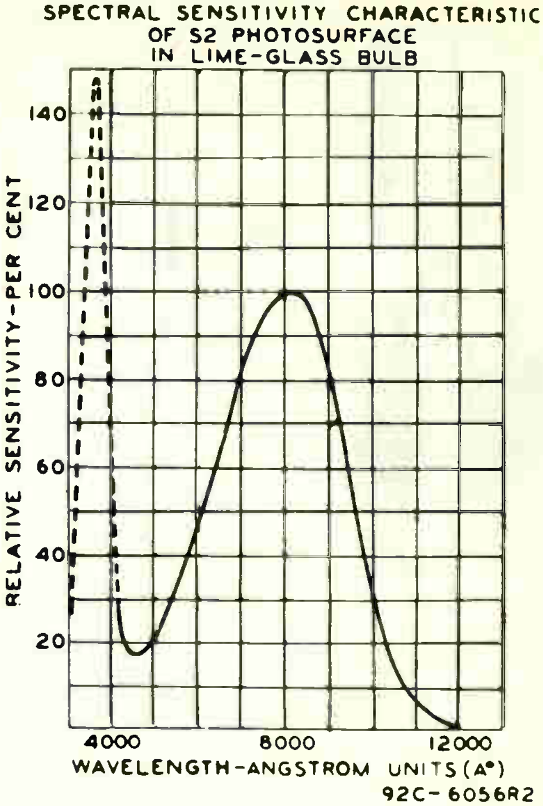
3. What advantage does a vacuum phototube have over a gas phototube?

4. What determines the spectral sensitivity of a photoemissive phototube?

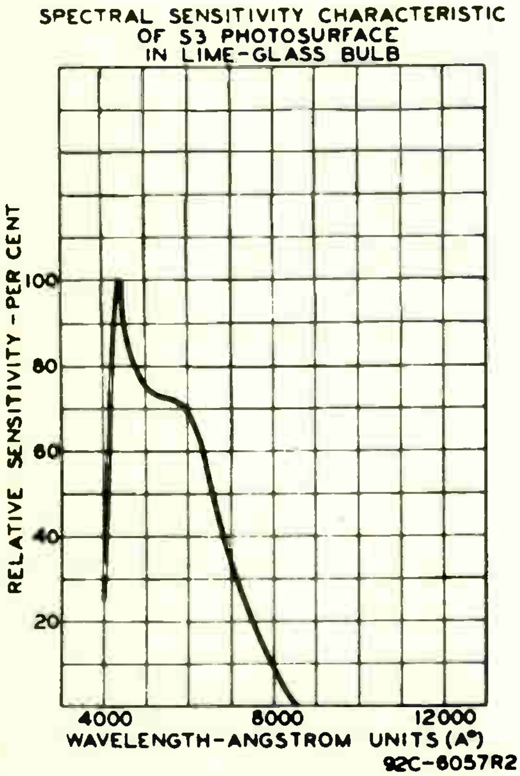
5. What type of cathode surface is most sensitive to infra-red rays?



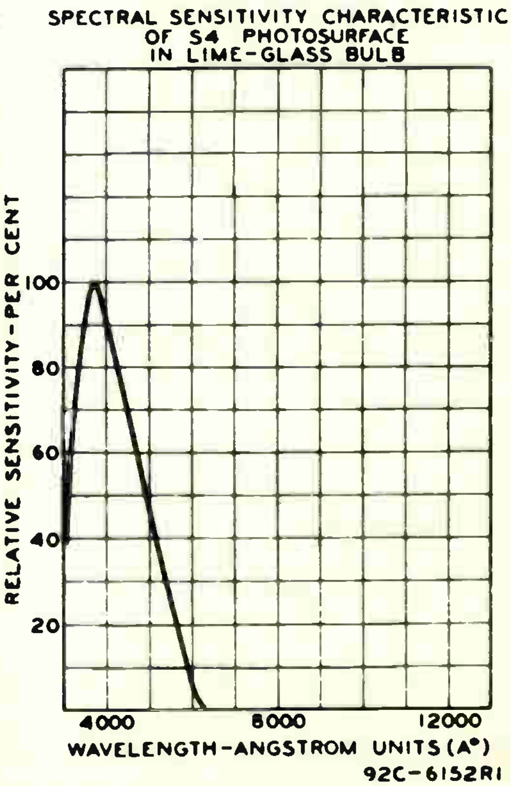

C-1




C-2




C-3




C-4

Fig. 10

# PHOTO-ELECTRIC CIRCUIT ANALYSIS

## Objective

To become familiar with the basic theory of photo-electric circuits and their use in industry.

## References

## Lesson Content

### A. General

Photo-electrics, several years ago was a highly specialized subject, interesting only to the physicist. Today every practical electrician needs a knowledge of this subject. Photo-electrics is a highly important and special part of electronics in industry.

A phototube is used in a circuit to transfer changes of light intensity into varying changes of electron flow through a resistor which in turn will cause varying changes of voltage across this resistor. This variation in voltage in turn is applied between the cathode and grid of either a vacuum tube or a thyratron tube which controls a relay. The relay contacts serve the purpose of a switch which controls the load circuit. The phototube control devices discussed in this lesson are ones of moderate sensitivity and speed and are operated with power from alternating power and lighting lines without the use of a rectifier.

### B. Types of Circuits

A photo-electric circuit is classified as either a forward circuit or a reverse circuit.

1. Forward circuit

A forward circuit is one in which light, or an increase of light, on the phototube cathode will cause plate electron flow or an increased plate electron flow through the amplifier tube. Fig. 1 illustrates a basic forward circuit.

In Fig. 1, during the positive alternation of the alternating input voltage the phototube electron flow will cause a difference of potential across resistor R, in such a manner that the grid of the amplifier tube V1 will become less negative with reference to its cathode. With its grid less negative with reference to its cathode, V1 electron flow will increase with an increase in light. The electron flow through V1 can be great enough to energize a sensitive magnetic relay.

2. Reverse circuit

A reverse circuit is one in which light, or an increase of ligh on the phototube cathode causes electron flow through the amplifier tube to decrease or stop. Fig. 2 illustrates a basic reverse phototube circuit.

In Fig. 2, during the negative alternation of the input voltage, the phototube electron flow causes a voltage drop across resistor, R, in such a manner as to decrease or stop electron flow through V1.

The basic circuits shown in Fig. 1 and 2 provide a way of distinguishing between forward and reverse circuits. That is, by assuming light rays are striking the phototube cathode and checking the direction of movement of electrons emitted by the cathode through the grid resistor, R, it can easily be determined whether the voltage drop across this resistor causes the control grid of an amplifier tube to become less negative or more negative with reference to its cathode. If the control grid becomes less negative with reference to the cathode, forward action is taking place. If the control grid becomes more negative with reference to the cathode, reverse action is taking place. After once it has been determined whether the circuit is forward or reverse, the complete basic circuit operation can be easily analyzed.

C. Applications

There is an almost endless variety of circuit arrangements used in various photoelectric apparatus. This variety results from the use of forward or reverse circuits, of relays of one type or another, of either vacuum or gas-filled phototubes, and of either vacuum amplifiers or thyratrons. To become further acquainted with the most commonly employed circuits, in this lesson, three types of phototube circuits will be explained thoroughly.

1. Amplitude controlled forward phototube circuit analysis.

Fig. 3 illustrates the schematic diagram of a forward phototube circuit operated directly from the 117 volt power source. Tube V1 is a gas-filled, shield-grid, thyratron. The shield-grid is connected directly to the cathode through a jumper on the tube socket so that this electrode will be at cathode potential.

Fig. 4 is a simplified diagram illustrating how the amplitude of the grid voltage is varied with reference to the cathode.

By varying the resistance between points B and C any amplitude of voltage from zero to 6.3 volts can be applied between the grid and cathode. In this particular circuit the contact arm of R2 must be set at a point so that the amplitude of the voltage applied across the grid and cathode is just below the critical grid potential of the tube, V1. This setting may be accomplished by observing the ionization of the gas within the tube and rotating contact arm R2 until the bluish glow disappears.

Fig. 5 illustrates the equivalent circuit paths existing during one complete cycle of input voltage. During the positive alternation of input voltage, the

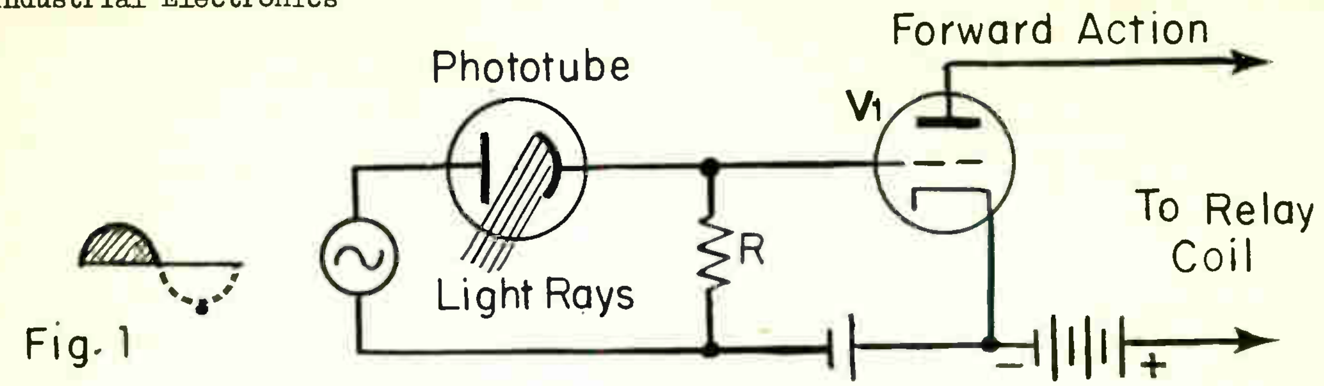



Fig. 1

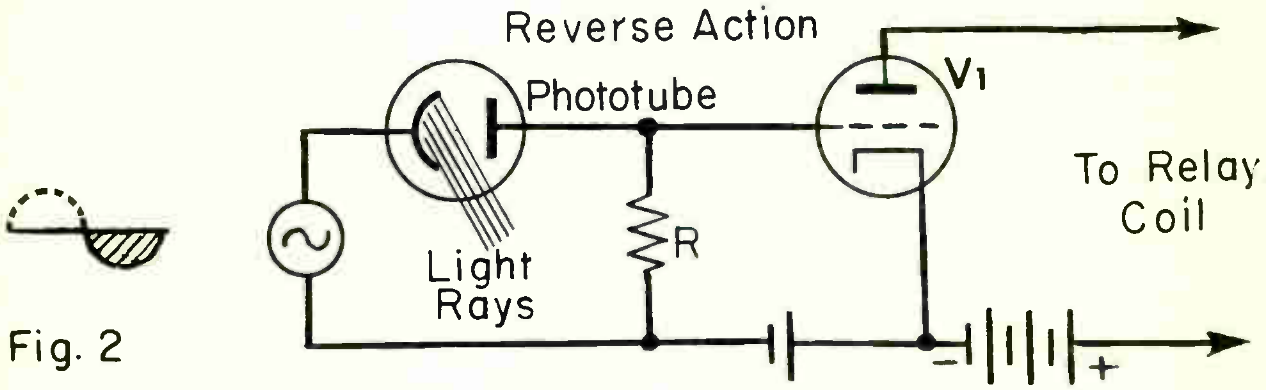



Fig. 2

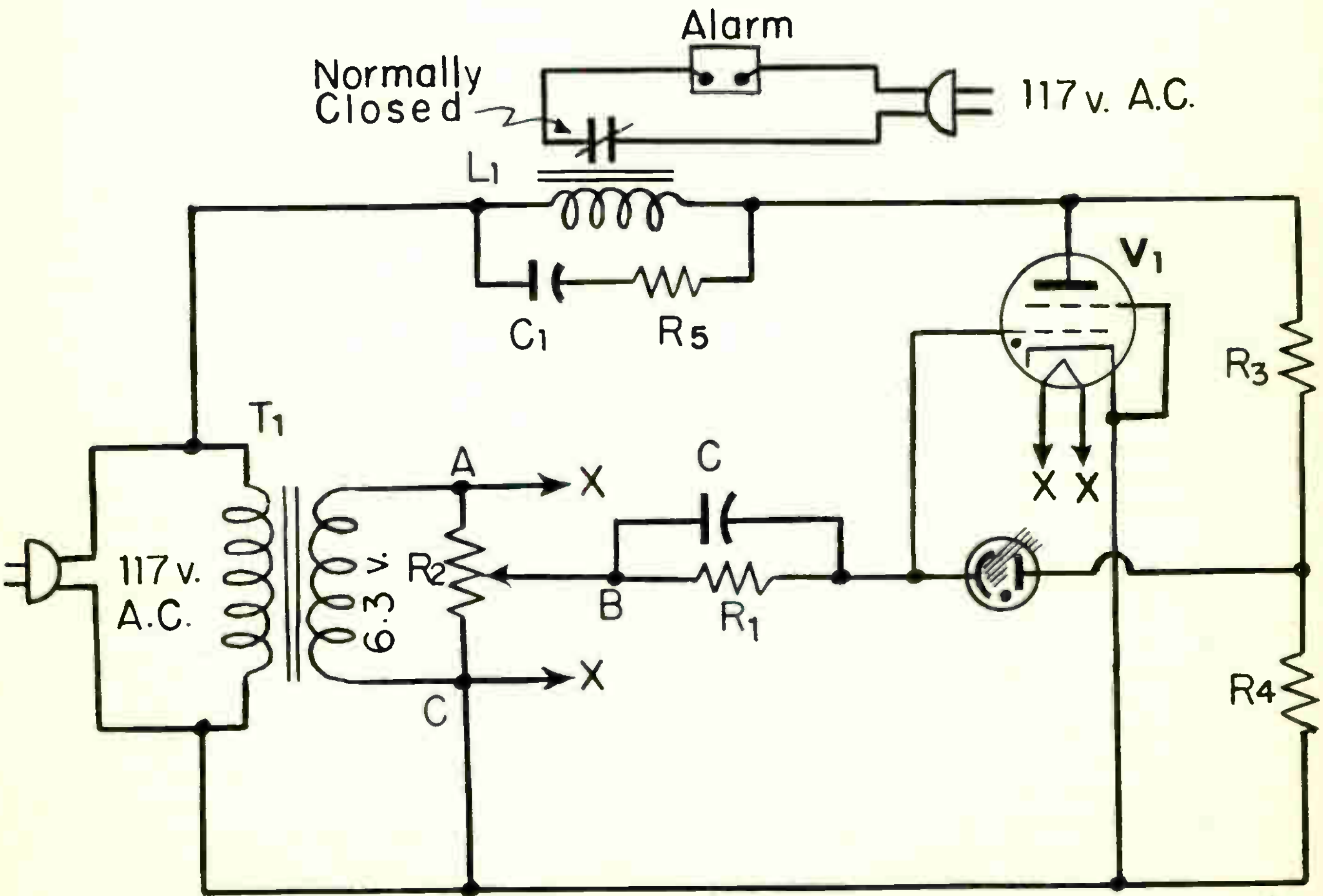



Fig. 3 Forward Phototube Circuit (Amplitude Controlled)

voltage drops across R3 and R4 supply the plate potential for the thyratron. The phototube plate voltage is supplied by the potential drop across R4 plus whatever the voltage drop is between points B and C (Fig. 6). The upper, positive, end of R4 is connected to the phototube plate and its lower, negative end is connected through the adjustable voltage divider R2 and resistor R1 to the phototube cathode.

When light rays reach the phototube cathode, the phototube electron flow through resistor R1 will cause the grid of the thyratron to become less negative. This will balance or cancel part of the negative grid bias which was applied to the grid previously and cause the thyratron to conduct. Fig. 7 illustrates the equivalent circuit the instant light strikes the phototube cathode.

Fig. 8 illustrates the equivalent thyratron tube circuit the instant the grid potential of the thyratron becomes sufficiently less negative to permit electron flow through the tube.

Capacitor C in Fig. 3 stabilizes the operation of this circuit in which the voltages and electron flow is pulsating. Although the resistor-capacitor combination of R1 and C may appear like a time-delay arrangement, it does not act so because of its exceedingly short time constant.

Capacitor C1 is a "smoothing capacitor". Since the electro-magnetic relay tends to drop out during the half cycles when there is no electron flow through its coil there is quite likely to be chattering or vibration of the relay armature to an extent that the contacts may be damaged or electron flow in the external load circuit partially or wholly interrupted. Such chattering may be prevented by a smoothing capacitor of suitable capacitance. The purpose of resistor R5 in series with the smoothing capacitor is to limit the instantaneous surge of electron flow at the time capacitor C1 charges.

2. Amplitude controlled reverse phototube circuit analysis.

Fig. 9 illustrates the schematic diagram of a reverse phototube circuit. The same type of thyratron tube is used as in the circuit of Fig. 3.

In the circuit of Fig. 9, note a positive bias is obtained from a voltage divider connected directly across the alternating potential source. The use of a power transformer is actually not necessary providing some means of proper voltage is obtained for the filament of the thyratron tube, V1. A resistor R6 can be used to drop the 117 volt alternating voltage to the desired filament voltage as shown in Fig. 9,or a filament transformer can be used.

For the proper operation of this circuit the moving contact arm of R3 must be set at a position so that tube V1 will not conduct when light rays strike the cathode of the phototube and will conduct with the light intensity decreased or completely cut-off. The exact setting of the contact arm of R3 will vary and will depend upon the intensity of light which the phototube cathode will be exposed to. Fig. 10A illustrates the equivalent circuit of how the grid bias is obtained for tube V1. During the positive alternation of input voltage, and with no light upon the phototube cathode, the polarity of the voltage drops across resistors R2, R3, and R4 would be such as to make the control grid of V1 positive with reference to the cathode. Tube V1 will therefore conduct, during every positive alternation of input voltage.

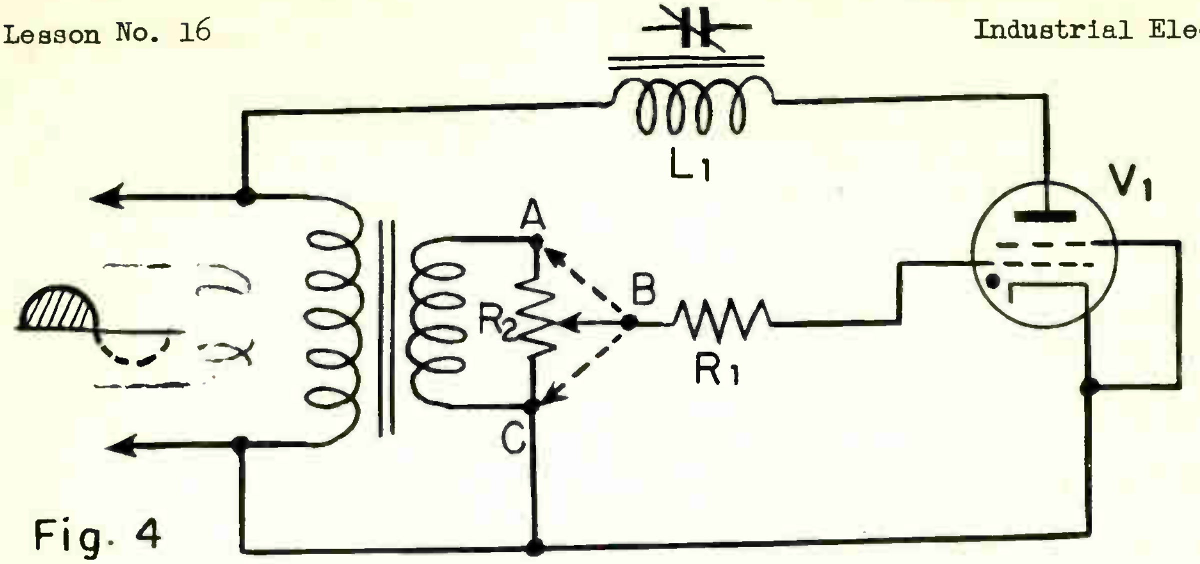



Fig. 4

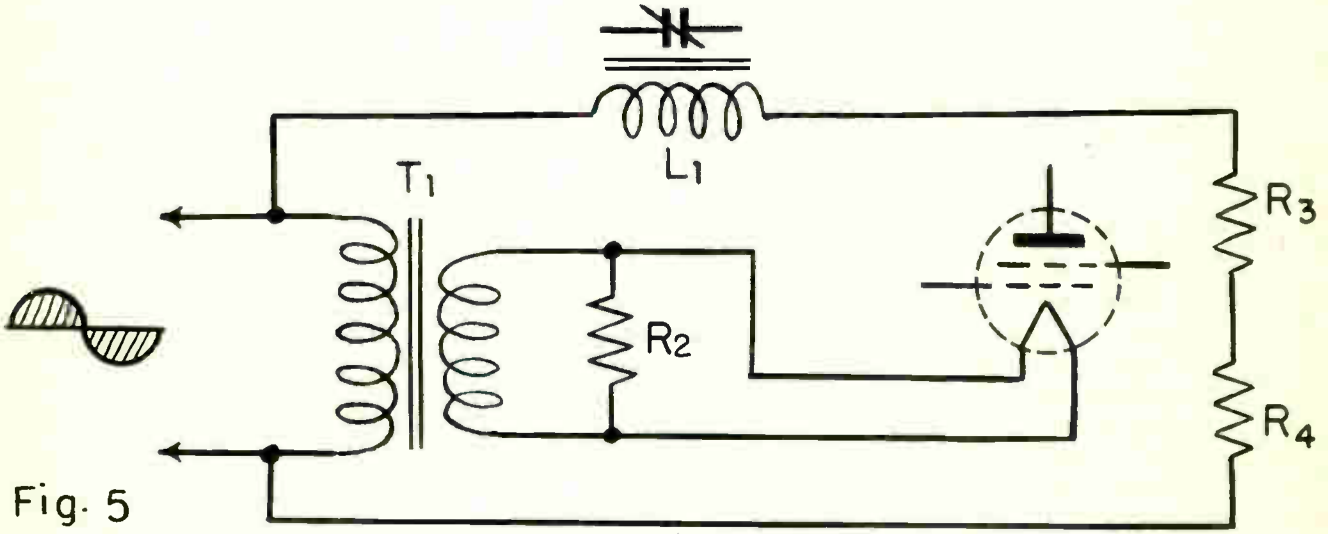



Fig. 5

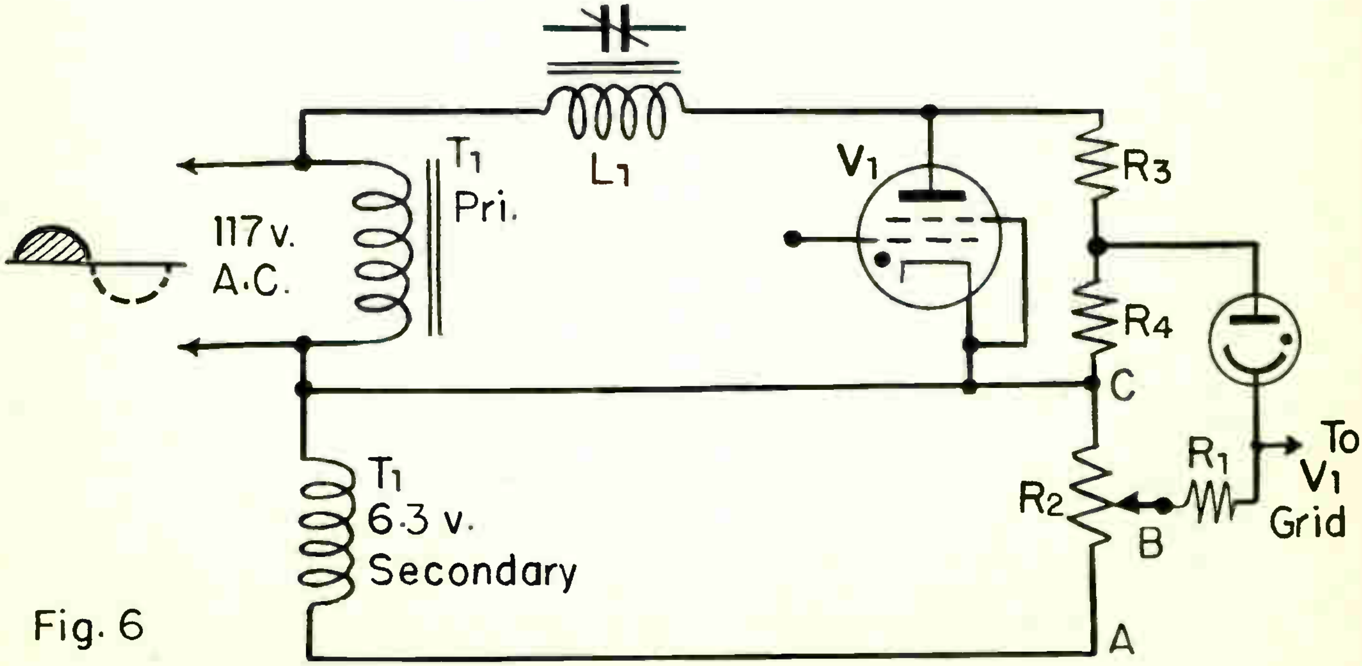



Fig. 6

Fig. 10B shows the voltage wave form that would exist across the thyratron tube from plate to cathode. It also shows the grid to cathode voltage wave form. The grid being positive will attract some electrons and the resulting voltage drop across R1 will cause the grid to cathode potential to become practically zero.

The instant light rays strike the phototube cathode the electron flow through the phototube and resistor R1 changes the potential at the control grid of V1 with respect to the cathode. The grid to cathode potential then becomes negative to such a value that V1 will not conduct. Fig. 11 illustrates the equivalent circuit.

3. Direct coupled phototube amplifier.

Fig. 12 illustrates a direct coupled phototube amplifier. The light needed to actuate the relay can be very small since two stages of amplification are used. When light, or an increase of light, strikes the phototube cathode, the relay coil L1 de-energizes. This circuit, as with the two previous circuits discussed, operates directly from a 117 volt alternating potential source without the necessity of a rectifier. The main difference between this circuit and the previous ones is that vacuum tubes are used instead of a gas-filled thyratron and also a direct method of coupling is used between V1 and V2. Referring to Fig. 12, note that the plate of tube V1 is directly connected to the grid of V2. Hence, the term "direct coupled amplifier".

To understand the theory of operation of this circuit, the circuit diagram of Fig. 12 will be broken down into several equivalent circuits for simplicity of explanation. Fig. 13 illustrates the heater circuit diagram. Note that the filaments of V1 and V2 and resistor R1 are in series with each other and connected across the 117 volt alternating potential source. The value of R1 will depend upon the filament ratings of V1 and V2. If the combined filament voltage were 50 volts, then R1 would have to be of great enough value to drop 117 volts down to 50 volts. Once the filament electron flow and the filament potential rating is known, R1 can be calculated by Ohm's law.

Considering that the upper side of the a-c line swings negative on the a-c cycle and no light strikes the phototube cathode, electrons will flow through R1, the V2 heater, and the parallel combination of R3 and the V1 heater. The polarity of the voltage drop across R3 will be such that a positive potential will be applied to the grid. Refer to Fig. 14 for the equivalent circuit.

When the control grid of V1 becomes more positive than the cathode, it will attract electrons and grid rectification will take place within the tube. The electron flow in the grid circuit of V1 will build up a negative bias voltage on C1. Fig. 15 illustrates the equivalent circuit during grid rectification of V1.

When the upper side of the a-c line swings positive, and still no light strikes the phototube, the plate electron flow of V1 will be small, due to the negative bias on the control grid of V1 limiting the number of electrons that will pass through the tube. The V1 plate electron flow passes through resistor R4 and builds up a direct voltage across this resistor and capacitor C2. The magnitude of this voltage is small because the bias voltage on the V1 control grid is negative and it in turn limits the amount of electron flow through R4. Since the positive end of R4 connects to the cathode of V2, and the negative end to the grid of V2, the negative bias on V2 is equal to the voltage across R4 and

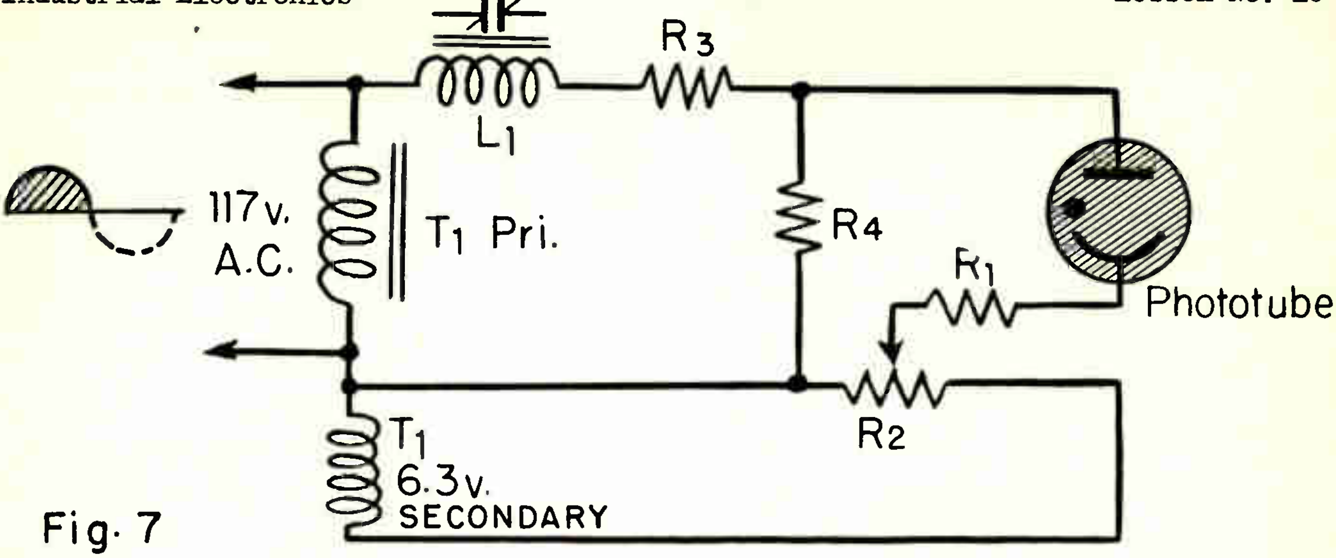



Fig. 7

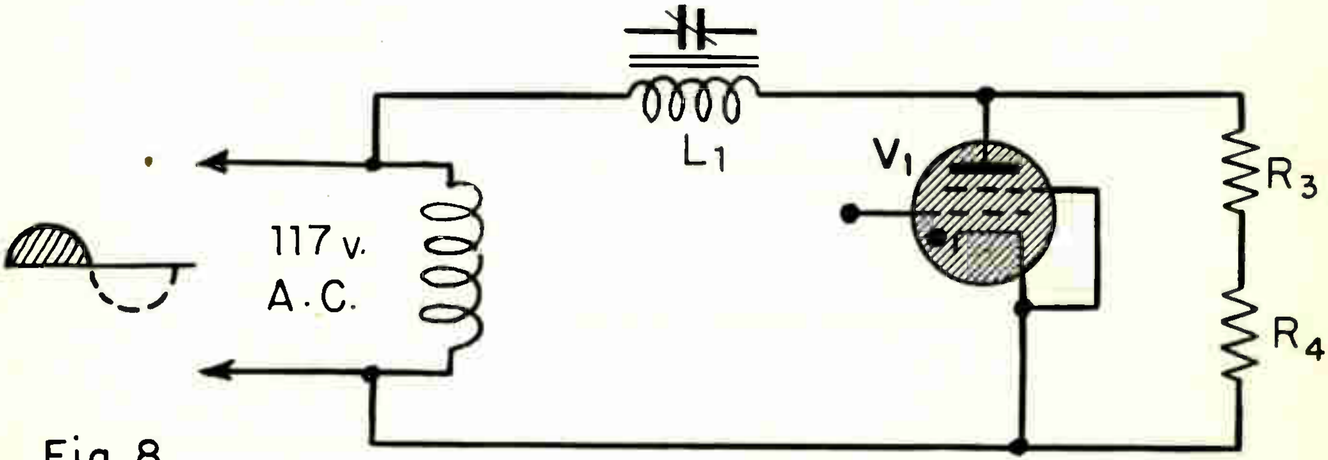



Fig. 8

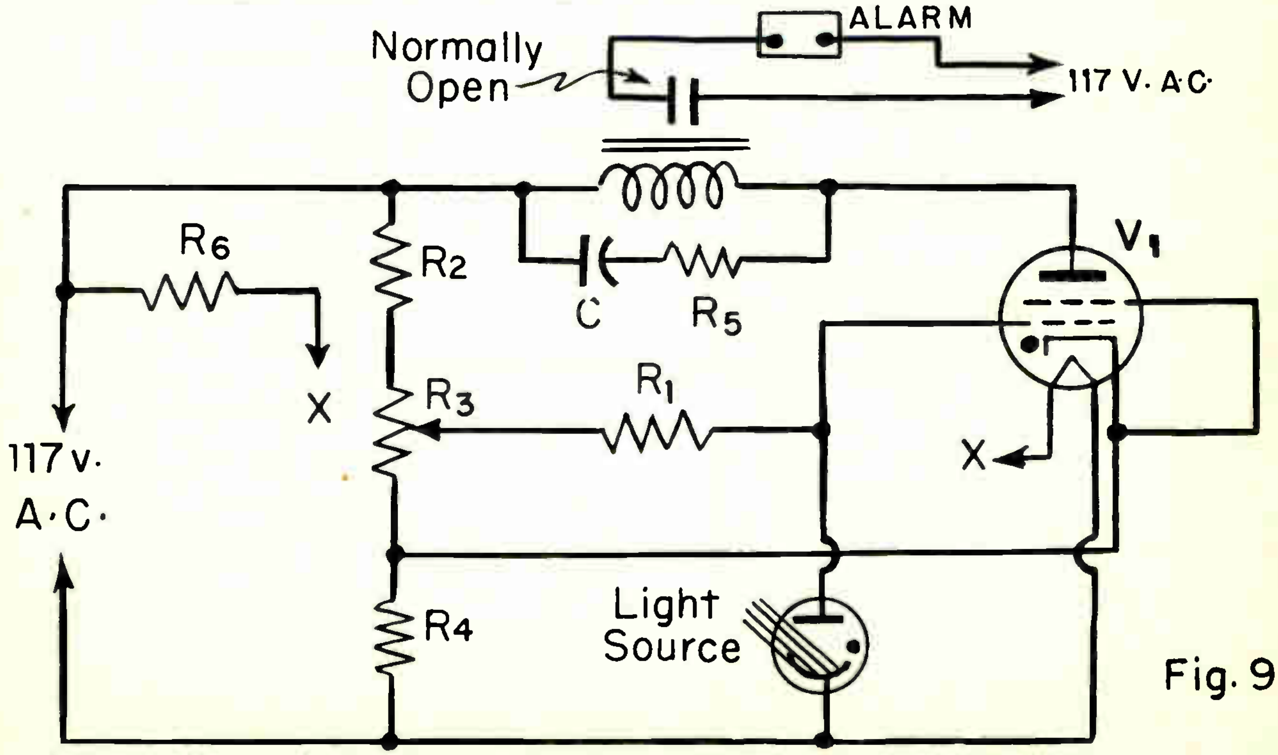



Fig. 9

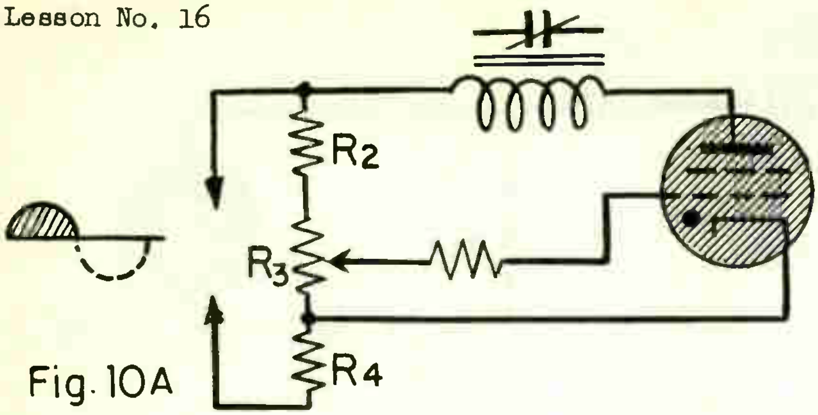



Fig. 10A

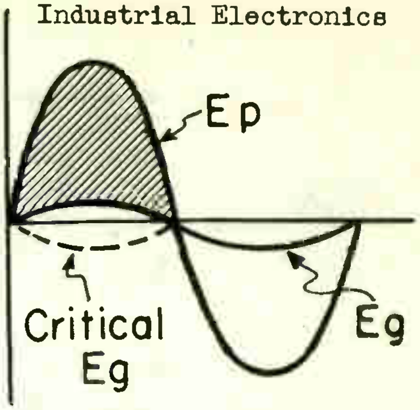



Fig. 10 B • PLATE AND GRID VOLTAGE WAVE FORMS EXISTING ACROSS $V_1$ WITH NO LIGHT ON PHOTOTUBE CATHODE

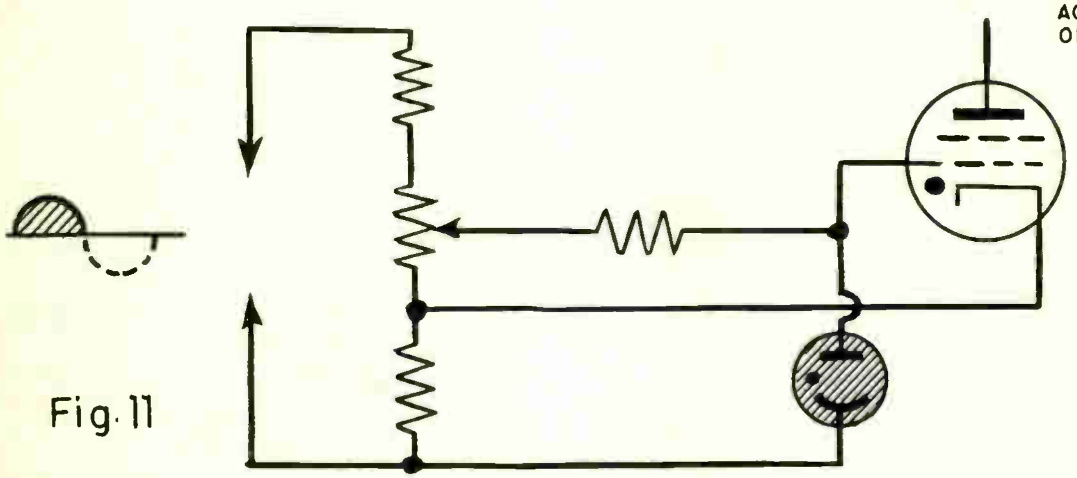


Fig. 11

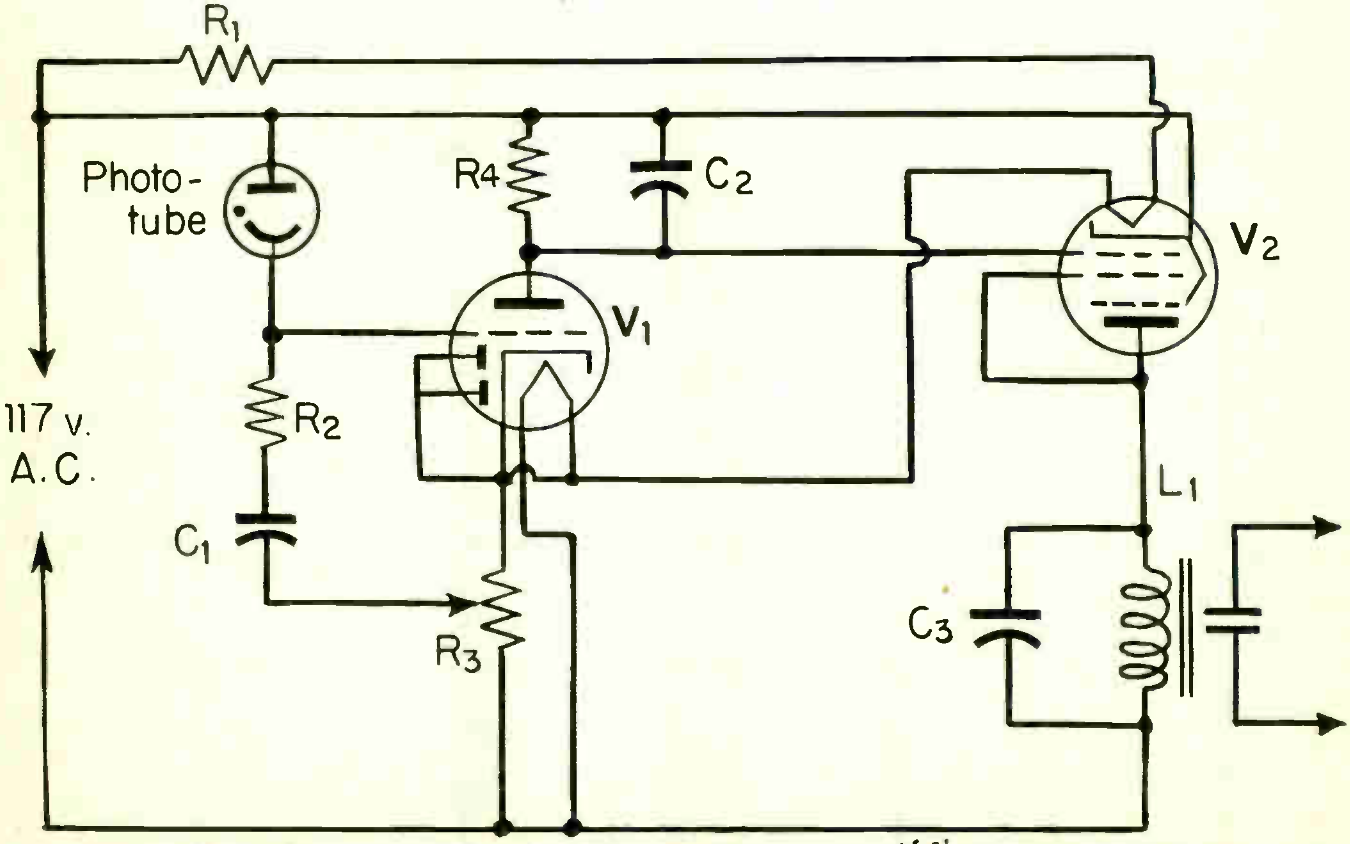



Fig. 12 • Direct Coupled Phototube Amplifier

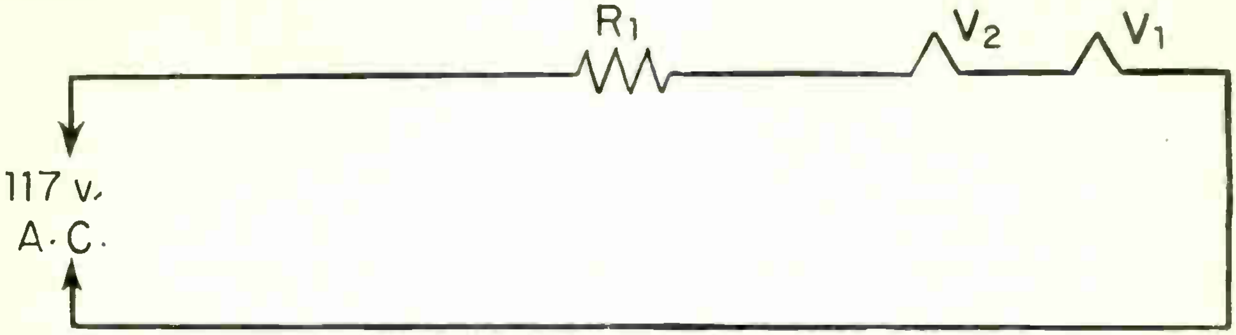



Fig. 13

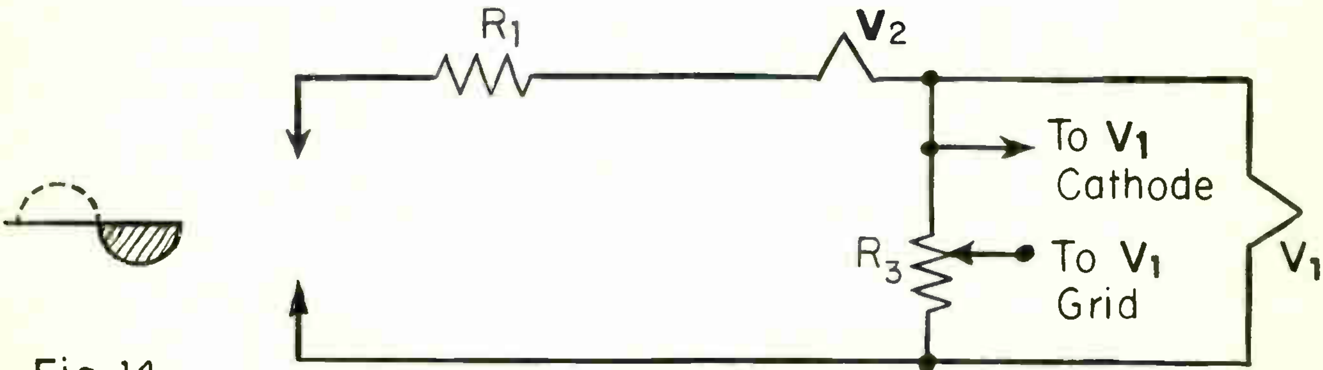



Fig. 14

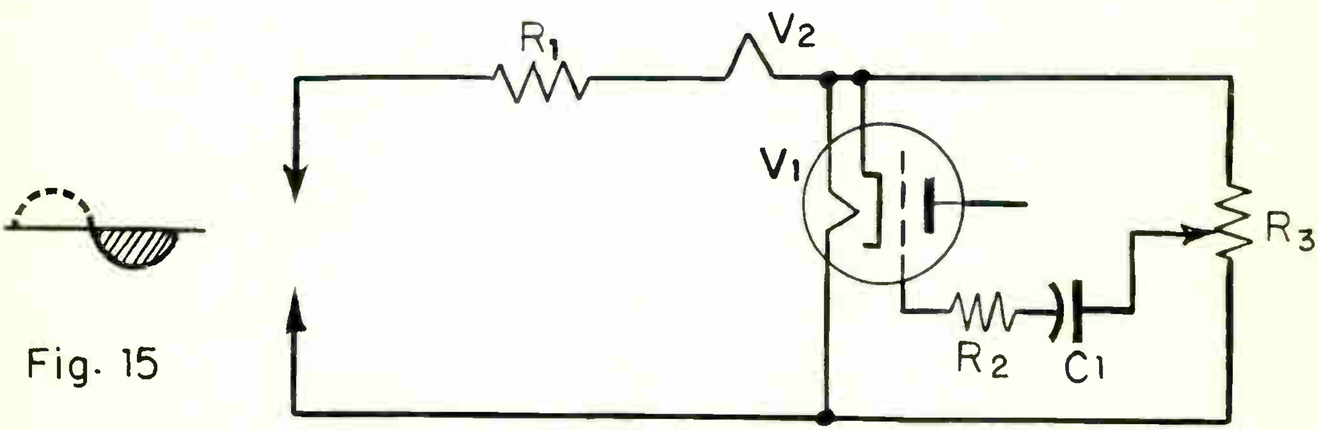



Fig. 15

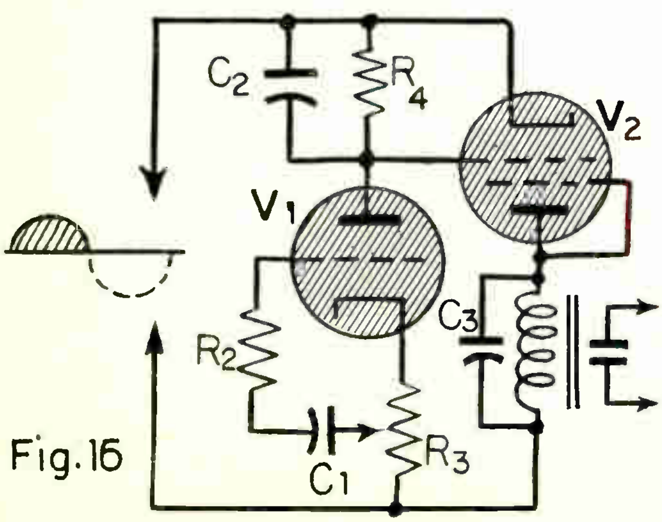



Fig. 16

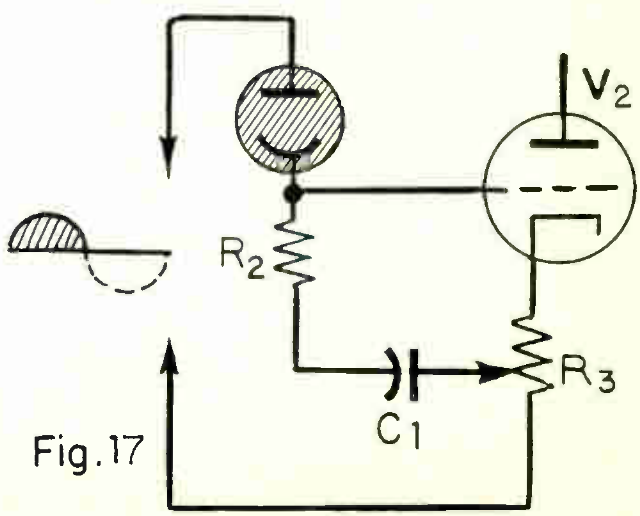



Fig. 17

C2. Therefore V2 passes plate electron flow whose rate depends upon the voltage across R4 and C2. Fig. 16 illustrates the equivalent circuit.

During the positive alternation of input voltage, the instant light strikes the phototube cathode, or an increase in the amount of light takes place, the average grid bias voltage on V1 becomes less negative since electrons will take another path. Electrons will flow through a portion of R3 and charge the cathode side of C1 negative. The electrons on the control grid side of C1 will flow through R2 the phototube, and to the positive side of the a-c line. The voltage drops across R2 and C1 will cause the grid of V1 to become less negative with reference to the cathode. The equivalent circuit is shown in Fig. 17.

With the control grid less negative, the direct plate electron flow of VI increases, this in turn will cause the direct voltage across R4 and C2 to increase which in turn will cause the grid bias voltage of V2 to become more negative with reference to the cathode. The negative bias voltage on V2 actually is great enough to block any electrons attempting to travel from cathode to plate of V2. Thus, light, or an increase of light, on the phototube cathode will cause the relay in the plate circuit of V2 to de-energize.

Capacitor C2 is connected across R4 to maintain a constant voltage drop across R4 during the negative alternations of input voltage which, in turn, will provide a constant control grid bias for V2. Capacitor C3 is a smoothing capacitor and prevents chattering of the relay.

E. Summary Questions

1. Explain the action of a "forward" phototube circuit.

2. Explain the action of a "reverse" phototube circuit.

3. The induced voltage across the secondary winding of transformer T1 (Figure 3 ) is in phase with the primary winding. Will tube V1 conduct with no light on the phototube?

4. What purpose does capacitor "C" (Figure 3) serve?

5. At what alternation of the input voltage does grid rectification occur in the circuit of Figure 12?

# PHOTO ELECTRIC CELLS, CIRCUITS AND APPLICATIONS

PHOTO EMISSIVE CELLS

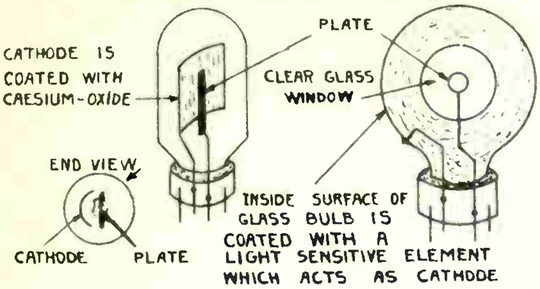



FIG. 1B PHOTO CONDUCTIVE CELL

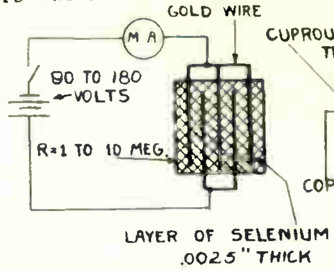
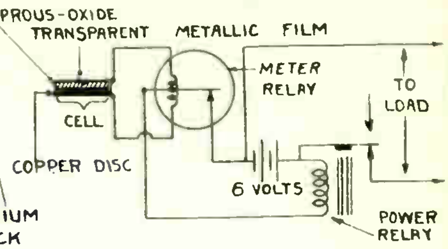
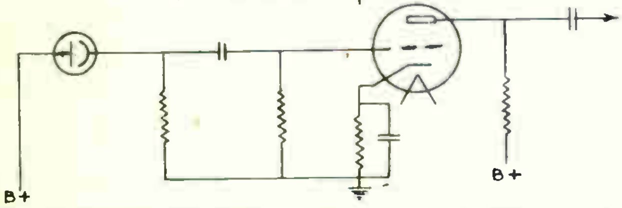


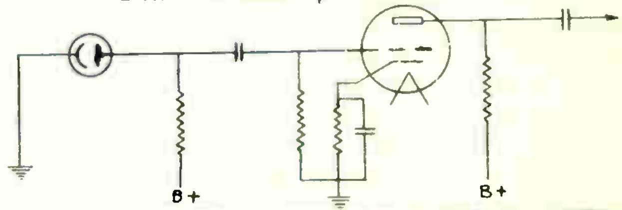

FIG. 1C PHOTO VOLTAIC CELL AND CIRCUIT



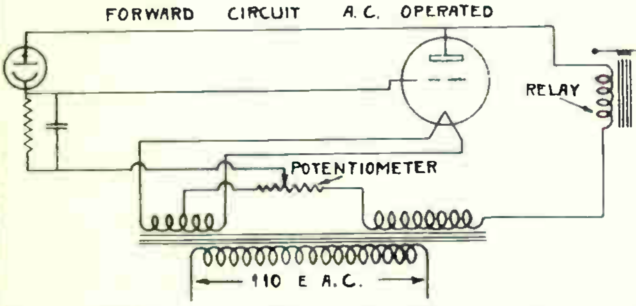

FORWARD CIRCUIT D. C. OPERATED
LIGHT INCREASE – $I_p$ INCREASE



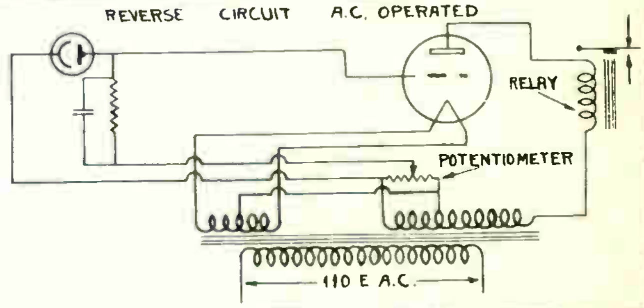

REVERSE CIRCUIT D. C. OPERATED
LIGHT INCREASE – $I_p$ DECREASE




FORWARD CIRCUIT A. C. OPERATED




REVERSE CIRCUIT A. C. OPERATED




INDICATING HAND ON AN INSTRUMENT ECLIPSING LIGHT BEAM

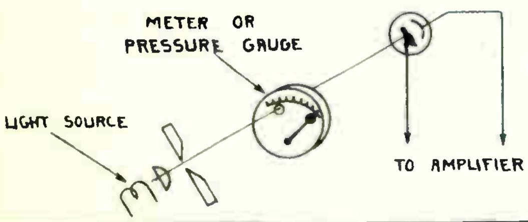
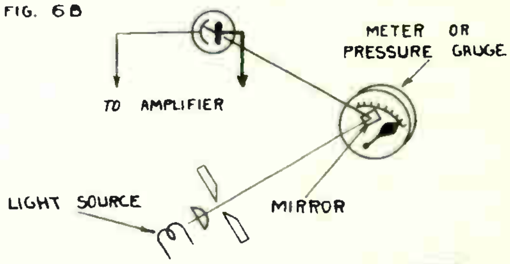
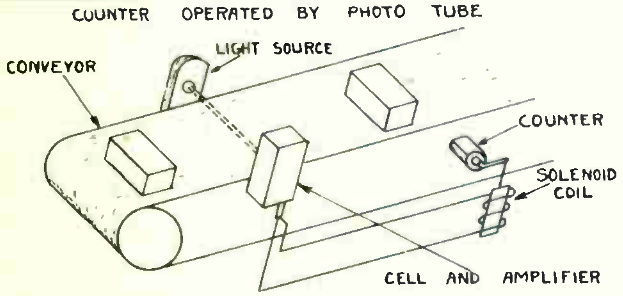


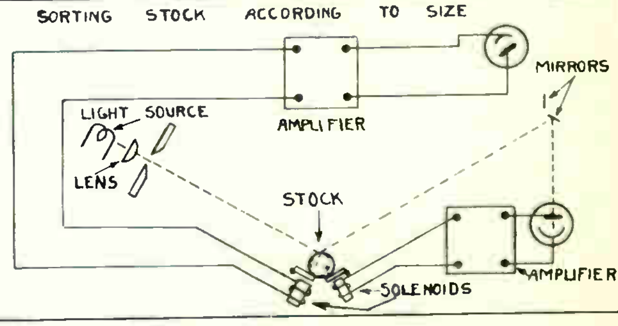

FIG. 6B



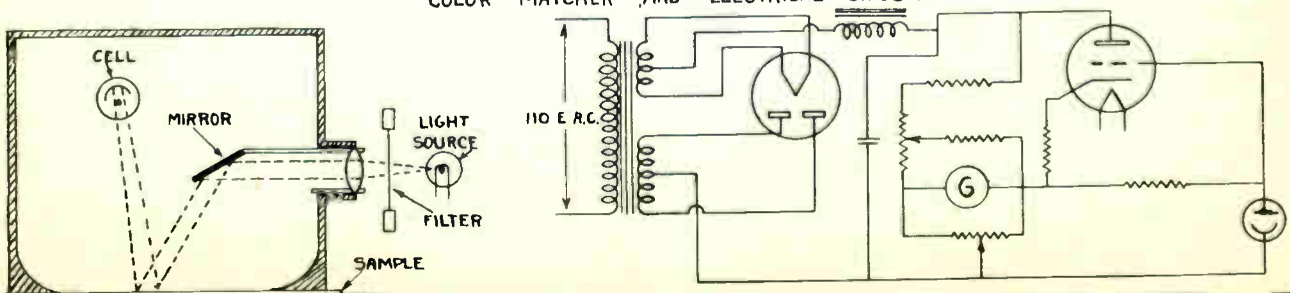

COUNTER OPERATED BY PHOTO TUBE




SORTING STOCK ACCORDING TO SIZE




COLOR MATCHER AND ELECTRICAL CIRCUIT



# VACUUM TUBE SIGNAL AMPLIFICATION

## Objective

To explain the basic principles of how the vacuum tube may be used as a device to amplify small signal voltages.

## References

## Lesson Content

### A. General

The vacuum tube amplifier is the heart of all electronic devices for industrial control. Vacuum tube circuits are used to amplify changes in pressure, expansion, temperature, vibration, humidity, moisture, speed, light, frequency, sound, voltage, electron flow and countless other industrial processes.

### B. Producing a Varying Signal Voltage

When "amplifying an a-c signal" it simply means that a weak signal of a certain frequency and wave form is applied to the input, or control grid circuit of a pliotron tube. In the plate circuit or load circuit of the pliotron tube there will occur an enlarged reproduction of the a-c signal that was applied to the grid circuit. This enlarged signal in the plate circuit is of the same frequency and same general wave shape as the signal voltage applied to the grid circuit.

In Fig. 1A a fixed voltage Eb of 150V, a fixed resistance RL of 15,000 ohms, and a variable resistance R, set for a resistance of 45,000 ohms, are connected in series with each other. The electron flow indicated by the miliammeter is 2.5 MA. The voltage drop across resistor Rl is 37.5 volts. Let us observe the results of varying the resistance, R.

Fig. 1 B illustrates the same circuit as Fig. 1A, except that the resistance of R has been decreased from 45,000 Ohms to 22,500 ohms. The electron flow in the series circuit is now 4 milliamperes instead of 2.5 milliamperes as in Fig. 1A. The voltage drop across RL has been increased from 37.5 volts to 60 volts. An increase of 22.5 volts has taken place.

In Fig. 1C the resistance of R has been increased from 45,000 ohms as in Fig. 1A to a value of 135,000 ohms, or an increase of 90,000 Ohms. The electron flow now is one milliampere, or a decrease of 1.5 milliamperes exists from that of Fig. 1A. The voltage drop across RL is now 15 volts. It has decreased 22.5 volts from that of Fig. 1A.

Review, for a moment, what has been accomplished by varying the resistance of R. Assume Fig. 1A to be the starting point. In Fig. 1B, the resistance of R was decreased by 22,500 ohms and the electron flow increased by 1.5 milliamperes or, in other words, a change of 2.5 milliamperes to 4 milliamperes has taken place. The voltage drop was increased from 37.5 volts to 60 volts, or an increase of 22.5 volts.

Starting with Fig. 1A again, and by increasing the resistance of R as shown in Fig. 1C, a decrease of voltage drop and a decrease in electron flow occurred by the same amount that it was increased in Fig. 1B. The change in voltage drop and the change in electron flow was the same in both cases. The only difference was in the direction of the change. The change in the resistance of R, however, was not the same in both cases. The resistance was decreased by 22,500 ohms in Fig. 1B, but it was increased by 90,000 ohms in Fig. 1C. Remember Fig. 1A is the reference point.

Using the values shown in Fig. 1A, as the reference point, and by rapidly varying the resistance of R between the values shown in Fig. 1B and 1C, it is apparent that the electron flow through resistor RL will be of a pulsating nature. The voltage drop will vary by equal amounts each side of the reference point of Fig. 1A. The variation of electron flow through resistor RL and the variation in voltage drop across R will vary at the same frequency as the change in the resistance of R.

Remember that by rapidly varying the resistance of R, the electron flow in the circuit becomes a pulsating direct electron flow instead of pure direct electron flow. The equivalent of a direct electron flow of 2.5 milliamperes with an alternating component electron flow of a maximum amplitude of 1.5 milliamperes superimposed upon it, is shown in Fig. 2A. This alternating component of electron flow through resistor RL creates a varying voltage drop across RL. This varying voltage drop may be fed through suitable capacitors to an amplifier tube as an alternating signal voltage, shown in Fig. 2B.

C. Amplification of Alternating Signal Voltages.

By replacing R with a triode pliotron tube it will be seen that a small alternating signal applied to the control grid circuit, or input circuit, of a pliotron tube will vary the d-c resistance of the tube. This variation of resistance will cause a pulsating direct electron flow through the load in the plate circuit. The output signal voltage will then be an enlarged reproduction of the signal voltage fed into the grid circuit of the pliotron tube.

In Fig. 3A, tube V1 replaces the rheostat "R" in the circuit similar to the one shown in Fig. 1A. The battery Ef represents the supply for heating the heater of the pliotron tube and causes the cathode to emit electrons. In the grid circuit of tube V1 is the grid load resistor Rc, which is in series with the grid bias battery "Ec". This grid bias battery voltage establishes the proper operating point of the pliotron tube's grid circuit according to the tubes characteristic curve. A signal voltage is shown applied to the grid circuit of the tube V1 through capacitor C1.

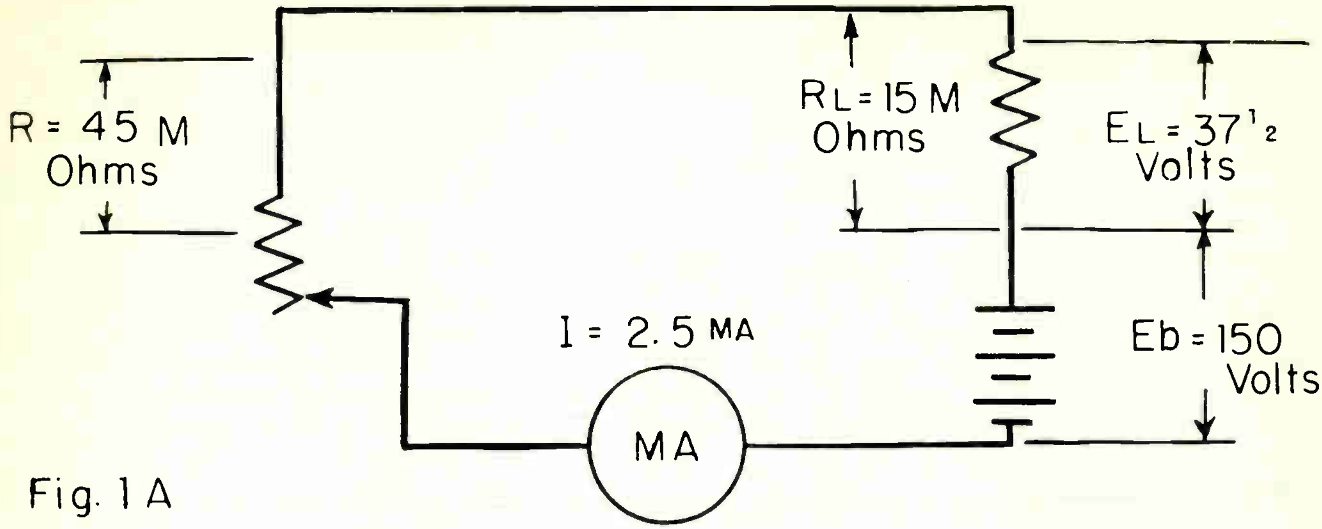



Fig. 1 A

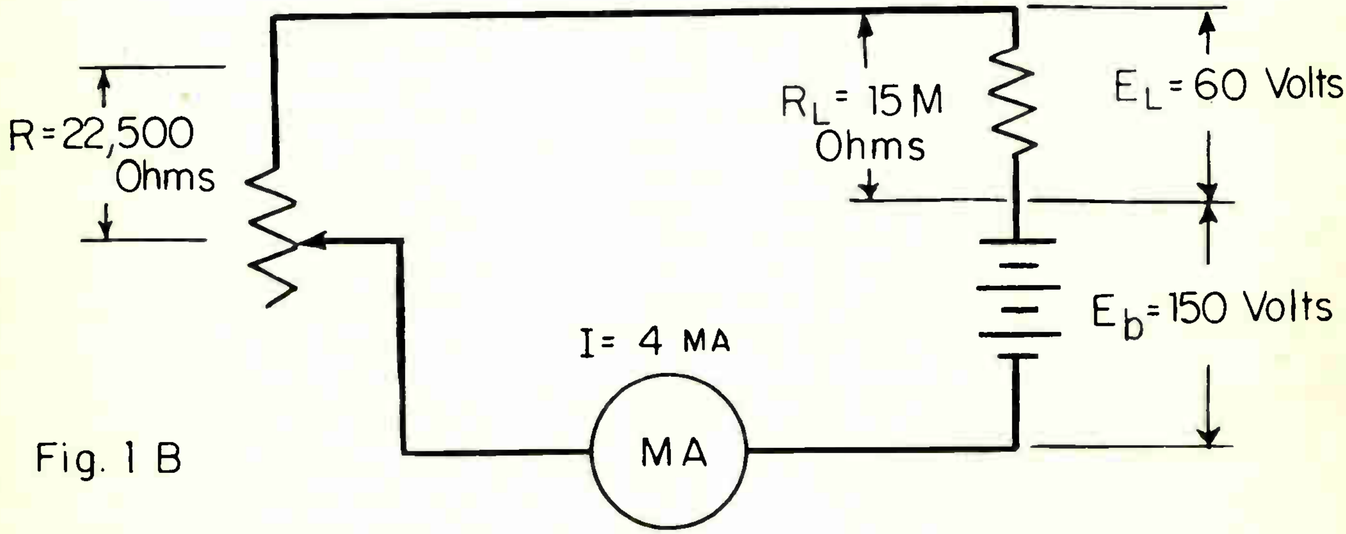



Fig. 1 B

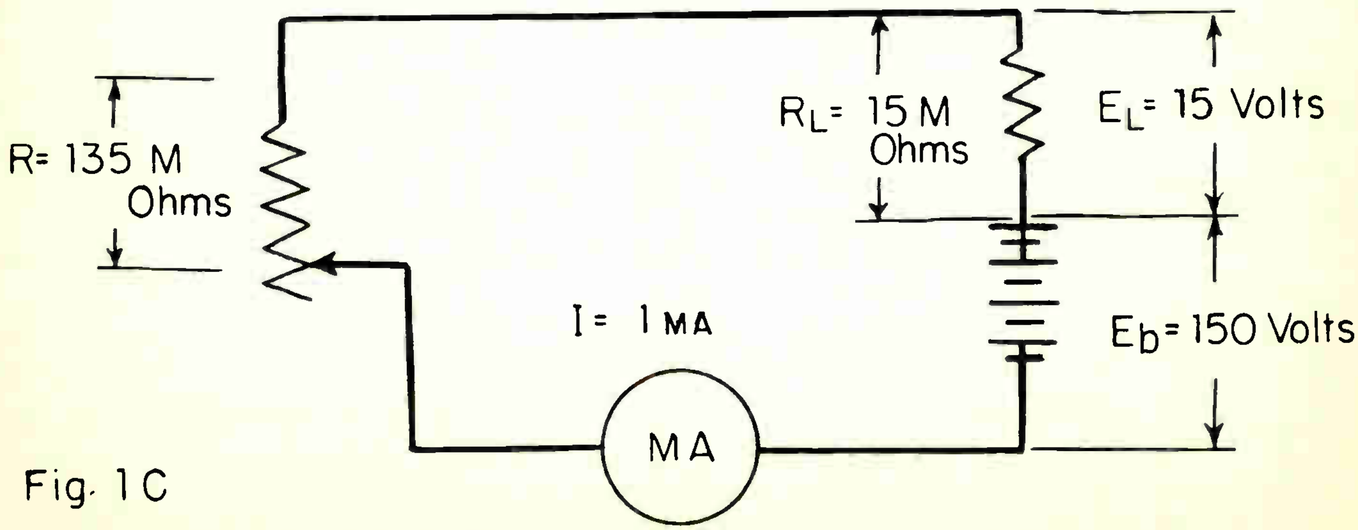



Fig. 1 C

There is assumed to be no signal voltage losses in capacitor C1. The output signal voltage appears across load resistor RL.

For practical purposes the d-c resistance of the pliotron tube V1 is assumed to be 45,000 ohms,with no alternating signal voltage applied to the grid circuit. Observe that the positive terminal of the grid bias battery Ec is connected to the same point as the cathode of tube V1. The negative terminal of the grid bias battery Ec is connected toward the control grid of tube V1 through the grid load resistor Rc. The control grid potential of tube V1 is four volts negative with respect to the cathode potential, with no signal voltage applied to the control grid. This negative control grid potential causes tube V1 to have a d-c resistance between the plate and cathode of 45,000 ohms, and this resistance being in series with resistor RL limits the tube electron flow to a value of 2.5 milliamperes.

$$I = \frac{E}{R} = \frac{Eb}{\text{R of V1 plus RL}} = \frac{150}{\text{45M ohms plus 15M ohms}} = \frac{150}{\text{60M ohms}} = 2.5\text{MA.}$$

The electron flow of 2.5 MA. through the load resistor causes a voltage drop across RL of 37.5 volts.

When an alternating signal voltage (eg) is applied across the grid load resistor (rc) it will alternately subtract from and add to the direct grid bias potential of 4 volts on the grid of tube V1. This alternating signal voltage will cause the instantaneous grid potential to be alternately less negative and more negative than when no signal voltage was applied. The varying grid potential due to the alternating signal voltage, will then cause the electro-static potential around the control grid to vary in strength. As the control grid potential is made less negative than it was with no signal voltage applied, the grid offers less repelling action to the electrons leaving the cathode and moving toward the positive potential on the plate of the tube V1. The d-c resistance of the tube V1 decreases and the voltage Eb will be able to force a greater electron flow through V1 and RL.

When the grid potential is made more negative by the alternating signal voltage, the control grid will offer a greater repelling action to the flow of electrons from the cathode toward the positive potential of the plate. The d-c resistance of the tube V1 will be increased by this action and bias voltage will cause a smaller electron flow through V1 and RL. The d-c resistance of tube V1 is varied by the action of the alternating signal voltage upon the control grid.

The alternating signal voltage to the left of Fig. 3A is shown by the sine curve a, b, c, d, and e. At point "a" the amplitude of the signal voltage is zero and will not vary the grid potential of tube V1.

When the amplitude of the signal voltage is 1.5 volts in a negative direction as at point "b", it will add to the negative bias voltage Ec (See Fig. 3b). This action will cause the potential of the control grid of V1 to be more negative and cause a greater repelling action by the control grid to the flow of electrons from this action. If the d-c resistance of V1 is assumed to be 135,000 ohms at this point, the electron flow through V1 and RL will be:

$$I = \frac{E}{R} = \frac{Eb}{\text{Res. of V1 plus RL}} = \frac{150}{\text{135M ohms plus 15M ohms}} = \frac{150}{\text{150M ohms}} = 1\text{ MA}$$

This amount of electron flow through the load resistor causes a voltage drop of only 15 volts.

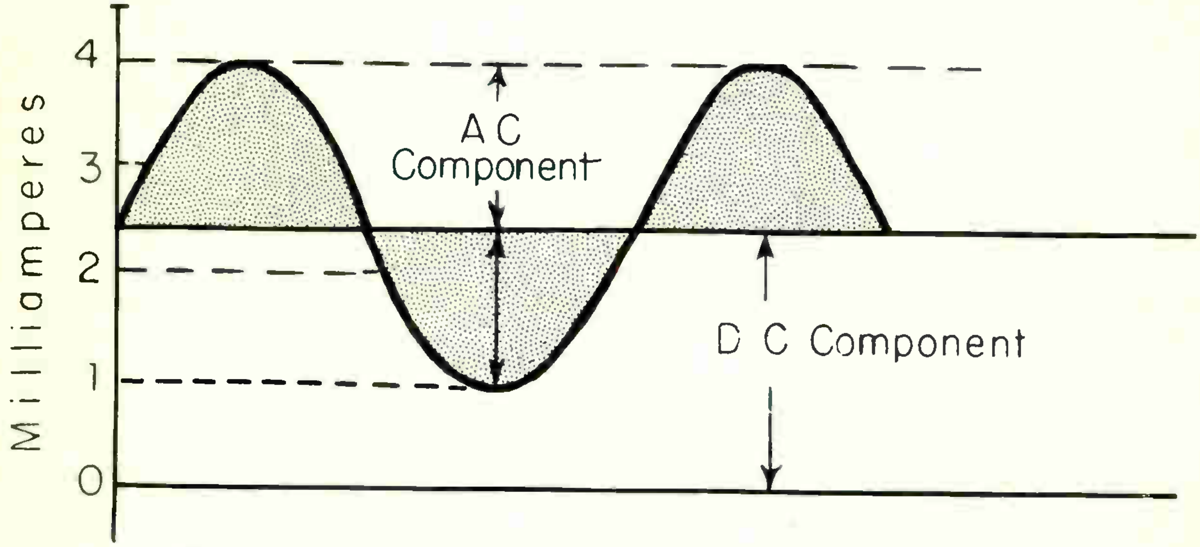



Fig. 2 A Electron Flow Through RL

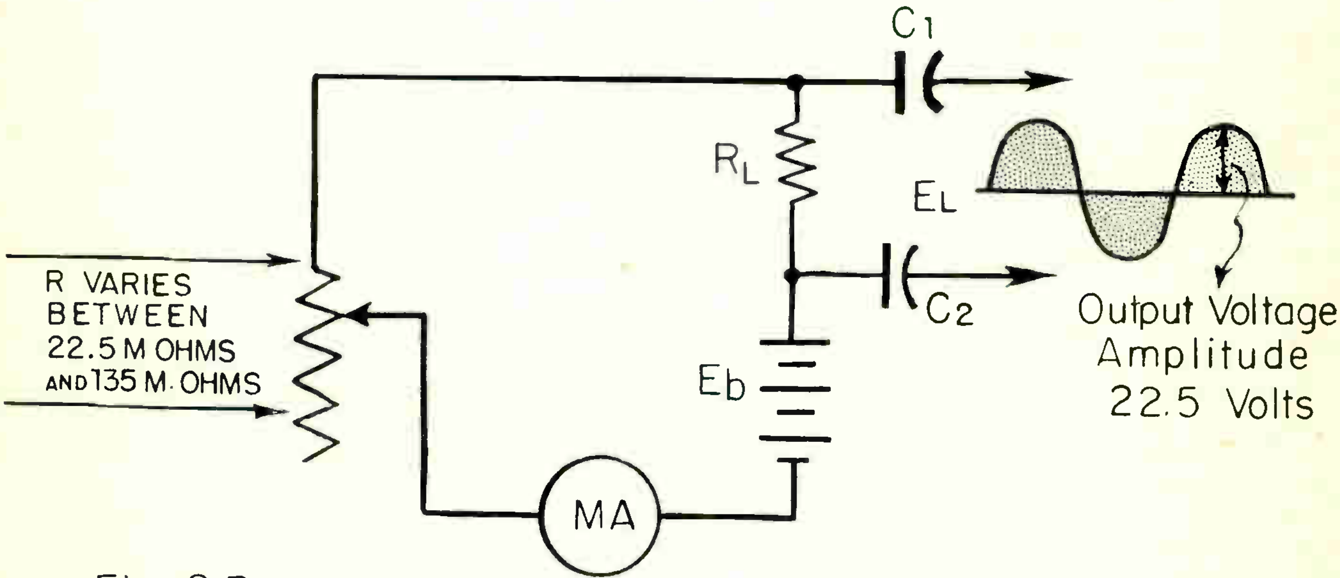



Fig. 2 B

At point c on the signal voltage curve, the amplitude of the signal voltage will again be zero and the grid bias voltage, Ec, will be the voltage applied between control grid and cathode of tube V1. The d-c tube resistance will again be 45,000 ohms and the electron flow through V1 and RL will again be 2.5 MA. The voltage drop across load resistor RL will be 37.5 volts.

At point d the instantaneous amplitude is 1.5 volts in a positive direction and will subtract from the grid bias voltage Ec (see Fig. 3B). The repelling action of the control grid will be reduced and allow the bias voltage to cause more electrons to flow through V1 and the load resistor. If the d-c resistance of tube V1 is reduced to 22,500 ohms by the signal voltage at this point, the electron flow through V1 and RL will be:

$$I = \frac{E}{R} = \frac{Eb}{\text{R of V1 plus RL}} = \frac{150\ E}{22.5M\ \text{ohms plus}\ 15M\ \text{ohms}} = \frac{150\ E}{37.5M\ \text{ohms}} = 4MA$$

This increase of electron flow from 2.5 milliamperes to 4 milliamperes through the load resistor will cause an increase of the voltage drop across RL from 37.5 to 60 volts, or an increase of 22.5 volts.

At point "e" of the signal voltage curve, the amplitude of the signal voltage is zero again, as at points "a" and "c", and the electron flow through the load resistor is again 2.5 milliamperes. The voltage drop across the load resistor is again 37.5 volts. By applying an alternating signal voltage across the grid load resistor Rc, an alternating voltage (eg) has been super-imposed upon the negative bias voltage Ec thereby causing the control grid potential of V1 to vary accordingly. This potential across the grid and cathode cause the d-c resistance between the plate and cathode of tube V1 to vary, which in turn causes a pulsating electron flow through the load resistor RL. Actually, the direct electron flow through RL has an alternating component superimposed upon it. The alternating component voltage appearing across RL can be applied to capacitors C2 and C3 as shown in Fig. 3A. The alternating component voltage in Fig. 3C is the reproduced signal voltage originally shown by curve a, b, c, d, and on the left hand side of Fig. 3A.

The maximum amplitude of the signal voltage applied to the grid circuit of the pliotron tube was 1.5 volts; however, the maximum amplitude of the output signal voltage is 22.5 volts. By dividing the output voltage by the input voltage the signal amplification can be found. In this circuit it is 15. The signal output voltage is of the same frequency and wave shape as the input signal voltage.

The pliotron tube V1 in Fig. 3A could be a tetrode or a pentode, in which case the d-c resistance of the tube would be much greater. However, the basic theory of operation remains the same. The frequency of the signal voltage applied to the grid circuit of V1 could be anything from a few cycles per second to several million cycles per second. The limiting factors, as far as frequency is concerned, are usually some other components than the pliotron tube.

When the frequency of the signal to be amplified is of high frequency, as radio frequency, the load for the pliotron tube is often a parallel resonant circuit, which is resonant at the frequency of the signal. When the signal frequency is of rather low frequency (audio frequency) the load for the pliotron tube may be a resistance as shown in Fig. 3A, or perhaps the primary of an audio transformer, in which case the output voltage would be taken from across the secondary terminals of this transformer.

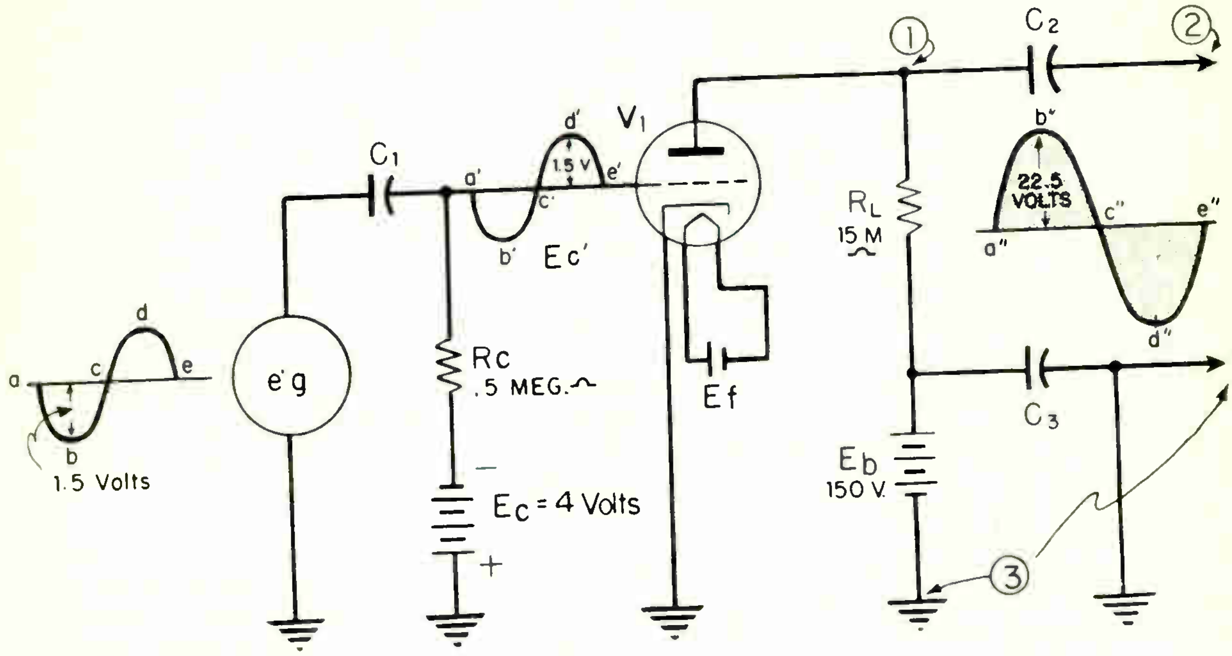



Fig. 3 a

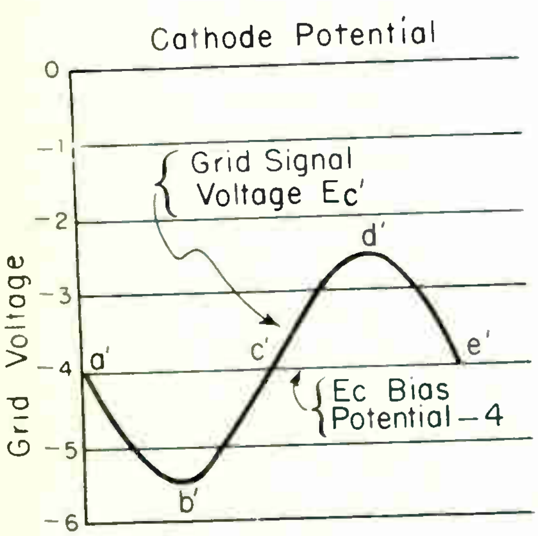



Fig. 3 b

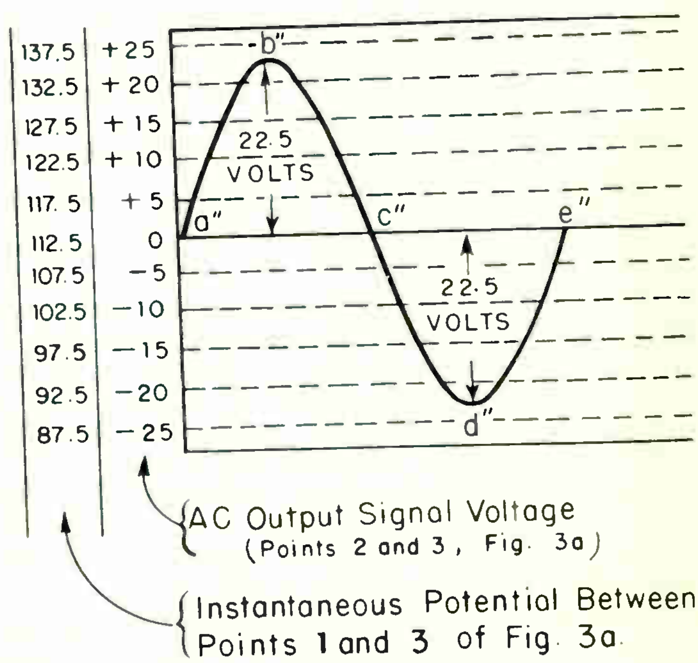



Fig. 3c

D. Power Amplification

In the previous sections, voltage amplification was explained. The primary interest was to apply a small signal voltage to the grid circuit of the pliotron tube and thereby develop across the load, in the plate circuit, a much enlarged signal voltage change. The amount of electron flow change in the load circuit of the pliotron tube was not of primary importance. In power amplifiers, however, the amount of electron flow change in the load circuit is of primary importance. The load device in the plate circuit of the pliotron power amplifier will be a power operated device and will require both a change in voltage and also a change in electron flow to have sufficient power to operate in a satisfactory manner. The device following a voltage amplifier is a voltage operated device and a great deal of power is not required to operate it. Power = voltage X electron flow.

Figure 4, shows a circuit similar to ones found in many public address and intercommunication amplifiers in the communication field of electronics. In this circuit, tube V1 represents a voltage amplifier while tube V2 represents a power amplifier.

The alternating signal voltage is applied to the grid circuit of tube V1 and an amplified reproduction of it is applied to the grid circuit of V2 through capacitors C2 and C3 as explained in sections A, B and C of this lesson. Tube V1 is voltage operated because its grid attracts no electrons from the power supply. Its control grid is biased negative with reference to its cathode. The load device connected to the plate circuit of tube V2 does require power from the load circuit of tube V2 to cause the diaphragm of the speaker to vibrate back and forth to supply sound waves for the human ear.

Assume that the primary of transformer T1 in the plate circuit of tube V2 offers an impedance of 2700 ohms at the signal frequency. This is approximately the value specified by the tube manufacturers for proper operation of the tube. Let it also be assumed that the impedance of the voice coil of the speaker is three ohms at signal frequency. The turns ratio of transformer T1 must therefore be approximately 30 to 1 in order to properly match the low impedance of the speaker coil to the much higher impedance of the plate circuit of tube V2. Turns ratio equals $\sqrt{2700/3}$. Remember that there is maximum transfer of power between two circuits when their impedances are matched to each other. Transformer T1 is an impedance matching device used to transfer power from the plate circuit of tube V2 to the speaker voice coil. It is often called an "output transformer".

How the signal applied to the grid circuit of the power tube V2 can cause the plate circuit to feed power to the speaker through transformer T1 will now be explained. The spacings of the elements of tube V2 in respect to each other are such that a one volt change on the grid of tube V2 will cause a change of 1.25 milliamperes in the plate circuit of tube V2. This characteristic of the tube is given in most tube characteristic charts supplied by the manufacturer. It is called the "mutual conductance" or "trans-conductance" characteristic.

A maximum signal voltage of 22.5 volts is developed across the load resistor RL of tube V1. This voltage is applied between the control grid and cathode of tube V2 and causes a maximum ampere change in the plate circuit of 28.1 milliamperes (22.5 x 1.25). This amount of change in electron flow through the primary of transformer T1, whose impedance at signal frequency is 2700 ohms, will develope a signal voltage with a maximum amplitude of almost 76 volts. (.028 x 2700).

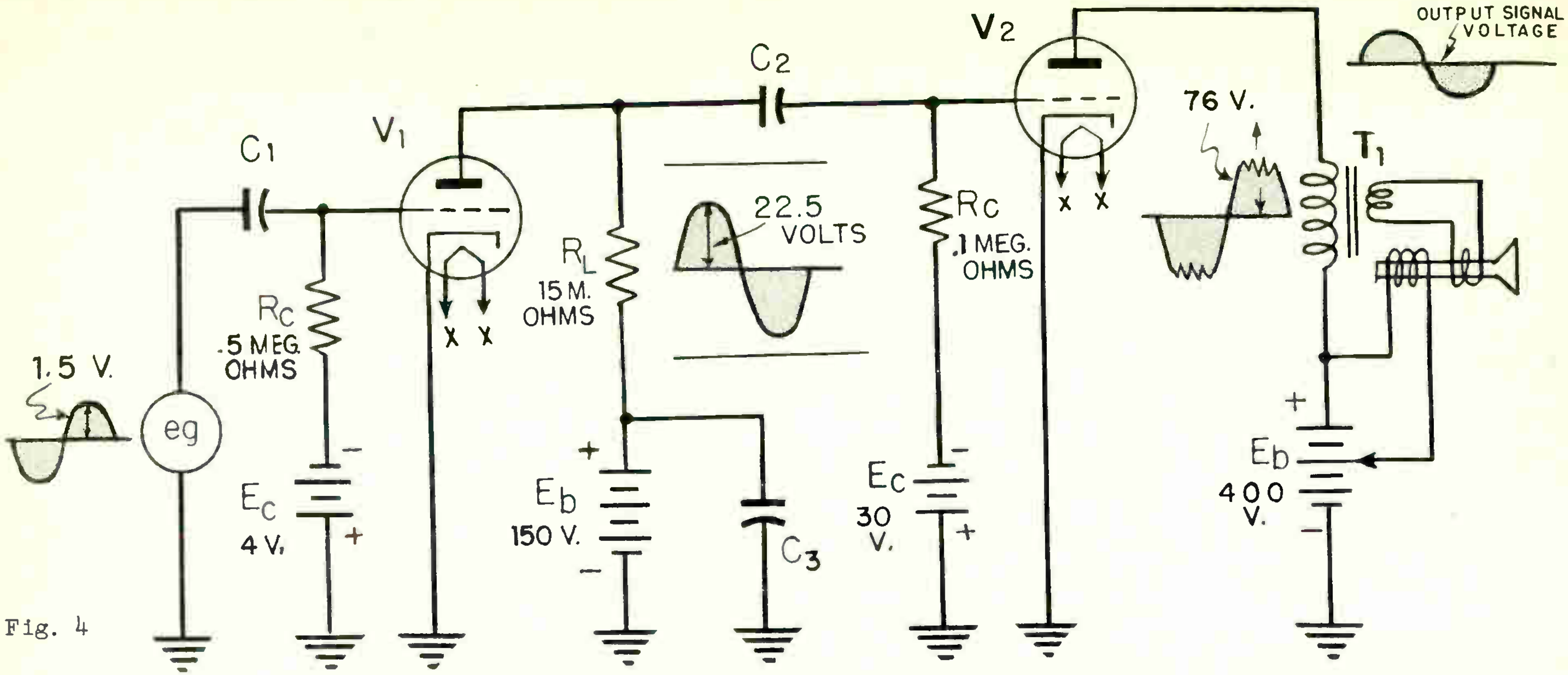



Fig. 4

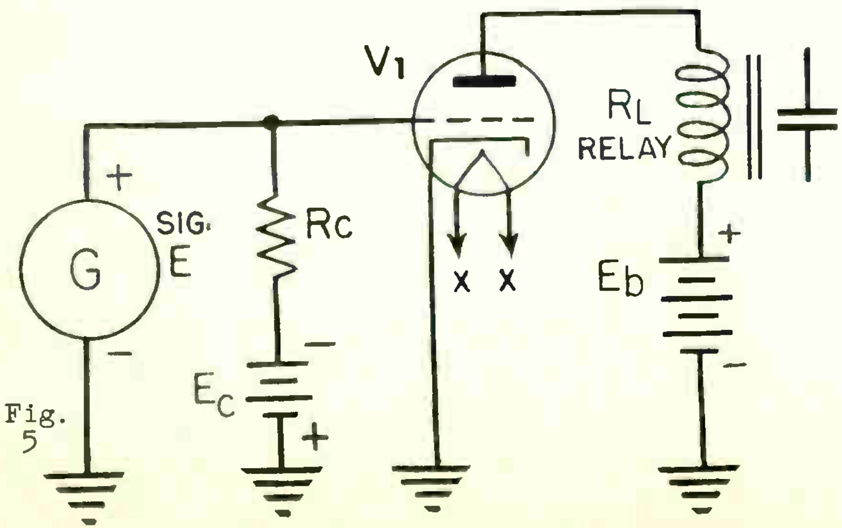



Fig. 5

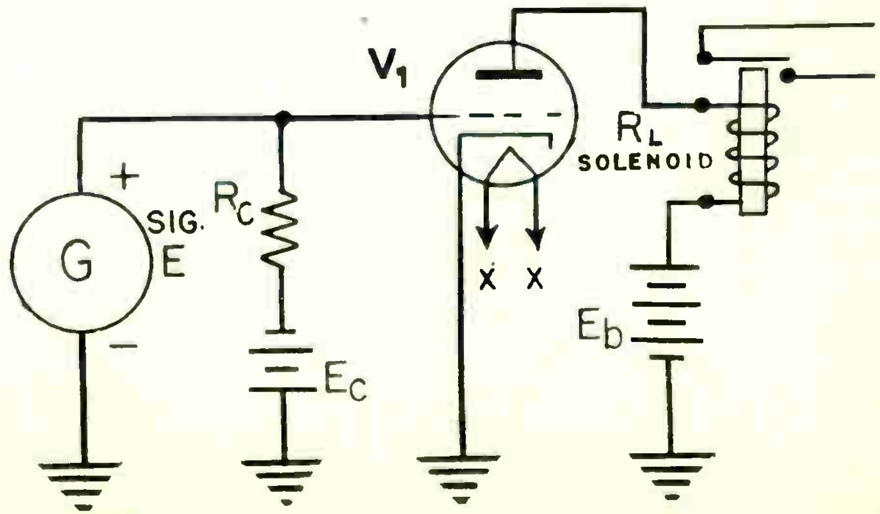



Fig. 6

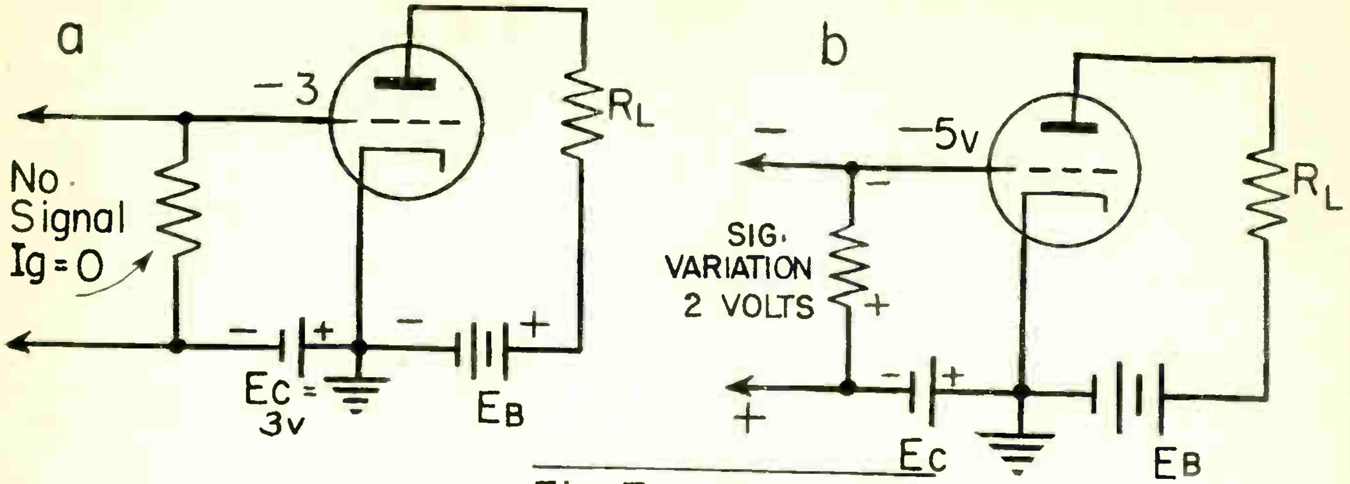
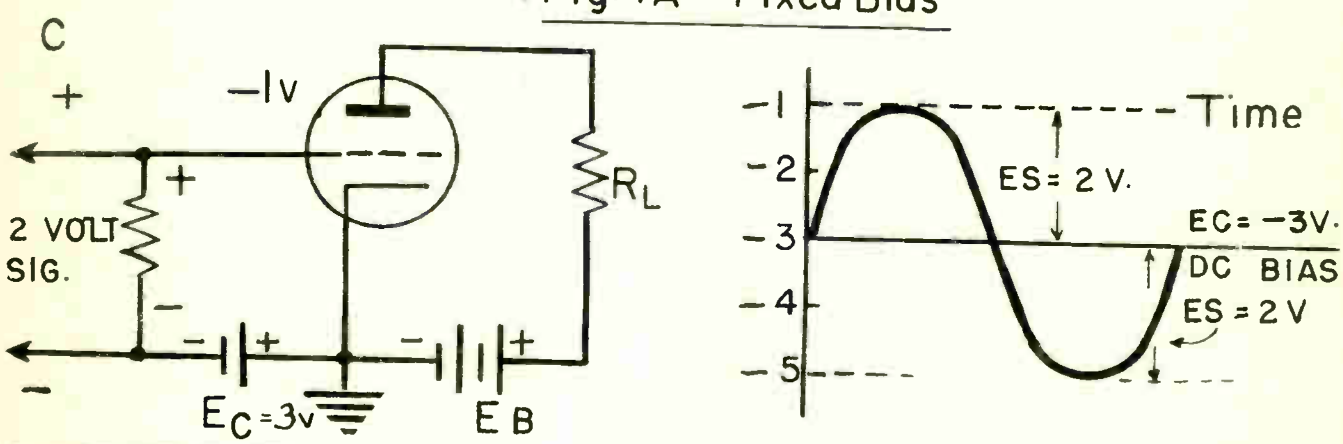



Fig. 7A - Fixed Bias



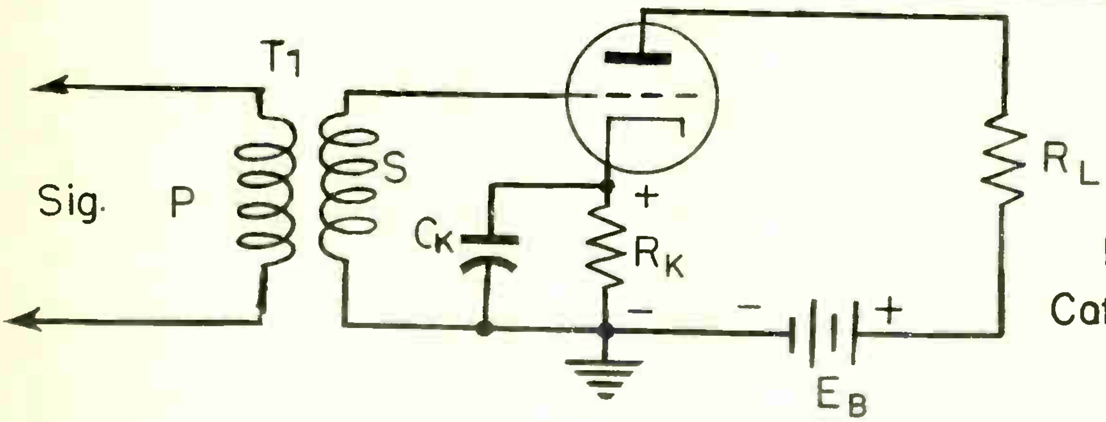




Fig. 7 B
Cathode Bias

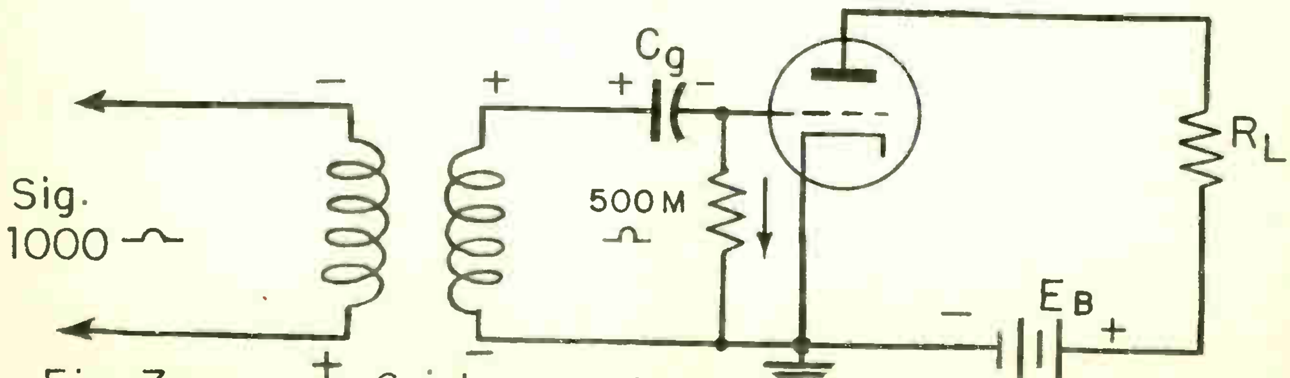



Fig. 7c Grid Leak Bias

This illustrates that the signal voltage was amplified almost 3.4 times. In the voltage amplifier tube V1, the signal was amplified 15 times. This low amplification factor for the power tube is a usual characteristic of power amplifiers. The large change in plate electron flow, as compared with voltage amplifiers, is also a usual characteristic of power amplifier tubes. This change in electron flow through the primary of transformer T1 at some audio frequency makes it possible to transfer power from the plate circuit of the power tube V2 to the secondary of transformer T1 and the load device due to the electro-magnetic coupling between the primary and secondary windings.

Power output tubes are often pentode pliotrons instead of a triode pliotron as shown in Fig. 4. This is because power pentodes have a greater power sensitivity than a triode, that is, the ratio of alternating power output to the alternating input grid voltage is greater.

E. Amplifying Direct Voltage Signals

A power tube is often used to actuate a relay or a solenoid. Fig. 5 illustrates the use of a pliotron power amplifier tube V1 to energize a relay and close a switch to turn on some device. A small direct signal voltage applied between control grid and cathode of tube V1 can cause the plate electron flow to increase a sufficient amount to actuate the relay.

In Fig. 6 is shown a circuit similar to the one in Fig. 5, except that the load is now a solenoid whose purpose is to open a switch in a circuit controlling some other device. When the grid of tube V1 is made less negative by a d-c signal voltage, the plate electron flow is caused to increase and actuate the solenoid plunger, thereby opening the switch.

A power amplifier tube can also be used to supply the d-c electron flow for controlling the reactance of a saturable reactor used in a phase shifter circuit, or as a dimming control of stage lights in theatres. Figs. 7A, 7B & 7C illustrates various methods of biasing a pliotron tube.

F. Summary Questions.

1. Why is a pliotron called an amplifier?

2. Describe the operation of a resistance coupled amplifier stage as shown in Figure 4.

3. What is meant by the term "turns ratio" of a transformer?

4. Name three methods of biasing a pliotron tube.

5. In what manner does the interstage coupling differ between a direct coupled amplifier and a resistance-capacity coupled amplifier?

# INDUCTIVE REACTANCE, CAPACITIVE REACTANCE - RESONANCE

## Objective

To familiarize the student with the fundamental theory of inductive and capactive reactance and resonant circuits.

## References:

## Lesson Content

### A. General

The condition of resonance is reached when the inductive reactance of a circuit is equal to the capactive reactance of that circuit. With the help of tubes operated as oscillators it is possible for an induction heater to heat a conductive material, such as iron. It is possible for a dielectric heater to heat non-conductive materials such as plastics uniformly throughout their entire mass. Danger spots are efficiently guarded, foods are protected against contamination as well as cooked perfectly in an incredibly short time, paints are dried and innumerable other things believed impossible only a few years ago are today practical.

### B. Inductance in Alternating Circuits

If a circuit contained a pure resistance only, and an alternating potential were applied to it, as in Fig. 1A, the voltage across resistor R and the electron flow through it would be "in phase" as shown in Fig. 1B. Although the amplitude of "E" and "I" may be different, both start from the zero point of the sine curve, reach the maximum amplitude in one direction at the same instant and decrease again to zero.

The same process occurs in the reverse direction during the next alternation. When a condition such as this occurs, "E" and "I" are said to be in phase.

Fig. 2 illustrates an inductance connected across an alternating source of voltage. For theoretical purposes, although practically not possible, it is assumed this circuit contains a pure inductance and no resistance whatever. A very different electrical phenomenon takes place.

When there is electron flow through an inductance, a magnetic field is produced around the inductor and this field varies with any variations in the electron flow. If an alternating electron flow passes through this inductance, the magnetic field will be constantly changing except at the two maximum points of the cycle, 90° and 270°. This changing magnetic field around one turn would then inter-link with the neighboring turns and thereby induce a voltage in these turns. The induced EMF developed across the inductance is known as a "counter electro-motive-force" (CEMF) and is always of opposite polarity to the applied voltage. See Fig. 3. Note that when the applied voltage reaches its maximum value in one direction at "b and in the opposite direction at d the self-induced or counter-electro-motive-force, has reached its maximum values at b and d" which is exactly equal and 180° opposite in phase to the applied voltage.

C. Inductive Reactance

The electron flow through a coil will vary inversely as both the frequency and the inductance, and for a given frequency a given inductance will offer a certain amount of opposition to the flow of electrons. This opposition to the flow of electrons offered by the inductance of the coil is called "inductive reactance". The inductive reactance varies directly as the frequency and as the inductance. The unit of measurement is the ohm. The formula for determining the inductive reactance of a coil is given as: XL equals $2\pi$ fL.

where $2\pi$ equals constant (or 6.2832)
f equals frequency in cycles
L equals inductance in henries

NOTE: The number 6.2832 is twice 3.1416, which is the ratio of the circumference of a circle to its diameter. The symbol for this ratio is the Greek letter "$\pi$".

Inductive reactance increases directly in proportion to frequency. The higher the frequency, the more rapid are the changes of electron flow and of the magnetic field. This causes the flow of electrons to have less time to rise and fall in direction, Fig. 4.

D. Voltage and Electron Flow Phase Relationship

The self induced EMF across a pure inductance in an a-c circuit not only opposes electron flow through the circuit but also causes it to lag by 90° behind the applied EMF. Assuming a circuit as in Fig. 2, the voltage and electron flow phase relationship would be as represented in Fig. 5.

E. Effect of Resistance in an Inductive Circuit

1. Of course it would be impossible to build a coil or a circuit without resistance. It is necessary therefore to know how to calculate the total opposition offered by this resistance and the inductance of the circuit. The resistance associated with the inductor may be considered as a separate resistor in series with an inductor which is purely inductive. Although both are calculated separately in ohms, yet the opposition offered by the two may not be figured merely by adding their values in ohms, as would be possible for two or more resistors. The reason is because of the difference in phase relationship of the electron flow through the resistance and inductance in respect to the applied voltage.

   The combined opposition of resistance and inductance in an a-c circuit is called "impedance" and is represented by the symbol "Z".

   The formula for "Z" in an a-c circuit is: $Z=\sqrt{R^2+XL^2}$

   $$Z=\sqrt{R^2+(2\pi fL)^2}$$

   When XL equals R, both units have an equal effect on the flow of electrons in the circuit shown in Fig. 6 therefore the electron flow will lag the applied voltage by 45 electrical degrees.

   When "R" is considerably larger than the inductive reactance, the effect of "R" tending to bring the flow of electrons in phase with the applied voltage is greater than the effect of the inductive reactance tending to cause a flow of electrons to lag by approximately 90 electrical degrees. The electron flow in the circuit of Fig. 7, will lag the applied voltage by the angle shown,

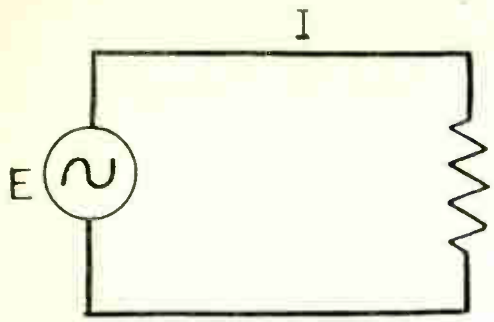



Fig. 1A

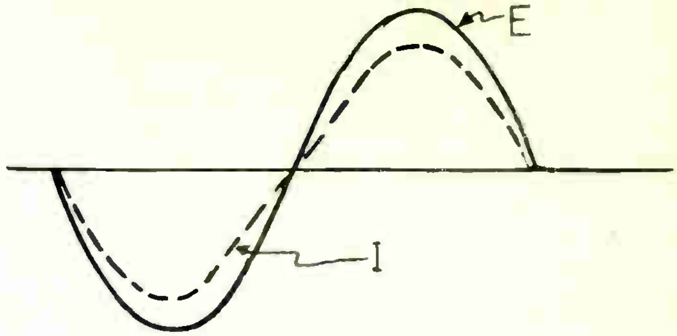



Fig. 1 B

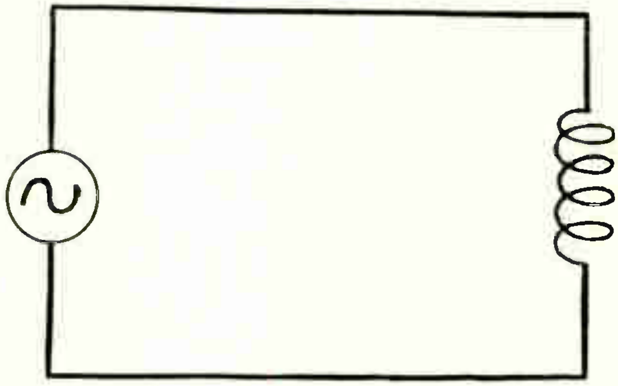
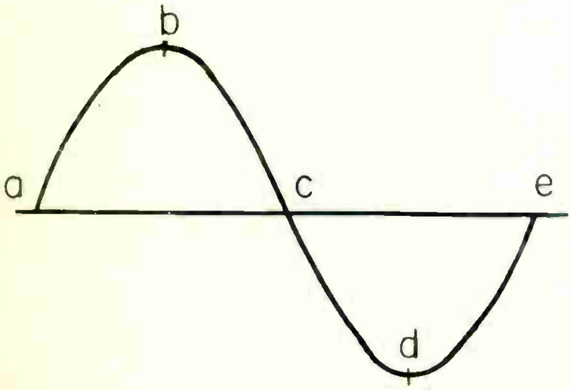
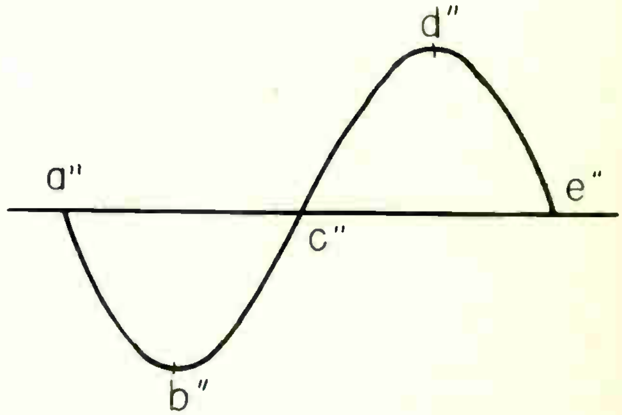


Fig. 2

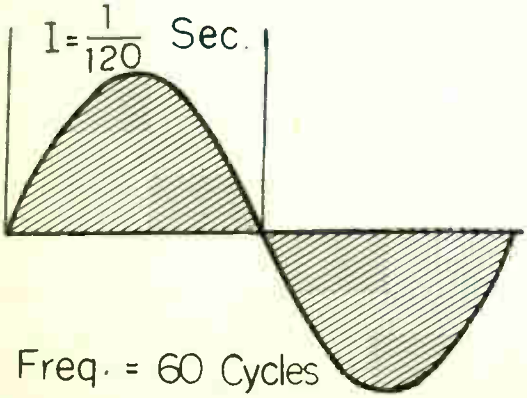



Applied Voltage across Inductance

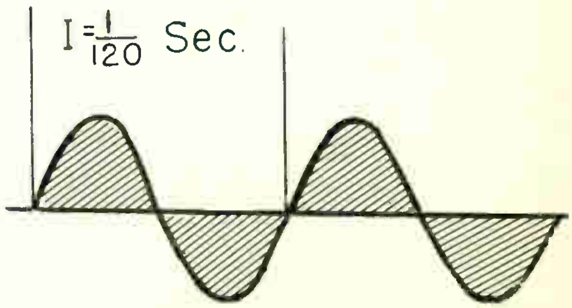



Induced Voltage (CEMF) across Inductance

Fig. 3




Freq. = 60 Cycles




Freq. = 120 Cycles

Fig. 4

which is considerably less than 45 degrees.

In Fig. 8, the inductive reactance is much greater than "R". The angle of the electron flow lag, therefore is greater than 45 degrees. The angles of Fig. 6, 7 and 8 were computed by trigonometry.

F. Capacitance in A-C Circuits

If a capacitor is connected into an a-c circuit, there will be a continual movement of electrons, first from one plate and then reversing, with reversal of EMF polarity, and then flowing from the other plate. See Fig. 9A and 9B. Thus in an a-c circuit with a capacitor, the flow of electrons continues to alternate even though the dielectric of the capacitor is an insulator.

Fig. 10, illustrates a capacitor connected across a 100 volt alternator. If the applied voltage remains the same, capacitance could be increased by increasing the plate area of the capacitor which means more electrons would have the effect of flowing in and out of a capacitor in a given period of time, the mathematical equation being: $Q = CE$

$Q$ = charge in coulombs
$C$ = capacity of capacitor in farads
$E$ = applied voltage in volts.

With a fixed capacitance and no increase in the applied potential, the capacitor would be charged and discharged more often in any given period of time, if the frequency of the applied potential were increased. The more often, within a definite time period, the capacitor charges and discharges, the more electrons would flow within the circuit. See Fig. 11.

Increased electron flow in an a-c circuit will then result from:

a. Increasing capacitor plate area.
b. Increasing the frequency of the applied voltage.

Since one ampere of electron flow is equal to one coulomb per second, then the greater the capacity of the capacitors and the higher the frequency, the greater will be the flow in amperes. An important fact to remember is that for a given capacitor, the electron flow, either on charge or discharge, will be greatest at the instant the voltage is varying most rapidly, which is at the $0^\circ$, $180^\circ$ and $360^\circ$ point of the voltage wave-form.

G. Capacitive Reactance

Opposition offered by a capacitor to alternating electron flow is called "capaci-

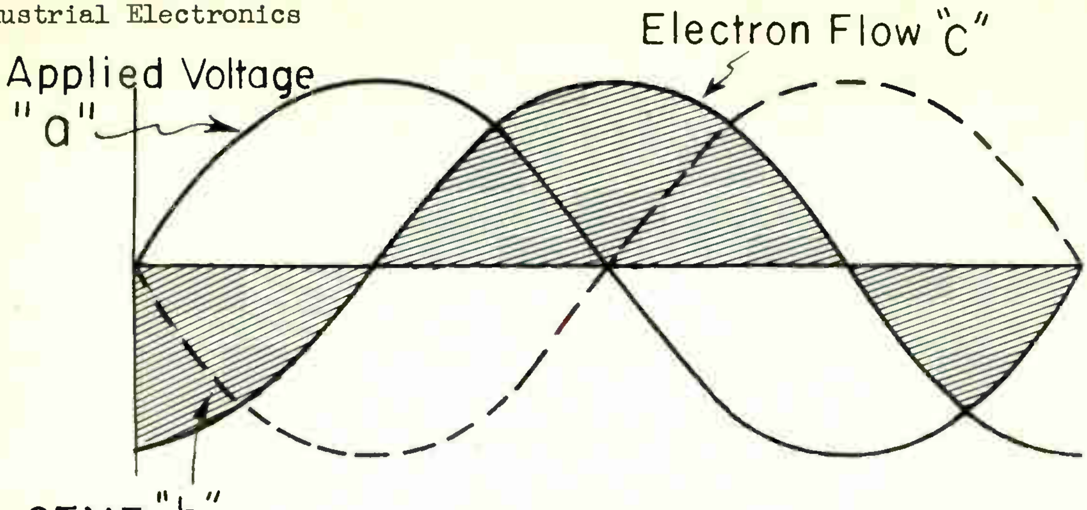



Fig. 5

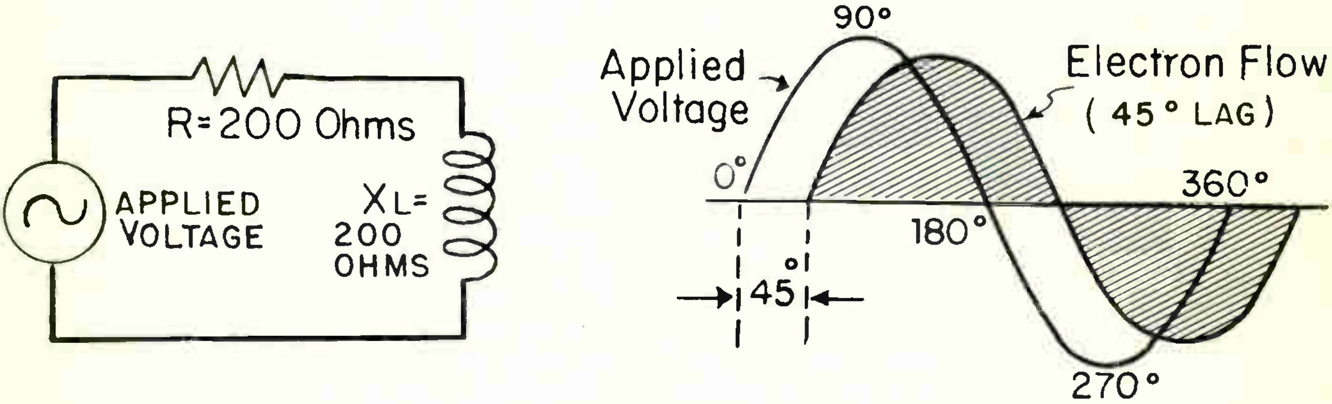



Fig. 6

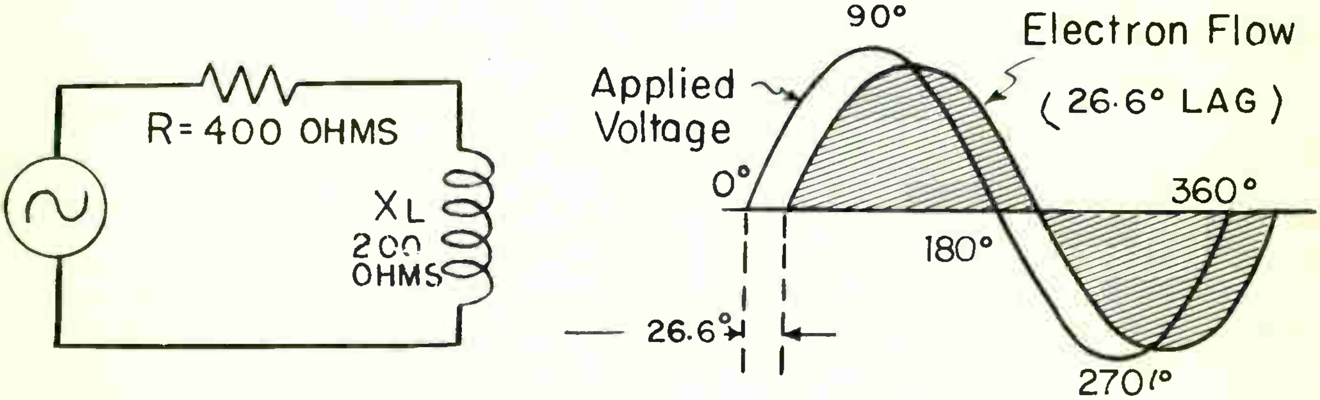



Fig. 7

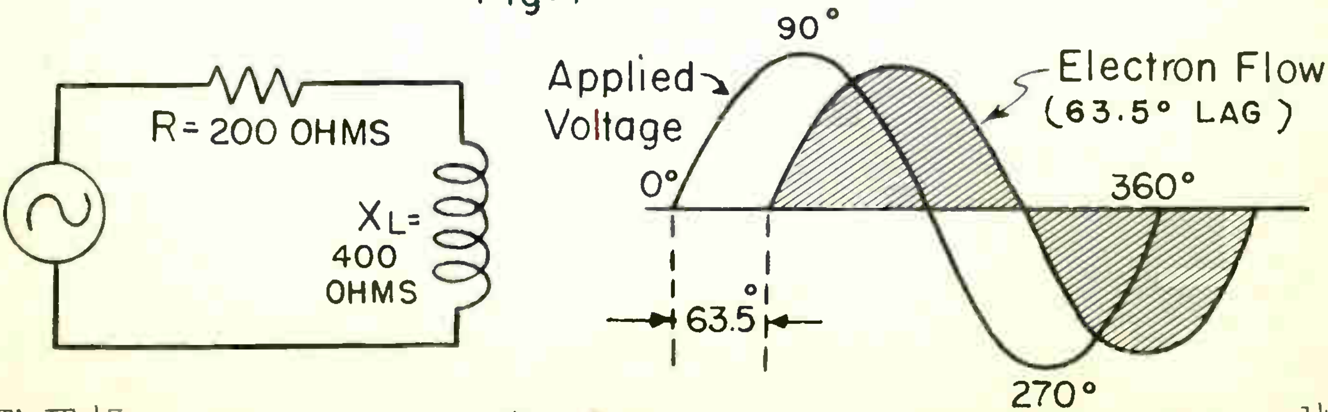



Fig. 8

tive reactance" and the symbol for capacitive reactance is "XC". The amount of this opposition is also measured in ohms like the opposition of a resistance or an inductance.

Capacitive reactance varies just the opposite to inductive reactance, when the frequency is changed. It is well to remember the opposite effects of these two reactances.

The formula for capacitive reactance is given as: $X_c = \dfrac{1}{2\pi fC}$

when: 2 = 6.28, f = frequency in cycles per second, C = capacity in farads.

However, inasmuch as capacitors are generally rated in micro-farads the formula can be re-written as: $XC = \dfrac{1{,}000{,}000}{2\pi fC}$

H. Phase Relationship of Voltage and Electron Flow.

A circuit is assumed containing an a-c source and a capacitor completely discharged with no resistance. Since the effects of capacity are manifest when voltage variations are taking place, the electron flow curve shown in Fig. 12 is based on the curve of the applied voltage.

In an a-c circuit containing capacity and no resistance, electron flow reaches maximum value at the instant applied voltage begins to rise above zero, has decreased to zero at the time voltage has risen to maximum and is again maximum when voltage has decreased to zero. Therefore, in a purely capacitive circuit, electron flow is 90° ahead of the applied voltage. This is exactly opposite to the effect of a pure inductance in an a-c circuit.

I. Effect of Resistance in a Capacitive Circuit

When a circuit contains resistance in addition to capacity, then the combined opposition is called "impedance" expressed in symbol form as "Z" and measured in ohms. Because of the difference in phase relationship of electron flow through a resistor and across a capacitor, the total opposition of the two cannot be figured by simply adding their values but has to be calculated by a formula which is:

$$Z = \sqrt{R^2 + XC^2} \qquad Z = \sqrt{R^2 + \left(\frac{1}{2\pi fC}\right)^2}$$

Example: R=25 ohms, XC =50 ohms, Find "Z".

$$Z = \sqrt{R^2 + XC^2} = \sqrt{25^2 + 50^2} = \sqrt{625 + 2500} = \sqrt{3125} = 56 \text{ ohms.}$$

When XC and R in a circuit are equal, each has an equal effect on electron flow through the circuit and electron flow will lead the applied voltage by 45° and the total impedance would be slightly more than 35 ohms. See Fig. 13.

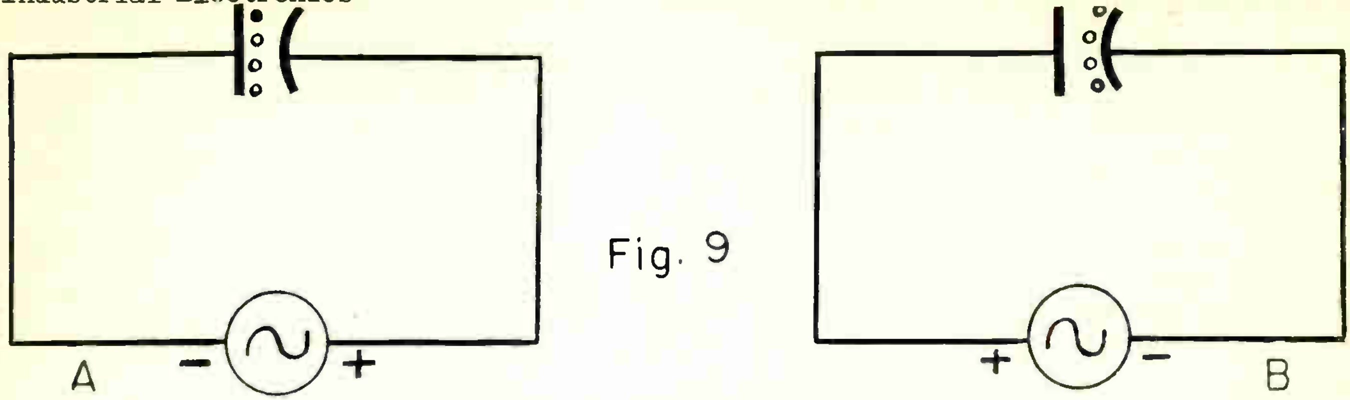



Fig. 9

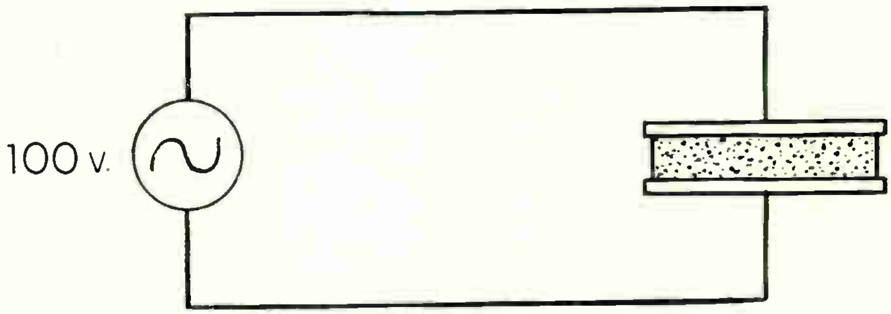



Fig. 10

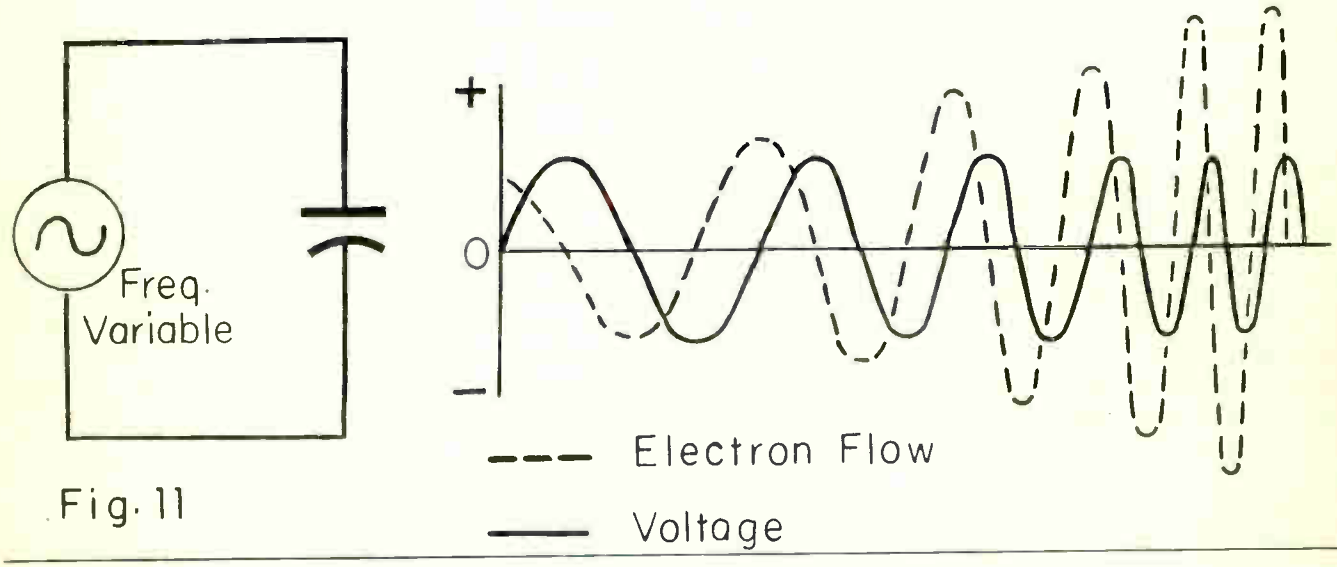



Fig. 11

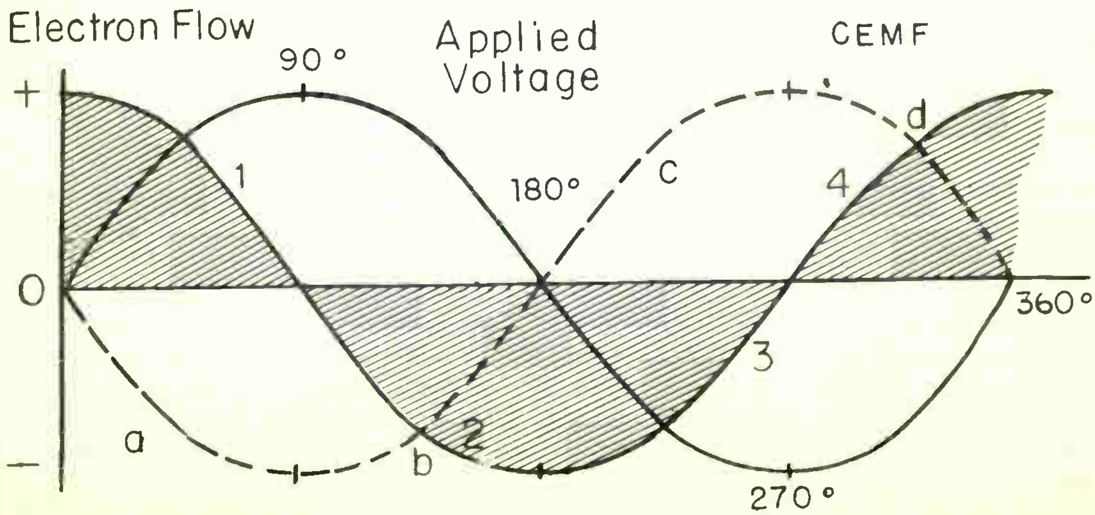



Fig. 12

When R is larger than XC, the effect of R trying to bring the electron flow in phase with the applied voltage is greater than that of XC trying to make the electron flow lead the applied voltage by 90°. The electron flow in such a circuit as shown in Fig. 14, will lead the applied voltage only by the angle shown, which is 26.6°.

If XC is much greater than R, then the effect of XC trying to force a leading flow of electrons will be much greater than R trying to keep the electron flow in phase with the applied voltage. The angle of lead in such a circuit, Fig. 15 would approach 63.5°.

The presence of a small amount of leakage will cause a capacitor to act as a pure capacitance shunted by a high resistance, as shown in Fig. 16. The flow of electrons drawn by the pure capacitance leads the voltage by 90 electrical degrees and the flow of electrons drawn by the resistor is in phase with the applied voltage. Since the resistance in parallel with the capacitance is very high, the resistance component of the flow of electrons is relatively small. Consequently the total flow of electrons through the circuit will lead the applied voltage by an angle which is slightly less than 90°.

Thus if the dielectric of a capacitor is poor, the effect of the phase relations between the flow of electrons and voltage will have the same effect.

In any practical circuit, it is impossible for the flow of electrons to lag 90 electrical degrees, in a capacitive circuit, from the applied voltage because there will always be some resistance, or some leakage in the dielectric material of a capacitor. It is also impossible, therefore, for the CEMF to be equal in magnitude to the applied voltage of an inductor. Due to this physical characteristic of a capacitor and an inductor they cannot be 100% perfect.

Since every practical technician will be working with practical equipment and not with imaginary ones, this phenomena of perfect units not existing must be taken into consideration. Both the theoretical and practical consideration of inductors and capacitors in alternating circuits are essential and should be understood. The first for ease of visualizing the theory of an inductor and capacitor in an a-c circuit and the second for reasoning with practical circuits.

## J. Resonance

Assume that the inductive reactance and capacitive reactance which are in series are exactly equal to each other. Then, as shown by Fig. 17, the voltage induced in the inductance will be exactly equal at every instant to the voltage on the capacitor, which is due to the charge of the capacitor. These two forces, however, are always acting in opposite directions at the same time. The result is that the opposition to changes of electron flow which is due to inductance is always counter balanced by the opposition to changes of current which is due to capacitance. These two forces nullify each other, the difference between their opposite values is always zero and there remains no reactive potential to oppose changes of electron flow.

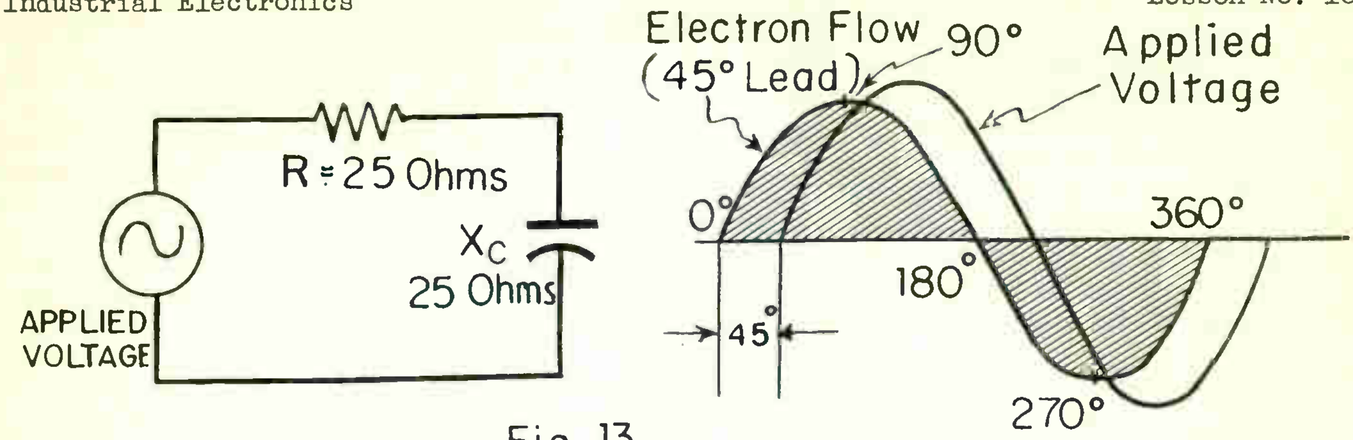



Fig. 13

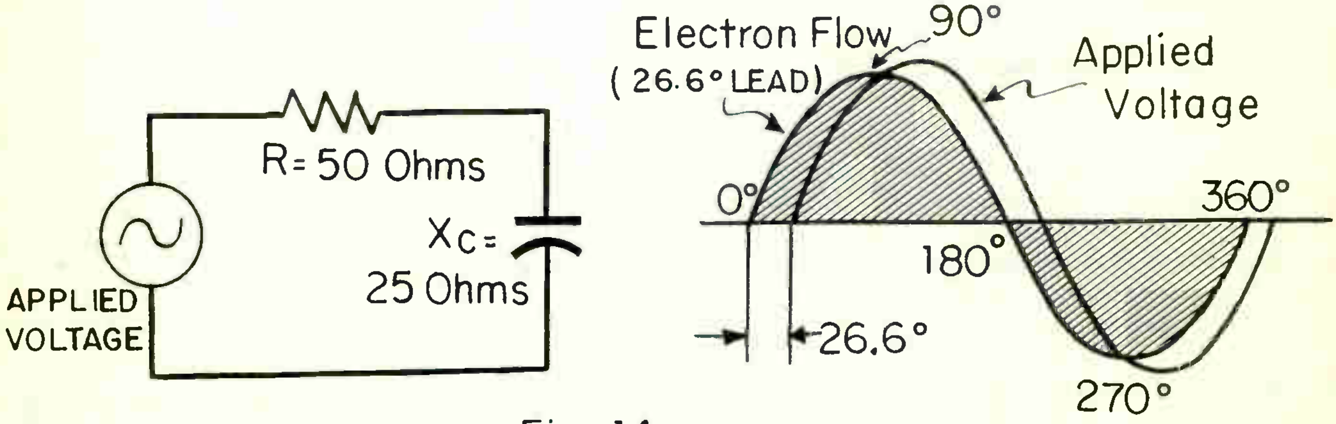



Fig. 14

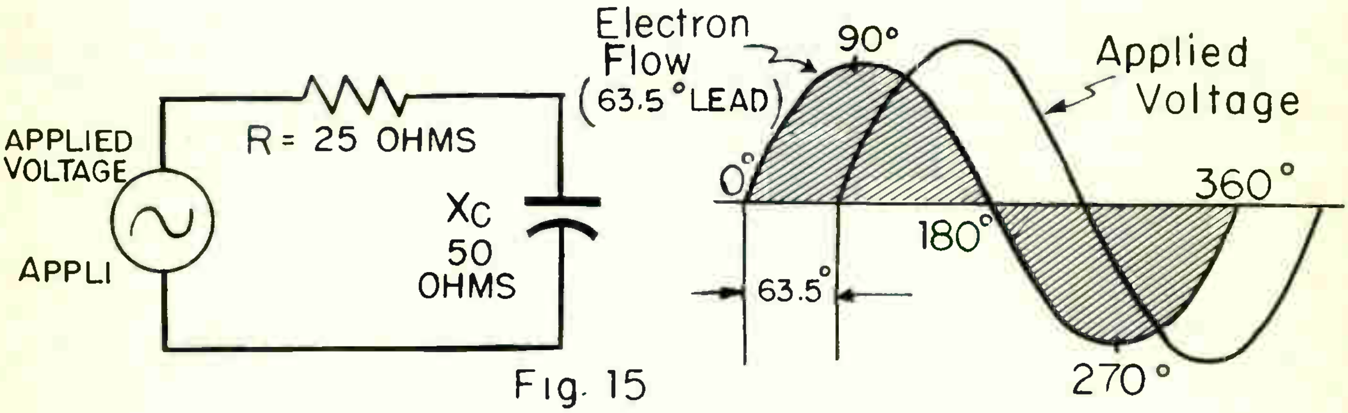



Fig. 15

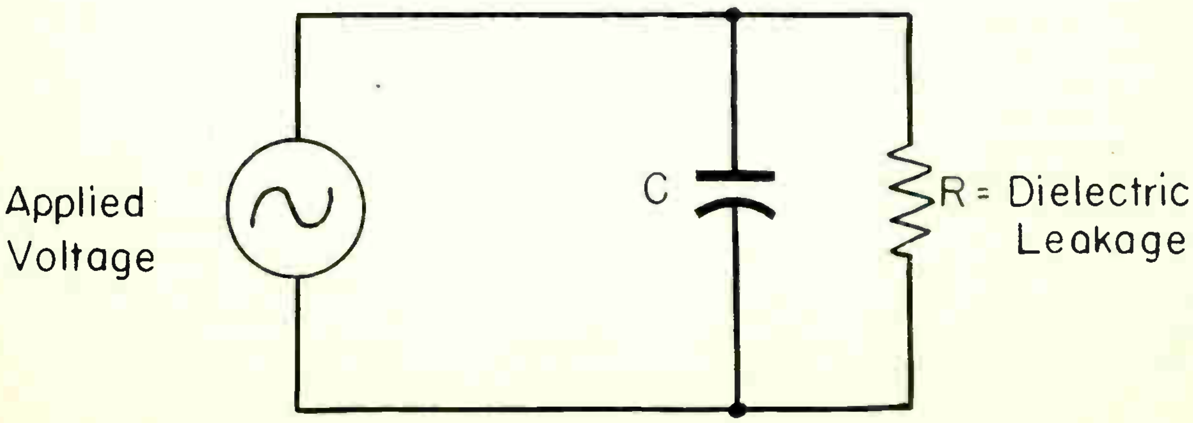



Fig. 16

This is the condition called "resonance". Resonance exists when the inductive reactance and capacitive reactance in the same circuit are exactly equal. The reactances neutralize each other, and there is no remaining reactance to oppose the alternating electron flow. In every practical circuit there must be some resistance. At resonance with all the reactance cancelled, the only remaining opposition to electron flow is that due to the d-c resistance. The amount of d-c resistance which may be in a series resonant circuit has no effect one way or the other on the frequency at which resonance occurs. Frequency depends only on the relative values of inductance and capacitance.

When resonance occurs in a circuit where the inductance and capacitance are in series with each other and with the source, such circuits may be called "series resonant circuits". Resonance occurs also in circuits where the inductance and capacitance are parallel with each other. Then the condition is called "parallel resonance".

K. Frequency and Resonance (Series Circuit)

The inductive reactance of a coil or of an inductive circuit increases with an increase of frequency. The capacitive reactance of a capacitor or of any capacitance decreases with increase of frequency. Therefore, as the frequency of the applied potential is gradually increased in a circuit containing inductance and capacitance, the induced reactance will rise and the capacitive reactance will fall until, at some particular frequency, their values become equal and the condition of resonance exists.

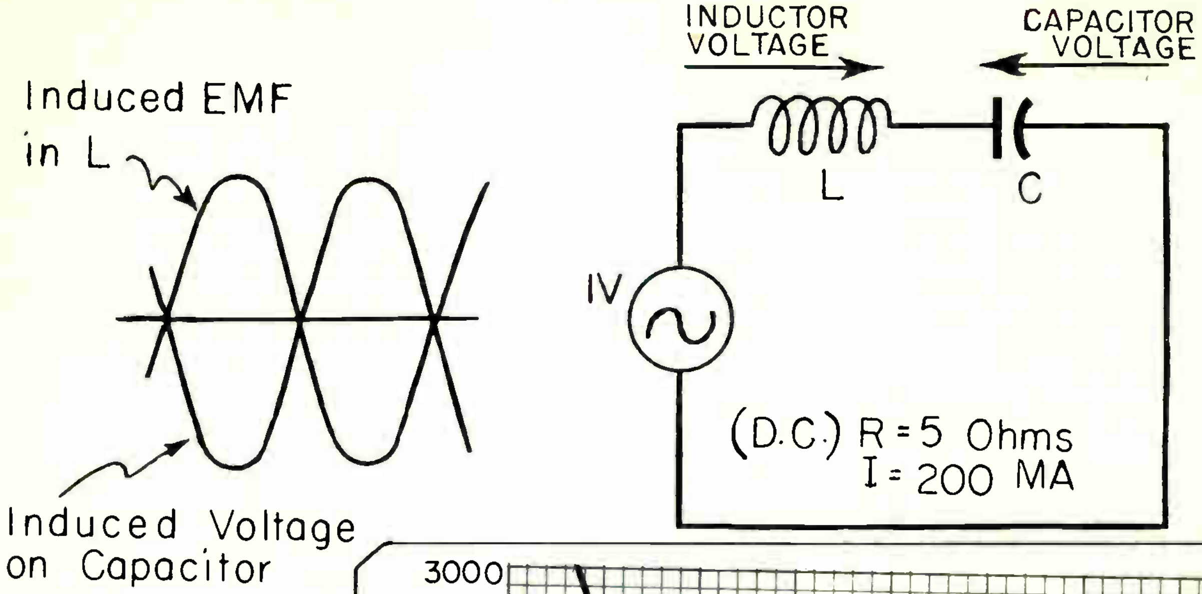
To illustrate what happens, assume an inductance of 270 microhenries and a capacitance of 100 micro-microfarads in a series circuit. Fig. 18 shows the increase of inductive reactance and the decrease of capacitive reactance of the assumed values of inductance and capacitance when frequency is changed from 500 to 1600 kilocycles. The increase of inductive reactance is directly proportional to frequency throughout the range, but the decrease of capacitive reactance is not at a uniform rate. The values of the reactances are computed from the two formulas.

$$X_L = 6.28 \times \text{frequency} \times \text{henries}$$

$$X_C = \frac{1}{6.28 \times \text{frequency} \times \text{farads}}$$

At a frequency of 968.5 kilocycles the two reactances are equal, and each has a value of 1643.2 ohms. Consequently, this combination of inductance and capacity is resonant at a frequency of 968.5 kilocycles.

At each frequency the net reactance is equal either to the inductive reactance minus the capacitive reactance, or to the capacitive reactance minus the inductive reactance, depending on which is greater. Fig. 19 shows the net reactances as they vary with frequency; these curves representing the differences between the two reactances of Fig. 18. As the frequency is changed from 500 kilocycles to the point of resonance, the net reactance decreases. This net reactance is the excess of capacitive over inductive reactance, and so, at frequencies lower than that for resonance, the circuit would behave like one having capacitive reactance. As the frequency is changed from resonance upward to 1600 kilocycles, the net reactance increases. Now the net reactance is the excess of inductive reactance over capactive reactance, which makes the circuit behave like one having inductive reactance at frequencies higher than resonance.




In a Series Resonant Circuit, the Opposing Potentials Balance Each Other When the Reactances are Equal

Fig. 17

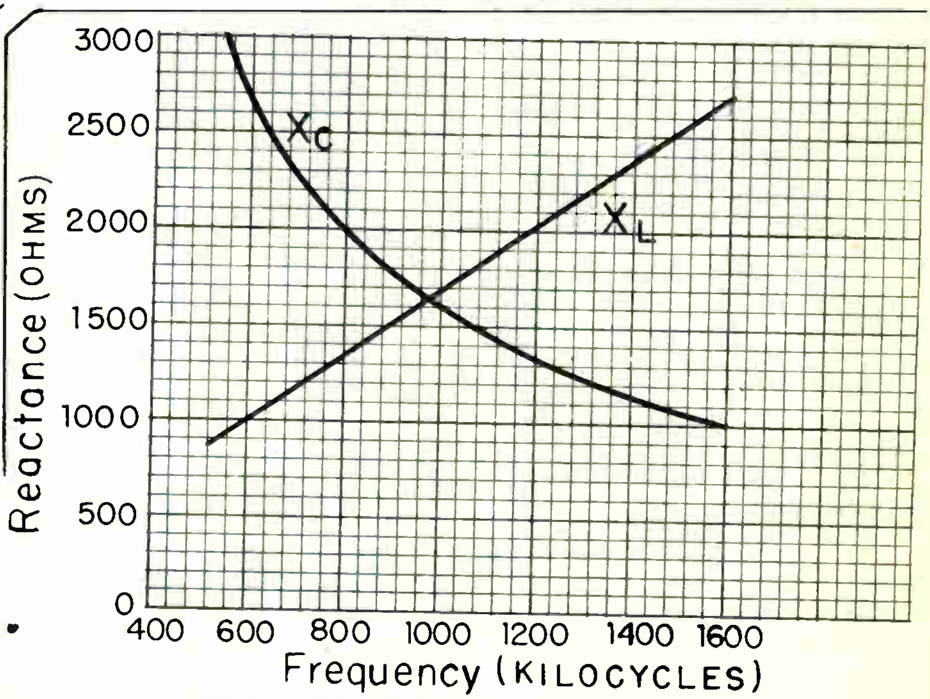



Fig. 18

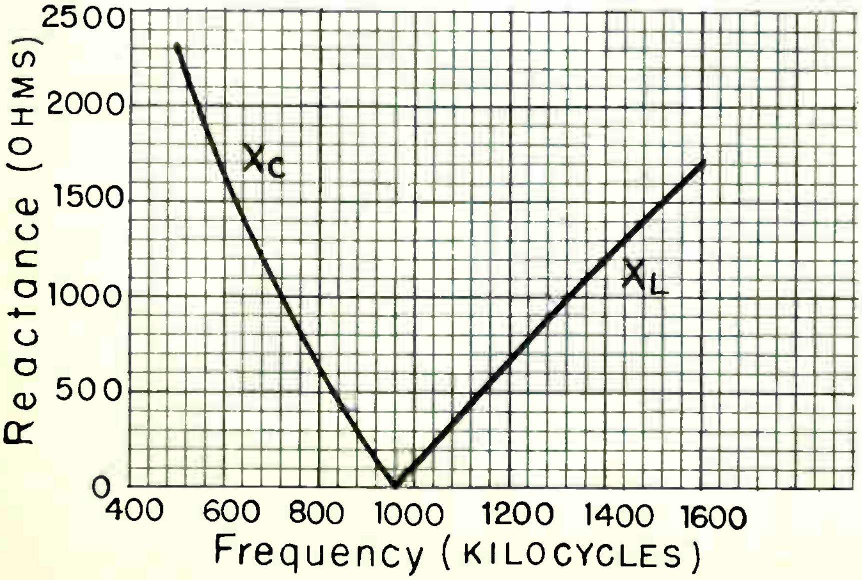



Fig. 19

L. Effect of Series Resistance

When a circuit contains resistance in addition to inductance and capacitance, the total impedance opposes electron flow. The reason that there is opposition to electron flow at resonance, even when the inductive and capactive reactances are exactly equal, is shown by Fig. 20. Here it is assumed that there is enough resistance associated with the inductance to displace the voltage induced in the inductance, which is the counter "emf" marked "Lcemf", by 30°. Where in Fig. 17 these two opposing foraces were in opposite phase with no resistance present, they now have displaced 30°/ or 150° with reference to each other because resistance has been introduced.

M. Voltages in a Series Resonant Circuit

The potential drops across the inductance (coil) and the capacitance (capacitor) in a series resonant circuit may be very great. In the circuit of Fig. 17, the electron flow is 5 ohms. But the reactances still are 1643.2 ohms, Fig. 18, and so the potential drops across the two elements must be equal to 0.2 ampere times 1643.2 ohms, or to 328.6 volts. This happens when the applied potential, from the source, is only 1 volt. These very great induced voltages in the inductance and capacitance are in opposite directions, and so they cancel each other so far as the external circuit is concerned. But the insulation of the coil and the dielectric of the capacitor must be able to withstand a potential difference several hundred times as great as the potential difference from the source. The dielectrics of capacitors frequently are punctured by the high reactive voltages, especially in transmitting apparatus where there is a large flow of electrons in the resonant circuits.

N. Parallel Resonance

In diagram "A" of Fig. 21 is shown the ideal "parallel resonant" circuit. Here the inductance L and the capacitance C are parallel with each other, or in parallel across the source potential E. In the parallel resonant circuit there may be resistance in the inductive branch as at B, or there may be resistance in the capacitive branch, as at C, or there may be resistance in both branches, as at D.

At the top of Fig. 22 is represented a series resonant circuit. Potential from an a-c source is applied at points A and C. The induced voltage across the inductive reactance acts in the opposite direction to the induced voltage across the capacitive reactance. At resonance,these two forces are equal; they nullify each other, and there is no reactive opposition to electron flow from the source through this series resonant circuit. The electron flow is the same in both parts of the series resonant circuit.

In the lower diagram of Fig. 22 the circuit has been folded at B so that points A and C are brought together. Now the inductance and capacitance are parallel with each other and we have a parallel resonant circuit with its terminals at B and A-C. Note where the two forces that oppose changes of electron flow act against each other in the series circuit, and leave zero opposition to the flow from the source,that in the parallel resonant circuit these two forces act together in opposing the potential of the source, and at resonance, provide maximum opposition to the flow of electrons from the source. That is, during the half-cycle in the parallel resonant circuit of Fig. 22 both C and L counter voltages act in the same direction (upward) to oppose at "B" the potential of the source that is acting toward "B". During the opposite half cycle C and L counter voltages will reverse their direction, but so will the potential from the source and again the forces in the parallel circuit will oppose the force from the source.

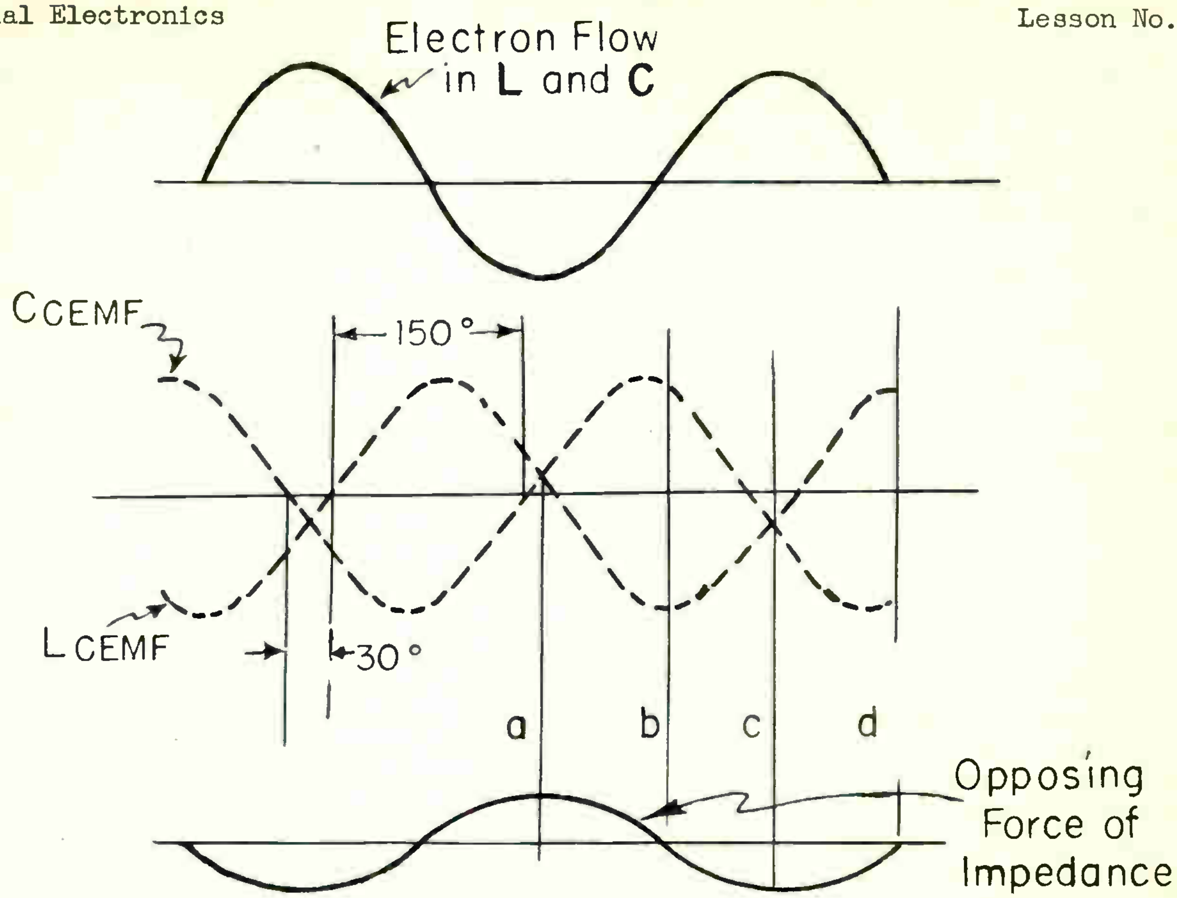



Fig. 20 Resistance Causes a Phase Difference at Resonance

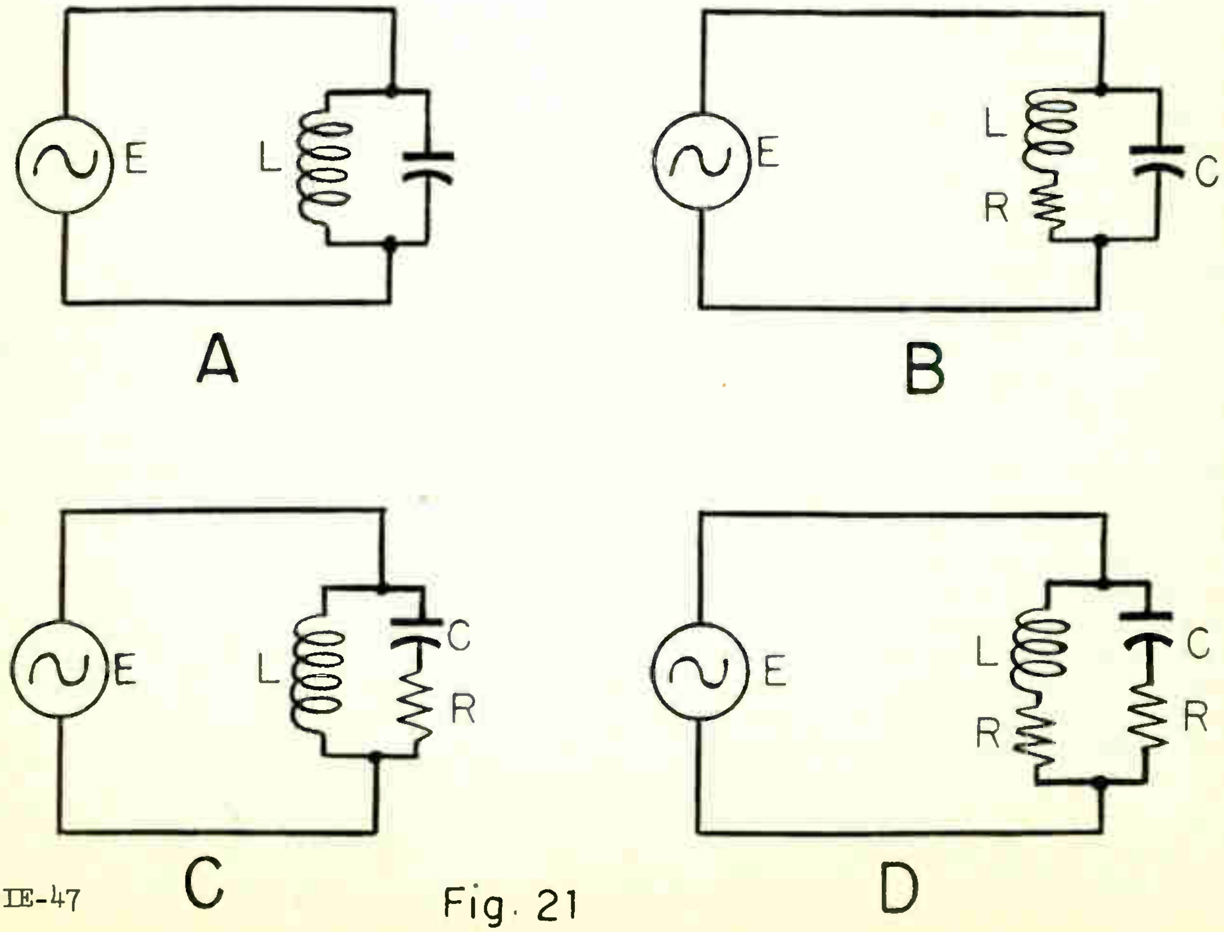



Fig. 21

In a parallel resonant circuit, the same potential differences exist across both branches. In any parallel resonant circuit the electron flow in the two branches may differ. This comes about because the reactances of the two branches change as the frequency is changed, and, at any instant, the electron flow in either branch is equal to the potential divided by the reactance. That is, reactive currents are $I=E/X$. With the potential E unchanged, it is plain that changes of reactance X must bring about changes of electron flow.

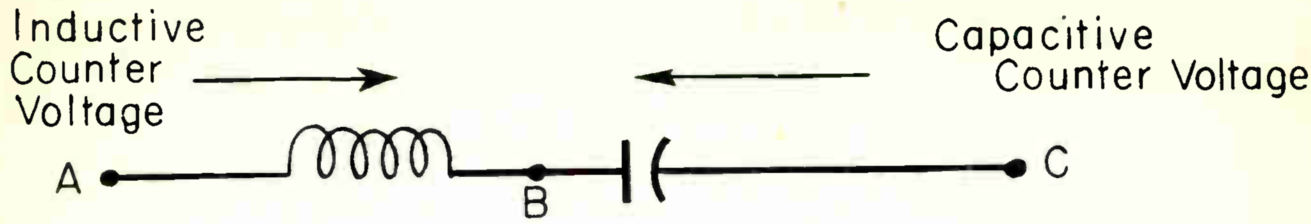
O. Currents in Parallel Resonant Circuits

At the frequency of resonance, the reactances of the two branches of the parallel circuit are equal, just as with series resonance. The potentials across the two branches also are equal, which means that the two counter voltages are equal. With the same potentials across the same reactances, the currents must be equal in the two branches, so $I_L$ is equal to $I_C$. Thus, one current, $I_L$, is in the inductance of the parallel circuit, and another current, $I_C$, is in the capacitance of the parallel circuit, and these two currents are in opposite directions, although their voltages are acting in the same direction. The simultaneous counter voltages and the currents $I_L$ and $I_C$ have the directions shown by Fig. 23. Considering the relative directions of electron flow, this means that electrons from the negative plate of the capacitor are flowing over into one end of the coil, while electrons from the other end of the coil are flowing over into the positive plate of the capacitor. Electron flow is circulating between the capacitor and the coil, going around in one direction during one half cycle, then reversing and going around in the opposite direction during the opposite half cycle. As electrons circulate first one way and then the other between the capacitance and the inductance of the resonant circuit, there is an accompanying transfer of energy from the electrostatic field in the dielectric of the capacitor to the magnetic field around the coil, and then back again.

The only energy losses in a parallel resonant circuit operating at resonant frequency are those in the resistance. The electron flow from the external source can be only enough to bring in the equivalent of the loss energy. If the circuit has but little resistance, there will be required only a correspondingly small flow from the source. Therefore, the flow of "line current" or electron flow from the external source, through a parallel resonant circuit at resonance, is only that corresponding tc the circuit resistance.

When the two electron flows in a parallel branch are unequal, the flow is as shown by Fig. 24. At frequencies below that for resonance, the flow of electrons in the inductance is greater than that in the capacitance. Then the electrons from the inductance flow as in the left hand diagram of Fig. 24, partly over into the capacitor and partly through the source as shown by arrows. At frequencies above resonance, there is a greater electron flow in the capacitor again. Then as at the right in Fig. 24, part of the electrons from the capacitor flow around through the inductance while the excess goes through the source as shown by the arrows.

As may be seen in Fig. 24, at frequencies below resonance, the electrons that flow through both the source and a parallel resonant circuit flow through the source in a direction corresponding to that of the electron flow in the inductance. At frequencies above reconsnace the electron flow through the source is in a direction that corresponds to the direction through the capacitance of the parallel resonant circuit. Therefore, at frequencies below resonance the parallel resonant circuit acts toward the source as though this circuit were an inductance, and at frequencies above resonance it acts like a capacitance.



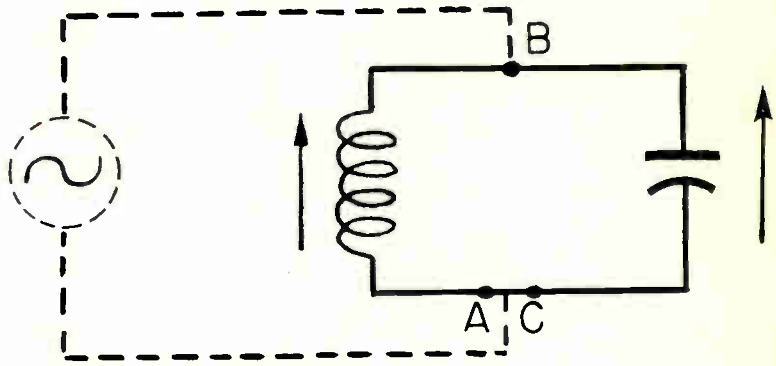




Fig. 22

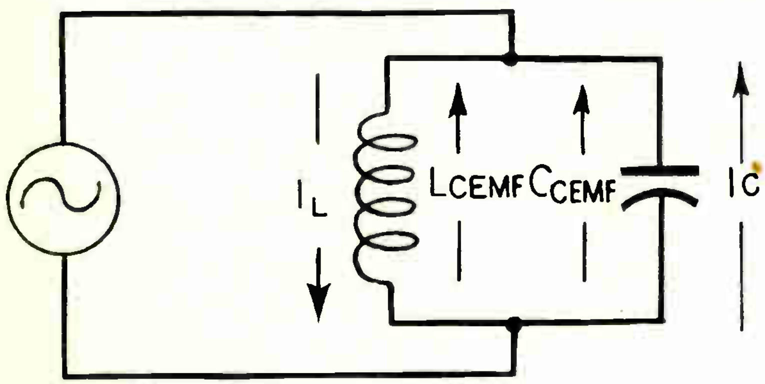
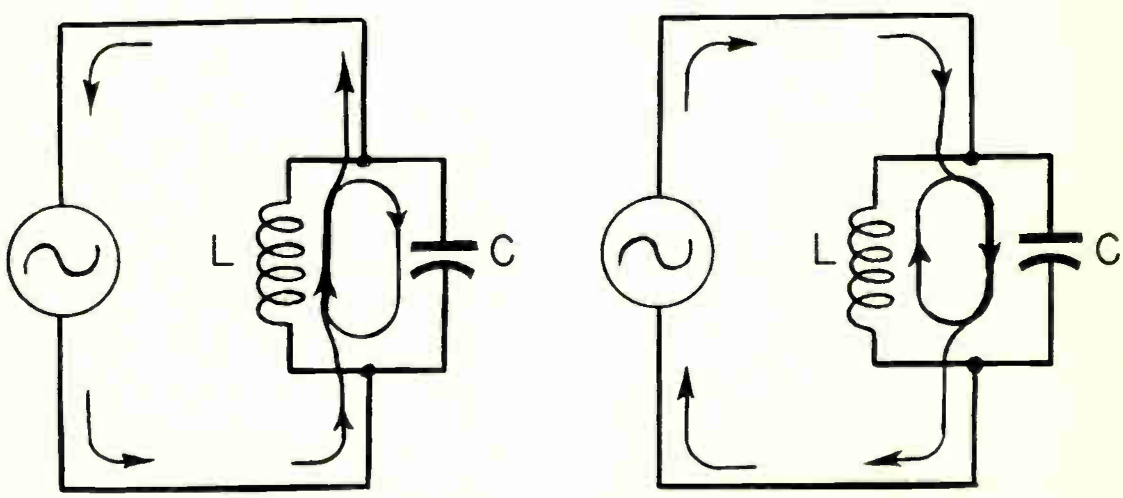



Fig. 23




Below Resonance Above Resonance

Fig. 24 • An Excess of Electrons May Flow in Either the Inductance or the Capacitance

The electron flow through the source in Fig. 24 is the difference between the flow of electrons in the inductance and in the capacitance. At frequencies below resonance, this difference in electron flow, which is like that in an inductive circuit, decreases steadily as the resonant frequency is approached and becomes zero at the resonant frequency. At frequencies above resonance the electron flow, which now is like that in a capacitive circuit, shows a steady increase. The electrons flowing in the portion of the circuit that contains the source must have a value shown by $I = E/Z$ where Z is the impedance of the whole circuit connected across the source. It is equally true that the impedance of this connected circuit must have a value shown by $Z = E/I$. At frequencies well removed, however, impedance commences to rise rapidly. At near resonance the impedance increases at a very great rate. Right at the resonant frequency, for this circuit which is assumed to contain no resistance, the impedance would become infinitely great, because it is known that at resonance no electrons would flow from the source through the parallel circuit, although there would be large circulating electron flow or oscillating electron flow in this circuit between its inductance and capacitance.

P. Summary Questions

1. In a parallel circuit, below resonance, does the circuit act inductive or capacitive?

2. How does a pure capacity in an AC circuit affect the phase relationship between electron flow and voltage?

3. What unit is used to represent the total opposition to alternating electron flow?

4. What term is used to describe the condition which exists when XL equals XC?

5. What is the phase relationship of the inductive and capacitive currents in a parallel resonant circuit?

# JOB SECTION STUDENT MANUAL

COYNE ELECTRICAL SCHOOL

CHICAGO, ILLINOIS

NOTES

Substitutions

| | | |
|---|---|---|
| 270 | Instead of | 250 |
| 2200 | " " | 2000 |
| 4700 | " " | 5000 |
| 270,000 | " " | 250,000 |
| 1,800,000 | " " | 2,000,000 |

## INTRODUCTION TO JOB SECTION

In order to satisfactorily complete the Department, all students must complete and receive a mark on all regular jobs in the curriculum.

Each student must carefully study the instructions for each job before starting so that he will understand the object of the job and what he is to accomplish. CLOSE ATTENTION SHOULD BE PAID TO EVERY DETAIL. GOOD JUDGMENT SHOULD BE EXERCISED IN ALL EXPERIMENTS.

In order to prevent damage to delicate instruments, the action and the functions of the various parts of the apparatus to be used should be studied and its operation understood. All equipment necessary should be examined for defects before attempting their use. Have everything in readiness before attempting to start any job.

Pay particular attention to warning notices and precautions to be observed while performing the job and follow the detailed procedure as given in instructions, step by step, until the experiment is completed and the necessary data is obtained. Circuit wiring experiments must be checked by an instructor immediately after completion, for initialing and grading.

Unsatisfactory shop jobs must be corrected by the student. The instructor will aid and supervise the student as he proceeds with his training.

Acceptable results depend upon the student's own ability to properly adjust the apparatus, obtain accurate readings, plan and execute the details of the experiment. It is important to determine the degree of accuracy of every result which is obtained as required by the job instructions. The experiments are performed under the guidance of the instructor, who will furnish any additional information necessary.

If damage occurs to either the experimental set-up or the associated equipment used in performing the job, the student will notify the instructor immediately, giving him the facts. The student is not to undertake repairs without first obtaining permission from an instructor.

## T A B L E   O F   C O N T E N T S

### JOB SHEETS

# ELECTRONIC DEVICES & SYMBOLS

Objective: To become familiar with Industrial Electronic parts & symbols.

Average Time Required:

References:

Tools, Equipment & Material

1. I.E. kit of parts
2. Pair of diagonal cutters
3. Pair of long nose pliers
4. Screw driver
5. Vacuum tube volt-ohm-meter & test prods
6. Soldering iron
7. Combination lock
8. Test lamp & test leads
9. Necessary solder & wire
10. Neon tester

Precautions

HANDLE ALL EQUIPMENT WITH CARE. Do not inter-mix tools and tubes in the same parts container -- considerable damage may result.

Procedure Steps

1. Study the schematic symbol chart for electronic diagrams, Pages 267 & 268.

2. Be able to redraw all symbols in each section without referring to the schematic symbol chart. This practice will enable you to become proficient in drawing and tracing circuits for which no diagrams are available.

3. In the spaces provided below record the quantity, RMA value, color code or specified values of each resistor on both parts-board sections #1 and #2 of the I.E. kit. Record the resistance value of the RF choke. Refer to the shop bulletin board for the approximate required values.

| QUANTITY REC'D | QUANTITY REQUIRED | R.M.A. VALUE | RMA COLOR CODE -A- | -B- | -C- | -D- |
|---|---|---|---|---|---|---|
| Parts-board #1 | | | | | | |
| 270Ω | 1-250Ω | 250 Ohm Res | Red | 7 Vio | 0 Br | 10% |
| 1200Ω | 1 | 1000 " " | Brown | 2 Red | 00 Red | 10% |
| 2200Ω | 1 | 2200 " " | Red | 2 Red | 00 Red | 10% |
| 10000 | 1 | 10 M " " | Brown | 0 Blk | 000 Or | 10% |
| 22000 | 1 | 20 M " " | Red | 2 Red | 000 Or | 10% |
| 47000 | 1 | 50 M " " | Yellow | 7 Vio | 000 Or | 10% |
| 100000 | 1 | 100 M " " | Brown | 0 Blk | 0000 Yel | 20% |
| 500000 | 1 | 500 M " " | Brown | 0 Blk | 00000 Grn | 20% |
| 2 | 2 | 5 M Ohm 10W | | | | |
| 1 | 1 | 10 M " 10W | | | | |
| 1 | 1 | R F Choke (30 Ohm) | | | | |
| 1 | 1 | Universal Clip | | | | |
| | | | | | | |
| Parts-Board #2 | | | | | | |
| 2-250000 | 1 | 250 M Ohm Res. | Red | Green | Yellow | 10% |
| 1-1000000 | 1 | 1 Megohm " | Brown | Black | Green | 20% |
| 1-2000000 | 1 | 2 " " | Red | Black | Green | 10% |
| 1-10000000 | 1 | 10 " " | Brown | Black | Blue | 10% |

4. Record the quantity, value, and types of capacitors included on the I.E. #1 and #2 parts-board sections of the mounting card. Record the color-code of all mica capacitors. (Refer to the shop bulletin board).

| QUANTITY REC'D | REQUIRED | VALUE (Mf.) | TYPE (PAPER) (MICA) | COLOR CODE -A- | -B- | -C- | -D- |
|---|---|---|---|---|---|---|---|
| Parts-board | #1 | | | | | | |
| 1 | 1 | .00025 | Mica | Black | Red | Green | Brown |
| 1 | 1 | .0005 | " | Red | — | — | — |
| 2 | 2 | .002 | " | Red | Black | Red | Black |
| | | | | | | | |
| | | | | | | | |

| QUANTITY REC'D | REQUIRED | VALUE (Mf.) | TYPE (PAPER) (MICA) | -E- | -F- |
|---|---|---|---|---|---|
| Parts-board | #2 | | | | |
| 1 | 1 | .005 | Paper | Black | Brown |
| 1 | 1 | .01 MFD | " | Black | Black |
| 1 | 1 | .025 | " | — | — |
| 2 | 2 | .05 | " | | |
| 2 | 2 | .1 | " | | |
| | | | | | |
| | | | | | |
| | | | | | |

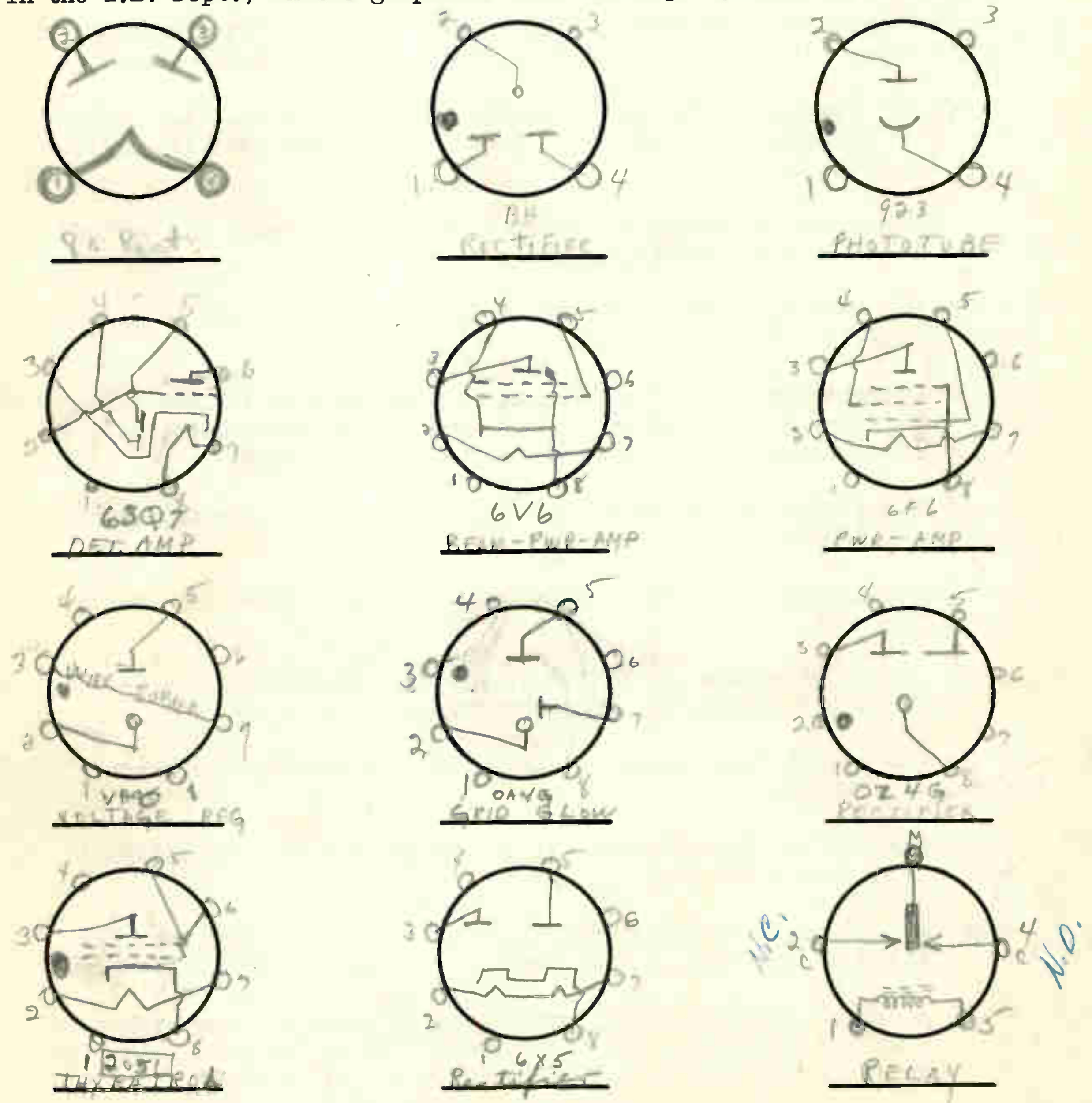
5. Record the values of all PARTS which are in the I.E. Chassis. (Refer to shop bulletin board).

| REC'D | REQUIRED | TYPE OF UNIT |
|---|---|---|
| 1 | 1 | 2 Way Relay (3,000 Ohms) |
| 1 | 1 | 250 M Ohm Potentiometer |
| 1 | 1 | 10 M " " |
| 1 | 1 | 10 M' Lin Resistor |
| 3 | 3 | 5 M " " " |
| 1 | 1 | Filter Choke (300 Ohms) |
| 1 | 1 | 3" Coil |
| 1 | 1 | 10 Mfd. Capacitor |
| 1 | 1 | 2" " " |
| 1 | 1 | 8x8 " Electrolytic Capacitor |
| | | |
| 1 | 1 | AC Test Lamp with 2 Universal clips attached. |

6. Record the quantity and type number of all tubes. Check ~~visually for an open cathode fuse link in the 2051 Thyratron tube and the 6x5 tube~~. Check all other tubes for physical defects.

| QUANTITY REC'D | QUANTITY REQUIRED | TUBE TYPE | VISUAL CHECK |
|---|---|---|---|
| 2 | 2 | 6V6GT | ok |
| 1 | 1 | 80 | ok |
| 1 | 1 | 6SQ7 | ok |
| 1-2051 | 2 | 2051 (or) VT-109 | ok ok |
| 1 | 1 | 6X5 | ok |
| 1 | 1 | 0Z4 | ok |
| 1 | 1 | VR-90 (OB3) | ok |
| 1 | 1 | 923 | ok |
| | | | |

7. Fill in the proper number of tube elements (corresponding with the tube type used in the I.E. Dept.) in the graphical tube envelope symbols provided below:




8. Mark the proper pin base number for each tube element. References for the bottom view of the tube base connections will be given in the shop.

ELECTRONIC PARTS AND SYMBOLS

1. A (X) B ( ) C ( ) D ( ) One kilovolt equals: (A) 1000000 millivolts (B) 100000 millivolts (C) 1000 millivolts (D) .000001 millivolts.

2. A (X) B ( ) C ( ) D ( ) Like charges: (A) repel (B) attract (C) multiply (D) subtract each other.

3. A (X) B ( ) C ( ) D ( ) Unlike charges: (A) attract (B) repel (C) subtract (D) multiply each other.

4. A (X) B ( ) C ( ) D ( ) One farad equals: (A) 1000000 (B) .00001 (C) .001 (D) .0001 microfarads.

5. A ( ) B (X) C ( ) D ( ) A positively charged body is one having: (A) an excess (B) an insufficient (C) a neutral number of electrons (D) a heavy nucleus.

6. A ( ) B (X) C ( ) D ( ) The flow of electrons is from: (A) positive to negative (B) negative to positive (C) positive to positive (D) less positive to more negative potential.

7. A ( ) B ( ) C (X) D ( ) Electrons in motion are defined as: (A) resistance (B) voltage (C) current (D) positive ions.

8 A (X) B ( ) C ( ) D ( ) One volt equals: (A) .001 kilovolt (B) 1000 kilovolt (C) .0001 kilovolt (D) .00001 kilovolt.

9. A ( ) B ( ) C (X) D ( ) Current consists of a movement of electrons in a circuit with: (A) no difference of potential at its ends (B) no resistance (C) a difference of potential at its ends (D) no voltage applied.

10. A ( ) B (X) C ( ) D ( ) The prefix "milli" means: (A) one-millionth (B) one-thousandth (C) 1000 (D) 100000.

11. A ( ) B ( ) C (X) D ( ) The prefix "kilo" means: (A) $\frac{1}{1000}$ (B) one million (C) one-thousand (D) .001.

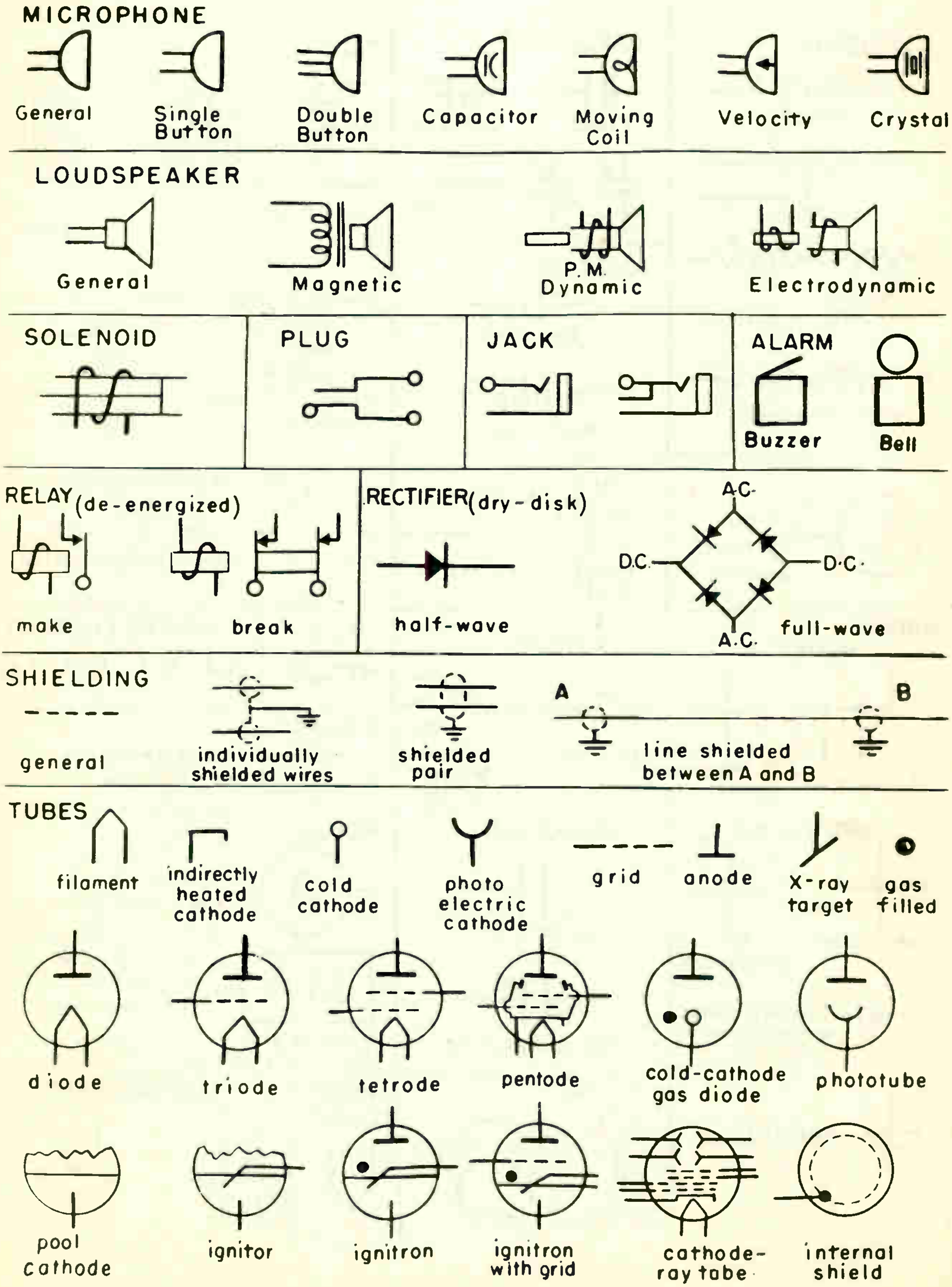
12. A ( ) B (X) C ( ) D ( ) .00025 mf equals: (A) 250000 farads (B) .00000000025 farads. (C).0000025 farad (C) 100000.(D) .00000025 farads.

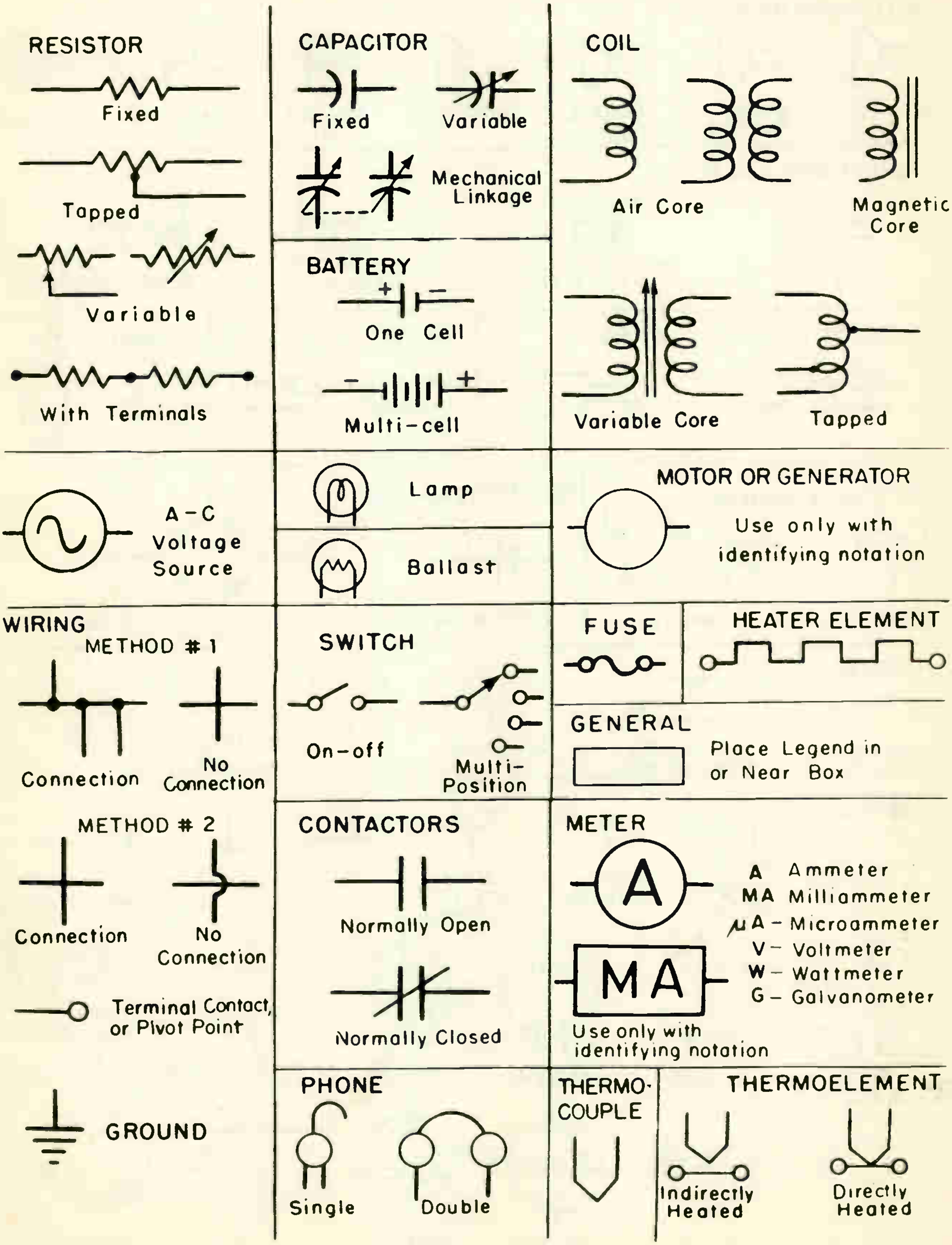
13. A ( ) B ( ) C (X) D ( ) The prefix "meg" means: (A) one millionth (B) one thousand (C) 1000000 (D) .000001.

14. A ( ) B (X) C ( ) D ( ) The prefix "micro" means: (A) one thousandth (B) one millionth (C) one tenth (D) 1,000,000.

15. A ( ) B (X) C ( ) D ( ) A resistor color coded red, black, brown, would have the value of: (A) 2000 ohms (B) .2 kilo-ohms (C) 20 ohms. (D) 200 kilo-ohms.

16. A ( ) B (X) C ( ) D ( ) A circuit containing two capacitors in parallel, one with a value of 2 mf and the other with the value of 0.5 mf the total capacitance would equal: (A) 0.5 mf (B) 2.5 mf (C) 0.25 mf (D) 25 mf.


MICROPHONE
General
Single Button
Double Button
Capacitor
Moving Coil
Velocity
Crystal
LOUDSPEAKER
General
Magnetic
P.M. Dynamic
Electrodynamic
SOLENOID
PLUG
JACK
ALARM
Buzzer
Bell
RELAY (de-energized)
make
break
RECTIFIER (dry-disk)
half-wave
A.C.
D.C.
D.C.
A.C.
full-wave
SHIELDING
general
individually shielded wires
shielded pair
A
B
line shielded between A and B
TUBES
filament
indirectly heated cathode
cold cathode
photo electric cathode
grid
anode
X-ray target
gas filled
diode
triode
tetrode
pentode
cold-cathode gas diode
phototube
pool cathode
ignitor
ignitron
ignitron with grid
cathode-ray tabe
internal shield


RESISTOR
Fixed
Tapped
Variable
With Terminals
CAPACITOR
Fixed
Variable
Mechanical Linkage
BATTERY
+ –
One Cell
– +
Multi-cell
COIL
Air Core
Magnetic Core
Variable Core
Tapped
A-C Voltage Source
Lamp
Ballast
MOTOR OR GENERATOR
Use only with identifying notation
WIRING
METHOD # 1
Connection
No Connection
SWITCH
On-off
Multi-Position
FUSE
HEATER ELEMENT
GENERAL
Place Legend in or Near Box
METHOD # 2
Connection
No Connection
Terminal Contact, or Pivot Point
CONTACTORS
Normally Open
Normally Closed
METER
A
MA
A Ammeter
MA Milliammeter
µA – Microammeter
V – Voltmeter
W – Wattmeter
G – Galvanometer
Use only with identifying notation
GROUND
PHONE
Single
Double
THERMO-COUPLE
THERMOELEMENT
Indirectly Heated
Directly Heated

## RESISTANCE - PARTS ANALYSIS

Objective: To become familiar with the vacuum tube volt-ohmmeter and to trouble shoot for faulty parts in the I.E. kit.

Average Time Required:

References:

Tools, Equipment & Material: 1. I.E. parts kit. 2. Vacuum tube volt-ohmmeter

Precautions

1. To prevent damage to the meter when checking voltages of unknown values, observe habitually the custom of switching the instrument first to its HIGHEST VOLTAGE RANGE before touching the test prods to the circuit under test. This applies to all a-c and d-c measurements.

2. Be sure that all power has been switched off in the apparatus before using the ohmmeter ranges for checking circuit components or continuity of wiring.

Procedure Steps

1. In the first column provided, record the color code or specified values of all resistance units and the RF choke mounted on parts-board sections #1 and #2 of the I.E. mounting card. (Refer to Job #1, step 3.)

2. Check the values of all resistances, listed in the first column, with the vacuum tube ohmmeter. Record values in spaces provided in the second column. Notify an Instructor if any resistances differ more or less than 20% of the color code or specified values.

| COLOR CODE VALUES OR SPECIFIED RESISTANCE VALUES PARTS-BOARD SECTIONS #1 & #2 | RESISTANCE OHMMETER VALUES (OHMS) PARTS-BOARD SECTIONS #1 & #2 |
|---|---|
| 220 Ω (ohms) | 220 |
| 1000 " | 250 |
| 2200 " | 2000 |
| 10000 " | 10 |
| 22000 " | 2 |
| 47000 " | 420 |
| 100000 | 100000 |
| 500000 " | 540000 |
| 250000 " | 25000 |
| 1000000 " | 1000000 |
| 2000000 " | 2000000 |
| 1000000 " | 1000000 |
| 25M " | 25 M |
| 270000 " | 35 M |
| 270000 " | 30 M |
| | |
| | |
| | |
| | |
| | |

3. Record, in the column provided, the specified values of all resistor units, relay coil, filter choke, and the 3" coil on the I.E. chassis. Refer to Job #1 step 5. Check, with the vacuum tube ohmmeter, the value of all resistances listed. Record these values in the spaces provided.

| SPECIFIED VALUES OF RESISTANCE | RESISTANCE OHMMETER VALUES (OHMS) |
|---|---|
| 2 wire relay 2000 Ω | 1750 ohms |
| potentiometer 250 M Ω | 350 |
| " 10 M Ω | 10 M |
| resistor 10 M Ω 10 W | 10 M |
| " 5 M Ω 10 W | 5 M |
| choke 300 Ω | 300 Ω |
| Capacitor 10 MFD | ok |
| 8 x 8 elec. cap | ok |
| 3" coil | 1.4 Ω |
| | |

4. Check the resistance of the primary and secondary windings of the power transformer across the specified lug numbers.

| TRANSFORMER LUG NUMBERS | | OHMMETER VALUES (OHMS) |
|---|---|---|
| 1 and 3 (Primary) | 1.5 to 3.5 | Primary Winding 1.2 |
| 2 and 4 | 100 to 300 Ω | Secondary Windings 55 Ω |
| 4 and 6 | 100 " " " | 75 |
| 2 and 6 | 200 " 400 Ω | 150 |
| 8 and 10 | .1 | .1 |
| 5 and 7 | .1 | .1 |
| 7 and 9 | .1 | .0 |
| 5 and 9 | .1 | .0 |

5. Turn the "selector switch" of the vacuum tube volt-ohmmeter to the proper a-c voltage range. Apply 115 volts AC to the primary of the power transformer. Take a voltage check across the points specified and record the results.

| TRANSFORMER LUG NUMBERS | SPECIFIED AC VOLTAGE | VOLTAGE CHECK |
|---|---|---|
| 1 and 3 | 115 volts | 130 |
| 2 and 4 | 350 volts | 420 |
| 4 and 6 | 350 volts | 420 |
| 2 and 6 | 700 volts | 900 |
| 8 and 10 | 5 volts | 6 |
| 5 and 7 | 3.15 volts | 4 |
| 7 and 9 | 3.15 volts | 4 |
| 5 and 9 | 6.30 volts | 6.5 |

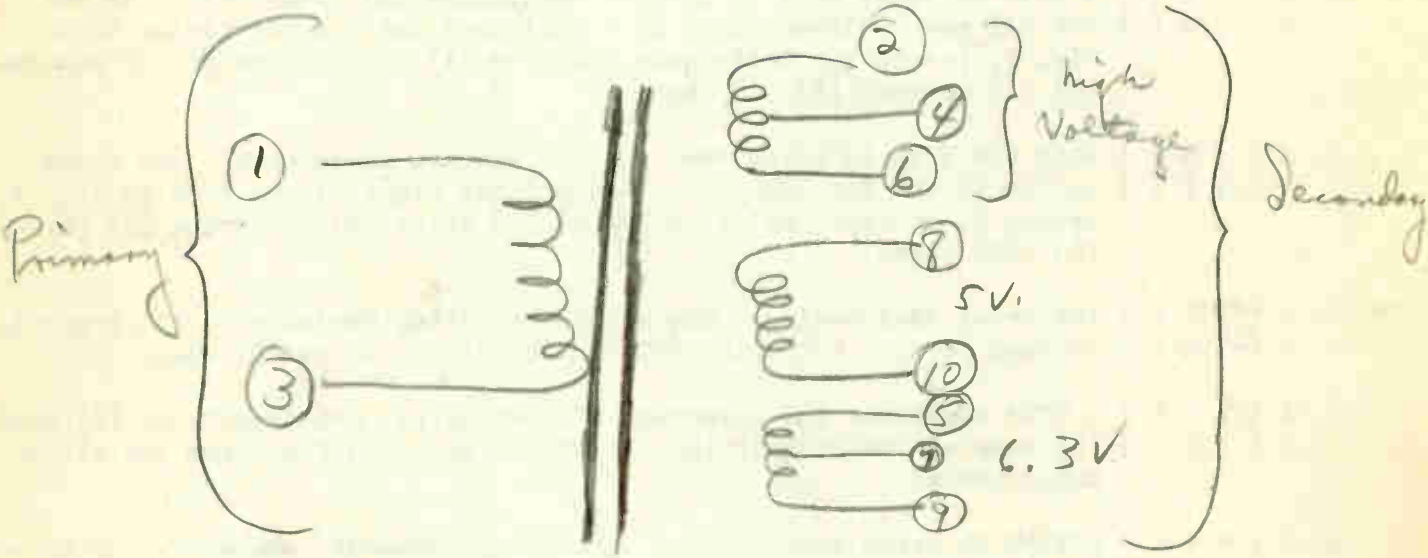
✓ R 90

OZ4

92-3

No T R

6. In the space provided below, draw a schematic symbol of the power transformer. Illustrate and identify the number of windings that actually exist.




7. Take an ohmmeter check, for continuity, on all thermionic tube filaments. Fill out spaces provided in columns below:

| THERMIONIC TUBE TYPE NUMBER | CONTINUITY TEST |
|---|---|
| 80 rectifier | 1 good. |
| 6SQ7 DET AMP | ok |
| 6V6 BEAM PWR AMP | ok |
| 6F6 PWR AMP | ok |
| VR 90 | no Test. |
| 30S1 | ok |
| 6X5 | ok |
| | |
| | |

VR 90
074
923
} No Test

RESISTANCE AND PARTS ANALYSIS

1. A ( ) B (X) When measuring alternating voltages, this VTVM scale indicates: (A)
   C ( ) D ( ) average value (B) effective value (C) peak value (D) RMS value.

2. A ( ) B ( ) A VTVM is being used to measure resistance and range switch is set
   C (X) D ( ) for RxI meg. Pointer stops at 3 divisions and 4 sub division as in Fig. 1, lesson 3. Resistance would be: (A) 380000 ohms (B) 38 megohms (C) 3.8 megohms (D) 3.8 ohms.

3. A ( ) B ( ) When the VTVM is being used for d-c voltage measurement, the range
   C (X) D ( ) switch is set for 100 volts, the pointer stops at position in Fig. 1, lesson 3, voltage indicated is: (A) 2.8 volts (B) 280 volts (C) 28 volts (D) 2800 volts.

4. A ( ) B ( ) The meter lead having a one megohm isolating resistor in its supports
   C (X) D ( ) is used for: (A) a-c volts (B) common (C) d-c volts (D) ohms.

5. A (X) B ( ) A VTVM possesses the advantage of drawing: (A) practically no (B) much
   C ( ) D ( ) (C) same as the circuit (D) all of the electron flow from the circuit being tested.

6. A (X) B ( ) A VTVM is being used for a-c voltage measurement. Range switch is set
   C ( ) D ( ) for 1000 volts Pointer stops at position indicated in Fig. 1, lesson 3, voltage is: (A) 280 (B) 680 (C) 80 (D) 6800.

7. A ( ) B (X) The VTVM has: (A) very low (B) very high (C) zero (D) no input resis-
   C ( ) D ( ) tance for both a-c and d-c potential measurements.

8. A ( ) B (X) This VTVM will not measure: (A) voltage (B) electron flow (C) resis-
   C ( ) D ( ) tance (D) ohms.

9. A (X) B ( ) Both black leads are used for measuring: (A) d-c volts (B) a-c volts
   C ( ) D ( ) (C) a-c amperes (D) ohms.

10. A (X) B ( ) The range switch is set at Rx1000, the pointer is as indicated in Fig.
    C ( ) D ( ) 1, lesson 3, the reading is: (A) 3800 ohms (B) 38 ohms (C) 38000 ohms (D) 3.8 ohms.

11. A (X) B ( ) The purpose of the d-c neg. and d-c pos. selector is to get: (A) proper
    C ( ) D ( ) polarities on d-c (B) proper readings on AC (C) read backwards (D) greater range.

12. A ( ) B (X) The ohmmeter covers ranges from: (A) 2 to 1000 (B) 0.2 to 1000 meg.
    C ( ) D ( ) (C) 20 to 100 ohms (D) .02 to 1000 Ma.

13. A ( ) B ( ) The VTVM is designed to measure: (A) voltage, resistance, current
    C (X) D ( ) (B) resistance, current, gain or less (C) voltage, resistance gain or loss of power (D) watts, gain or loss of power, voltage.

14. A ( ) B ( ) The range switch on the VTVM is set at 30v, the pointer indicates:
    C (X) D ( ) (A) .85v (B) 85v (C) 8.5v (D) 850v as indicated in Fig. 1, lesson 3.

15. A ( ) B (X) When measuring unknown voltage with this VTVM, the range switch should
    C ( ) D ( ) be placed on the: (A) 300v scale (B) 1000v scale (C) 100v scale (D) 30v scale.

# SINGLE-PHASE FULL-WAVE RECTIFIER

Objective: To construct, study the operation, and make tests on a single-phase full-wave rectifier.

Average Time Required:

References

Tools, Equipment & Materials

1. V1 = 80 Rectifier tube
2. T1 = Power transformer
3. C1 = 10 mf. capacitor
4. C2 = 2 mf.
5. Filter choke
6. $R_1$, R2, $R_3$, each = 5,000 ohm 10 watt resistors.
7. R4 = 10,000 ohm 10 watt resistor
8. Necessary tools, wire and solder
9. Vacuum tube volt-ohmmeter

Precautions

1. The bleeder resistors should be connected properly across the output of the rectifier in order to prevent electrical shocks while experimenting with this rectifier.

2. For convenience of disassembling your circuit do not make pigtail connections to the tube socket lugs.

3. Be sure the tube is out of the socket during the wiring procedure.

Procedure Steps

1. Set the apparatus in compact form and wire it neatly. (Refer to schematic diagram and chassis layout drawing.)

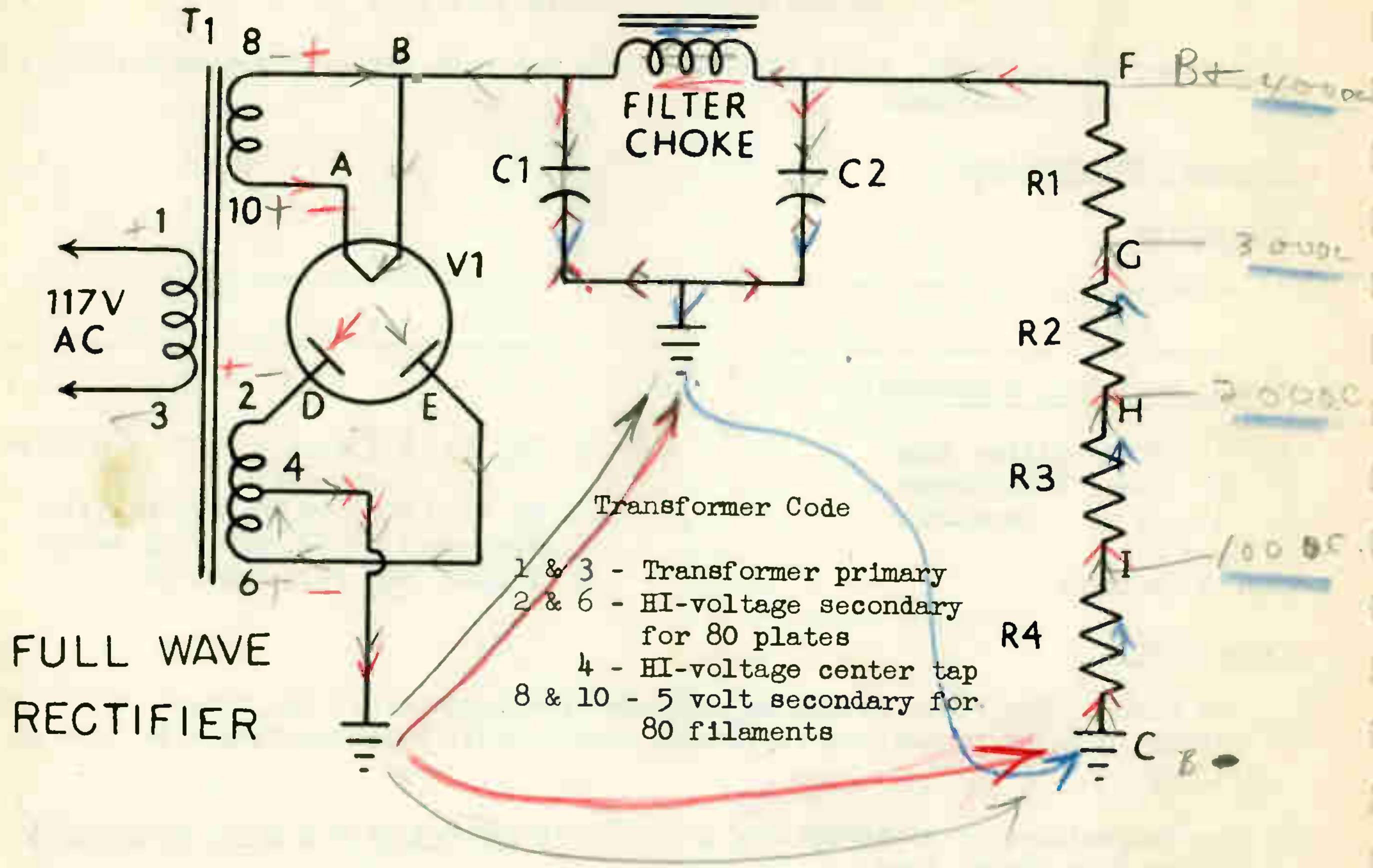
2. Wire the circuit as follows:

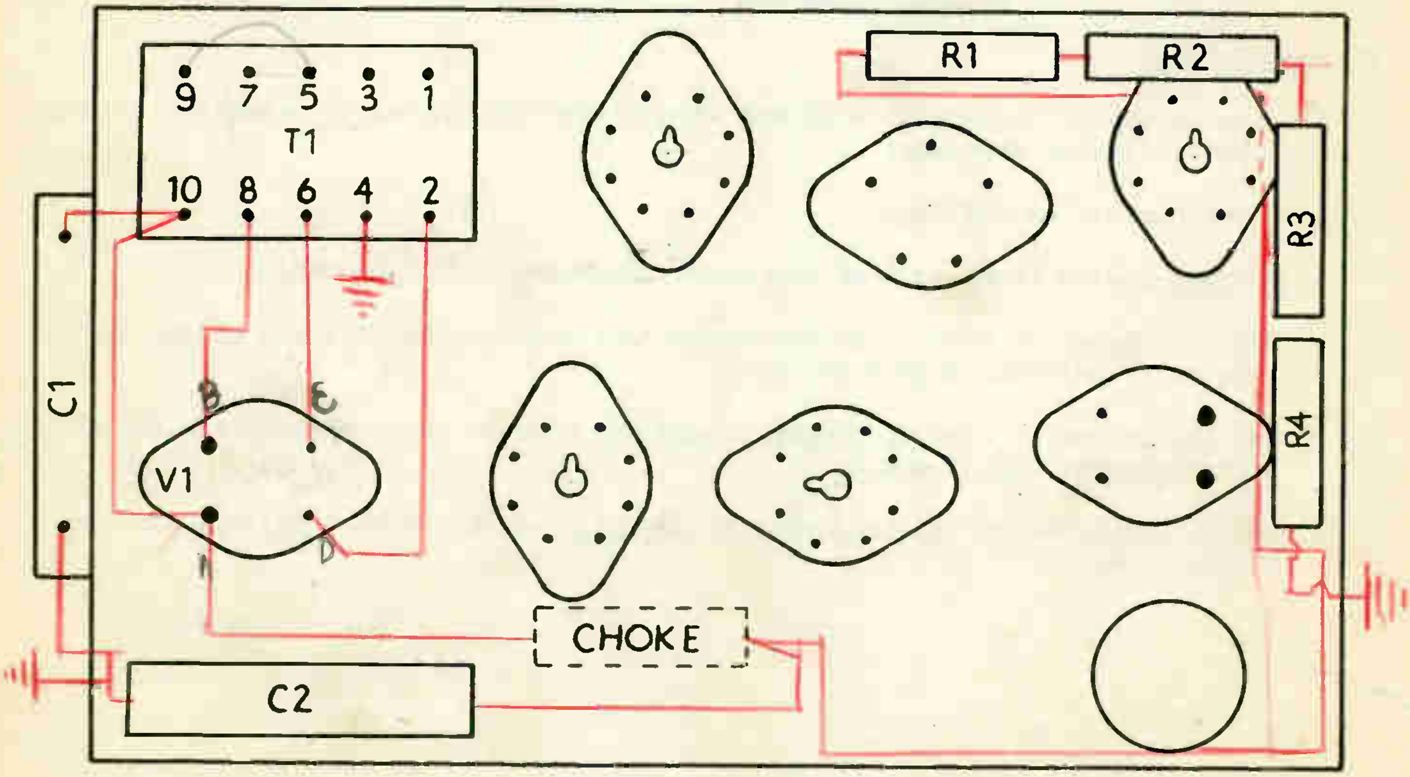
   a. Connect a wire from lug 4 of the power transformer to a grounding lug.

   b. Cut two pieces of wire of proper length and connect the filament of the 80 tube to transformer lugs 8 and 10.

   c. Cut two pieces of wire of proper length and connect the plates of the 80 tube to transformer lugs 2 and 6.

   d. With a short length of wire, connect one side of the 80 tube filament to the filter choke.




CHASSIS LAYOUT DRAWING

e. Connect the other side of the filter choke to the 5,000 ohm bleeder resistor, $R_1$.

f. Connect $R_1$, $R_2$, $R_3$, and $R_4$ in series. Connect one end of $R_4$ to a grounding lug.

g. Connect one side of $C_1$ to point B and other side to a grounding lug.

h. Connect one side of $C_2$ to point F and other side to a grounding lug.

3. Trace the electron flow on the schematic diagram, showing the various electron paths when one cycle of input voltage is applied to the primary of $T_1$.

4. With the 80 rectifier tube out of the socket take ohmmeter resistance readings with the ohmmeter connected between specified points and record the readings in the column "Ohmmeter Readings".

5. With the 80 rectifier tube out of the socket, apply 117 volts to the primary of the transformer. Take the a-c voltage readings across specified points.

NOTE: In measuring unknown voltages, always start with the highest range of the meter.

6. Insert the 80 rectifier tube in the socket. Measure a-c voltage across specified points.

7. Record steps 5 and 6 in the column under the heading "AC voltage analysis."

8. Take d-c voltage readings across specified points before and after the 80 rectifier tube is inserted in the socket. Record this information in the column under the heading "DC voltage analysis".

| BETWEEN POINTS | OHMMETER READINGS |
|---|---|
| F and R | 24,000 Ω (25,000 Ω or better) |
| A and B | .2 Ω |
| B and F | 100.2 Ω |
| A and D | 20,000 Ω |
| A and E | 21,000 Ω |
| D and C | 70 Ω |
| E and C | 70 Ω |
| D and E | 150 Ω |

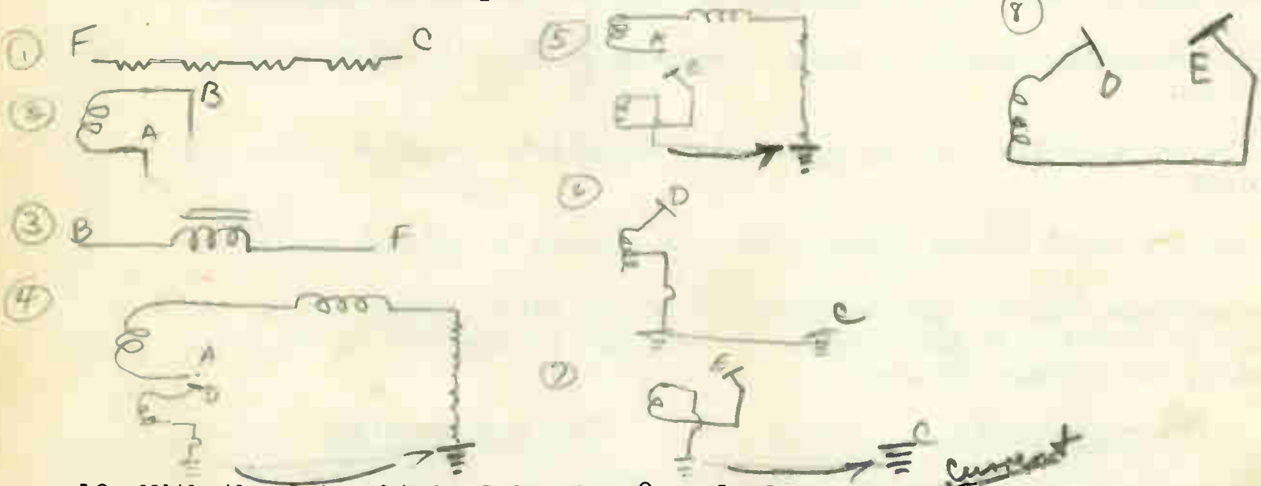
A-C VOLTAGE ANALYSIS

| Across Points | 80 Tube not inserted | 80 Tube inserted |
|---|---|---|
| A and B | 200 | 110 |
| D and C | 440 | 435 |
| E and C | 430 | 435 |
| F and C | 70 | 45 |
| B and F | 200 | 225 |

## DC VOLTAGE ANALYSIS

| Across Points | 80 Tube not inserted | 80 Tube inserted |
|---|---|---|
| B and C | 0 | 475 |
| F and C | 0 | 475 |
| G and C | 0 | 380 |
| H and C | 0 | 380 |
| I and C | 0 | 185 |
| B and F | 0 | 80 |
| F and G | 0 | 100 |
| G and H | 0 | 100 |
| H and I | 0 | 100 |
| B and E | 0 | 475 |
| B and D | 0 | 475 |

9. Draw, in the space below, the equivalent circuits for the ohmmeter readings you have obtained in step 4:




10. With the data obtained in step 8, calculate the DC current through the voltage divider, using "Ohm's Law" Formula. Show all work.

1

$$24000\overline{)475.000}\ \ .019$$
24000
235000
216000
19000

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

F and C = 24000 Ω
F an C = 475 Volts.

$$\frac{475\text{ V}}{24000\ \Omega} = .019\ I$$

Rectifier Output direct Electron Flow. Calculated .019 I Ampere.

Jot 7
58



1. A. (X) B. ( ) C. ( ) Capacitor C1 in job #3 and #3A is charged while the potential difference from the rectifier is: (A) increasing (B) decreasing (C) discharging.

2. A. ( ) B. (X) C. ( ) The inductor L1 offers: (A) no (B) great (C) little opposition to changes in the rate of electron flow in the load.

3. A. (X) B. ( ) C. ( ) The omission of C1 will: (A) lower (B) raise (C) neutralize the potential difference across the load.

4. A. (X) B. ( ) C. ( ) The inductor L1 offers: (A) little (B) great (C) no opposition to the direct electron flow in the load.

5. A. ( ) B. ( ) C. (X) One purpose of the voltage divider is to: (A) raise the potential (B) dissipate the heat across C2, (C) obtain various potentials from one rectifier system.

6. A. ( ) B. ( ) C. (X) Greater current output can be obtained with a: (A) kenotron (B) hexagon (C) phanatron.

7. A. ( ) B. (X) C. ( ) Compared with choke input filter systems, the capacitor input arrangement gives: (A) less (B) more (C) approximately the same direct current output voltage.

8. A. ( ) B. (X) C. ( ) In a bridge type of rectifier circuit the maximum inverse peak potential of the bridge tube would be: (A) twice (B) one-half (C) one-fourth the inverse peak voltage for a conventional full-wave rectifier furnishing the same output load voltage.

9. A. (X) B. ( ) C. (X) The "80 tube used in job #3 has a: (A) indirectly heated, (B) cold cathode (C) directly heated emitter.

10. A. ( ) B. (X) C. (X) An important characteristic of the Kenotron tube is: (A) the electron flow is from plate to filament (B) the tube envelope contains an inert gas (C) high voltage-low current operation.

11. A. ( ) B. ( ) C. (X) A three phase rectifier requires: (A) more (B) no (C) less filtering as compared to a single phase rectifier.

12. A. (X) B. ( ) C. ( ) The purpose of any rectifying device is: (A) to change A.C. to P.D.C. (B) change D.C. to A.C. (C) to change the frequency.

13. A. ( ) B. (X) C. ( ) For high voltage rectification Kenotrons possess the advantages over gas tubes in that: (A) gas tubes cannot be used as rectifiers (B) there is practically a perfect insulation on the inverse cycle when plate is negative due to vacuum within the tube (C) gas tubes will not carry heavy currents.

14. A. ( ) B. (X) C. ( ) In a capacitor input filter as the load in increased the terminal voltage: (A) increases (B) decreases (C) remains unchanged.

15. A. ( ) B. (X) C. ( ) The capacitor input filter is undersireable for loads which require: (A) small (B) large (C) medium electron flow.

16. A. ( ) B. (X) C. ( ) Using a choke input filter, as the load increases the terminal voltage: (A) greatly decreases (B) decreases to a lower value and then remains nearly constant (C) increases to a larger value.

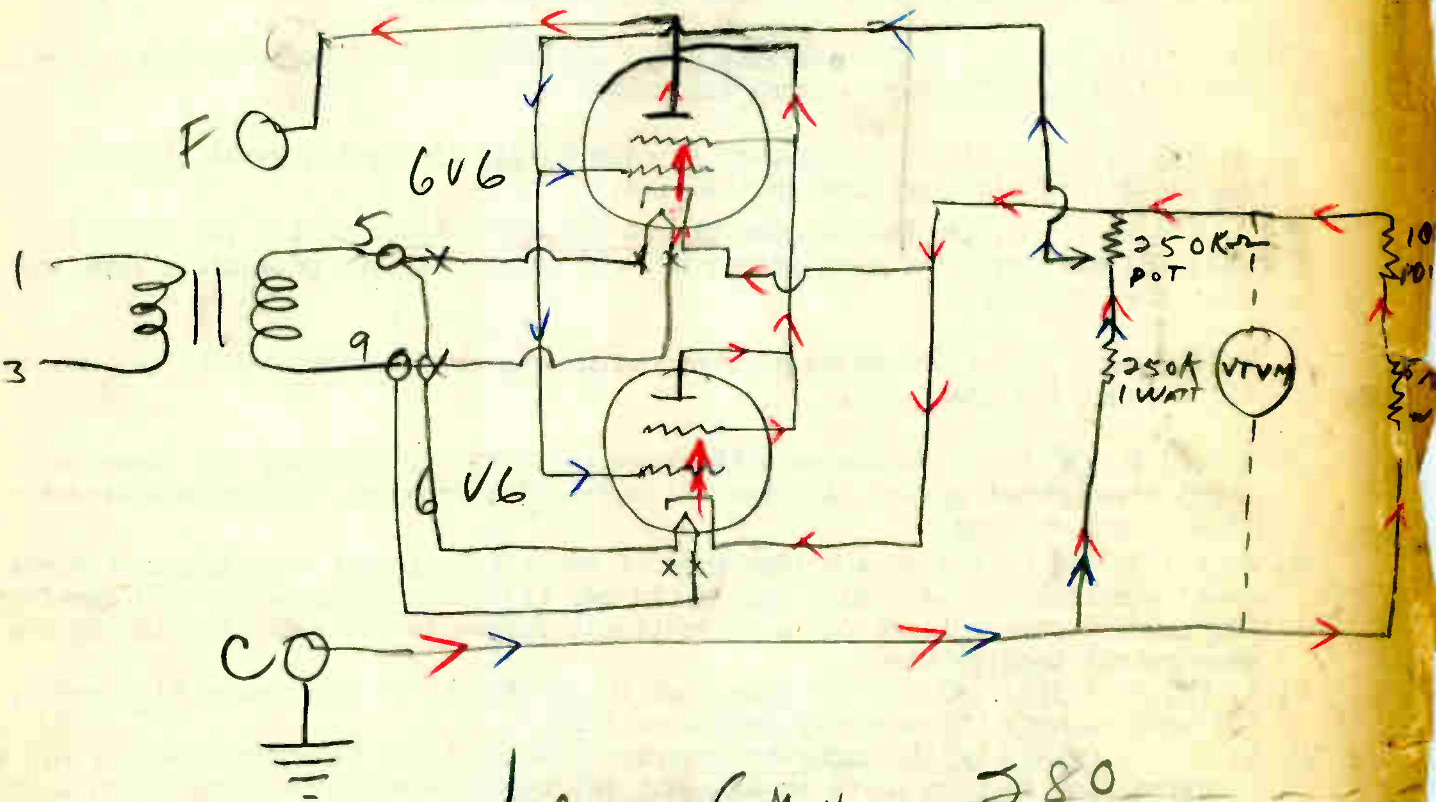
17. A. (X) B. ( ) C. ( ) The "Pi" filter could be classed as: (A) capacitor input (B) inverted "L" (C) choke input.

I P = Grid Bias

Job 3B

xx = heaters

K = 1000




Voltage { MIN - 380
MAX - 450

1. Explain briefly How Voltage is varied by changing Potentiometer. It changes voltage to the bias

2. Are the 6V6 tubes in series or Parallel? They are in Series with the load

3. The 6V6 tubes act as a Variable Voltage Power Supply

4. Why are 2 - 6V6 Tubes used? They give more voltage.

5. When would 3-6V6 tubes be used? For a Bigger Load

## SINGLE PHASE FULL WAVE RECTIFIER

1. A ( ) B ( ) C (X) D ( ) A kenotron is a: (A) gaseous tube (B) mercury vapor tube (C) vacuum tube (D) four element tube.

2. A ( ) B ( ) C (X) D ( ) A kenotron contains: (A) three elements (B) four elements (C) two elements (D) one element.

3. A (X) B ( ) C ( ) D ( ) The reason electrons travel one way through a rectifier tube is: (A) the plate does not emit electrons (B) the plate is red hot (C) AC is used on the filaments (D) because of secondary emission.

4. A ( ) B (X) C ( ) D ( ) Space charge in a kenotron tube consists of the electrons in the space between: (A) grid and plate (B) plate and filament (C) filament and glass bulb (D) grids.

5. A ( ) B ( ) C (/) D ( ) A change of potential from zero to maximum and back to zero is called: (A) cycle (B) wave length (C) alternation (D) angstrom.

6. A ( ) B ( ) C (X) D ( ) The number of cycles per second of an alternating potential is called: (A) wave length (B) voltage (C) frequency (D) microns.

7. A ( ) B ( ) C (X) D ( ) The purpose of a kenotron tube is to: (A) amplify the voltage (B) produce a large current (C) pass electron flow in one direction only. (D) generate AC.

8. A (/) B ( ) C ( ) D ( ) Electron flow through a kenotron takes place only while the plate is: (A) positive (B) negative (C) heated (D) emitting electrons.

9. A ( ) B ( ) C (X) D ( ) Electronic tubes are generally rated at: (A) effective potential for the plate (B) average plate (C) maximum potentials for the plate (D) minimum grid current.

10. A (X) B (/) C ( ) D ( ) Peak inverse potential is the maximum potential difference that may be applied when: (A) plate is positive (B) the plate is negative and filament positive (C) filament is negative (D) grid is positive.

11. A (/) B ( ) C ( ) D ( ) A rectifier which furnishes pulses of DC from alternate half cycles of alternating potential applied to the rectifier is called: (A) half-wave (B) polyphase (C) full wave (D) three phase.

12. A (X) B ( ) C ( ) D ( ) A rectifier which furnishes pulses of DC from both half cycles of alternating potential applied to the rectifier is called: (A) fullwave (B) half-wave (C) polyphase (D) two phase.

13. A ( ) B ( ) C (X) D ( ) The type 80 is a: (A) halfwave rectifier (B) polyphase rectifier (C) fullwave rectifier (D) magnetron.

14. A (/) B ( ) C ( ) D ( ) To change the pulsating electron flow to a smooth direct flow a: (A) filter is used (B) kenotron is used (C) cathode is used (D) oscillator is used.

15. A ( ) B (X) C ( ) D ( ) The small circle in the kenotron tube symbol represents: (A) vacuum (B) tube envelope (C) getter (D) ignitor:

Job No. ~~3A~~ 6

Formula $\frac{R_1 \times R_2}{R_1 + R_2}$

Industrial Electronics

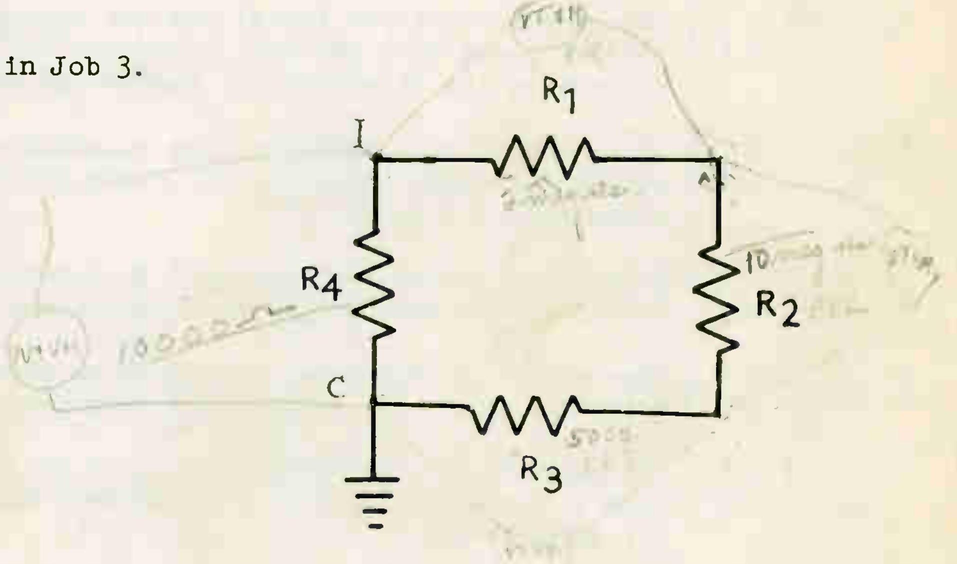
## VOLTMETER READING COMPARISON

Objective:

To learn of the difference in readings between a low and high input impedance meter across the same voltage drops.

Tools, Equipment & Materials

1. Power supply constructed in Job 3.
2. VTVM
3. Multimeter
4. R1 = 2 megohm $\frac{1}{2}$W
5. R2 = 10 megohm $\frac{1}{2}$W
6. R3 = 5000 ohm W 10W




Procedure Steps

1. Connect R1 to point I, and R3 to C, Job No. 3.

2. Take VTVM readings across R1, R2, R3 and R4 using 300 E scale.

3. Take multimeter readings across R1, R2, R3, and R4, using 300 E Scale.

| METER | ER1 | ER2 | ER3 | ER1 + ER3 + ER3 | ER4 |
|---|---|---|---|---|---|
| VTVM | 25 | 135 | 0. | 160 | 195 |
| MULTIMETER | 2.5 | 25 | 0 | 27.5 | 182 |

4. Answer Following Questions.

   a. Which meter gives the most accurate reading? VTVM

   b. Why doesn't the sum of the drops across R1, R2, R3 add up to the drop across R4? Meter Resistance is in Parallel that is were loss is due to.

   c. If the multimeter is 500 OHMS per volt what is the resistance of the circuit when it is measuring the drop across the 10 megohm resistor? 147,783 Ω

300 x 500 = 150,000

$\frac{R_1 \times R_2}{R_1 + R_2}$ 10,000,000

150,000

10,150,000

1500,000,000,000

## CAPACITOR TESTING

Objective: To obtain practice in testing capacitor units using the terminal to terminal voltage test method.

Average Time Required:

References:

Tools, Equipment & Materials

1. Single-phase, full-wave power supply
2. Vacuum tube volt-ohmmeter
3. Neon lamp
4. Capacitor units in I.E. kit
5. Phono-terminal board, J-1.
6. Electrolytic Capacitor.

Procedure Steps

1. Use the high voltage power supply that you built previously. This high voltage will be used to test most of the capacitors.

2. Determine, by voltage measurement, a point on the voltage divider circuit of the power supply where approximately 350V DC can be measured to ground.

3. With the a-c voltage disconnected from the power supply, connect the phono-terminal, J-1, across the points found in step 2.

4. Connect the capacitor unit to be tested in series with the neon lamp, connect this combination directly across the phono-terminals, Fig. 1. Apply 117 volts AC to the power supply, and test each individual paper and mica capacitor in the I.E. kit for:

   a. Short - Excessive electron flow through the neon test lamp indicates a shorted capacitor. The neon lamp glows brightly all the time.

   b. Open - Absence of electron flow indicates an open circuit in the capacitor. The neon lamp will not glow at any time.

   c. Leaky - Electron flow above normal flowing through the neon test lamp, either intermittently or continuously, indicates a leaky capacitor. The neon lamp will flicker rapidly or glow slightly.

   d. Normal - Electron flow through the neon lamp occurs only during the charging period of the capacitor. The neon lamp will glow once momentarily and then extinguish.

5. Record results of step 4 on the chart provided. If tests indicate that a capacitor is not in satisfactory condition, notify an instructor. R×1 MEG

6. Check the electrolytic capacitor in your kit for shorts. Use the ohm scale of your meter. Make readings between points indicated in Fig. 2 and record resistance values in the proper space below:

| | A & B | B & C | A & C |
|---|---|---|---|
| Faulty | | | |
| Good | X | X | X |

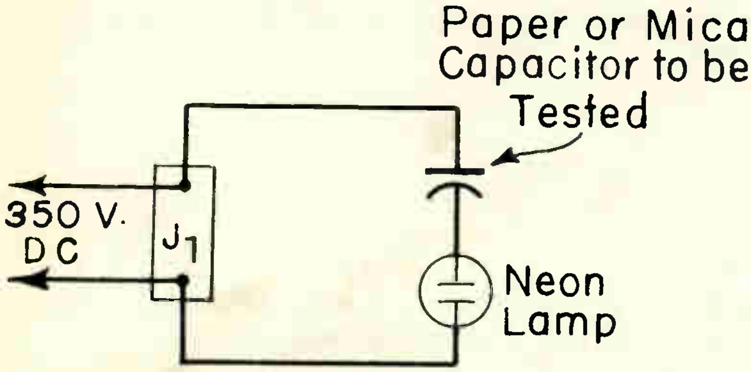



Fig. 1

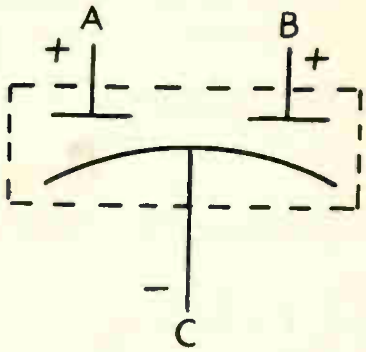



Fig. 2

Paper

Mica

| PAPER and MICA CAPACITOR CHART | | | | |
|---|---|---|---|---|
| Size MF | CONDITION | | | |
| | Shorted | Open | Leaky | Normal |
| .1 | | | | X |
| .1 | | | | X |
| .05 | | | | X |
| .05 | | | | X |
| .025 | | | | X |
| .01 | | | | X |
| .005 | | | | X |
| .000 | | | | X |
| .002 | | | | X |
| .002 | | | | X |
| 250 | | | | X |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

2.5 Milliamp for leakage per MF

## CAPACITOR TESTING

1. A (X) B ( ) C ( ) D ( ) Four, 8 MF capacitors in parallel equal: (A) 32 MF (B) 16 MF (C) 8 MF (D) 2 MF.

2. A (X) B ( ) C ( ) D ( ) The capacity of a capacitor is measured in: (A) farads (B) ohms (C) coulombs (D) voltage.

3. A (X) B ( ) C ( ) D ( ) A microfarad is: (A) .000001 farads (B) .001 farads (C) .1000000 farads. (D) 1000000 farads.

4. A (/) B (X) C ( ) D ( ) The term "paper capacitor" means that the capacitor has: (A) paper insulation (B) paper plates (C) paper container (D) low capacity.

5. A (X) B ( ) C ( ) D ( ) To obtain maximum capacity in a circuit connect all of the capacitors: (A) in parallel (B) in series (C) in series parallel (D) in inverse parallel.

6. A ( ) B (/) C ( ) D (X) Electrolytic capacitors should not exceed a leakage of: (A) $\frac{1}{2}$ MA per MF (B) $\frac{1}{4}$ MA per MF (C) 1 milliamperes per microfarad (D) 2.5 MA for an 8 MF capacitor.

7. A (X) B (/) C ( ) D ( ) In electrolytic capacitors the dielectric consists of: (A) thin layer of mica (B) thin layer of oxide film (C) thin layer of oil (D) mica and paper.

8. A ( ) B ( ) C (X) D ( ) An electrolytic capacitor may be tested by: (A) connecting it directly to a source of AC and measuring the electron leakage with a milliammeter (B) measuring the voltage drop across it (C) measuring the DC resistance of it (D) reversing the capacitor and measuring electron leakage.

9. A ( ) B ( ) C (/) D (X) An 8 MF electrolytic capacitor is allowed a leakage of: (A) .2 MA (B) .02 MA (C) 2 MA (D) 2.5 MA.

10. A ( ) B ( ) C (X) D ( ) In testing large industrial capacitors: (A) no special caution is necessary (B) test in a manner similar to testing electrolytic capacitors (C) great care should be exercised (D) no danger is present.

11. A ( ) B (X) C ( ) D ( ) Electron flow above normal indicates that the capacitor is: (A) in good condition (B) in poor condition (C) open (D) acting as a battery.

12. A ( ) B ( ) C (X) D ( ) When the rectifier potential difference reaches maximum a capacitor is: (A) completely discharged (B) partly charged (C) fully charged (D) bad.

13. A ( ) B (X) C ( ) D ( ) Industrial capacitors may: (A) discharge rapidly (B) hold their charge for days (C) be removed while in use (D) be handled without any care.

14. A ( ) B ( ) C (X) D ( ) A vacuum capacitor is designed: (A) only for DC currents (B) for low frequency AC circuits (C) for high frequency a-c circuits (D) for PDC.

15. A ( ) B (X) C ( ) D ( ) A paper or mica capacitor: (A) will not withstand as much potential difference in one direction as in the opposite direction (B) will withstand as much potential difference equally in both directions (C) will not pass AC (D) must be put in the circuit in the correct polarity.

16. A ( ) B (X) C ( ) D ( ) In Fig. 1 of No. 4 the neon lamp in series with a good capacitor would: (A) remain energized when 350 VDC was applied until the potential was removed (B) would flash and go out (C) would not become energized (D) would flicker rapidly.

17. A ( ) B (X) C (X) D ( ) Electrolytic capacitors are suitable for: (A) filtering a-c potentials (B) filtering PDC (C) use where extreme accuracy is required. (D) use with industrial equipment.

18. A (X) B (X) C ( ) D ( ) In Job No. 3, C1 is being charged: (A) while the potential difference from the rectifier is increasing (B) while the potential difference from the rectifier is decreasing (C) when there is no electron flow (D) when the plate is negative.

19. A ( ) B (X) C ( ) D ( ) The plates of a mica capacitor are generally made from: (A) brass (B) aluminum foil (C) copper (D) copper oxide.

20. A (X) B (X) C ( ) D ( ) If a capacitor is connected to a source of a-c potential the capacitor will be: (A) charged in alternate directions corresponding to the frequency of the a-c source (B) charged only in one direction (C) not charged (D) discharged.

21. A ( ) B (X) C ( ) D ( ) The term "mica" capacitor means: (A) the case is made of mica (B) the dielectric is made of mica (C) the plates are made of mica (D) the capacitor has a high capacity.

22. A (X) B ( ) C ( ) D ( ) An RMA color coded capacitor determines the capacity of the unit in: (A) MMF (B) MF (C) farad (D) Xc.

23. A ( ) B ( ) C (X) D ( ) If the dielectric is punctured there will be: (A) no electron flow through the capacitor (B) an open circuit (C) electron flow through the capacitor (D) increased capacity.

24. A ( ) B (X) C ( ) D ( ) Two capacitors in parallel, the values being 20 MF and 20 MF will give a capacitance of: (A) 10 MF (B) 40 MF (C) 20 MF (D) 30 MF.

25. A ( ) B (X) C ( ) D ( ) If a capacitor under test retains its charge for 60 seconds: (A) the capacitor is shorted (B) it is a good capacitor (C) it is open (D) its frequency is 60 cps.

# CAPACITOR CONSTRUCTION

## Objective

To become acquainted with the mechanical construction of a capacitor.

## Tools, Equipment & Materials

1. Old capacitor

## Precaution

Be sure to copy all important data, such as the size of the capacitor and voltage rating, before destroying the wrapper.

## Procedure Steps

1. Obtain one old capacitor at the desk.
2. Take the capacitor apart, Note carefully how it is constructed.
3. In the space below, draw a sketch of the capacitor showing how the different parts are put together.
4. Indicate on your drawing, what each part is and what type of material it is made of.
5. Explain on Page 278D, the application of this type of capacitor and list the advantage of the particular type you have just drawn.
6. Answer Summary questions on Page 42

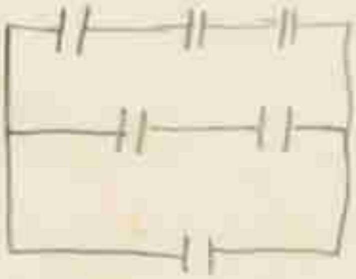

TYPE 1066
1 MFD
600 V.D.C.

Thin foil is with paper insulating both sides of the foil. It's rolled to size when then it has a wax coating for protection.

COND ROLLED IN THIS MANNER

1 Its an insulator & a charger as well

2 Cyramic, Pyranol, Electrolytic, paper, Mica & vacuum

3 


4 


5 
$$\frac{628 \times 60 \times 100 \times 2000}{1,000,000}$$

200000
× 60
12000000
× 628
96000000
24000000
72000000
7.536~~000000~~

75.36 MA

# ELECTRONIC TRIGGER TIMING CIRCUIT

Objective: To construct and study the operation of an electronic trigger timing circuit.

DON'T CONNECT CLIP TO A

Average Time Required:

References:

Tools, Equipment & Materials

1. V1 = OZ4 cold cathode tube
2. V2 = VR-90 tube
3. C1 = 10 mf. capacitor
4. T1 = power transformer
5. R1, R2, R3, R4 = 250M ohm Resistors
6. R5 = 250 M ohm potentiometer
7. L1 = relay coil
8. Necessary tools, wire and solder
9. Test lamp and leads.
10. Universal clip
11. Vacuum tube volt-ohmmeter

Precautions

1. Be sure all tube connections are properly made. Wrong connections may cause considerable damage to the tubes and parts.

2. For convenience of disassembling your circuit do not make pigtail connections to the tube socket lugs.

3. Be sure that the tubes and relay are removed from sockets before wiring the circuit.

Procedure Steps

1. Set up the apparatus in compact form and wire it neatly. Refer to the schematic diagram and chassis layout drawing.

2. Wire the circuit as follows:

   a. Choose an octal socket closest to the power transformer, to position the V1 tube. Refer to the chassis layout drawing.

   b. Connect, with proper length of wire, the plates of the V1 tube to transformer lugs 2 and 6.

   c. With a short length of wire, connect the cathode of V1 to a grounding lug.

   d. Connect resistors R1, R2, R3, and R4 in series and mount the series combination on five insulated tie-terminals.

   e. Connect transformer lug 4 to point A Solder a suitable length of wire to one side of R5, attach a universal clip to the opposite end of this wire, and clip it to point D. Refer to schematic diagram.

   f. Connect one side of L1 and C1 to the rotating contact of R5. Connect the other side of L1 to the cathode of V2.

g. Connect the other side of C1 and also plate of V2 to a grounding lug.

h. Connect the test lamp in series with the normally open relay contacts and apply 117 volts AC across the combination.

3. Insert tubes in proper sockets and apply 117 volts AC to the primary of T1. Observe operation of the circuit. Rotate contact arm of R5 gradually from minimum to maximum resistance. Note gradual change in trigger action.

4. With the rotating contact of R5 set at a predetermined point, vary the trigger action by disconnecting the tap from point D and connecting it to individual tap points B, C and E. NOTE: (Do not connect the universal clip on point A because damage will result to the potentiometer R5).

5. Determine and record the results of step 4. on the chart provided. Use tap D as the reference point. Print the proper word in the spaces provided.

6. Trace electron paths through the circuit, showing charge and discharge path of C1 Use different arrow markings or colored pencils to distinguish various electron paths.

| R5 connected to following points | Time Constant (increased) (decreased) | C1 charges to 63.2% of sources voltage (Faster) (Slower) | Trigger action (Faster) (Slower) |
|---|---|---|---|
| D | REFERENCE POINT | REFERENCE POINT | REFERENCE POINT |
| C | | | |
| E | | | |
| B | | | |

7. Set VTVM to 1000 V range. With the d-c prod on the chassis, measure d-c voltage between the chassis and point 4 of T1. Record voltage measured.

8. Set VTVM on 300 V range. With DC prod on plate of V2, measure DC voltage between lug terminals 2 & 5 of tube V2. Record minimum and maximum readings.

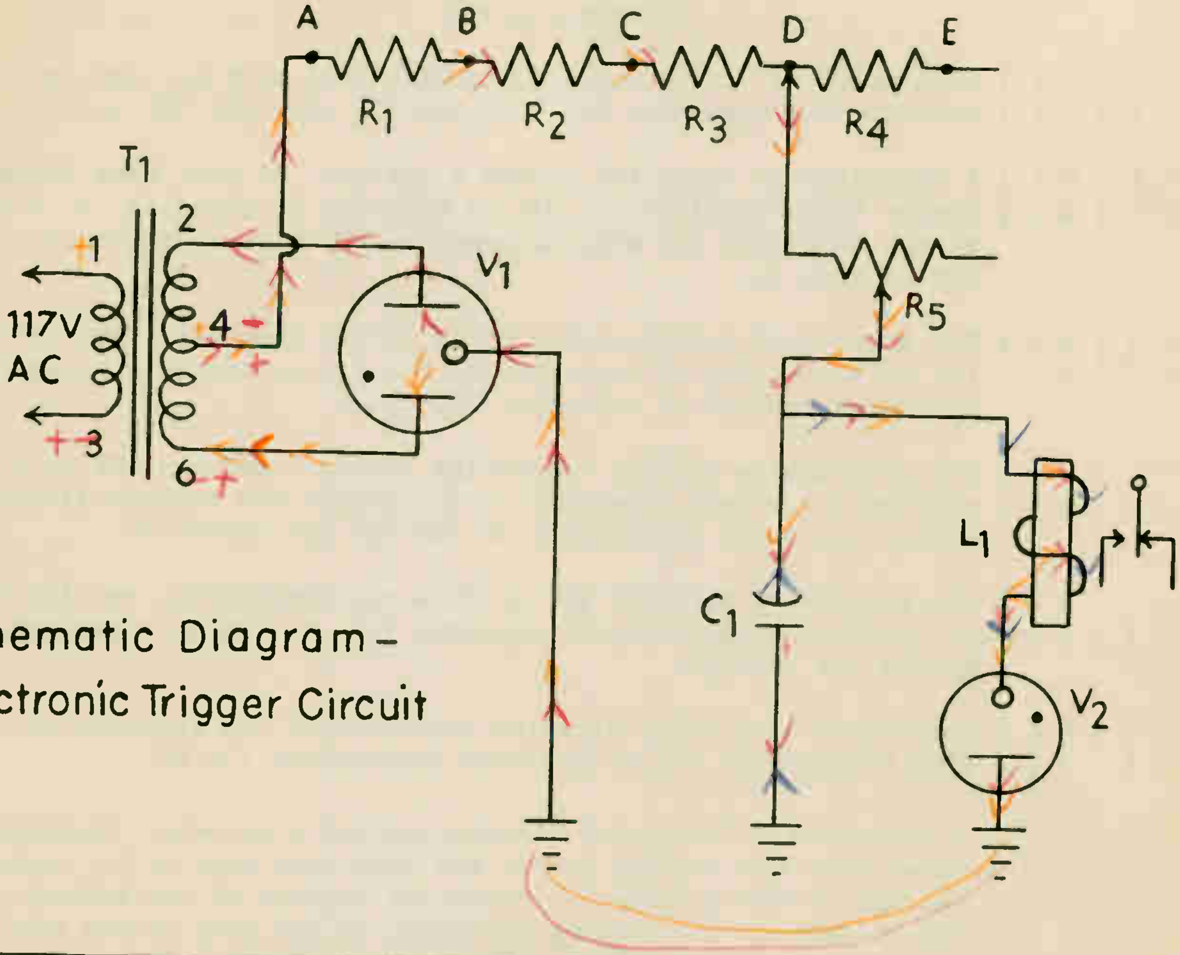
VOLTAGE ANALYSIS

Procedure Steps

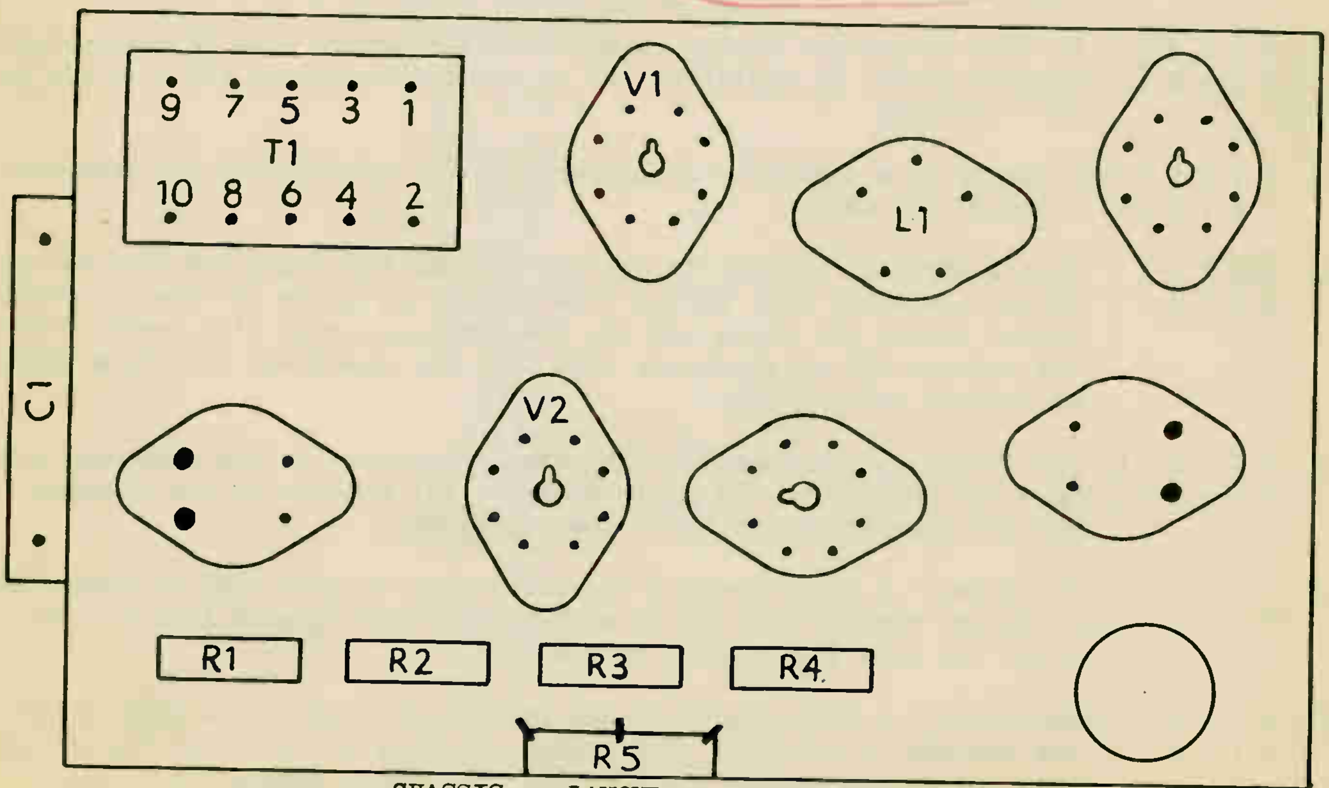
7 - - - - - - - - - - - - - - dc volts ____________

8 - - - - - - - - - - - - - - dc volts, Min. ______

dc volts Max. _______




Schematic Diagram - Electronic Trigger Circuit




CHASSIS LAYOUT DRAWING

## TRIGGER CIRCUIT

1. A ( ) B ( ) C ( ) D ( ) From point "A" to ground a continuity test with an ohmmeter should indicate: (A) zero ohms (B) infinity (C) 150 ohms (D) short circuit.

2. A ( ) B ( ) C ( ) D ( ) A capacitor is connected across a battery. It will take longer to charge this capacitor: (A) with a resistor in parallel (B) with a resistor in series (C) with no resistor (D) with another capacitor in series with it.

3. A ( ) B ( ) C ( ) D ( ) The purpose of potentiometer R5 is to: (A) vary with bias voltage (B) vary charging of capacitor C1 (C) reduce output voltage (D) limit discharge current of capacitor C1.

4. A ( ) B ( ) C ( ) D ( ) The alternating voltage across the points 2 and 4 of T1 is first applied: (A) across capacitor C1 (B) across the voltage divider (C) a across one plate and cathode of the OZ4 (D) across V2.

5. A ( ) B ( ) C ( ) D ( ) The purpose of V1 is to: (A) produce oscillation (B) amplify the signal (C) produce a pulsating DC electron flow to charge capacitor C1 (D) double the voltage.

6. A ( ) B ( ) C ( ) D ( ) Electronic time delay circuits generate: (A) low frequencies (B) ultra-high frequencies (C) no spurious frequencies (D) DC.

7. A ( ) B ( ) C ( ) D ( ) A capacitor is connected directly across a battery. Charging will cease when the voltage across the capacitor will be: (A) equal to the voltage of the battery (B) twice the voltage of the battery (C) half the voltage of the battery (D) equal to the drop on the resistor.

8. A ( ) B ( ) C ( ) D ( ) In this electronic timing circuit the electronic tube V2 serves the purpose of: (A) an amplifier (B) an electronic switch (C) a rectifier (D) a battery.

9. A ( ) B ( ) C ( ) D ( ) A charge on a capacitor is measured in: (A) microfarads (B) coulombs (C) ohms (D) watts.

10. A ( ) B ( ) C ( ) D ( ) When sufficient voltage is applied between the plate and cathode of V2: (A) electrons will travel from cathode to plate (B) the ions will travel toward the plate and the few free electrons will travel toward the cathode (C) no electrons will flow (D) electrons flow from plate to cathode takes place.

11. A ( ) B ( ) C ( ) D ( ) The charge upon a capacitor: (A) does not depend on the charging voltages (B) depends on the plate material (C) depends on the charging voltage (D) depends on the $X_L$ of the capacitor.

12. A ( ) B ( ) C ( ) D ( ) The potential drop across a rectifier type of glow tube as compared to a similar vacuum tube: (A) is much greater (B) is much less (C) is about the same (D) depends on the load.

13. A ( ) B ( ) C ( ) D ( ) Excessive ion bombardment of the cathode of a phanatron tube while the cathode is cold: (A) will damage the tube (B) will not damage the tube (C) cannot damage the tube (D) will disintegrate the plate.

# ELECTRONIC AC TIME DELAY CIRCUIT

Objective: To construct and study the operation of an a-c time delay circuit.

Average Time Required:

References:

Tools, Equipment & Materials

1. T1 = power transformer
2. V1 = 6V6 beam power amplifier tube
3. C1 = 2 mf. Capacitor
4. C2 = 8 mf. Electrolytic Capacitor.
5. L1 = Relay Coil
6. R1 = 50,000 ohm resistor
7. R2 = 250,000 ohm potentiometer
8. R3 = 2 megohm resistor
9. R4 = 10,000 ohm resistor 10 W
10. J1 = Phono-terminal
11. Test Lamp and leads
12. Necessary tools, wire and solder.

Precautions

1. Be sure all tube connections are properly made. Wrong connections may cause considerable damage to the tubes and parts.

2. For convenience of disassembling your circuit do not make pigtail connections to the tube socket lugs.

3. Be sure that the tube and the relay are removed from sockets before wiring the circuit.

Procedure Steps

1. Set up the apparatus in compact form and wire it neatly. Refer to chassis layout drawing and schematic diagram.

2. Wire the circuit as follows:

   a. Cut two pieces of wire of the proper length, twist the pair, and connect the twisted pair between the transformer lugs 5 and 9 and the heater lugs of V1.
   b. Connect one side of R1, relay coil L1, resistor R4, and primary terminal 1 of T1 to an insulated tie terminal. Solder all connections.
   c. Connect the open end of:

      1) R1 to one side of R2
      2) Relay coil L1 to plate of V1
      3) R4 to cathode of V1.

   d. With a small piece of wire, jumper the plate and screen grid elements of V1. Connect C2 across relay coil L1. Observe the polarities of C2. Damage to this unit will result if connected improperly.
   e. Connect R3 and C1 in parallel. Solder one end of the combination to the rotating contact of R2 and the other end to the grid of V1. Solder all connections.
   f. Use phono-terminal board J1 for the switch connections. Connect primary terminal 3 of T1 and the open end of R2 to one side of the phono-terminal board. Connect the cathode of V1 and a short length of wire to the other side of the phono-terminal board. Fasten a universal clip to the open end of the wire. Jumpering the phono-terminals will close the switch.

g. Connect a test lamp in series with the normally open relay contacts. Apply 117 volts AC to the combination.

3. Insert V1 in the proper socket. With the switch open, apply 117 volts AC to the primary winding of T1. Observe the operation of the circuit then close the switch and observe the operation of the circuit.

4. Open the switch and set R2 at point A, close the switch and note the variation in the length of time delay. Open the switch again and set R2 at point C. Close the switch and note the variation in the length of time delay. Record the results on the chart.

5. With the switch open and R2 contact arm set at point A, measure the a-c voltage across points B and D. Record the information on the chart.

6. With the switch open, set R2 contact arm at point C. Measure the a-c voltage across points B and D. Record the information on the chart.

7. Use different arrow markings or colored pencils, to distinguish electron paths in steps 8 and 9.

8. Assuming that the switch is open, trace the electron flow on the schematic diagram, showing the various electron paths when one cycle of input voltage is applied to the primary of T1.

9. Assuming that the switch is closed, trace the electron flow on the schematic diagram, showing the various electron paths when one cycle of input voltage is applied to the primary of T1.

10. Give a theoretical explanation for determining your answer printed in column 4 of the chart.

RECORD CHART

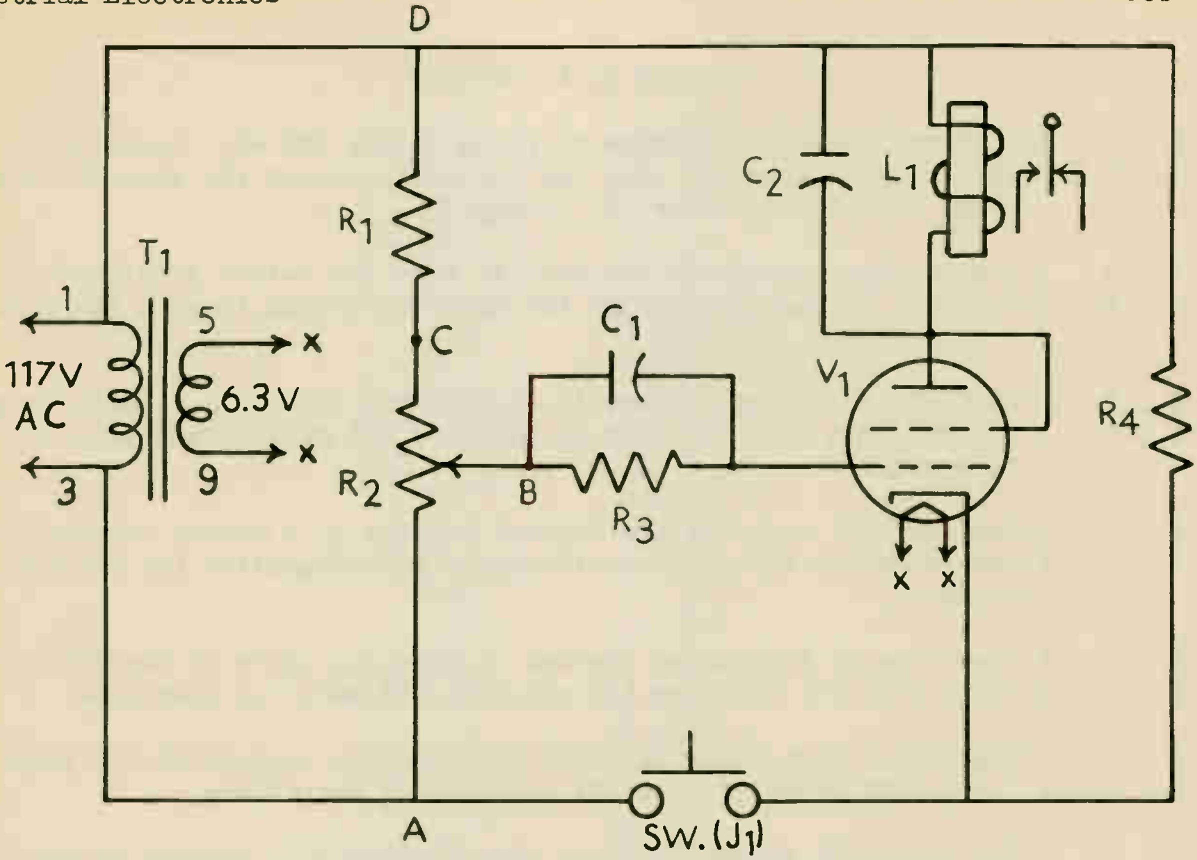
| 1 | 2 | 3 | 4 |
|---|---|---|---|
| R2 contact arm set at following points (switch open) | A-C voltage test across points "B" and "D" | Voltage across R3 | Length of time delay (long) (short) |
| | | | |
| | | | |

Explain in the space below, the answer given in Column 4 ______________________

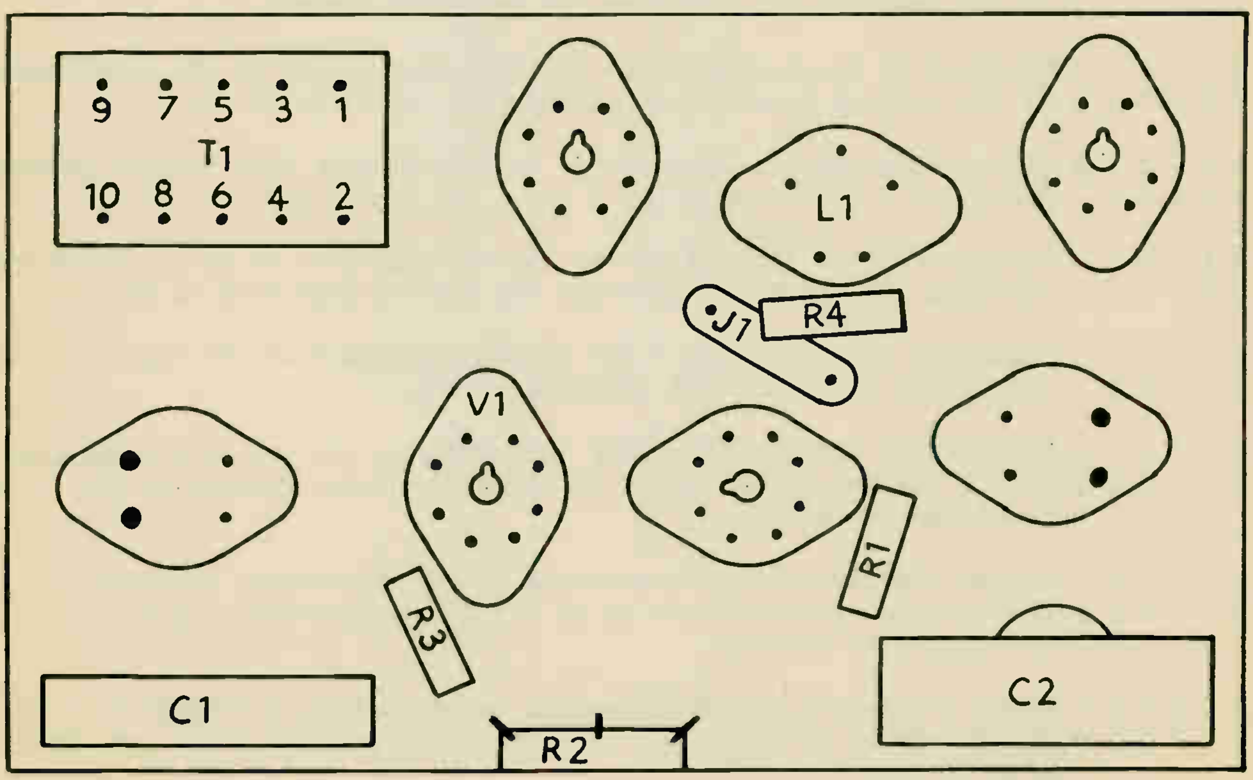
______________________________________________

______________________________________________

______________________________________________




SCHEMATIC - TIME DELAY CIRCUIT




CHASSIS LAYOUT DRAWING

## A-C TIME DELAY CIRCUIT

1. A ( ) B ( ) C ( ) D ( ) Electron flow from cathode to plate in the 6V6 will begin: (A) when the plate is positive (B) when the switch is closed (C) when C1 voltage leaks down sufficiently (D) through R4.

2. A ( ) B ( ) C ( ) D ( ) Timing capacitor C1 is charged: (A) when the switch is closed (B) when filament voltage is applied (C) when the switch is open (D) when point D is positive.

3. A ( ) B ( ) C ( ) D ( ) With the switch open there is no electron flow from cathode to grid of the 6V6 when the: (A) grid is negative (B) grid is positive (C) cathode is negative.

4. A ( ) B ( ) C ( ) D ( ) Capacitor C1 receives its initial voltage by a method called: (A) plate rectification (B) grid rectification (C) saturation (D) secondary emission.

5. A ( ) B ( ) C ( ) D ( ) Capacitor C2 discharges through L1 when the plate of the 6V6 is: (A) conducting (B) negative (C) positive (D) emitting electrons.

6. A ( ) B ( ) C ( ) D ( ) Electronic time delay circuits are used for control of: (A) phase shift (B) cutoff point of tube (C) welding (D) rectifiers.

7. A ( ) B ( ) C ( ) D ( ) The nearer R2 slider is moved toward point "C"; voltage across C1 will be: (A) larger (B) Zero (C) smaller (D) infinity).

8. A ( ) B ( ) C ( ) D ( ) Grid rectification occurs during the interval when the top end of T1 is: (A) negative (B) positive (C) zero (D) neutral.

9. A ( ) B ( ) C ( ) D ( ) Movement of R2 slider varies the: (A) capacity of C1 (B) resistance of R3 (C) voltage to which C1 charges (D) capacity of C2.

10. A ( ) B ( ) C ( ) D ( ) With switch open C1 will charge to the voltage drop between points: (A) B and A (B) B and D (C) B and C (D) 1 and 3.

11. A ( ) B ( ) C ( ) D ( ) Capacitor C1 is charged by: (A) the voltage drop on R3 (B) plate rectification (C) secondary emission (D) the voltage drop on R4.

12. A ( ) B ( ) C ( ) D ( ) Capacitor C2 is used as a: (A) smoothing capacitor (B) bypass capacitor (C) filter capacitor (D) coupling capacitor.

13. A ( ) B ( ) C ( ) D ( ) With switch closed time delay ends when: (A) C1 starts discharging (B) C1 changes polarity (C) platecurrent flows through V1 (D) L1 and C2 become resonant.

14. A ( ) B ( ) C ( ) D ( ) Longer time delay may be obtained by: (A) increasing capacity of C1 (B) decreasing resistance of R3 (C) decreasing capacity of C1 (D) decreasing line voltage.

15. A ( ) B ( ) C ( ) D ( ) Relay chattering may be prevented by connecting a capacitor across: (A) the relay contacts (B) the relay coil (C) the plate and screen grid (D) R3.

# LINEAR TIME DELAY CIRCUIT

Objective: To construct and study the operation of a linear time delay circuit.

Average Time Required:

References

Tools, Equipment & Materials

1. $T_1$ = Power Transformer
2. $V_1$ = 6x5 Tube
3. $V_2$ = 6V6 Tube
4. $V_3$ = 6SQ7 Tube
5. $C_1$ = 2 mf. capacitor
6. $C_2$ = 8 mf. electrolytic capacitor
7. $R_1$ = 250,000 ohm potentiometer
8. $R_2$ = 20,000 ohm resistor
9. $L_1$ = Relay coil
10. $J_1$ = Phono-terminal board
11. Test lamp and leads.
12. Necessary tools, wire & solder

Precautions

1. Be sure all tube connections are properly made. Wrong connections may cause considerable damage to the tube and parts.

2. For convenience of disassembling your circuit do not make pigtail connections to tube socket lugs.

3. Be sure tubes and relay are removed from sockets before wiring the circuit.

Procedure Steps

1. Set up the apparatus in compact form and wire it neatly. Choose the proper tube sockets to retain tubes $V_1$, $V_2$, and $V_3$. Refer to chassis layout drawing and schematic diagram.

2. Wire the circuit as follows:

   a. Connect heaters of V2, V3, and $V_1$ in parallel and in the rotation listed. Use the twisted pair of wires. Connect the entire tube heater circuit from the heater lugs of V1 to transformer lugs 5 and 9.

   b. Connect lug 3 of the transformer, one lead of $C_1$, plate of $V_3$, and cathode of V2.to grounding lugs.

   c. With a short length of bare, wire, jumper the plate and screen grid of V2.

   d. Connect negative (-) lead of C2 and one end of relay coil $L_1$ to the plate of $V_2$.

   e. Connect the other end of relay coil $L_1$ and the positive (+) lead of $C_2$ to the moving contact arm of the relay.

   f. Connect lug 1 of the transformer to the moving contact arm of the relay.

g. Connect the cathode of $V_1$ to the normally open contact of the relay.

h. With a short length of wire jumper the plates of V1 together and connect them to one lug of the phono-terminal board, J1.

i. Connect $R_2$ between the other lug of phono-terminal board and the control grid of $V_3$. Attach universal clip to a short length of wire and solder the wire to this phono-terminal board lug.

j. Connect the control grid of $V_2$, remaining lead of $C_1$, and one outer terminal of $R_1$ to the control grid of $V_3$. Connect a short bare wire from this outer terminal of $R_1$ to the center terminal of $R_1$.

k. Jumper, with a short length of wire, the two diode plates and the cathode of $V_3$ and connect them to the remaining outer terminal of $R_1$.

l. Jumper the a-c plug of the test lamp unit with a short piece of bare wire. Clip one lead of the test lamp unit to the chassis and the other to the normally closed contact of relay $L_1$. Do not plug the test lamp into the 117 V outlet at any time.

3. Measure the resistance of potentiometer R1. The meter should read between zero and 250,000 ohms on the R x 1,000 scale when varying $R_1$ resistance from min. to max.

4. Insert tubes $V_1$, $V_2$ and $V_3$ in proper sockets.

5. Set $R_1$ for minimum resistance and close $J_1$ momentarily. Observe operation of the circuit and note length of time delay. Record results on the chart.

6. After the test lamp extinguishes, set R1 for maximum resistance and close $J_1$ momentarily. Note length of time delay. Record results on the chart.

7. Pull $V_3$ out of the socket and close $J_1$ momentarily. Set $R_1$ for minimum and then maximum resistance. Note length of time delay. Record results on the chart.

8. Trace the electron paths through the circuit, with different arrow markings or colored pencils, when the following predetermined conditions exist:

   a. Point A negative (-) and $J_1$ open.

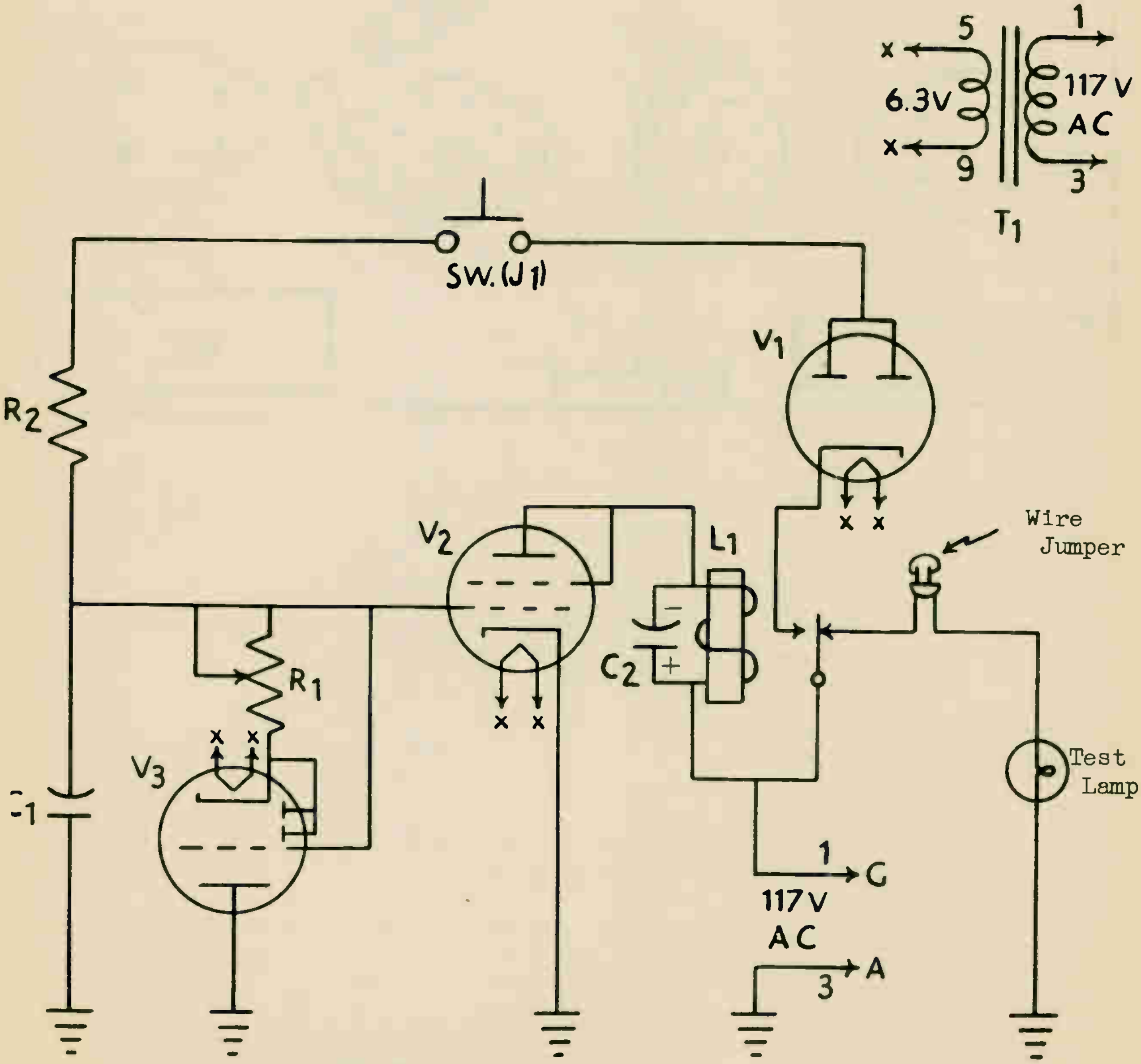
   b. Point G negative (-) and $J_1$ open.

   c. Point A Positive (+) and $J_1$ closed.

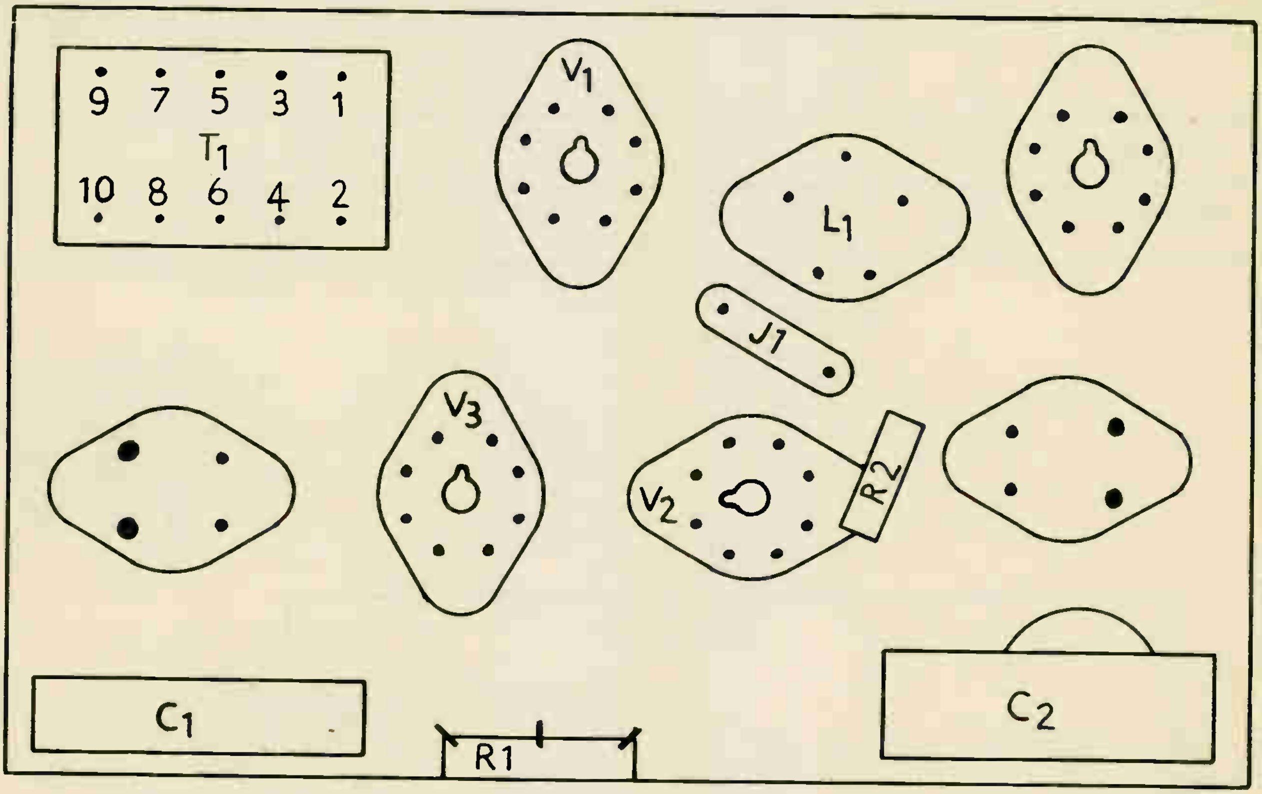
   d. With relay $L_1$ de-energized, $C_1$ charged, and $J_1$ open trace for one complete cycle of input voltage applied to points A and G.

9. Set $R_1$ for minimum resistance. Apply 117v AC to the circuit. Set the selector SW. of VTVM to DC- and range SW. to 100 volts. Connect the common lead of the VTVM to chassis. Place the d-c probe on the ungrounded side of capacitor C1 Close $J_1$ momentarily and observe the rate of charge and discharge of $C_1$. Set R1 for maximum resistance. Observe rate of charge and discharge. Record the results on the chart.

| Resistance of $R_1$ set for | LENGTH OF TIME DELAY Long or short | | C DISCHARGES Faster or Slower |
|---|---|---|---|
| | Procedure Steps 5 and 6 | Procedure Step 7 | Procedure Step 9 |
| MINIMUM | | | |
| MAXIMUM | | | |




LINEAR TIME DELAY CIRCUIT


9 7 5 3 1
T1
10 8 6 4 2
V1
L1
J1
V3
V2
R2
C1
R1
C2

# LINEAR TIME DELAY

1. A ( ) B ( ) C ( ) D ( ) The charge on C1 places a negative cut off bias on the grid of the: (A) 6V6 (B) 6SQ7 (C) 6X5 (D) 80.

2. A ( ) B ( ) C ( ) D ( ) As C1 starts to discharge through the variable resistor R1 this causes the plate to cathode resistance of the 6SQ7 to change and be dependent upon the value of the: (A) discharge current (B) bias applied to the grid of the 6V6 tube (C) changing plate voltage (D) resistor R2.

3. A ( ) B ( ) C ( ) D ( ) Time delay action may be increased by connecting in place of C1 a: (A) larger capacitor (B) smaller capacitor (C) resistor (D) neutralizing capacitor.

4. A ( ) B ( ) C ( ) D ( ) Varying R1 varies the grid bias of the: (A) 6SQ7 (B) 6V6 (C) 6X5 (D) 6C5.

5. A ( ) B ( ) C ( ) D ( ) The circuit in this job can be used to: (A) accurately control exposure timeiin the use of a photographic printer and enlarger (B) heat metal (C) shift phase (D) run motors.

6. A ( ) B ( ) C ( ) D ( ) Moving the slider contact arm of R1 toward the cathode of the 6SQ7: (A) increases the time interval (C) decreases the time interval (C) has no effect on the time interval (D) cuts off the tube.

7. A ( ) B ( ) C ( ) D ( ) This circuit has a more linear time discharge curve as compared to Job No. 6 because: (A) tube V3 acts like a varying inductance (B) tube V3 acts like a varying resistance (C) tube V3 acts like a varying capacitance (D) of R2.

8. A ( ) B ( ) C ( ) D ( ) Variable resistor R1 is connected in the: (A) grid circuit of the 6V6 tube (B) grid circuit of the 6SQ7 (C) cathode circuit of the 6SQ7 tube (D) screen circuit.

9. A ( ) B ( ) C ( ) D ( ) When point "G" is negative and the switch is open: (A) the 6V6 tube does not conduct (B) the V1 tube conducts (C) capacitor C1 discharges (D) R2 has a voltage drop across it.

10. A ( ) B ( ) C ( ) D ( ) C2 sends its stored up energy through the relay coil when: (A) point "A" is negative (B) V1 is not conducting (C) point "A" is positive (D) the relay is denergized.

11. A ( ) B ( ) C ( ) D ( ) The negative charge on C1 puts a negative cut off bias on the control grid of the: (A) 6SQ7 (B) 6V6 (C) 6X5 (D) 205I.

12. A ( ) B ( ) C ( ) D ( ) As C1 discharges, the negative voltage controlling the 6V6 tube is decreased, thus: (A) causing the plate of V3 to become neutral (B) causing the relay coil to become de-energized (C) causing the relay coil to energize again (D) cutting off the 6V6 tube.

13. A ( ) B ( ) C ( ) D ( ) If switch No. 1 remains closed and R1 set at minimum resistance: (A) this circuit has a long time delay (B) this circuit acts like a trigger time delay circuit (C) capacitor C2 will discharge (D) R2 is shorted out.

14. A ( ) B ( ) C ( ) D ( ) The 6V6 tube in this job is used as a: (A) rectifier (B) phanatron (C) electronic switch (D) oscillator.

15. A ( ) B ( ) C ( ) D ( ) The 6V6 tube: (A) will conduct at all times (B) will not conduct at all times (C) will conduct when plate potential is zero (D) will conduct when cathode is positive.

16. A ( ) B ( ) C ( ) D ( ) C2 sends its stored up energy through the relay coil when point "A" is: (A) neutral (B) positive (C) negative (D) connected to point G.

17. A ( ) B ( ) C ( ) D ( ) Time delay action may be decreased by connecting in place of C1 a: (A) smaller capacitor (B) larger resistor (C) medium resistor (D) larger capacitor.

18. A ( ) B ( ) C ( ) D ( ) When L1 is de-energized the test lamp will: (A) flicker on and off (B) be energized (C) be de-energized (D) be across the V1 tube.

19. A ( ) B ( ) C ( ) D ( ) By varying R1: (A) the time range is provided (B) the bias of the 6V6 tube is changed (C) the test lamp gets brighter (D) V2 is made to pass more or less current.

20. A ( ) B ( ) C ( ) D ( ) With an abundance of electrons on the plate side of C2 and the plate of V2 negative: (A) capacitor C2 will charge (B) capacitor C2 will discharge (C) V2 will fire (D) V2 will conduct from plate to cathode.

21. A ( ) B ( ) C ( ) D ( ) The purpose of C2 is to provide a steady electron flow through the relay coil L1 when: (A) V2 plate is negative (B) V2 plate is positive (C) plate of V1 is negative (D) smooth DC flows through L1.

22. A ( ) B ( ) C ( ) D ( ) Heaters of V1, V2, and V3 are connected: (A) series - parallel (B) series (C) parallel (D) to 1 and 3 on the power transformer.

23. A ( ) B ( ) C ( ) D ( ) The size of R2 determines how fast: (A) C1 will discharge (B) C1 will charge (C) C2 will discharge (D) C2 will charge.

24. A ( ) B ( ) C ( ) D ( ) The filament pins of the 6SQ7 are the: (A) 2 and 7 pins (B) 7 and 8 pins (C) 3 and 7 pins (D) 1 and 9 pins.

# ELECTRONIC AMPLITUDE CONTROL CIRCUIT

Objective: To construct and study the basic operation of electronic amplitude control circuit.

Average Time Required:

References:

Tools, Equipment & Materials

1. T1 = Power Transformer
2. V1 = 2051 Thyratron
3. R1 = 50,000 Ohm Resistor
4. R2 = 10,000 Ohm Potentiometer
5. R3 = 250 Ohm Resistor
6. C1 = 8 Mf. Electrolytic Capacitor
7. L1 = Relay Coil
8. Vacuum Tube Volt-Ohmmeter
9. Necessary Tools Wire & Solder

Precautions

Be sure all tube connections are properly made. Wrong connections may cause considerable damage to the tubes and parts.

For convenience of disassembling the circuit, do not make pigtail connections to the tube socket lugs.

Be sure that the tube and relay are removed from sockets before wiring the circuit. DO NOT CLOSE SWITCH UNTIL 2051 HAS WARMED UP.

Procedure Steps

1. Set up the apparatus in compact form and wire it neatly. Choose the proper tube socket to retain tube V1. Refer to chassis layout drawing and schematic diagram.

2. Wire the circuit as follows:

   a. With a short piece of wire, connect transformer T1 and lugs 3 and 9 together.

   b. By means of a twisted pair of wires, connect the V1 tube heater to T1 transformer lugs 5 and 9.

   c. Strip a short length of wire and connect together; V1 cathode, shield grid, and lug 7 of the heater.

   d. Connect a wire from T1 lug 1 to lug 1 of the relay coil, L1. Connect the other lug of L1 to J1 and the other end of J1 to the plate lug of V1.

   e. Mount an insulated tie terminal to the chassis between V1 socket and R2.

   f. Connect one lead of R1 to grid lug of V1 socket and the other lead to the insulated tie terminal. With a short length of wire, connect the center lug of R2 to the insulated tie terminal.

   g. Connect the cathode of V1 to one outer lug of R2. Connect V1 lug 2 to the remaining lug of R2.

h. Mount an insulated tie terminal between C1 and relay coil socket L1. Connect the negative lead of C1 and one end of R3 to the tie terminal. Connect the other end of R3 to J1.

i. Connect the positive lead of C1 to lug 1 of L1.

4. Check with the ohmmeter (on low ohm scale) for continuity between lug 9 to T1, and lug 7 of V1. <u>If meter does not indicate zero ohms</u>, <u>reverse</u> connection of twisted pair of wires on transformer lugs 5 and 9.

5. If unable to turn light on and off with R2 reverse T1 5, and 9 connections.

6. With V1 out of the socket, apply 117V AC to primary of T1. Measure the AC voltages specified in the chart. Record the results.

| TEST | V1 TUBE OUT OF SOCKET<br>ACROSS POINTS | AC VOLTAGE |
|---|---|---|
| a | 1 and 3 of PWR Transformer | |
| b | 1 and 5 of PWR Transformer | |
| c | Plate and Cathode lugs of socket V1 | |
| d | Heater lugs of socket V1 | |
| e | Control Grid & Cathode Lugs of V1 (R2 set for minimum voltage) | |
| f | Control Grid & Cathode lugs of V1 (R2 set for Maximum voltage) | |
| g | Relay Coil (Lugs 1 and 5) | |

7. Insert the 2051 tube into the socket. Measure voltages across points specified in chart. Record the results.

<table>
<tr><th colspan="3">V1 TUBE INSERTED IN SOCKET</th></tr>
<tr><td>Control Grid & Cathode lugs of V1<br>R2 set for Maximum Voltage</td><td colspan="2">Relay Coil (Lugs 1 & 5)<br>DC Voltage</td></tr>
<tr><td>AC Voltage Analysis</td><td>R2 Set for Minimum Voltage between V1 Grid & Cathode</td><td></td></tr>
<tr><td>______________________ Volts</td><td>R2 Set for Maximum Voltage between V1 Grid & Cathode</td><td></td></tr>
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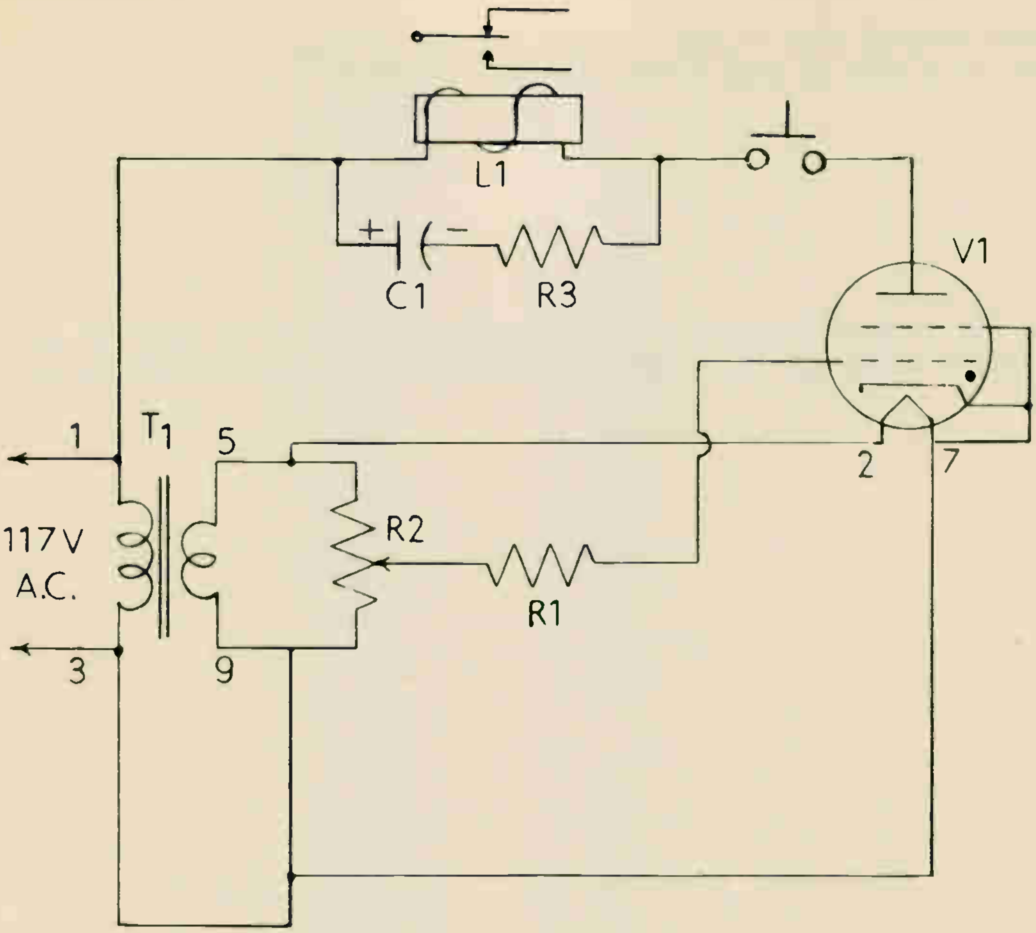
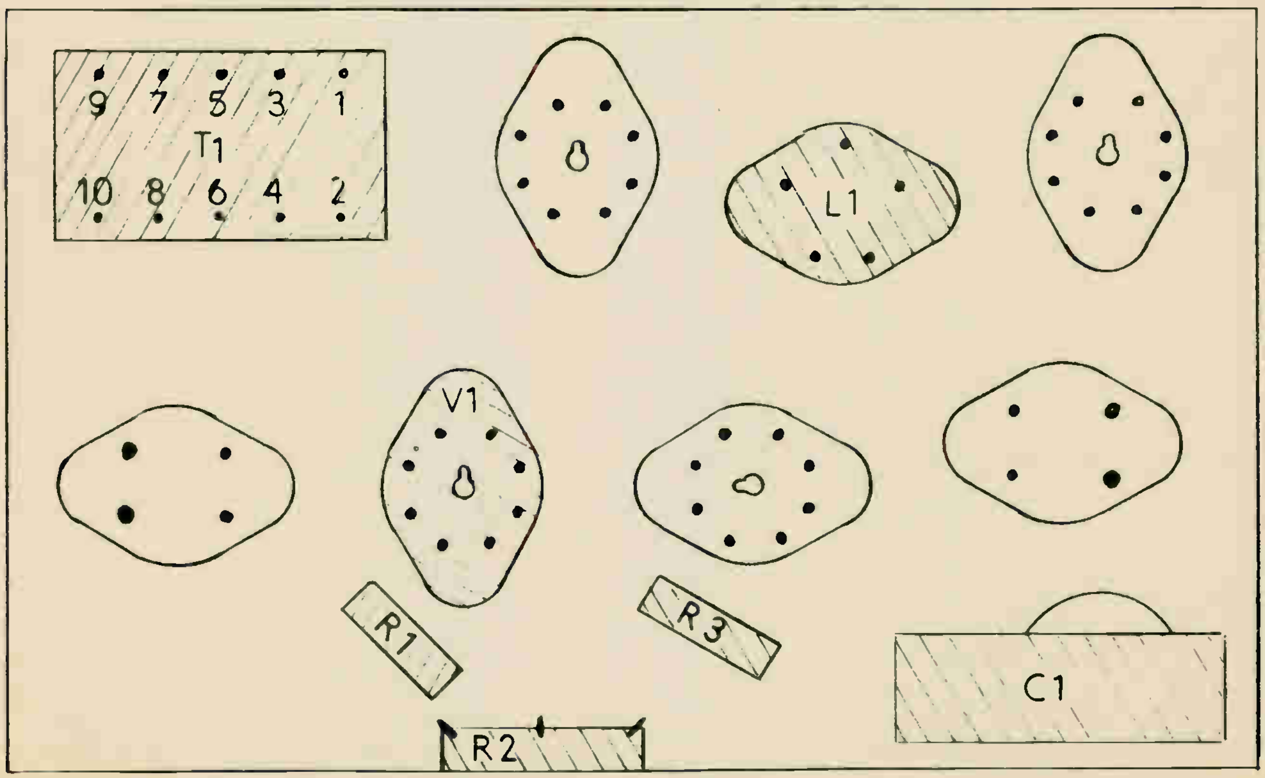



Amplitude Control Circuit




Chassis Layout Drawing

7. Explain briefly what causes the a-c voltage reading of step 5, test "f", to differ from that of step 6 with the V1 tube inserted.

8. Trace the various electron paths, assuming one complete cycle of input voltage is applied to T1 and R2 is set for minimum resistance between cathode and grid of V1.

## AMPLITUDE CONTROL

1. A ( ) B ( ) C ( ) D ( ) Amplitude control of a thyratron with a-c voltage applied to the plate is done by varying the: (A) amplitude of the plate voltage (B) d-c grid bias voltage (C) shield grid voltage (D) d-c voltage on the plate.

2. A ( ) B ( ) C ( ) D ( ) With variable d-c voltage applied to the grid and AC on the plate; plate current can be controlled from: (A) 0° to 180° (B) 90° to 180° (C) 0° to 90° (D) 0° to 360°.

3. A ( ) B ( ) C ( ) D ( ) With d-c voltage on the plate of a thyratron the grid assumes control (A) once each cycle (B) only until tube conducts (C) when made highly negative (D) when made highly positive.

4. A ( ) B ( ) C ( ) D ( ) Critical grid potential is the potential at which: (A) grid current begins to flow (B) grid becomes overheated (C) plate current begins to flow (D) plate current ceases to flow.

5. A ( ) B ( ) C ( ) D ( ) A thyratron is a mercury vapor tube and therefore: (A) is not affected by large temperature changes (B) is affected by ordinary changes in temperature (C) is not affected by ordinary changes in temperature (D) will conduct more at lower temperatures than at higher temperatures.

6. A ( ) B ( ) C ( ) D ( ) A thyratron tube: (A) requires a warmup period (B) does not require a warmup period (C) is used in oscillator circuits (D) is used as an amplifier.

7. A ( ) B ( ) C ( ) D ( ) Positive ions: (A) gather at the cathode thereby enlarging the space charge (B) dispel the space charge (C) are caused by secondary emission (D) bombard the cathode after it is heated sufficiently.

8. A ( ) B ( ) C ( ) D ( ) Positive ions: (A) gather at the cathode thereby enlarging the space charge (B) dispel the space charge (C) are caused by secondary emission (D) bombard the cathode after it is heated sufficiently.

9. A ( ) B ( ) C ( ) D ( ) A thyratron needs a warmup period so that positive ions will not bombard the cathode: (A) before a space charge is formed (B) after a space charge is formed (C) when the cathode is positive (D) during the time the time the tube does not conduct.

10. A ( ) B ( ) C ( ) D ( ) Ionization is caused by (A) positive ions bombarding the cathode (B) space charge forming around the cathode (C) negative electrons knocking other negative electrons out of an atom of gas (D) reducing the plate voltage to zero or slightly negative.

11. A ( ) B ( ) C ( ) D ( ) The purpose of the shield grid is (A) the same as a screen grid in a vacuum tube (B) to shield the control grid from the heat of the cathode (C) to suppress secondary emission (D) to give greater amplification.

12. A ( ) B ( ) C ( ) D ( ) The reason that the control grid loses control over electron flow after ionization takes place is that: (A) positive ions gather around it and neutralize the electrostatic field (B) electrons from the cathode are attracted to it (C) plate voltage is falling to zero (D) the space charge is dispelled.

13. A ( ) B ( ) C ( ) D ( ) A characteristic curve for a thyratron tube will show: (A) values of grid voltage for plate current (B) values of grid voltage and plate voltage at which the tube will begin to conduct (C) values of grid voltage and grid current (D) values of plate voltage and plate current.

14. A ( ) B ( ) C ( ) D ( ) A resistor is placed in the grid lead to: (A) limit plate current (B) bias the grid (C) limit grid current during time grid is positive (D) stop current in the grid circuit.

15. A ( ) B ( ) C ( ) D ( ) According to the characteristics table lesson No. 12 the GL 2051 tube average plate current is: (A) 375 ma. (B) 600 ma. (C) 75 ma. (D) .075 ma.

16. A ( ) B ( ) C ( ) D ( ) With a-c voltage on the plate and variable a-c voltage on the grid plate current is obtained for periods of: (A) full alternation or none (B) 90° to 180° (C) 180° to 360° (D) 45° to 90°.

17. A ( ) B ( ) C ( ) D ( ) With a-c voltage on the plate and in phase ac plus variable d-c bias on the grid, control is obtained from: (A) 0° to 90° (B) 90° to 180° (C) 45° to 90° (D) 0° to 45°.

# AMPLITUDE CONTROLLED FORWARD PHOTOTUBE CIRCUIT

Objective: To construct and study the basic principles and operation of a forward phototube circuit.

Average Time Required:

References:

Tools, Equipment & Material

1. T1 = Power transformer
2. V1 = 2051 Thyratron
3. V2 = 923 Phototube
4. R1 = 2 Megohm resistor
5. R2 = 10,000 ohm potentiometer
6. R3 = 500,000 ohm resistor
7. R4 = 1 Megohm resistor
8. R5 = 250 ohm resistor
9. C1 = .00025 mf. Capacitor
10. C2 = 8 Mf. electrolytic capacitor
11. L1 = Relay coil
12. VTVM

Precautions

Be sure all tube connections are properly made. Wrong connections may cause considerable damage to the tube and parts.

For convenience of disassembling the circuit, do not make pigtail connections to the tube socket lugs.

Be sure tubes and relay are removed from sockets before wiring the circuit.

DO NOT CLOSE SWITCH UNTIL 2051 has warmed up.

Procedure Steps

1. Set up the apparatus in compact form and wire it neatly. Choose the proper sockets to retain tubes V1 and V2. (Refer to chassis layout drawing and schematic diagram.)

2. Wire the circuit as follows:

   a. With a short piece of wire, connect transformer T1 lugs 3 and 9 together.

   b. By means of a twisted pair of wires, connect the V1 tube heater to T1 transformer lugs 5 and 9.

   c. Strip a short length of wire and connect together V1 cathode, shield grid, and lug 7 of the heater.

   d. Connect a wire from T1 lug 1 to lug 1 of the relay coil L1. Connect the other lug of L1 to the plate lug of V1.

   e. Mount an insulated tie-terminal to the chassis between the V1 socket and R2.

   f. Connect capacitor C1 and resistor R1 in parallel. Connect one end of combination to grid lug of V1 socket and the other end to the insulated tie-terminal. With a short length of wire, connect the center lug of R2 to the insulated tie-terminal.

g. Connect the cathode of V1 to one outer lug of R2. Connect V1 lug 2 to the remaining lug of R2.

h. Mount an insulated tie-terminal between C2 and relay coil L1. Connect negative lead of C2 and one end of R5 to the tie-terminal. Connect the other end of R5 to J1 and the other end of J1 to the plate of V1.

i. Connect the positive lead of C2 to lug 1 of L1.

j. Mount a tie-terminal between V1 socket and relay. Connect one end of R4 to V1 cathode and the other end to a tie-terminal.

k. Connect one end of R3 to a tie-terminal and the other end to lug 5 of L1.

l. With a suitable length of wire, connect V1 control grid to V2 cathode. Also connect V2 plate to the junction point of R3 and R4.

4. Check with VTVM ohmmeter (on Rx1 scale) for continuity between lug 9 of T1, and lug 7 of V1. If the meter does not indicate zero ohms, reverse connection of twisted pair of wires on transformer lugs 5 and 9.

5. With V1 and V2 out of their sockets, apply 117 V AC to the primary of T1. Measure the AC voltages across points specified in the chart. Record the results. If unable to turn light on or off with R2, reverse lugs 5 and 9 on T1.

| TEST | V1 and V2 tubes out of sockets | |
|---|---|---|
| | ACROSS POINTS | AC VOLTAGE |
| a | 1 and 3 of PWR. Transformer | |
| b | 1 and 5 of PWR. Transformer | |
| c | Point A and V1 cathode lug (R2 set for maximum resistance between point "A" and V1 cathode) | |
| d | Point A and V1 cathode lug (R2 set for minimum resistance between point A and V1 cathode) | |
| e | Voltage across R3 | |
| f | Voltage across R4 | |

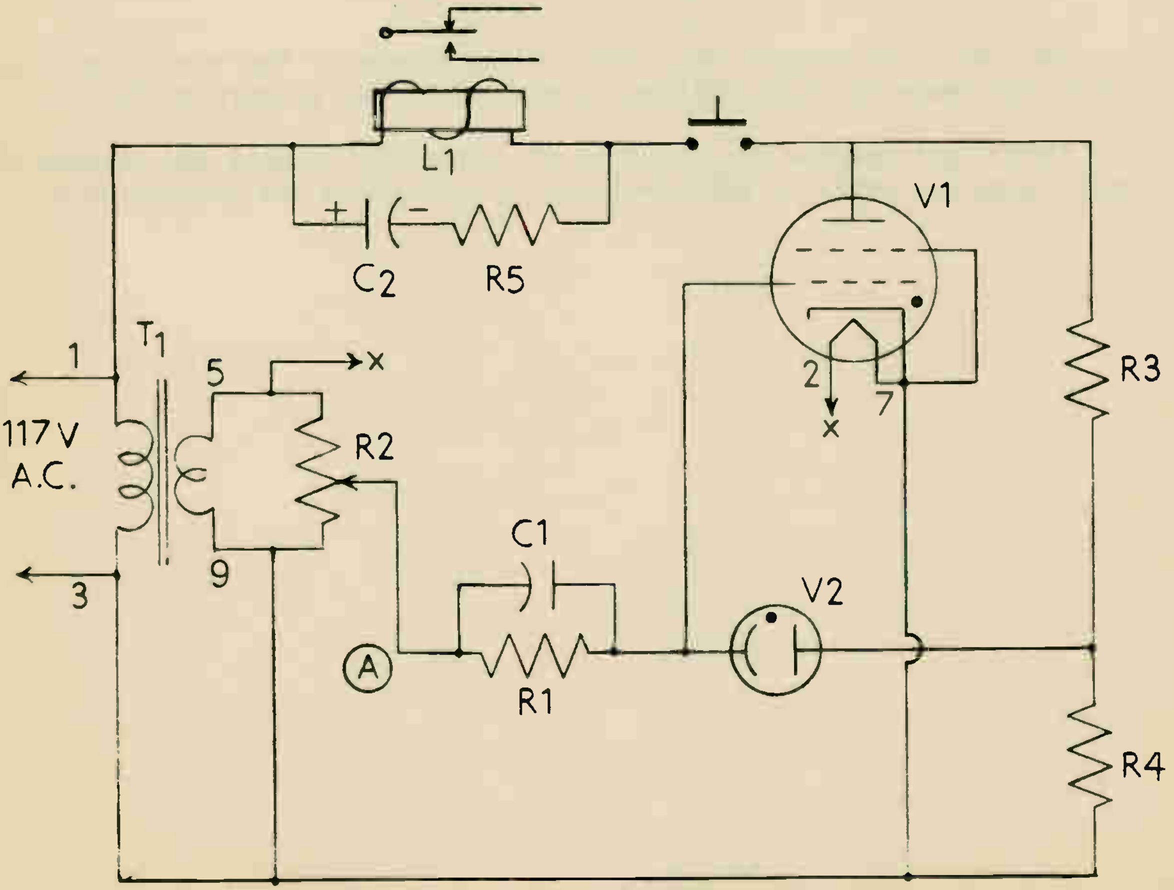
6. Insert tubes V1 and V2 into proper sockets. Connect test lamp to normally open contacts of relay L1. Apply AC voltage to the circuit and to the test lamp.

7. Obstruct as much light as possible to the phototube cathode. Adjust R2 so that the V1 tube grid voltage is just below the critical grid potential of the tube. Relay L1 should then become de-energized.

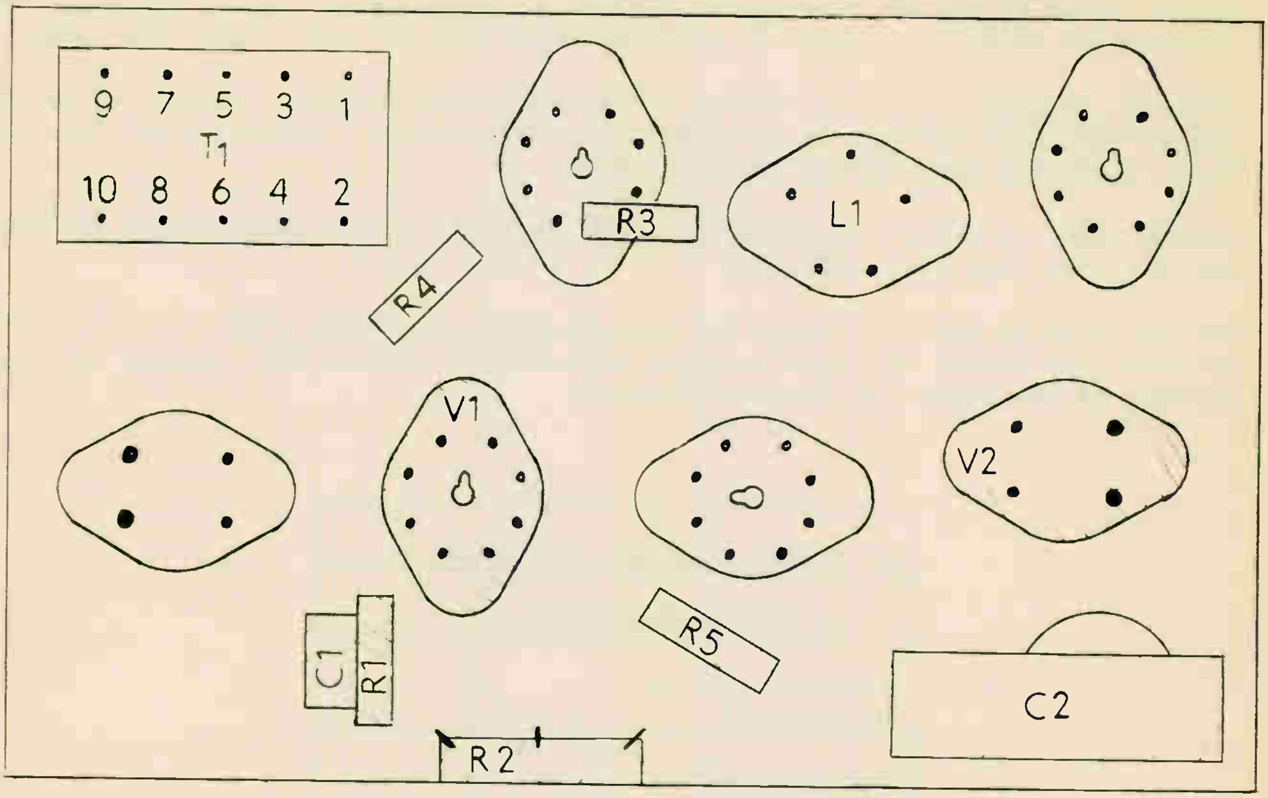
8. Permit light to strike the cathode of V2. Relay L1 should then become energized, and the test lamp will light up.

9. Set the VTVM to 300 V DC range and connect it across relay coil L1. Increase and decrease the amount of light entering tube V2 and observe the voltage reading. Record, in the chart the results obtained.

| V1 and V2 inserted in sockets | |
|---|---|
| DC VOLTAGE ACROSS L1 | |
| Minimum Light on V2 Cathode | |
| Maximum Light on V2 Cathode | |




Amplitude controlled forward phototube circuit




10. Assuming that no light reaches V2, trace on the schematic the various electron paths when one cycle of input voltage is applied to the primary of T1.

11. Assuming that light reaches V2, trace on the schematic diagram the various electron paths when one cycle of input voltage is applied to the primary of T1.

## AMPLITUDE CONTROLLED FORWARD PHOTOTUBE CIRCUIT

1. A ( ) B ( ) C ( ) D ( ) The number of micro amps. of electron flow per lumen of flux on the cathode of a phototube is called the phototube (A) flux sensitivity (B) amplification sensitivity (C) luminous sensitivity (D) magnetic flux sensitivity.

2. A ( ) B ( ) C ( ) D ( ) The purpose of R4 in this job is to: (A) decrease the charge of capacitor C1 (B) produce a direct potential for the V1 tube (C) maintain a positive potential for the 923 anode (D) maintain a negative potential for the 923 anode.

3. A ( ) B ( ) C ( ) D ( ) The purpose of potentiometer R2 in this job is to (A) make the 2051 control grid negative with respect to the cathode (B) cause a lower voltage across transformer terminals 5 and 9 (C) lower the filament potential of the 2051 (D) make the grid negative.

4. A ( ) B ( ) C ( ) D ( ) The purpose of capacitor C1 in this job is to (A) produce a time delay (B) establish a constant voltage across resistor R1 (C) drive the V2 platennegative (D) produce a negative potential for the 923 cathode.

5. A ( ) B ( ) C ( ) D ( ) Listed sensitivities of vacuum phototubes usually are between: (A) 100 to 1000 micro amps. per lumen (B) 1 to 4 micro amps. per lumen (C) 5 to 45 micro amps. per lumen (D) 75 to 80 micro amps per lumen.

6. A ( ) B ( ) C ( ) D ( ) The electron flow in a vacuum phototube: (A) decreases (B) increases (C) becomes practically constant (D) varies inversely, for any given light flux after the anode voltage exceeds some low value.

7. A ( ) B ( ) C ( ) D ( ) The purpose of R5 in this job is to: (A) deionize the 2051 (B) actuate the relay (C) limit the instantaneous charge of C2 (D) make the plate of the V1 negative.

8. A ( ) B ( ) C ( ) D ( ) The phototube is a: (A) cold cathode tube (B) thermionic tubes (C) hot cathode tube (D) ionic tube.

9. A ( ) B ( ) C ( ) D ( ) The inner surface of a phototube cathode is coated with a: (A) heat sensitive material (B) anti-sensitive material (C) light sensitive material (D) electromagnetic sensitive material.

10. A ( ) B ( ) C ( ) D ( ) Under normal operating conditions, electron flow within a phototube: (A) can reverse (B) cannot reverse (C) never will reverse (D) reverse sometimes.

11. A ( ) B ( ) D ( ) D ( ) The anode of the 923 phototube is: (A) straight vertical wire (B) part of cylinder (C) wire mesh (D) round piece of metal.

12. A ( ) B ( ) C ( ) D ( ) Intensity varies as the: (A) inverse square of the distance (B) square root of the distance (C) square of the distance (D) cube of the distance.

13. A ( ) B ( ) C ( ) D ( ) The majority of phototubes have light sensitive cathode surfaces consisting of a thinllayer of: (A) silver (B) uranium (C) caesium (D) copper oxide.

14. A ( ) B ( ) C ( ) D ( ) Gas phototube sensitivity: (A) increases rapidly with the anode voltage (B) decreases rapidly with the anode voltage (C) neutralizes rapidly with the anode voltage. (D) remains constant with the anode voltage.

15. A ( ) B ( ) C ( ) D ( ) Increasing the light energy on V2: (A) decreases the electron flow through the 2051 (B) increases the electron flow through the 2051 (C) neutralizes the electron flow through the 2051 (D) keeps the electron flow through the 2051 constant.

16. A ( ) B ( ) C ( ) D ( ) The purpose of resistor R3 in this job is to limit the electron flow to L1 when: (A) V2 is on so that L1 will not become energized (B) V1 and V2 are conducting (C) V1 is off (D) V1 is on.

17. A ( ) B ( ) C ( ) D ( ) V2 and V1 will conduct: (A) at different times (B) when their plates are negative (C) at the same time (D) when AC is used as the cathode voltage in this job.

18. A ( ) B ( ) C ( ) D ( ) With the insertion of a small amount of inert gas in a phototube envelop the tubes sensitivity: (A) decreases (B) fluctuates (C) increases (D) remains constant.

19. A ( ) B ( ) C ( ) D ( ) The flow of light energy is called: (A) flux (B) luminous flux (C) magnetic flux (D) rosin flux.

20. A ( ) B ( ) C ( ) D ( ) Lumens per square foot are measured in: (A) foot candles (B) flux (C) microns (D) electrons.

21. A ( ) B ( ) C ( ) D ( ) The purpose of the capacitor C1 in this job is to produce: (A) a negative potential for the 923 cathode (B) a negative potential for the V1 grid (C) a less negative potential for the V1 grid (D) time delay.

22. A ( ) B ( ) C ( ) D ( ) The voltage drop in a gas filled cold cathode tube is greater nearest the: (A) plate (B) control grid (C) cathode (D) screen grid.

23. A ( ) B ( ) C ( ) D ( ) With the light off, the 923 in this job, slider R2, is set so that: (A) the 2051 grid is more positive than the critical grid potential (B) the 2051 grid is more negative than the critical grid potential (C) the cathode of the V2 is neutral (D) resistor R4 draws current.

24. A ( ) B ( ) C ( ) D ( ) The 923 phototube contains a: (A) cathode, grid and anode (B) cathode and filament (C) cathode and anode (D) screen grid and anode.

25. A ( ) B ( ) C ( ) D ( ) The 923 tube is a: (A) phototube (B) vacuum tube (C) thyratron (D) kenotron.

# AMPLITUDE CONTROLLED REVERSE PHOTOTUBE CIRCUIT

Objective: To construct and study the operation of a reverse phototube circuit.

Average Time Required:

References

Tools, Equipment & Material

1. T1 = Power transformer
2. V1 = 2051 Thyratron
3. V2 = Phototube
4. R1 = 10 Megohms
5. R2 = 10,000 Ohms
6. R3 = 10,000 ohm potentiometer
7. R4 = 5,000 Ohms
8. R5 = 250 Ohms
9. C1 = 8 mf. Electrolytic
10. L1 = Relay Coil
11. VTVM
12. Necessary solder and wire.

Precautions

1. Be sure all tube connections are properly made. Wrong connections may cause considerable damage to the tubes and parts.

2. For convenience of disassembling your circuit do not make pigtail connections to the tube socket lugs.

3. Be sure tubes and relay are removed from the sockets before wiring the circuit.

4. Do not close switch until 2051 has warmed up.

Procedure Steps

1. Set up the apparatus in compact form and wire it neatly, (refer to schematic and chassis layout drawing.)

2. Choose the proper sockets to retain tubes V1 and V2.

3. Wire the circuit as follows:

   a. By means of a twisted pair of wires, connect the V1 tube heater to T1 lugs 5 and 9.

   b. Mount an insulated tie-terminal to the chassis between the tube socket of V1 and T1. With a suitable length of wire, connect the cathode of V2 and T1 lug 3 to this tie-terminal. Connect R4 between this tie-terminal and V1 cathode.

   c. Jumper the cathode of V1, shield grid, and heater lug 7, with a short piece of bare wire. Connect the cathode of V1 to one outer lug of R3.

   d. Mount a second tie-terminal between V1 tube socket and R3. Connect R1 between this tie-terminal and the control grid of V1. Connect the center lug of R3 to tie-terminal with a suitable length of wire.

e. With a suitable length of wire, connect control grid of V1 to plate of V2.

f. Mount a third insulated tie-terminal between C1 and L1 socket. Connect negative lead of C1 and one end of R5 to this tie-terminal. Connect the other end of R5 and J1 to the socket lug of 5 of L1, and other end of J1 to the plate of V1.

g. Connect lug 1 of T1 and the positive lead of C1 to lug 1 of L1.

h. Mount a fourth insulated tie-terminal between L1 and R3. Connect the unused outer end of R3 and one end of R2 to the tie-terminal. Connect the other end of R2 to L1 socket lug 1.

4. Disconnect the relay lead from lug 1 of T1. Make a resistance circuit analysis with the vacuum tube ohmmeter across points specified in chart. Record results.

| RESISTANCE | | OHMS | |
|---|---|---|---|
| FROM | TO | | |
| Disconnected lead | V1 Plate | | |
| T1 Lug 3 | V1 Cathode | | |
| Disconnected lead | T1 Lug 3 | | |
| T1 Lug 3 | V2 Cathode | | |
| Disconnected lead | V2 Plate | | |
| V2 Plate | V1 Control grid | | |
| Center Lug of R3 | V1 Cathode | Max. Resistance | |
| | | Min. Resistance | |
| V1 Filament | V1 Filament | | |

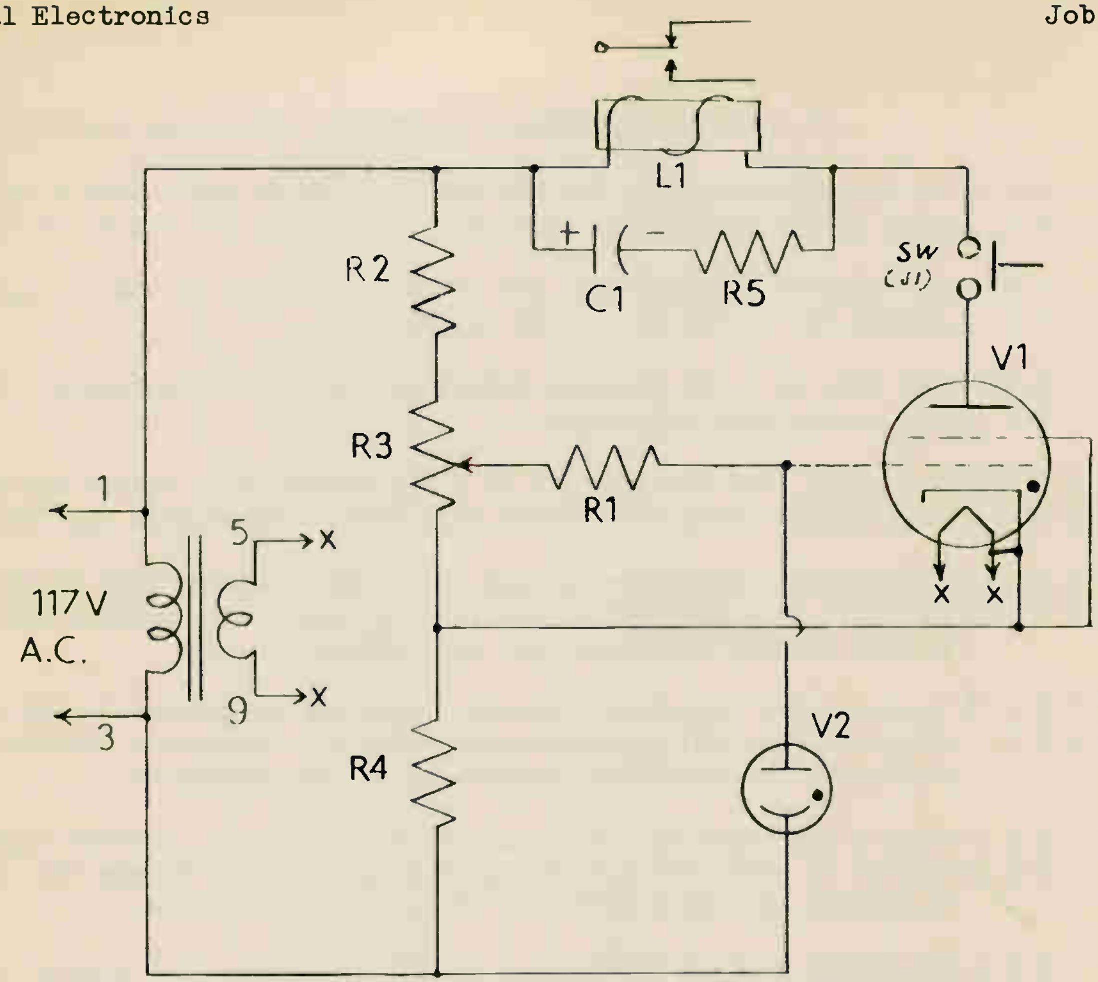
5. Connect relay lead to lug 1 of T1. Insert tubes V1 and V2 into proper sockets. Apply a-c voltage to the circuit.

6. Apply a-c voltage to the test lamp. Use the test lamp as the phototube light source and adjust R3 so that the V1 grid voltage is just below the critical grid potential of the tube. Relay L1 should then become de-energized.

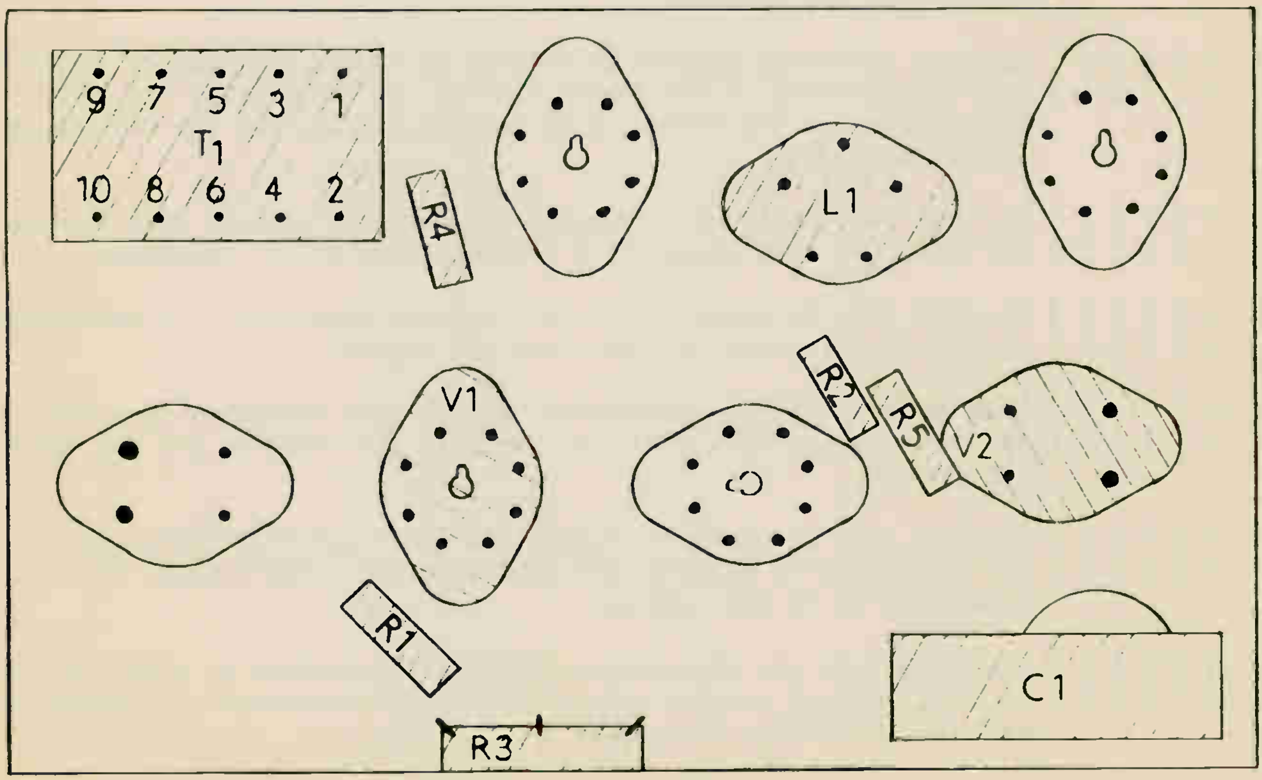
7. Obstruct the path of light rays to the phototube cathode. Relay L1 should then become energized.

8. Assuming that light reaches V2, trace on the schematic diagram the various electron paths when one cycle of input voltage is applied to the primary of T1.

9. Assuming that no light reaches V2, trace on the schematic diagram the various electron paths when one cycle of input voltage is applied to the primary of T1.




Amplitude Controlled Reverse Phototube Circuit




Chassis Layout Drawing

## AMPLITUDE CONTROLLED REVERSE PHOTOTUBE CIRCUIT

1. A ( ) B ( ) C ( ) D ( ) In constructing this job the grid and plate leads should be: (A) kept well separated (B) run parallel (C) twisted (D) connected together.

2. A ( ) B ( ) C ( ) D ( ) The control grid in this job is made negative by the voltage drop across: (A) R1 (B) R3 (C) R3 (D) V2.

3. A ( ) B ( ) C ( ) D ( ) The 2051 is a: (A) tetrode thyratron (B) triode thyratron (C) pliotron (D) screen grid thyratron.

4. A ( ) B ( ) C ( ) D ( ) The relay used in this job is a: (A) single pole double throw (B) double pole single throw (C) double pole double throw type (D) heavy duty type.

5. A ( ) B ( ) C ( ) D ( ) The common connection through which the electron flow of all external circuits is connected to the tube is called (A) cathode return (B) heater circuit (D) anode (D) grid return.

6. A ( ) B ( ) C ( ) D ( ) In a reverse phototube circuit, light on the phototube: (A) starts electron flow (B) stops electron flow (C) decreases current in the phototube (D) increases resistance of the phototube.

7. A ( ) B ( ) C ( ) D ( ) When a phototube is not connected in a circuit, intense light shining on it will: (A) not damage the cathode (B) damage the cathode (C) cause secondary emission (D) overheat the tube.

8. A ( ) B ( ) C ( ) D ( ) The plate voltage at which a shield grid thyratron starts to conduct depends upon: (A) screen grid voltage only (B) control grid voltage only (C) both control grid and shield grid voltage (D) amount of light shining on the cathode.

9. A ( ) B ( ) C ( ) D ( ) After a thyratron starts to conduct it may be stopped by: (A) reversing the polarity of the anode voltage (B) increasing the grid voltage (C) increasing the screen grid voltage (D) making the control grid highly negative.

10. A ( ) B ( ) C ( ) D ( ) In this job the relay is energized when the control grid becomes: (A) open (B) more negative (C) less negative (D) saturated.

11. A ( ) B ( ) C ( ) D ( ) In this job, C1 serves as a: (A) feedback capacitor (B) smoothing capacitor (C) coupling capacitor (D) bypass.

12. A ( ) B ( ) C ( ) D ( ) When grid to cathode potential becomes more negative than the critical point, the tube will: (A) overheat (B) conduct (C) not conduct (D) ionize.

13. A ( ) B ( ) C ( ) D ( ) In this job, V1 conducts during: (A) the negative alternation only (B) the positive alternation only (C) both alternations (D) the time that it is not ionized.

14. A ( ) B ( ) C ( ) D ( ) When light on the phototube causes electron flow to stop, it is known as a: (A) direct coupled circuit (B) forward circuit (C) reverse circuit (D) amplifier circuit.