RADIO DATA BOOK

The RADIO & ELECTRONICS Handbook

SECOND EDITION

WILLIAM F. BOYCE, PUBLISHER

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The
RADIO & ELECTRONICS HANDBOOK

by

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and

JOSEPH J. ROCHE

SECOND EDITION

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TO

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INTRODUCTION

The RADIO ELECTRONIC HANDBOOK is a development of the Radio Data Book upon which preparation was begun in 1943. The book was developed as a direct result of the needs of an electronic engineering company engaged in a new science of publishing and education. This group was Boland & Boyce, an industrial engineering organization devoted to the preparation of electronic technical manuals for the armed services.

The gigantic task of furnishing electronic knowledge and techniques to men in the services in simple easy to understand, properly organized and illustrated form created the need for a basic manual—providing a reference source for information on circuits, tubes, theory, basic circuits, etc.

It was found that no such manual existed and over 300 separate texts had to be consulted constantly—this lack of centralized and concentrated information caused considerable expense and loss of time. For example information on the vacuum tubes used in a typical radar set, required reference to 4 separate vacuum tube manuals. In many cases the Signal Corps required that each basic circuit of a system be illustrated and described separately. It was found that no reference text, up to that time, contained descriptions of all the basic circuits and so each time a manual was prepared a complete development of this information was necessary.

It was decided that it would be highly desirable to create a single handbook-style volume containing the majority of this knowledge, convenient for use on the board, the bench, the desk or in the field.

The book had immediate acclaim and the sale of its first printing rapidly exhausted the supply. We received thousands of constructive criticisms from our readers and from these the new edition was planned.

The original edition started with the basic circuits discussion. Many readers requested that a briefing on fundamentals be added. They pointed out that no matter how far advanced one might be in electronics coverage of fundamentals and components would be helpful for reference purposes.—This was added.

In the original edition all discussion of systems and equipment was purposely omitted as it has thorough coverage in other good texts. However, it again seemed that condensed reference on these subjects was desirable.

Many suggestions indicated that the tube section should be charted to conserve valuable space and that cathode-ray, regulator and control tubes should be added.—This was done. Many other little features have been added such as complete R G cable listings, V T number chart, and J A N nomenclature systems explanation.

The authors will appreciate receiving suggestions from readers for incorporation in future editions.

W. F. BOYCE
J. J. ROCHE

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Section 1

FUNDAMENTALS

1. All matter is electrical in nature. For proof of this statement consider the molecular structure of matter. Any substance, iron, steel, water, wood, trees, rubber, etc., is composed of a vast number of tiny particles known as molecules. A molecule is the smallest part into which a substance may be divided and still retain its original properties. If a molecule is divided further, the particles which make up the molecule will not be identifiable as the original substance. For instance, if a molecule of water is divided, two other substances will be found, namely hydrogen and oxygen. The hydrogen and oxygen particles, which combined form the water molecule, are known as atoms. There are ninety odd known elements, or kinds of atoms, which in various combinations produce the molecular pattern of all the substances known to man.

The atom is composed of two parts, a nucleus, containing neutrons and protons, and a number of electrons which revolve around the nucleus. The protons are positively charged and the electrons are negatively charged. The neutrons have no electrical charge. It is the electron which is of prime interest in the discussion of radio-electronic circuits.

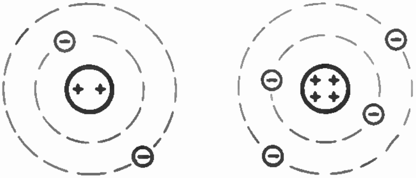


Fig. 1.—The Atom.

2. Electrons.—Electrons are extremely small negatively charged particles. All atoms are composed of a nucleus and a number of electrons. See Fig. 1. The number of electrons varies for the different atoms and depends upon the amount of positive charge of the nucleus. There is normally a sufficient number of the negatively charged electrons in an atom to balance the positive charge of the protons in its nucleus. The electrons travel in orbits around the nucleus in a manner similar to the way the earth travels around the sun.

The number of electrons in the atoms of an element varies somewhat, and consequently some atoms, of the same kind, have more electrons than others. Some of the electrons in those atoms having more than an average number of electrons are not firmly held, and at times are jarred loose from their orbits and out of the atom's influence. This happens when electrons collide as they travel through their irregular orbits.

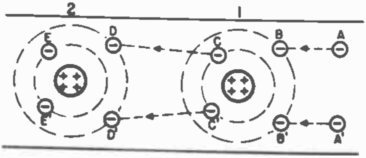


Fig. 2.—Current flow in a conductor.

Electrons which have broken away from their atoms are commonly referred to as "free" electrons. Only a small minority of the electrons of an atom can ever break away and become free.

3. Electrical Charges.—The electrons and protons of an atom obey one of the basic laws of electricity; namely, UNLIKE CHARGES ATTRACT. It is this attraction of oppositely charged particles which holds the atom together.

Another basic law is that LIKE CHARGES REPEL. It is due to this that the electrons in the outer ring of the atom sometimes break away and become free electrons. At the outer ring, the influence of the protons is not as great, and as the electrons collide in their paths, the reaction of the collision and the repulsion of the like charges is sufficient to overcome the proton's attraction. When electrons leave an atom in the manner described above or as a result of some external force, the atom has a deficiency of electrons. Such atoms, or any substance of which they are part, are then said to be positively charged. That is, the atom is in an unbalanced state, with more positive charge than negative charge.

The term free electron has been used to describe electrons which break away from their atoms. These electrons do not remain in a free state. They are attracted by the protons of other atoms, even though the other atoms are in a stable condition. It is possible, therefore, for an atom to contain more than its normal number of electrons. Any substance containing atoms having an over-abundance of electrons is said to be negatively charged.

4. Electrical Current.—Electrical current is defined as a flow of electrons through a conductor. Such a flow is illustrated in Fig. 2. The electrons labelled "A" in the figure are free electrons, supplied from an external source. Since unlike charges attract, the positive nucleus of atom "1" draws the two "A" electrons into its orbit. In joining the orbit, electrons "A" collide with electrons "B" causing them to move to the position of electrons "C" which, in turn, break from their orbit in atom "1" and move into atom "2", displacing electrons "D", etc. The displacement of the electrons causes them to be in continuous motion along the wire. It is this electron drift which constitutes current flow.

5. Insulators and Conductors.—The atoms of some substances have more electrons than others. Among those having a great many electrons are silver, copper, aluminum, iron and mercury. In these substances electrons are easily dislodged and moved from one atom to another. Due to the ease with which the electrons are caused to move from one atom to another in these substances, electric current is readily passed through them. These substances are known as conductors.

Items such as quartz, glass, mica, polystyrene and ceramics are examples of insulators. The electrons in the atoms of these substances are few in number and not easily disturbed from their atoms. It is thus extremely difficult to cause an electrical current to flow through them. Insulators are used therefore, whenever it is desired to prevent the flow of electricity.

6. Units of Current Flow.—Since current flow is the movement of electrons, it is expressed in terms of the number of electrons which flow past a given point. Because electrons are extremely small units, the coulomb has been adopted as a unit of quantity of electricity. A coulomb is equal to approximately 620 million electrons. In practice we are usually interested in the rate of current flow, or the number of coulombs which flow past a point each second. To simplify matters the term "ampere" has been adopted. An ampere is equal to one coulomb per second. Rather than indicate current flow in **coulombs per second** it is thus given in **amperes.**

Although the ampere is commonly used in electrical work, it is seldom used in radio. The more commonly used unit is the milliampere, or one-thousandth of an ampere, usually abbreviated ma. For example, a current flow of 0.250 amperes can be expressed as 250 milliamperes. Another, still smaller unit of current flow encountered in radio circuits is the microampere, micro meaning millionth. Thus, a measurement of current flow may be given in three units, amperes, milliamperes or microamperes.

Examples: .00054 amperes = 0.54 milliamperes = 540 microamperes.

7. Potential and E.M.F.—Electrons, being negatively charged particles, are attracted by a positive potential, and repulsed by a negative potential. Note the use of the terms positive potential and negative potential. If a point is positive, or at a positive potential, it has a deficiency of electrons and therefore has an attraction for electrons. A point having a negative potential is one that has an excess of electrons which it will release to a positive potential in an attempt to establish an equilibrium. A point is only positive with respect to a point of greater electron content. A point is never said to be positive or negative without stating or inferring that it is so in relation to a reference point. The difference in potential between two points is the electrical pressure which causes current to flow and is measured in volts. Two other commonly used terms for this potential difference are voltage and electromotive force, abbreviated e.m.f.

If a conductor is connected between two points which have a difference in potential, one positive with respect to the other, a current will flow from the negative point, through the conductor to the positive point. The amount of electron flow will depend, in part, upon the magnitude of the difference in potential, or voltage, between the two points.

8. Resistance and Conductance.—The amount of current that will flow through a conductor depends upon two factors. One of these is the voltage or pressure, the other is the resistance of the conductor. Resistance is a measure of the impedance offered by the conductor to the flow of current. The greater the resistance the lower will be the current flow for a given voltage and conversely, the lower the resistance the greater will be the current flow. The unit of measurement of resistance is the "ohm". A conductor is said to have **a** resistance of **one ohm** when a voltage of **one volt** forces a current of **one ampere** through it. If the resistance of a conductor is two ohms, and the potential across it is one volt, the current through it will be one-half of an ampere. The resistance of most conductors is extremely small, so that high resistance materials are used to make the known value resistors which are used throughout radio circuits. The symbol for resistance is R.

Conductance is the reciprocal of resistance and is a measure of the ease with which a conductor will pass current. The term "mho", which is ohm spelled backward, has been applied to the unit of measurement of conductance. The mho, is a very large unit and is seldom used, conductance usually being expressed in micromhos.

Example: Resistance = 1000 ohms, conductance = 1/1000 = .001 mhos = 1000 micromhos.

9. Ohm's Law.—Ohm's law expresses the relationship between the voltage, current and resistance in an electrical circuit.

It has been pointed out that the amount of current flow in any circuit depends upon two factors, the voltage or potential difference which causes the current to flow, and the amount of resistance in the circuit which tends to oppose the current flow. A conductor is said to have one ohm of resistance when one volt causes a current of one ampere to flow through it. If the resistance is doubled, twice as much difficulty is encountered in passing a current through it, and as a result, the current is only one-half of an ampere. With the resistance doubled one ampere can still be passed through the conductor by doubling the voltage. This relationship is expressed by Ohm's Law as follows:

The current in amperes, in an electrical circuit or any part of a circuit, is equal to the voltage, in volts, divided by the resistance in ohms.

The mathematical statement of this is, $Current = \dfrac{voltage}{resistance}$

Using the symbols I = current; R = resistance; E = voltage

it become $I = \dfrac{E}{R}$

Example: To find the current that will flow through a 5 ohm resistance with 45 volt applied.

$$I = \frac{E}{R} = \frac{45}{5} = 9 \text{ amperes}$$

Using the example as a basis it can be shown that if the relationship above is true, it is also true that $E = IR$.
Then $E = I \times R = 9 \times 5 = 45$ *volts*, which is the voltage assumed in example 1.

Also $R = \dfrac{E}{I} = \dfrac{45}{9} = 5$ *ohms*.

The reader will note that if any two values of the circuit are known, the third can be found by applying the correct form of Ohm's Law. The three forms are:

Current — equals the voltage divided by the resistance.

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

Resistance — equals the voltage divided by the current.

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

Voltage — equals the current multiplied by the resistance.

$$E = IR$$

10. Power.—Power is the rate at which electrical energy is expended. The unit of electrical power is the "watt". One watt is equal to one volt multiplied by one ampere or:

$$P = E \times I = \frac{E^2}{R} = I^2R$$

The watt is a small unit; therefore, whenever large values are mentioned, the term kilowatt is used, kilo representing thousand. Another common term is the milliwatt or one-thousandth of a watt.

11. Electrical Circuits.—Electrons will flow from a point of negative potential to a point which is positive with respect to it if a path is provided between the two points. This path, which includes the source of voltage, is known as a circuit.

If the path is broken, there can be no current flow. If the switch in Fig. 3A is closed, there will be a complete path from the negative side of the source to the positive side and a current will flow in the circuit. The lamps which are part of the path will glow as evidence of the current flow. When the switch is opened, the lamps stop glowing because the circuit has been interrupted and current can no longer flow. The circuit of Fig. 3A is an example of a series circuit. It is called a series circuit because all of the elements, the voltage source, the switch, and the lamps are connected so that there is only one path for the electron flow. Important facts to remember about series circuits are: the same amount of current will flow through every part of the circuit; the sum of the voltage drops across each element in the circuit will equal the supply voltage.

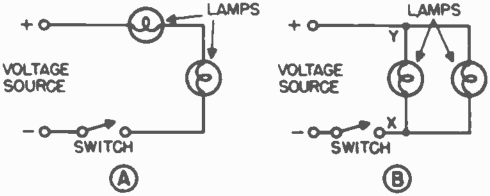


Fig. 3.—A. Series circuit; B. Parallel circuit.

Figure 3B illustrates a parallel connected circuit. One side of each lamp is connected to the positive side of the voltage source, and the other sides of the lamps to the negative terminal of the source. When the switch is closed, electrons flow from the negative side of the source to point "X". At this point two paths are available through which the electrons may flow, so the total electron flow divides and a portion flows through each path, lighting the lamps. At point "Y" only one path is available back to the positive side of the source, so the currents through the branches combine and complete their paths to the positive side of the source. Each lamp is connected across the voltage source; therefore the same voltage is applied across each branch of the parallel circuit. The amount of current flowing in each branch may not be the same, since the current is also dependent upon the amount of resistance in the branch.

12. **Resistors in Series.**—In the circuit of Fig. 4 three resistors of 5, 10, and 15 ohms are connected in a series circuit across a 60 volt source. When two or more resistors are connected in series, the individual resistances are added to find the total resistance offered to the flow of current. Adding the resistances of Fig. 4, gives a total resistance of 30 ohms. Applying Ohm's Law to find the current in the circuit:

$$I = \frac{E}{R} = \frac{60}{30}\ 2\ \textit{amperes.}$$

Since the same amount of current flows through every part of a series circuit, the voltage across each resistor can be found.

$$\begin{array}{lllll} \text{Resistor ``A''}: & E = I \times R & = 2 \times 15 & = & 30 \text{ volts} \\ \text{Resistor ``B''}: & E = I \times R & = 2 \times 10 & = & 20 \text{ volts} \\ \text{Resistor ``C''}: & E = I \times R & = 2 \times 5 & = & 10 \text{ volts} \\ \hline & & \text{Total voltage} & & 60 \text{ volts} \end{array}$$

Note that the sum of the voltage drops around the series circuit equals the applied voltage.

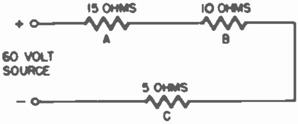


Fig. 4.—Resistors in series.

13. **Resistors in Parallel.**—When a five ohm resistor is connected across a 10 volt source, a current of 2 amperes will flow through it. Raising the resistance to 10 ohms, double the original value, will cut the current flow to one ampere, half its original amount. If another resistor, also of 10 ohms, is added in parallel with the first one, the current finds two paths through which it may flow. What happens in this case may best be explained by comparison with the flow of water through a small pipe. Assuming a constant water pressure, a certain number of gallons will flow from the pipe in a given time. Another pipe of the same size added in parallel with the first one, will carry the same amount of water, so the total flow is doubled. When equal value resistors are connected in parallel, the same thing takes place. In the example used above, the current will rise to 2 amperes, its original value. The effect of connecting resistors in parallel, then, is to reduce the total resistance.

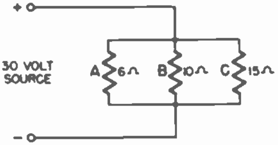


Fig. 5.—Resistors in parallel.

In parallel circuits the same voltage is across each branch. Applying Ohm's Law, the current through each resistor of the circuit in Fig. 5 can be found.

$$\text{``A''}: \quad I = \frac{E}{R} = \frac{30}{6} = 5 \text{ amps.}$$

$$\text{``B''}: \quad I = \frac{E}{R} = \frac{30}{10} = 3 \text{ amps.}$$

$$\text{“}C\text{”}: \quad I = \frac{E}{R} = \frac{30}{15} = 2 \ amps.$$

The total current of a parallel circuit is equal to the sum of the currents in all of its branches; adding the branch currents of Fig. 5, the total current is found to be 10 amperes. Using the total current and the applied voltage, the joint resistance is found:

$$R = \frac{E}{I} = \frac{30}{10} = 3 \ ohms.$$

Note that the joint resistance is less than any of the individual resistances. This is always true of resistors in parallel.

The total resistance of two resistors in parallel is equal to their product divided by their sum. In the circuit of Fig. 5 consider resistors A and B.

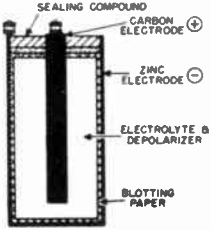


Fig. 6.—Dry cell construction.

$$R_T = \frac{A \times B}{A+B} = \frac{30 \times 10}{40} = \frac{300}{40} = 7.5 \ ohms \ total \ reistance.$$

Another method, called the reciprocal method, may be used to find the combined resistance of two or more resistors connected in parallel.

The resistance of a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual resistances. Therefore in Fig. 5:

$$R_T = \frac{1}{\frac{1}{A}+\frac{1}{B}+\frac{1}{C}} = \frac{1}{\frac{1}{6}+\frac{1}{10}+\frac{1}{15}} = \frac{1}{\frac{5}{30}+\frac{3}{30}+\frac{2}{30}} = \frac{1}{\frac{1}{3}} = 3 \ ohms.$$

14. **Primary Cells.**—There are four common methods of obtaining d-c voltages for operating radio-electronic equipment. They are primary cells, secondary cells, d-c generators and rectifiers. The more common type of primary cell is the dry cell shown in Fig. 6. It consists of two dissimilar metals, such as carbon and zinc, called the electrodes and an electrolyte, often sulphuric acid. The electrolyte is in paste form and therefore the cell is not actually dry. The cell is sealed to prevent the moisture in the paste from escaping.

Chemical action within the cell creates a potential difference between the electrodes. This chemical action takes place as follows:

When sulphuric acid is dissolved with water, the result is an electrolyte consisting of hydrogen and sulphuric ions. The hydrogen ions are positively charged and the sulphuric ions negatively charged. When the cell is in use, the negative sulphuric ions combine with the zinc, forming zinc sulphate. This process removes positive charges from the zinc electrode and it becomes negatively charged. As this action takes place, the zinc electrode disintegrates.

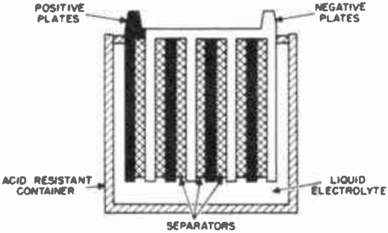


Fig. 7.—Storage battery construction.

The hydrogen ions move to the carbon electrode and collect around it. This action raises the internal resistance of the cell, and if not counteracted, severely limits the life of a cell. The formation of hydrogen gas around the positive electrode is called "polarization". In commercial cells an oxidizing agent such as manganese dioxide is mixed with the electrolyte. The hydrogen combines with the oxygen in the agent and forms water.

The closed circuit voltage of commercial dry cells is approximately 1.5 volts. The current capacity depends, generally, upon the size of the elements, the distance between electrodes and the internal resistance of the cell. Primary cells are connected as batteries in series, parallel or both to give increased terminal voltage and current capacity. At the end of their useful life, dry cells must be discarded.

15. Storage Batteries.—Secondary cells, which make up storage batteries, differ from primary cells in one major respect. Secondary cells are rechargeable, primary cells are not. Lead peroxide is used as the positive plate of a secondary cell, and spongy lead as the negative plate. Dilute sulphuric acid is the electrolyte. The construction of a storage battery is shown in Fig. 7.

When a secondary cell is discharged, passing current through an external circuit, both the positive and negative plates of the cell are chemically changed to lead sulphate.

The electrolyte is partially changed to water. The change from dilute sulphuric acid to water reduces the density, (specific gravity) of the electrolyte, affording a means of directly measuring the charge of the cell. The specific gravity of a fully charged cell is normally between 1.285 and 1.3000; the voltage under load should be approximately 2 volts. A discharged cell has a specific gravity of 1.150 and a terminal voltage of approximately 1.8 volts.

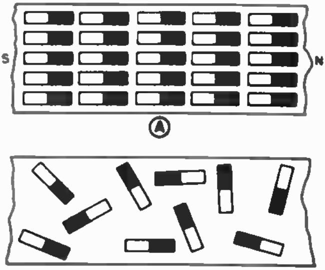


Fig. 8.—A. Alignment of molecules in a magnet; B. Molecules in a non-magnet.

If a cell is allowed to discharge below a specific gravity of 1.175, it may be damaged by excessive sulphation. In addition, if a cell is left in a discharged condition for too long a period, it will be difficult to convert the lead sulphate back into active materials. When a discharged or "sulphated" cell is being charged, particles of the lead sulphate drop to the bottom of the cell and collect there. If this accumulation is great enough, it will contact both plates, shorting the cell. Particles are apt to fall more readily if the plates become dry and are exposed to the air. For this reason, the level of the electrolyte must be checked periodically and the liqiud lost through evaporation replaced with distilled water.

Electrons flow from the negative terminal of a cell through the external circuit to the positive side of the cell. Within the cell itself, however, the electrons flow from the positive plate back to the negative plate. When recharging a secondary cell, the flow of current is reversed within the cell. This reversed current, now flowing from the negative plate to the positive plate, restores the plates to their original condition and reactivates the electrolyte by chemical action. Each time this renewing process takes place, some lead sulphate drops from the plates forming a layer at the bottom of the battery. It is due to this process that storage batteries wear out.

MAGNETISM

16. **Magnets.**—A magnet is a substance which is surrounded by a field of magnetic force. Magnets are divided into two general kinds, natural and artificial. Natural magnets

occur in nature. Magnetite, an iron ore, is a natural magnet. A magnet differs from a non-magnet in that the molecules of a magnet are aligned as shown in Fig. 8A while those of a non-magnet are disarranged as shown in Fig. 8B.

It is possible to create artificial magnets in several ways. One way is to stroke a piece of magnetic material, such as iron, with a natural magnet. This will align the molecules in the iron causing it to become a magnet. The iron will slowly lose its magnetism. The ability of the iron to hold its magnetism is called its retentivity. Steel will retain magnetism longer than iron. For this reason, most of the artificial magnets in common use are made of steel or steel alloys.

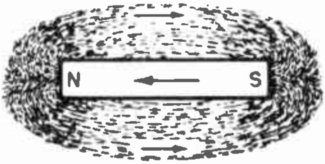


Fig. 9.—The field surrounding a bar magnet.

The earth is surrounded by a magnetic field, the effects of which can be noticed with an artificial magnet. If a magnet is suspended on a string, free to rotate, it will line itself up with the magnetic lines of force of the earth, one end pointing to the earth's north pole, and one end to the south pole. The ends of the magnet are also called poles; the end which points to the north pole being referred to as the magnet's north pole (N), and the other end its south pole (S). All magnets have these poles.

The law of attraction and repulsion applies to magnets as well as to electrical charges. LIKE POLES REPEL. If two suspended bar magnets are placed with their south poles close to each other, they will rotate away from each other. UNLIKE POLES ATTRACT. As the suspended magnets rotate, the north pole of one and the south pole of the other will attract each other, eventually stopping with the two unlike poles pointing to one another.

17. Magnetic Fields.—The attraction and repulsion of poles of magnets gives evidence of the fields of force surrounding magnets. Fig. 9 illustrates a strong bar magnet and the lines of force surrounding it. When small pieces of magnetic material are placed close to the bar magnet, they will line up as shown in the figure. A comparatively large number of pieces will be grouped around the two poles of the magnet indicating a concentration of magnetic lines of force at these points.

The lines of force, in passing through the pieces of magnetic material, cause the molecules in each piece to line up creating temporary magnets. The lines of force, also referred to as flux, travel within the magnet from south to north; the number of lines in the magnet greatly exceeding the number in the external path. The magnet itself offers very little opposition to the magnetic flux, whereas air offers much greater resistance. This magnetic resistance is known as reluctance and is the magnetic equivalent of resistance in an electrical circuit. Just as some conductors offer more resistance to the flow of current than others, so some substances have greater reluctance than others. However, there are no magnetic insulators in the same sense as electrical insulators.

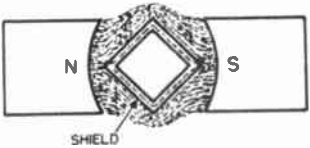


Fig. 10.—Magnetic shielding.

Magnetic lines of force will take the path of least reluctance, just as current flow seeks out the path of least resistance. In order to shield any particular space or object, all that is necessary is to provide a path of lower reluctance for the lines of force. See Fig. 10.

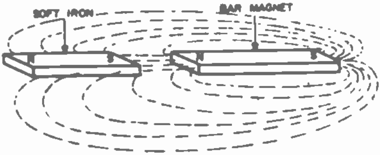


Fig. 11.—Magnetic induction.

Soft iron has a very low reluctance and is generally used whenever shielding is required. It is also used whenever it is desired to strengthen the field density between two poles of a magnet by providing a low reluctance path and shortening the air gap through which the lines of force must pass. The ability of soft iron and other metals to pass magnetic lines of force is a measure of their permeability. Permeability is defined as the ratio of the number of lines of force which pass through a given space when it is occupied by a substance, to the number of lines of force passing through the same space when it is occupied by air.

Example: 1500 lines of force pass through the air between the poles of a horseshoe magnet. When a soft iron bar is inserted between the poles, 15,000 lines of force pass through. The permeability of the iron would then be 15,000 divided by 1500 or 10.

18. Magnetic Induction.—When a magnet is placed near a piece of soft iron, the iron will become a magnet. The process by which this takes place is called magnetic induction. The soft iron is magnetized because the lines of force surrounding the bar magnet pass through it aligning the molecules of the iron, as illustrated in Fig. 11.

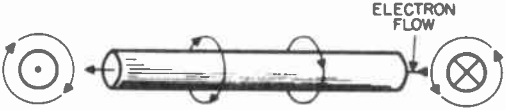


Fig. 12.—Field surrounding a conductor.

The molecular structure of some magnetic materials is such that as soon as the magnetizing force is removed, the material loses its magnetic properties because the molecules return to their original state of disarray. Soft iron and annealed steel are two such materials. Magnetic materials which fall into this classification are generally used in temporary magnets. These are magnets which are not expected to have magnetic properties without the presence of an external magnetizing force.

Hard steel and certain alloys, such as alnico which is composed of aluminum, nickel and cobalt, are used to make permanent magnets. These materials, once magnetized, retain their magnetic strength at the same level for long periods of time. Thin magnets are stronger in proportion to their weight than thick ones. For this reason, many permanent magnets are made of layers of thin magnets bound with like poles together. Rough handling or heat will cause a magnet to lose its strength by throwing some of the molecules out of alignment.

19. Field Surrounding a Conductor.—Every electron has a magnetic field surrounding it, and when electrons are flowing through a conductor they produce a magnetic field around the conductor. The lines of force produced by the electron flow surround the wire as illustrated in Fig. 12. These lines of force have a definite direction determined by the direction of electron flow. On the right the cross mark indicates electrons flowing into the paper. The dot on the left represents the current flowing out of the paper. A simple rule to determine the direction of the magnetic lines of force is called the left hand rule. Grasp the conductor in the left hand with the thumb pointing in the direction of the electron flow. The fingers will curl around the conductor in the direction of the magnetic field. This is illustrated in Fig. 13.

The existance of the magnetic field around the conductor can be demonstrated by suspending a needle magnet near it.

The needle will align itself at right angles to the conductor; parallel with the magnetic lines of force.

The greatest distance at which the needle will be acted upon depends upon the strength of the magnetic field. The strength of the field depends upon the amplitude of the electron flow through the conductor; the greater the current flow, the stronger will be the field produced.

20. Field Surrounding a Coil.—If a straight conductor, carrying current, is bent into a one-turn loop, magnetic lines of force will surround the wire as shown in Fig. 14A. Due to the new configuration of the conductor, the lines of force are concentrated in the area within the loop. If the loop is cut along the plane AB, the field around the half loop from B to A will appear as shown in Fig. 14B. Note that on the inside the lines of force are acting in the same direction, producing a strong field.

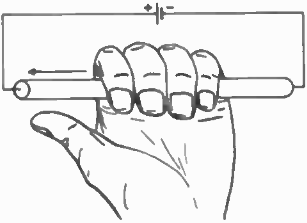


Fig. 13.—Left-hand rule for conductors.

Closely spacing a number of turns to form a coil will increase the strength of the magnetic field. The direction of the lines of force around each turn is the same through the area in the center and on the outside of the coil. The fields surrounding the individual conductors therefore aid one another forming a stronger field as shown in Fig. 15. Between the turns of the coil, the fields are opposing and tend to cancel each other. Therefore, the magnetic field is strong in the center of the coil and on the outside of the coil due to the

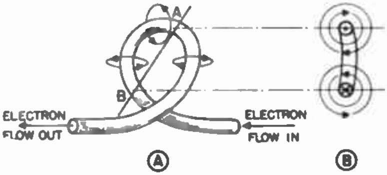


Fig. 14.—A. Field surrounding a one-turn loop; B. Cross section of field surrounding a loop.

adding of the lines of force from each individual turn. This is exactly the same concentration of lines of force as that around a bar magnet. Like the bar magnet, the coil has a north and south pole when current is passing through it.

To determine the polarity of a coil, grasp the coil in the left hand with the fingers pointing in the direction of electron flow and the thumb extended at right angle to the fingers. The thumb will point toward the north pole.

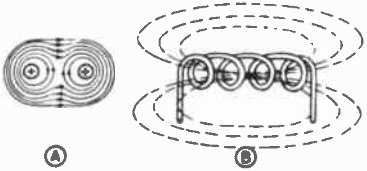


Fig. 15.—A. Field around adjacent turns of a coil; B. Field around a coil.

The number of lines of force through the center of a coil may be increased by placing a core of a magnetic substance such as steel or soft iron in the coil. The core material will be magnetized by the lines of force passing through it and will form an electromagnet. The strength of the electromagnet depends upon a number of factors. Among them are the amount of current flowing through the coil, the number of turns in the coil and the permeability of the core material.

21. Induced Voltage.—As previously stated, current flowing through a conductor will produce a magnetic field around the conductor. Conversely, a magnetic field can induce an electromotive force in a conductor thereby causing a current to flow in the conductor; provided it is a closed circuit.

In order to accomplish this, the following conditions must be satisfied: (1) A magnetic field must be present. (2) Either the conductor, in a closed circuit, must cut through the lines of force, or the lines of force must cut through the conductor.

In Fig. 16, the first condition is satisfied by the magnet. To satisfy the second condition, the conductor AB must move through the magnetic field. It must move through the field in a path that will cut through the magnetic flux. Moving the conductor in any direction except parallel to the lines of force will cause a voltage to be induced, and a current will flow through the wire. The greatest amount of current will flow when the conductor is moved at right angles to the lines of force. As the conductor in Fig. 16 is moved down through the magnetic flux, the meter needle will swing to the right, indicating that the electron flow is from B, through the meter to A. Reversing the direction of motion of the conductor will cause the meter needle to deflect to the left, indicating a reversal in direction of current flow. Reversing the direction of the magnetic flux will have the same effect. This confirms the fact that the polarity of the electromotive force induced in a conductor depends upon the direction of motion and the direction of the magnetic flux. The direction of current flow due to an induced voltage can be determined by the following rule: Extend the thumb, forefinger and middle finger of the **LEFT HAND** at right angles to one another. Point the thumb in the direction of motion, and the forefinger in the direction of the magnetic flux; the middle finger will then point in the direction of current flow.

22. Self-Induction.—When magnetic lines of force are building up around a coil carrying current, the turns of the coil will be cut by the expanding lines of force. In this case, the two conditions necessary to induce a voltage in a conductor are satisfied. A voltage will be induced in each turn of the coil, even though the expanding magnetic field is caused by the current flow in the coil. This is known as self-induction.

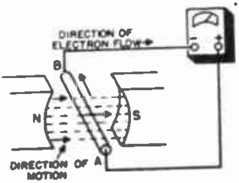


Fig. 16.—Induced e.m.f.

The voltage induced in a conductor by self-induction will always be in such a direction that it will oppose any change of existing conditions. Consider the circuit and curve in Fig. 17. The circuit consists of a battery, a conductor wound in the form of a coil, an ammeter and a switch, all connected in series. When the switch is closed, electrons will instantly begin to flow through the circuit from the negative side of the battery, through the coil and switch, to the positive side of the battery. As the current begins to flow through the coil, a magnetic field is built up around the coil. The magnetic field expands outward from the coil, cutting the turns of the coil and inducing a voltage in them by self-induction.

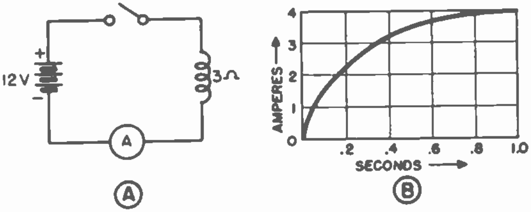


Fig. 17.—Self-induction in a coil.

The induced voltage is opposite in polarity to that of the applied (battery) voltage. It therefore opposes the flow of current through the coil. The induced voltage, or back e.m.f. as it is sometimes called, is never as great as the applied voltage, so the current rises gradually, as shown in Fig. 17B, until it reaches its maximum value as determined by the applied voltage and the resistance of the circuit.

The amplitude of the induced e.m.f. is determined by the number of turns in the coil, the strength of the magnetic field and the rate at which the field builds up.

When the current reaches its maximum value, the field around the coil ceases to expand and, since the lines of force are no longer cutting the conductor, back e.m.f. is no longer present. As long as the switch remains closed, current flows through the circuit as determined by Ohm's Law.

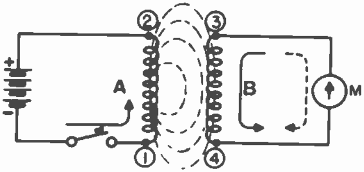


Fig. 18.—Mutual inductance between two coils.

Opening the switch in the circuit will cause the magnetic field around the coil to collapse since there is no current flow to maintain it. As the field collapses, the magnetic lines of force again cut the turns of the coil, this time inducing a voltage which tends to support the field surrounding the coil.

23. Inductance.—The amount of opposition offered by a coil to a change in current flow through it, is a measure of the inductance of the coil. The unit of measurement of inductance is the **henry**. A circuit is said to have **one henry** of inductance when a current change of **one ampere per second** will cause an induced e.m.f. of **one volt**.

Electrical inductance is best compared to mechanical inertia. Before current flow in a circuit can reach its maximum value, the inductance of the circuit must be overcome, just as it is necessary to overcome inertia before an automobile can be pushed easily.

Inductance is not a material thing but is a property of a circuit. It does not exist until current is passed through the circuit. The amount of inductance in a circuit depends in part upon the strengths of the magnetic fields surrounding the various portions of the circuit. If means are taken to concentrate a magnetic field, such as inserting an iron core in a coil, the inductance will be comparatively high. If the coil has an air core and few turns, its inductance will be comparatively low.

There is no loss of power in a purely inductive circuit. Energy is stored in the magnetic field and is returned to the circuit when the field collapses. Of course, there is no such thing as a pure inductance since all conductors have some resistance.

24. Mutual Inductance.—Coil A in the circuit of Fig. 18 is connected in series with a battery and a switch. Coil B is placed very close to coil A but is not electrically connected to it; a center-zero meter is placed across the terminals of coil B. When the switch is closed, current begins to flow through coil A from 1 to 2, and a magnetic field builds up around coil A. As the field expands, the lines of force in the field cut the turns of coil B, inducing a voltage in it and causing a current to flow. The current flow in coil B will be in such a direction that the magnetic field built up around B will oppose the magnetic field around A. The directions of current flow when the switch is first closed is indicated by the solid arrow in each coil. The current flow of coil B lasts until the field around A becomes stationary.

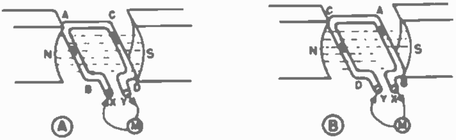


Fig. 19.—Voltage induced in rotating loop.

When the switch is opened a spark will jump across the terminals of the switch, because the collapsing field around coil A induces a voltage in A which tends to keep current flowing. The collapsing field around A cuts the turns of coil B in a reverse direction, inducing a voltage that causes the current flow in B to follow the broken arrow. The field around B again opposes the magnetic field around coil A.

Since the magnetic field of coil A links the turns of coil B, the two coils are said to be inductively coupled. The degree of coupling, called the **coefficient of coupling**, is determined by the number of lines of force of coil A, which cut the turns of coil B. If they all do, the coefficient of coupling is unity; however this is seldom the case.

The voltage induced in coil B is caused by mutual induction. The two circuits, since they are situated so that the magnetic flux of one cuts the turns of the other, are said to possess mutual inductance.

When a change of one ampere per second in one circuit induces one volt in another circuit, the two circuits have a mutual inductance of one henry.

25. Generators.—An electrical generator is a machine which transforms mechanical energy into electrical energy. Its operation is based upon the fact that an electromotive force is set up in a conductor; when the conductor is moved through a magnetic field cutting lines of force. Consider the one turn loop in Fig. 19A.

If the loop is rotated so that side AB is moving down and side CD up, a current will flow in the loop from x to y. The left-hand rule for finding the direction of an induced e.m.f. verifies this.

In Fig. 19B, the loop of wire has completed one-half revolution. Applying the left-hand rule in this new position indicates that the current flow is now from y to x. This represents a complete reversal of current flow in one-half revolution. The induced voltage which causes the current flow is maximum when the loop is in the positions shown in the figure, because in these positions it is cutting the maximum number of lines of force. The induced voltage is zero when the loop is rotated 90 degrees from the positions shown. At this point no lines of force are being cut because the loop is moving parallel to the lines of force. It is at this point that the reversal of current in the loop takes place. The reversing current in the generator is known as "alternating current."

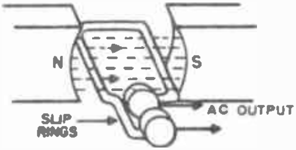


Fig. 20.—Alternating-current generator.

The amplitude of the voltage induced in a single turn loop is extremely small. In practice, the single turn loop is replaced by a great number of turns of wire; and the magnetic field is reinforced by placing coils around the pole pieces and passing current through them.

Electrical generators are of two types, a.c. and d.c. The internal action of each type is the same. As previously mentioned, the current flow produced in the rotating winding is alternating current. In an a-c generator the ends of the winding contact slip rings as shown in Fig. 20; consequently, the output of the generator is the same as the current flow in the winding. Direct current generators employ brushes and a commutator instead of slip rings. The commutator is made of segments, only two of which are in use at any one time. The commutator may be likened to a rotary switch, with the segments representing the contacts; and the brushes, the poles. Every time the voltage induced in the winding reverses, the commutator switches the brush connections; thus one brush is always positive and the other negative.

26. Motors.—Unlike poles of magnets attract; like poles repel. The same is also true of magnetic fields. Fields of unlike poles attract, while fields of like poles repel. A coil, through which current is passing, is surrounded by a magnetic field, as shown in Fig. 21. If the coil is placed between the poles of a permanent magnet, a force will be exerted on the coil. The south pole of the coil will be attracted to the north pole of the magnet, and the north pole of the coil to the south pole of the magnet. If the coil is free to rotate, it will move so that its south pole will be near the north pole of the magnet. If the direction of current through the coil is reversed, the position of the coil will reverse. If the coil is mounted on a shaft which is free to rotate and a suitable switching arrangement is provided, the application of a voltage to the coil will cause it to rotate. This is the action on which all electric motors are based. The electric motor is capable of transforming electrical energy into mechanical energy.

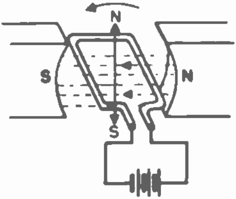


Fig. 21.—Motor action.

Motors, like generators, are of two general types, a.c. and d.c. Motors may be further classified as to whether they are series-wound, shunt-wound or compound-wound. A series-wound motor is one in which the field winding, used to produce the strong stationary magnetic field, is in series with the armature winding. The field winding of a shut-wound motor is connected in parallel with the armature winding.

27. Capacitance.—When two conductors are placed close together but insulated from one another a capacitor is formed. The functioning of a capacitor is illustrated in Fig. 22. Plates x and y are conductors, and z is an insulator. When the battery is connected across the plates, electrons flow from

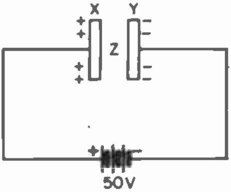


Fig. 22.—Action of a capacitor.

the battery to plate y, negatively charging it. Since like charges repel, the negative charge on plate y repels the negative electrons in plate x causing some of them to flow to the positive terminal of the battery. When a sufficient number of electrons have left plate x, a state of equilibrium is reached and current will no longer flow in the circuit. When this state exists, plate y has many more electrons than plate x and the capacitor is said to be charged.

If the battery is disconnected, the capacitor will remain charged because there is no path by which the surplus electrons on plate y can reach plate x. If a meter is connected across the plates, electrons will flow through it and its indicating pointer will move, demonstrating the ability of a capacitor to store energy. If the capacitor is a perfect one, the quantity of energy released will be exactly equal to the energy originally required to charge it.

A capacitor will store energy if the space between its plates is empty or if it contains an insulating material. In fact, a capacitor of given dimensions will store more energy if an insulating material is present than it will without it. This is so because, although current will not flow through an insulator, the presence of a difference of potential will cause a distortion of its molecules. This distortion consists of a movement of negative charges within the molecules of the insulator. The negative charges are forced to the end of the molecule away from the negatively charged plate. This makes it easier to charge the capacitor. The ratio of the capacity of a capacitor with air between its plates to its capacity with a given insulating material between its plates is called the "dielectric constant" of the insulating material.

The capacitance of a capacitor is dependent upon the size of its plates, the distance between them and, as previously described, the dielectric constant of the insulating material.

The unit of capacitance is the "farad." When an e.m.f. of one volt across a capacitor produces a current of one ampere, the capacitor has a capacitance of one farad. The farad is an extremely large unit and is not encountered in radio work. The units commonly used are the microfarad (one-millionth of a farad), and the micro-microfarad (one-millionth of a microfarad).

ALTERNATING CURRENT

28. An alternating current is defined as one which reverses itself periodically. This process does not happen instantaneously; it is a gradual increasing of current in one direction to a maximum value, and then a gradual decline to zero followed by a gradual increase in current flow in the opposite direction, etc. This can be illustrated graphically as shown in Fig. 23.

Alternating current displays many properties which direct current does not. Consider its effect on an inductance. Since the current through an inductance carrying a.c. is always changing, the field surrounding the inductance is constantly building up and collapsing. If a second inductance is placed near the inductor carrying the alternating current so that there is coupling between them, a current will flow continuously in the second inductance, if it is in a closed circuit.

Alternating current will flow through a capacitor continuously because a state of equilibrium is never reached as with direct current.

The rate at which an alternating current changes its direction is referred to as its "frequency". Each complete change is a cycle. Each half-cycle is an alternation and is further identified as either the positive or negative alternation. See Fig. 23. Most commercial power has a frequency of 60 cycles per second; that is, it goes through a complete reversal 60 times each second.

Alternating current frequencies encountered in radio work cover the range from 60 cycles per second (c.p.s.) to more than 30 million cycles per second. The frequencies from a few c.p.s. to 20,000 c.p.s. are audio-frequencies, identified as such because they are audible to the human ear. Frequencies above 20,000 c.p.s. are radio-frequencies. Frequency is expressed in cycles per second or c.p.s. Other units used are; kilocycle (kc.) or one thousand c.p.s., megacycle (mc.) or one million c.p.s.

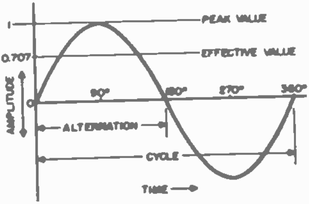


Fig. 23.—Sine-wave alternating current or voltage.

29. Peak, R.M.S. Average and Instantaneous Values.—Due to their continuous change in amplitude, values of alternating current and voltage cannot be expressed in the same terms as direct current. There are two common terms used when referring to values of alternating current or voltage; these are "peak" value and the "r.m.s." (root mean square) or "effective" value.

The peak value is the greatest instantaneous value reached in the positive and negative directions.

The value generally used is the r.m.s. or effective value. Most meters indicate effective values. An alternating current has an effective value of one ampere when it produces the same heating effect in a given resistance as will a direct current of one ampere. The same units, volts and amperes, are used in a-c measurements as are used in d-c measurements.

The effective value of alternating current is less than the peak value. Peak values may be converted to r.m.s. values by multiplying the peak value by 0.707. Multiplying the effective value by 1.414 will give the peak value.

Occasionally it is necessary to find the average value of an alternating current or voltage when either the peak value or the effective value is known. The average value is equal to 0.636 times the maximum, or peak, value. If the effective value is known, it may be multiplied by 0.9 to find the average value.

Another term frequently encountered is "instantaneous value". The instantaneous value of an alternating current or voltage can be any value between its peak value and zero, depending upon the instant, during the current or voltage cycle, in question.

30. Resistance in A-C Circuits.—The effect of resistance in an a-c circuit is similar to its effect in a d-c circuit. Resistance offers opposition to the flow of current through a circuit. The voltage developed across a resistor is equal to the resistance multiplied by the amplitude of the current. If the effective value of the current is used for computation, the voltage developed is also the effective value. Using the peak value of current will give the peak value of the voltage.

The presence of resistance in an a-c circuit will not cause a difference in phase between the current and voltage waves.

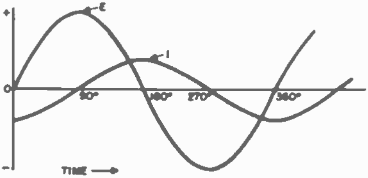


Fig. 24.—Phase difference.

31. Phase Relations.—The current and voltage in an a-c circuit seldom pass through their zero values at the same time. A typical case is illustrated in Fig. 24. Here the current wave passes through zero after the voltage wave. When such a conditions exists, the current is said to "lag" the voltage. The difference in time between the instant the voltage passes through zero and the instant the current passes through zero is expressed in degrees as shown in the figure. The complete cycle is divided into 360 units or degrees. In the example shown, the current passes through zero 90 degrees after the voltage. The current therefore "lags" the voltage by 90 degrees. Another way of stating the condition illustrated is to say that there is a "phase" difference of 90 degrees between the voltage and the current.

When the current and voltage pass through zero at the same instant, they are said to be "in phase". Phase differences may exist between two or more currents, two or more voltages, or between currents and voltages.

32. Inductance in A-C Circuits.—Inductance always opposes a change in current. The greater the rate of current change, the greater the opposition. The opposition to a change in current is a result of the counter e.m.f. induced in an inductance when the current through it changes. The amplitude of the induced e.m.f. is proportional to the rate of current change. The greater the rate of current change, the greater the induced voltage.

When an alternating current is applied to a pure inductance, the relationships of the applied voltage, the current, and the induced voltage are as illustrated in Fig. 25. As the current wave passes through zero, the rate of current change is greatest; therefore the induced voltage is at maximum. When the current is near maximum, the rate of current change is at a minimum and the induced voltage is near zero. The applied voltage is always equal and opposite to the induced voltage; therefore when the current is at zero, the applied voltage is at maximum. Consequently the current through an inductance lags the applied voltage and is 90 degrees out of phase with it.

Pure inductance exists in theory only; actually all inductors have some resistance. The effect of the resistance is such that the phase angle is always less than 90 degrees; the greater the resistance the smaller the phase angle.

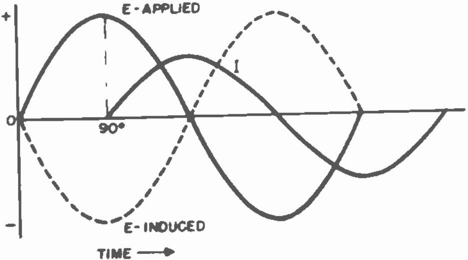


Fig. 25.—Current and voltage in an inductance.

33. Capacitance in A-C Circuits.—A charge of electricity may be stored in a capacitor, and it will be retained until it is either dissipated by leakage or released into a circuit.

When there is no charge on a capacitor, it is capable of permitting the greatest current flow. At the instant that a voltage is applied to an uncharged capacitor, the current is maximum. Since the capacitor is not opposing the flow of current, there is no voltage drop across it at that time. When the charge across the capacitor is maximum, the current through it is zero and the voltage drop across it is maximum.

If an alternating voltage is applied to a capacitor, the relationship between the applied voltage and the current will be as illustrated in Fig. 26. When the current is maximum, the voltage across the capacitor is zero. The charge stored in the capacitor at this instant is zero. When the voltage across the capacitor reaches maximum, the current is zero and the charge stored in the capacitor is maximum. The current reaches its maximum value before the voltage; therefore the current through a capacitor leads the voltage by 90 degrees.

In practice all capacitors have some losses. The effect of the losses is such that the phase angle is always less than 90 degrees.

34. Power Factor.—The energy absorbed by an inductance or a capacitance is not dissipated but is returned to the circuit. Ordinarily a circuit contains resistance, capacitance, and inductance. Since no power is dissipated by the inductance and capacitance, the only power loss is due to the resistance. If the voltage and current in the circuit are measured and used to find the power, the value found will be greater than the actual power. This value is referred to as the apparent power and is equal to the voltage, in volts, multiplied by the current, in amperes. The actual power in an a-c circuit is equal to the current squared multiplied by the resistance, or I^2R.

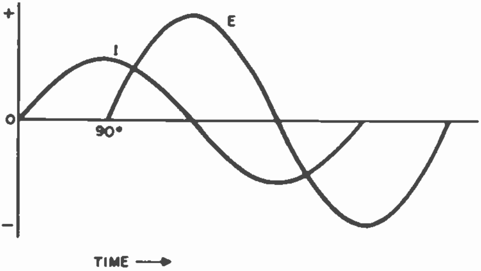


Fig. 26.—Current and voltage in a capacitor.

The ratio of the actual power to the apparent power is called the power factor. It is expressed by the formula:

$$\text{Power factor} = \frac{\text{Watts}}{\text{volts} \times \text{amperes}} = \frac{I^2R}{E \times I}$$

35. Reactance.—Reactance is the opposition offered by inductance, capacitance, or both to the flow of alternating current through a circuit. It is represented by the symbol "X" and is measured in ohms. Reactance is not a constant value for any particular inductor or capacitor; it varies with the frequency of the alternating current in the circuit. When a circuit is composed of both inductance and capacitance, the total reactance of the circuit is found by subtracting the reactance offered by the inductance and the reactance of the capacitance. They must be subtracted because they work in opposition to each other, inductance causing a lagging current and capacitance causing a leading current.

36. Inductive Reactance.—Inductive reactance is the opposition offered by an inductance to the flow of alternating current. The symbol for inductive reactance is X_L and the unit of measurement is the ohm. The reactance of an inductor is found from the following formula.

$$X_L = 2\pi FL$$

Where X_L = *Inductive reactance in ohms*
F = *Frequency in cycles per second*
L = *Value of inductance in henries*

It is apparent from this formula that inductive reactance varies directly with frequency as well as with inductance. The reactance of an inductor will increase with an increase in the applied frequency or an increase in its inductance.

When two or more inductances are connected in series in a circuit, the total reactance is the sum of the individual reactances. This is true since the total inductance is equal to the sum of the individual inductances.

If inductances are connected in parallel, then the total inductance will always be less than that of the smallest inductance. The reactance of a parallel group of inductances can be determined by finding its total inductance, using the reciprocal method in the same manner as when finding the value of resistors in parallel. After determining the joint value of the parallel inductors, the reactance is found by substituting this value in the inductive reactance formula given above.

37. Capacitive Reactance.—The opposition offered by capacitance to the flow of alternating current is known as capacitive reactance. The symbol for capacitive reactance is X_C and it is measured in ohms. The formula for capacitive reactance is:

$$X_C = \frac{1}{2\pi F C}$$

Where X_C = *Capacitive reactance in ohms*
F = *Frequency in cycles per second*
C = *Capacity in farads*

Capacitive reactance varies inversely as the frequency and/or capacity. An increase in either frequency or capacity will cause a decrease in reactance. Decreasing either the frequency or the capacity will increase the reactance.

The total capacitance of two or more capacitors connected in parallel is the sum of their individual capacities. The capacitive reactance of the combination is found from the formula after determining the joint capacity.

When capacitors are connected in series, the product over the sum or the reciprocal method may be used to determine the joint capacitance, and then the reactance can be found by using the capacitive reactance formula given above.

38. Impedance.—Impedance is the total opposition to the flow of alternating current. It is the result of the total reactance and resistance of the circuit and is measured in ohms. The symbol for impedance is Z.

The impedance of an a-c circuit is found from the formula:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

A pure inductance will cause the current to lag the voltage by 90 degrees; while a pure capacitance causes the current to lead the voltage by 90 degrees. Resistance has no effect on the phase angle if the voltage and current applied are in phase. Since this is true, inductive reactance can be depicted graphically as acting at right angles to resistance as illustrated in Fig. 27A. The illustrations in Fig. 27 are called vector diagrams.

Capacitive reactance also acts at right angles to resistance, but in the opposite direction from inductive reactance, as shown in Fig. 27B.

In a series circuit containing only inductance and resistance, the impedance is found by taking the square root of the sum of the squares of R and X_L; $Z = \sqrt{R^2 + X_L^2}$

When capacitance and resistance are combined in a series circuit, the impedance $Z = \sqrt{R^2 + X_C^2}$.

To determine the impedance of a series circuit containing all three elements, the combined effect of the inductive reactance and the capacitive reactance must first be determined. Since the capacitance and inductance cause equal and opposite phase shifts, the two reactances oppose each other. This is illustrated by the diagram of Fig. 27C. The combined effect of the reactances is found by subtracting the smaller from the larger, the result being capacitive reactance or inductive reactance depending upon which is greater. The impedance is then calculated.

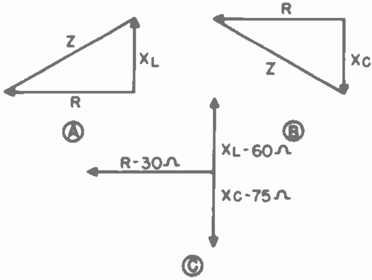


Fig. 27.—Impedance triangles.

Example:

$$
\begin{aligned}
R &= 30 \text{ ohms} \\
X_C &= 75 \text{ ohms} \\
X_L &= 60 \text{ ohms} \\
Z &= \ ? \\
Z &= \sqrt{R^2 + (X_C - X_L)^2} \\
&= \sqrt{(30)^2 + (75-60)^2} \\
&= \sqrt{900+225} \\
&= \sqrt{1125} \\
Z &= 33.5 \text{ ohms}
\end{aligned}
$$

39. Ohm's Law for A-C Circuits.—Ohm's Law must be modified to account for the phase differences between voltage and current before it can be applied to a-c circuits. The a-c version of the law is:

$E = IZ$

Where E = *voltage in volts*

I = *current in amperes*

Z = *impedance of the circuit in ohms.*

The phase difference is accounted for when finding the impedance. The law may be applied to an entire circuit or to any portion of a circuit. However, the voltage drops around the circuit cannot be added algebraically to arrive at the input voltage. Due to the phase shift, they must be added vectorially.

Examples: A series circuit consisting of a 10 millihenry inductance and a 15 ohm resistor is connected across a 1000 cycle, 100 volt a-c source. Find the voltage across each element.

$$X_L = 2\pi FL$$

$$= 6.28 \times .01 \times 1000$$

$$X_L = 62.8 \text{ ohms}$$

$$Z = \sqrt{R^2 + X_L^2}$$

$$= \sqrt{225 + 3943.84}$$

$$Z = 64.5 \text{ ohms}$$

$$I = \frac{E}{Z} = \frac{100}{64.5} = 1.55$$

Voltage across $L = IX_L = 1.55 \times 62.8 = 97.34$ *volts*
Voltage across $R = IR = 1.55 \times 15 = 23.25$ *volts*

Note that the sum of the two voltages is greater than the applied voltage. This is due to the phase shift caused by the inductance. If the two voltages are added vectorially, the vector sum will equal the supply voltage. Since the two voltages are at right angles to each other, the vector sum can be found by squaring both values, adding them and taking the square root of the sum.

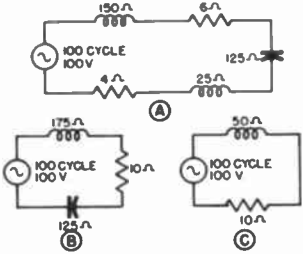


Fig. 28.—Series L, C, R, circuit.

$$E_L^2 = 9475$$

$$E_R^2 = 540$$

$$E_L^2 + E_R^2 = 10015$$

$$E = \sqrt{10015} = 100 \text{ volts. (approx.)}$$

40. Series L, C, R Circuits.—Inductance, resistance and capacitance are often connected in series in a-c circuits. The resistance is the effective resistance which includes power losses due to hysterisis, eddy currents, "skin" effect at high frequencies, etc. In diagrams effective resistance is often shown as a resistor. The inductance and capacitance can then be considered as pure reactances.

When solving a series L, C, R circuit, the first step is to simplify the circuit. In Fig. 28A the ohmic values of resistance and reactance are given for each element. All like elements, in a series circuit, can be combined and considered as one. Simplifying the circuit of Fig. 28A results in the circuit shown in Fig. 28B. The circuit can be further simplified by combining the inductive and capacitive reactances. They must be combined by subtracting the smaller from the larger since their effects are in opposite directions. The final circuit is shown in Fig. 28C.

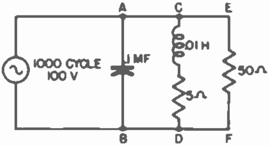


Fig. 29.—Parallel L, C, R, circuit.

Using the formula $Z = \sqrt{R^2 + X_L^2}$

the impedance of the circuit is

$$\begin{aligned} Z &= \sqrt{(10)^2 + (50)^2} \\ &= \sqrt{100 + 2500} \\ &= \sqrt{2600} \\ Z &= 51 \textit{ ohms approx.} \end{aligned}$$

The current in the circuit can be found from the formula

$$I = \frac{E}{Z} = \frac{100}{51} = 2 \textit{ amps. (approx.)}$$

When the current is known, the voltage across each part of the circuit is found from the formula.

$$E = IZ$$

Often the reactance of the inductance and capacitance is not known and must be computed from the reactance formulas.

41. Parallel L, C, R Circuits.—The three elements, inductance, resistance and capacitance, can be combined in a parallel circuit in a number of ways. One branch may consist of inductance and resistance, another of capacitance and resistance or inductance, and a third of reistance alone.

The first step in solving a parallel L, C, R network is to find the values of the reactances at the applied frequency. In Fig. 29 $X_C = 1{,}592$ ohms and $X_L = 62.8$ ohms.

The impedance of branch CD may be found using the formula

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{(5)^2 + (62.8)^2} = 63 \textit{ ohms}$$

The impedances of branches AB and EF are known since they consist of pure capacitance and pure resistance, respectively. The combined impedance of two branches is found from the formula

$$Z = \frac{Z_1 \times Z_2}{Z_S}$$

where Zs = impedance of the two branches considered as a series circuit.

The process is repeated using the combined impedance of the first two branches and the impedance of the third. The result will be the joint impedance. When this is known, the total current flow in the circuit may be found by applying Ohm's Law for a-c circuits.

42. Transformers.—A transformer is a device used to transfer electrical energy from one circuit to another. A simple transformer consists of two coils, called the primary and the secondary. When an a-c or pulsating d-c voltage is applied to the primary, it sets up a field around it. Since the secondary is located close to the primary, it is surrounded by this field. Because the field is constantly changing, due to the variation in the applied voltage, an e.m.f. is induced in the secondary. Thus energy may be transferred to the secondary without connecting it directly to the primary. In the process of transfer, the primary voltage may be stepped up or down.

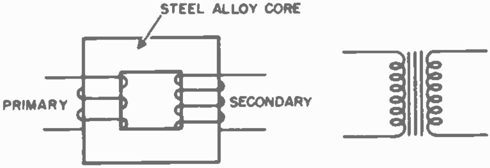


Fig. 30.—Transformer.

Transformers are usually wound on cores of magnetic material, as shown in Fig. 30. Since the core has a higher permeability than air, the inductance of the coils is increased. This reduces the number of turns required in the coils. The core introduces power losses, due to hysterisis and eddy currents, and since these losses increase with frequency, the use of cores is generally limited to power and audio frequencies.

Power and audio transformers use cores of steel alloy. Their coils are normally wound one on top of the other to increase the mutual inductance between them. Many power transformers have more than one secondary winding in order to supply power to circuits requiring different voltages.

As stated previously, power may be transferred at the same voltage, at higher voltage, or at a lower voltage.

When a-c or pulsating d-c is applied to the primary of a transformer having a greater number of secondary turns than primary turns, the voltage induced in the secondary will be greater than the voltage applied to the primary. The values of the two voltages will be in the same proportion as the number of primary and secondary turns. The ratio of the number of turns in the primary and secondary is called the "turns ratio." Thus a transformer having a turns ratio of 10:1 is a step-up transformer which will produce ten times as much voltage across its secondary as is impressed across its primary. A ratio of 1:10 indicates the reverse. The following formula states the relationship between the primary and secondary turns and voltages.

$$\frac{N_S}{N_P} = \frac{E_S}{E_P}$$

Where E_P = *primary voltage*
N_P = *primary turns*
E_S = *secondary voltage*
N_S = *secondary turns*

Since the transformer is used to transfer power from one circuit to another, and power is equal to the voltage times the current, each time the voltage is changed the current must also change. A step-up transformer increases the voltage at the expense of the current. The voltage times the current in the secondary, plus losses is equal to the input power.

The amount of current in the secondary of a step-down transformer is greater than that flowing in its primary. Since the voltage has been reduced, the current can increase until the power in the secondary approximately equals the primary power. This relationship of current and turns ratio is expressed as:

$$\frac{I_S}{I_P} = \frac{N_P}{N_S}$$

Where I_S = *secondary current*
I_P = *primary current*
N_P = *primary turns*
N_S = *secondary turns*

If a transformer were 100% efficient, the power transferred to the secondary would exactly equal the primary power. Power is lost due to the resistance of the coils and hysterisis and eddy currents in the core. The power consumed in this manner cannot be delivered to the output; thus the efficiency of a transformer is less than 100%. The percentage of efficiency of a transformer may be determined from the following formula:

$$\%\ \text{Efficiency} = \frac{P_S}{P_P} \times 100$$

P_S = *power in secondary*
P_P = *power in primary*

43. Impedance Matching.—Impedance matching transformers are often used when it is necessary to transfer power between two circuits of different impedances.

Maximum power is transferred from the source to the load when the impedance of the load equals the impedance of the source. To satisfy this condition, a matching transformer can be designed so that:

$$Z\ \text{source} = \left(\frac{N_P}{N_S}\right)^2 \quad Z\ \text{load.}$$

Where N_S = *primary turns*
N_S = *Secondary turns*

This relationship may also be stated as:

$$\frac{N_P}{N_S} = \sqrt{\frac{Z\ source}{Z\ load}}$$

44. Autotransformer.—The autotransformer contains a single winding and depends upon self-induction rather than mutual induction for its operation. The winding is tapped so that a portion of it may be used for one winding and the entire coil for the other winding. In Fig. 31, if the portion labelled "A" is used as the primary, a stepped up voltage will be present across the secondary "B". Reversing the connections will give a lower voltage across the secondary, which would then be the portion labelled "A".

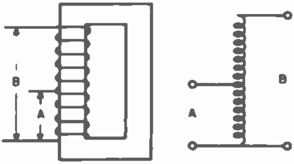


Fig. 31.—Autotransformer.

RESONANT CIRCUITS

45. Series Resonant Circuits.—Resonance is defined as the condition existing in a circuit when the inductive and capacitive reactances cancel. Consider the circuit shown in Fig. 32. A 1000 cycle source is connected in series with a .318 microfarad capacitor, a 10 ohm resistor and an inductor of .079 henries. Computing, X_C is found to be 500 ohms and X_L 500 ohms. Applying the impedance formula:

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$
$$Z = \sqrt{10^2 + (500 - 500)^2}$$
$$Z = \sqrt{10^2} = 10\ ohms$$

The total impedance then is the value of the resistor, and the circuit is said to be series resonant at 1000 cycles per second. This condition will exist at only one frequency for given values of L and C. The impedance offered by the circuit at resonance is extremely small; if the frequency is increased the inductive reactance will increase, the capacitive reactance decrease thus increasing the impedance of the circuit. A decrease in frequency will lower the inductive reactance but increase the capacitive reactance, thus increasing the total impedance.

The following are the characteristics of series-tuned, or series-resonant, circuits:

1. Their impedance at resonance is very low.
2. Current at resonance is very high.
3. Voltage across the entire circuit is low. Across either the inductor or the capacitor, the voltage will be high, possi-

bly much higher than the overall voltage.

4. Series-tuned circuits may be used to pass one frequency and exclude others.

46. Parallel Resonant Circuits.—The condition of resonance in a parallel circuit occurs when the inductive reactance equals the capacitive reactance. In Fig. 33, one branch con-

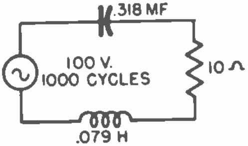


Fig. 32.—Series resonant circuits.

tains pure inductance and a 5 ohm resistor; the other branch is pure capacitance.

The impedance of the two branches in parallel is computed from the formula:

$$Z = \frac{Z_1 \times Z_2}{Z_s} \quad \textit{(impedance considered in series)}$$

$$Z = \frac{500 \times 500}{5} = \frac{250{,}000}{5} = 50{,}000 \textit{ ohms}$$

Zs will equal zero and the combined impedance would be infinite if there were no resistance in the circuit. This never occurs because some resistance is always present in a circuit. Note that the combined impedance in the example is greater than either alone, and that they do not cancel. Since the impedance is high, the voltage at resonance is also high.

At resonance, a parallel LCR circuit offers the maximum impedance to the flow of current through it; therefore current flowing from "A" to "B" will be at its minimum. On either side of resonance, the impedance will drop considerably, and the circuit will exhibit either inductive or capacitive reactance depending on whether the frequency is above or below resonance.

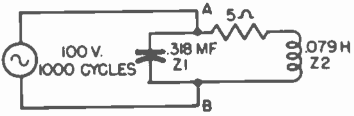


Fig. 33.—Parallel resonant circuit.

Although the current flow through the circuit in Fig. 33 is minimum at resonance, the current circulating within the circuit may be very high. This is due to what is called the "fly-wheel" effect of the circuit. The capacitor stores a charge first in one direction and then the other. The capacitor must discharge through the coil and in doing so it passes a current through the coil. The current builds up a magnetic field around the coil. When the capacitor is completely discharged, the field around the coil collapses and self-induction causes a current to flow which charges the capacitor with a polarity opposite that of its original charge. This process, called "oscillation", keeps repeating and would continue indefinitely if power were not lost due to the resistance in the circuit. Since the circuit acts like a storage tank, the parallel resonant circuit is often referred to as a tank circuit.

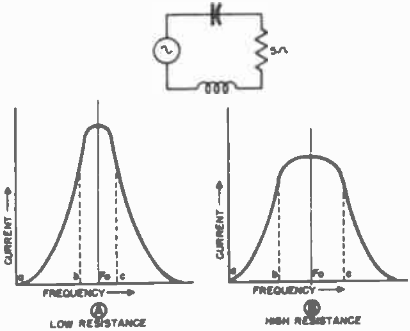


Fig. 34.—Selectivity of series circuit.

The formula for finding the frequency at which a given series or parallel circuit will be resonant is:

$$Fo = \frac{1}{2\pi\sqrt{LC}}$$

47. Selectivity of Resonant Circuits.—In the previous discussion it was stated that series-tuned and parallel-tuned circuits are often used to pass one frequency and reject others. The selection of a single frequency by a circuit is possible only in theory. Actually the resistance present in all tuned circuits modifies this effect so that a "band" of frequencies will be passed. The amount of resistance determines the width of the band. Consider the series-tuned circuit and its "resonance curve" shown in Fig. 34. At frequency "a" the impedance of the circuit is mainly capacitive and negligible current flows in the circuit. As the frequency approaches resonance, Fo, the current increases because the impedance decreases until, at resonance, inductive and capacitive reactance cancel each other, leaving only the resistance to limit the current. If the resistance of the circuit is low, the current will rise sharply approaching resonance and decrease sharply beyond resonance. As a result, the band of frequencies in the range b to c will be passed by the circuit.

When the resistance of the circuit is increased, the current that flows at resonance is reduced and as a result, the top of the curve is flattened or broadened as shown in Fig. 34B. The band of frequencies that pass through the circuit is thus effectively increased.

Fig. 35 shows the current-frequency relationship in a parallel tuned circuit.

Since the impedance of a parallel tuned circuit is greatest at resonance, the current through the circuit will be at a minimum, increasing above and below resonance. Decreasing the value of resistance in the circuit, decreases the current flow, increasing the selectivity. As the resistance is increased, the current will increase and the curve will be as shown by B. Note that reference is made to current passing through the circuit and not to that circulating in it. The selectivity of a parallel-tuned circuit is broadened by increased resistance just as in the series-tuned circuit.

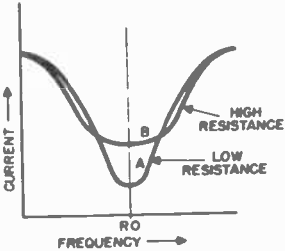


Fig. 35.—Selectivity of a parallel circuit.

48. Q Factor.—The Q of a capacitor or coil is a rating of its merit or quality. A perfect capacitor or coil would have no resistance. Since all coils and capacitors have some resistance, the term Q is used to indicate the relationship between their reactance and resistance. The Q of a coil or capacitor is equal to its reactance divided by its resistance. It is expressed by the formula:

$$Q = \frac{X}{R}$$

The term Q is also used in reference to tuned circuits. A perfect tuned circuit would have no losses and would be infinitely selective. Since all tuned circuits include some resistance and the resistance of a tuned circuit determines its selectivity, the Q of a resonant circuit gives an indication of the selectivity of the circuit. The higher the Q of a circuit, the greater its selectivity. In practical circuits only the resistance of the coils need be considered at low frequencies. At very high frequencies, the resistance of capacitors must also be taken into consideration.

49. L/C Ratio.—The selectivity of a tuned circuit can be increased by increasing the L/C ratio. This is done by increasing L and decreasing C. The L/C ratio affects the circuit as illustrated in Fig. 36. Curve A is the resonance curve of a series circuit tuned to 1000 c.p.s. with given values of L, C and R. The current in the circuit decreases on either side of resonance since the reactances no longer cancel and one, either inductive or capacitive, predominates. If the value of L is doubled and that of C is halved, the resonant frequency will be the same. However, at any frequency below resonance, the capacitor will now offer twice as much impedance. The decrease in current below resonance is thus more rapid. Above resonance, since L has been doubled the reactance of L is doubled causing the current to decrease more rapidly. The result is illustrated by curve B in Fig. 36. The higher the L/C ratio, the more selective is the tuned circuit.

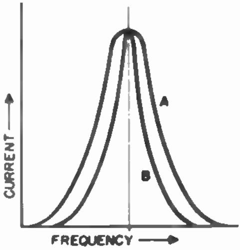


Fig. 36.—Effect of changing L/C ratio.

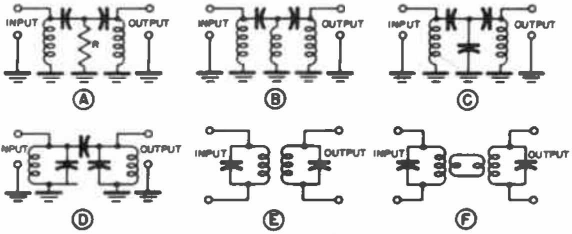


Fig. 37.—Coupling methods.

50. Coupling.—To transfer energy from one circuit to another, some form of coupling must be used. Several types of couplings commonly used in radio equipment are illustrated in Fig. 37. A, B, and C are called direct coupling. In these circuits, a component has been made common to both the primary and secondary circuits. The common component in A is resistor R. B and C are identical except that an inductance is used in B and a capacitance in C.

The circuits of Fig. 37 D, E and F are indirectly coupled. In D capacitive coupling is used. In E inductive coupling is used. F illustrates another type of inductive coupling called link coupling. This type of coupling has the advantage of not requiring that the coupled circuits be located close together. In addition, it is helpful in minimizing stray capacitive coupling.

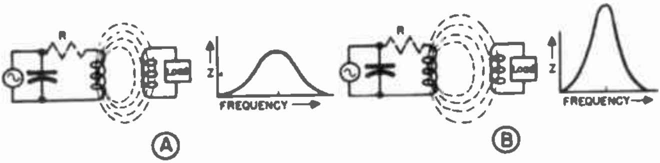


Fig. 38.—Effect of coupling on selectivity.

51. Coefficient of Coupling.—The term used to express the degree of coupling between two coils is "coefficient of coupling". It is usually expressed as a decimal part of one and is determined by the formula:

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

Where k = *coefficient of coupling*
M = *mutual inductance*
L_1 = *inductance of one coil*
L_2 = *inductance of the other coil*

Power transformers usually have a 0.98 or 0.99 coefficient of coupling; whereas tuned radio-frequency transformers may have coupling coefficients as low as 0.05.

When tuned r-f transformers have a high coefficient of coupling, they are said to be tightly coupled, and the tuning of the circuits is affected in the same manner as when resistance is added to a circuit. The result is to lower the Q and broaden the response curve as shown in Fig. 38. The effective reflected resistance is labelled R.

Fig. 38A illustrates medium coupling and the resonance curve which results. The reflected resistance R is sufficiently small so that little broadening of the response curve occurs. A loosely coupled circuit, shown in Fig. 38B, has a very high Q and resulting sharp selectivity.

The type of coupling best suited for radio use is some value between loose and tight coupling. The maximum transfer of energy at the resonant frequency is obtained at the point called "critical coupling". At this point, the energy transfer is maximum and the selectivity of the circuit is comparatively sharp. Tighter than critical coupling results in further broadening of response.

Section 2

VACUUM TUBES

1. A vacuum tube consists of an evacuated envelope containing two or more electrodes. One of these electrodes is called the cathode. It emits electrons when heated. A second electrode, called the anode or plate, is operated at a positive potential with respect to the cathode and attracts or collects the emitted electrons. In more complex vacuum tubes, other electrodes, called control grids, screen grids, and suppressor grids, are added to control the flow of emitted electrons.

2. **Thermonic Emission.**—The atom is composed of a positively charged nucleus and a number of electrons which balance its positive charge. The electrons are in constant motion about the nucleus. Some of the electrons, in certain materials, are not firmly bound to the nucleus and are able to pass from the influence of one atom to that of another. These electrons are referred to as "free electrons".

The velocity at which the electrons move about increases with increasing temperature. If the temperature is increased sufficiently, the velocity of the free electrons will be great enough so that some of them will leave the confines of the substance. This action is called thermonic emission.

3. **Cathode.**—The electron emitting electrode in a vacuum tube is referred to as the cathode. It is constructed of, or coated with, a good electron emitting material such as thoriated tungsten or metallic oxide. The temperature to which the cathode must be heated before electron emission occurs is extremely high; ranging from approximately 700° C. for oxide coated cathodes, to 2200° C. for pure tungsten cathodes. If these temperatures were attained in open air, the oxygen present would destroy the cathode. For this reason, the cathode and other elements of a vacuum tube are enclosed in an envelope from which almost all air has been exhausted.

4. Thoriated-Tungsten Cathodes.—Thoriated-tungsten cathodes are made from tungsten to which a small quantity of thorium oxide has been added. After the cathode has been formed, it is heated to a high temperature in order to reduce the thorium oxide to thorium. The cathode is then placed in a vacuum and heated to slightly above normal operating temperature in order to permit some of the thorium to work its way to the surface of the cathode, where it deposits in a thin layer. It is from this layer that emission takes place. As the layer of thorium is dissipated, it is replaced from within the cathode. A thoriated-tungsten cathode will last for several thousand hours of use after which the thorium will be almost completely dissipated and the emission from the cathode will decrease rapidly. Thoriated-tungsten cathodes are operated at approximately 1700 degrees centigrade.

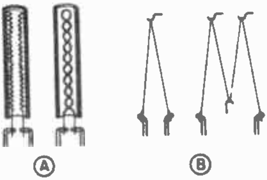


Fig. 1.—A. Indirectly heated cathode.
B. Directly heated cathode.

5. Oxide-Coated Cathodes.—Oxide-coated cathodes consist of a metallic base which has been coated with a suitable oxide. Nickel alloy is the most widely used base material; while a mixture of barium and strontium oxide is generally used for the coating. The oxide coating is formed by: depositing barium and strontium carbonates on the base material; placing the cathode in the tube; and heating it to a temperature considerably above normal operating temperature for a short period. This reduces the carbonates to oxides and releases carbon dioxide which is then drawn from the tube.

Oxide-coated cathodes are very efficient emitters, requiring very little heating power to produce sufficient electron emission for the operation of a vacuum tube. They operate at temperatures between 700 and 750 degrees centigrade. They are seldom used in tubes operating at plate voltages in excess of 600 volts, because the oxide coating is easily damaged when struck by the positively-charged ions of gas which are present in vacuum tubes.

6. Indirectly Heated Cathodes.—One type of cathode widely used is heated by indirect means. Indirectly heated cathodes are usually cylindrical in shape as shown in Figure 1A. The top of the cylinder is closed. Inside the cylinder, close to its walls but insulated from it, is a heater eement called the filament. The cathode is heated by passing a current through the filament which heats up and in turn heats the cathode.

This construction has the disadvantage of requiring a comparatively heavy current to heat the cathode to proper operating temperature. Heating the cathode indirectly in this manner also has several advantages. Alternating current may be used to heat the filament without introducing a 60 cycle variation in the electron flow from the cathode which might be superimposed on the signal. In addition, a number of filaments can be connected in series to operate from the same source of power. This latter often makes possible more economical construction of equipment.

7. **Directly Heated Cathodes.**—This type of cathode, also referred to as a filament-cathode, is heated by passing a current directly through the electron emitting element. Direct current is usually required because alternating current introduces a 60-cycle variation in the cathode emission. Since the heating current is passed directly through the cathode, less power is required for a filament cathode than for an indirectly heated cathode. An example of filament type cathode construction is shown in Figure 1B.

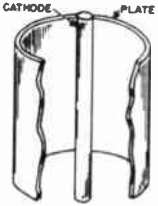


Fig. 2.—Diode construction.

8. **Diode.**—The diode, shown in Figure 2, is the simplest type of vacuum tube. It contains a cathode, either directly or indirectly heated, and a second electrode called the plate. The plate is constructed so that it surrounds the cathode. External connections to the elements of the tube are made through leads which are brought out through the base of the tube.

9. **Plate Current in a Diode.**—When the cathode of a diode is heated to operating temperature, electrons leave the surface of the cathode, as shown in Figure 3A. Since the plate of the diode is positive with respect to the cathode, the plate attracts the electrons emitted by the cathode and a current flows in the external circuit. The number of electrons attracted to the plate is determined by the value of positive voltage applied to the plate. Assume that the plate is connected to point A on the battery. Note that the plate is now negative with respect to the cathode. The negative voltage on the plate will repel electrons and no plate current will flow through the

tube. This is represented graphically in Figure 3B. When the plate tap on the battery is advanced to point B, the plate and cathode are at the same potential. The plate neither attracts nor repels electrons; however, due to the velocity with which the electrons leave the cathode, a few electrons will hit the plate and cause a very slight plate current flow. This is known as the Edison effect.

Advancing the tap on the battery to point C makes the plate positive with respect to the cathode causing plate current to flow. If the plate is advanced to point D the plate is made more positive and the current through the tube is further increased. Current flows through the tube only when the plate is positive with respect to the cathode. Thus the circuit is complete through the tube when the plate is positive but is open when the plate is negative.

10. Space Charge.—When the cathode of a diode is heated and no plate potential is applied, the electrons emitted by the cathode gather around it in a cloud. The number of electrons in the cloud is always the same for a given cathode temperature. The limit on the number of electrons surrounding the cathode is imposed by the negative charge of the electrons in the cloud. This charge is referred to as the "space charge". Since the electrons being emitted are negatively charged, the negative space charge repels them, forcing them to fall back to the cathode. When plate voltage is applied, electrons in the cloud are drawn to the plate. These electrons are then replaced by new electrons, emitted from the cathode because of the reduction in the space charge which results when electrons are drawn to the plate.

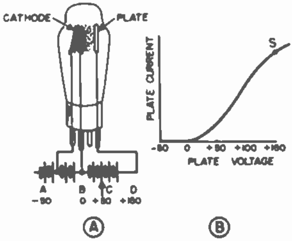


Fig. 3.—Plate current flow in a diode.

The space charge thus acts in a manner opposite to that of the plate potential; it tends to prevent electrons from being emitted, while the plate tends to permit more electrons to be emited. Thus the space charge impedes the flow of plate current and determines the amount of plate current flow through a tube for a given plate voltage. This is true only when the number of electrons emitted is in excess of the plate current.

When all of the electrons emitted are drawn to the plate, the plate current is limited by the saturation effect.

11. **Saturation.**—As electrons are drawn from the cloud surrounding the cathode, the repelling force of the space charge is reduced permitting the cathode to emit more electrons. If the plate voltage is slowly increased, electrons will be drawn to the plate more and more rapidly. Since the maximum number of electrons which the cathode will emit remains the same with constant cathode current, a value of plate potential will be reached at which all of the electrons emitted by the cathode will be drawn to the plate. Increasing the plate potential beyond this value will not produce a corresponding increase in plate current. The value of plate current at which this occurs is referred to as the saturation current and the place on the plate-voltage, plate-current curve corresponding to it is called the saturation point. It is represented by point S in Figure 3B.

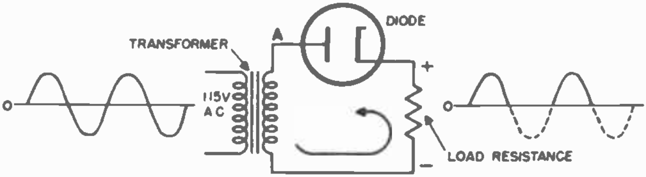


Fig. 4.—Diode used in rectifier circuit.

12. **Rectification.**—As previously explained, electrons will flow from the cathode of a diode to its positively charged plate, but they will not flow from the plate to the cathode. This property of the diode is used to rectify alternating current. Figure 4 is a simple schematic of a diode used in a rectifying circuit. The cathode shown is of the indirectly heated type; the actual heater-element is not shown for purposes of simplicity. Each time point A of the transformer swings positive, the plate attracts electrons emitted by the cathode. The path of these electrons through the external circuit is shown by the arrow. This electron flow through the resistor causes a voltage to be developed across it. When point A becomes negative, during the next alternation of the input voltage, the plate is negative and no current flows in the external circuit. The shape of the output voltage wave is as shown in the illustration; the dotted line is the negative half cycle of the input which is eliminated in the output. Although the output voltage is still varying, it is always positive and therefore is a d-c voltage.

Rectification is the major use to which diode tubes are put, both in power supply and signal circuits.

13. **Triode.**—As its name implies, a triode vacuum tube contains three elements. Two of these, the plate and the cathode, are the same as the corresponding elements of a

diode. The third element is known as the control grid and is placed between the plate and the cathode as shown in Figure 5. The control grid is constructed of wire wound around supports with fairly large openings between turns. The material from which the grid is constructed must be one that does not readily emit electrons. The most common of the materials employed is mangenese nickel. The grid structure extends the full length of the cathode and all of the electrons which flow from the cathode to the plate must pass through it.

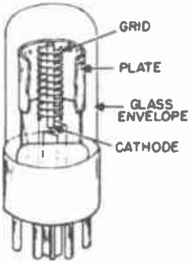


Fig. 5.—Triode construction.

14. **Grid Action.**—The purpose of the grid is to control the flow of electrons from the cathode to the plate. The grid is normally operated at a negative potential. Figure 6 illustrates how the various potentials are applied to a triode. The cathode is negative with respect to the plate and the grid is negative with respect to both the plate and the cathode. Since the plate is positive, it attracts electrons from the cathode, just as it does in a diode. The electrons must pass through the openings in the grid in order to reach the plate, and thus they are acted upon by the negative charge on the grid. This charge repels the electrons, acting in a manner opposite to that of the positive charge on the plate. As a result, the plate current flow is less than it would be if the grid were not present. If the grid is made sufficiently negative, its repelling force will be greater than the attraction of the plate and

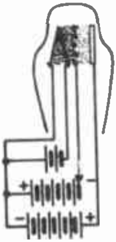


Fig. 6.—How potentials are applied to a triode.

no current will flow throuh the tube. Electrons do not enter the grid itself as long as it is negative.

If the grid is made positive with respect to the cathode, it will attract electrons from the cathode. Most of the electrons attracted by the grid will pass through the grid to the plate because of the greater attraction of the plate. Thus the plate current will be greater with a positive grid than it would if the grid were not present. When the grid is positive some of the electrons passing from the cathode to the plate will be drawn to the grid, causing current to flow in the grid circuit.

The great importance of the grid lies in the fact that a given change in grid voltage will produce a greater change in plate current than will an equivalent change in plate voltage. Another way of stating this is to say that a small change in grid voltage will produce the same change in plate current as will a much larger change in plate voltage. The grid has this ability because it is located closer to the cathode than the plate. Consequently, if equal potentials are applied to the plate and grid, the field of force of the grid will have more effect on the electrons near the cathode, because the effectiveness of a field increases with decreasing distance.

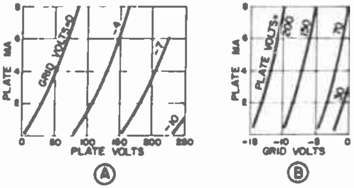


Fig. 7.—Effects of grid and plate voltage changes on the plate current of triode.

It is this characteristic of the triode which makes amplification possible. A small voltage change applied to the grid is amplified into a large voltage change in the plate circuit.

15. **Triode Characteristics.**—The effects of changes in grid voltage and plate voltage on the plate current of a vacuum tube can be depicted graphically as shown in Figure 7. This type of curve is commonly used to show the characteristics of individual tube types.

Figure 7A illustrates the manner in which the plate current changes when the plate voltage is varied. Four curves are shown, each for a different fixed value of grid voltage. Each curve illustrates the change in plate current which occurs as the plate voltage is varied and while the grid voltage remains fixed at the value indicated on the curve. These curves are known as plate characteristic curves, and the group is referred to as a family of curves. As an example of how the curves are used, refer to the curve marked —4. The —4 indicates that the curve is the plate characteristic when the grid voltage is fixed at —4 volts. The curve tells us that a plate voltage of 100 volts will give a plate current of approximately 2 milliamperes, and that if the plate voltage is increased to 150 volts, the plate current will rise to 6 milliamperes. The curve thus makes it possible to predict the plate current of the tube at any value of plate voltage in the usable range.

Figure 7B shows the transfer characteristic family of curves of a vacuum tube. These curves convey much the same information as the plate characteristic curves. They illustrate the manner in which the plate current of the tube changes when the grid voltage is varied. This time the plate voltage remains fixed. Four curves are shown; one for each of four different values of plate voltage. The plate and transfer characteristic curves illustrate the static characteristics of the vacuum tube and are useful in circuit design.

16. Amplification Factor.—As previously mentioned, it is possible to amplify a voltage using a triode connected in a suitable circuit. The relative ability of a tube to amplify a voltage applied to its grid is expressed by its amplification factor. The amplification factor relates the effects of grid voltage and plate voltage on the plate current. The ratio of the change in plate voltage required to produce a given change in plate current, to the change in grid voltage required to produce the same change in plate current is the amplification factor of the tube.

If a 20 volt change in the plate voltage of a tube is required to produce the same change in plate current that is produced by a 1 volt change in grid voltage, the amplification factor of the tube is 20.

17. Plate Resistance.—It is apparent from the previous discussion that a vacuum tube offers resistance to the flow of current through it. The resistance of a vacuum tube is not the same as that of a conductor, and consequently it does not follow Ohm's Law. In vacuum tubes, we are interested in the effects of plate voltage changes on the plate current; consequently the term plate resistance is used to express the relationship between plate voltage change and plate current change in a tube.

The dynamic plate resistance of a vacuum tube is expressed by the formula:

$$Rp = \frac{dEp}{dIp}$$

Where: Rp = *dynamic plate resistance in ohms*
dEp = *small change in plate voltage*
dIp = *change in plate current produced by dEp*

The plate resistance of a tube is not always the same. Generally it will change as the voltages applied to the tube are changed.

18. Transconductance.—This term expresses the effect of grid voltage upon the plate current of a tube. The grid-plate transconductance of a tube is equal to a change in plate current divided by the change in grid voltage necessary to produce the plate current change. Grid-plate transconductance is often called mutual conductance. It may be expressed by the formula:

$$g_m = \frac{dI_p}{dE_g} \quad (\textit{with plate voltage constant})$$

Where: g_m = *transconductance in mhos*
dI_p = *small change in plate voltage*
dE_g = *the change in grid voltage necessary to produce* dI_p

19. Amplification.—It is possible to transform a small voltage change to a larger voltage change using a triode in a suitable circuit. The voltage change to be amplified is applied to the grid of the tube. By converting the change in plate current produced by the grid voltage change, to a change in voltage at the plate, an amplification of the original voltage change at the grid is realized. Current flowing through a resistor will produce a voltage drop across the resistor in accordance with Ohm's Law. Varying the current through the resistor will vary the voltage across it. If, then, a resistor is connected in series with the plate circuit of a tube as shown in Figure 8, the plate current change produced by the grid voltage change will be converted into a voltage change at the plate.

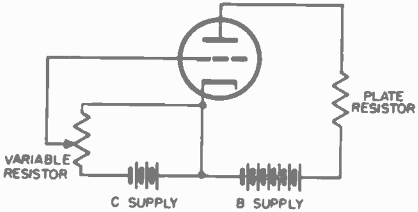


Fig. 8.—Amplifying circuit using triode.

The curves of Figure 9A illustrate graphically how amplification takes place in the circuit of Figure 9B. The grid voltage is —3 volts. The plate voltage is 300 volts and a 20,000 ohm resistor is connected in series with the plate circuit. A source of varying voltage is connected in series with the grid circuit. The plate current curve in Figure 9A indicates that at a grid voltage of —3 volts, a plate current of 5 milliamperes will flow. This condition exists when the varying voltage connected in series with the grid circuit is zero. A current flow of 5 milliamperes through the resistor causes a voltage drop of 100 volts across it with the polarity indicated. Subtracting this voltage drop from the plate supply potential leaves a voltage of 200 volts present at the plate.

If the signal voltage in series with the grid circuit varies up and down causing the voltage at the grid to swing 1 volt more and then one volt less than —3 volts, that is from —2 volts to —4 volts or a total change of 2 volts, the plate current will vary from 2.5 milliamperes to 7.5 milliamperes, a variation of 5 milliamperes.

The voltage drop across the resistor with the lowest value of current, 2.5 ma., will be 50 volts. Subtracting this from the supply voltage of 300 volts, the plate voltage is found to be 250 volts. When the grid reaches its maximum potential in the positive direction (—2 volts), a plate current of 7.5 milliamperes flows causing a voltage drop of 150 volts across the resistor. This reduces the plate voltage to 150 volts; thus, a grid voltage change of 2 volts has caused a plate voltage change of 100 volts, from 150 to 250 volts. This represents an amplification of 50. The presence of the resistor in the plate circuit, called the plate load resistor, made it possible to convert the plate current variation to a plate voltage variation. It should be noted that the plate voltage variation is an a-c voltage superimposed on a d-c voltage. Another important fact to be remembered is that when the grid voltage reached its maximum negative point, the plate voltage reached its maximum positive point. The signal voltage across the plate load resistor is therefore inverted in phase in respect to the original grid signal.

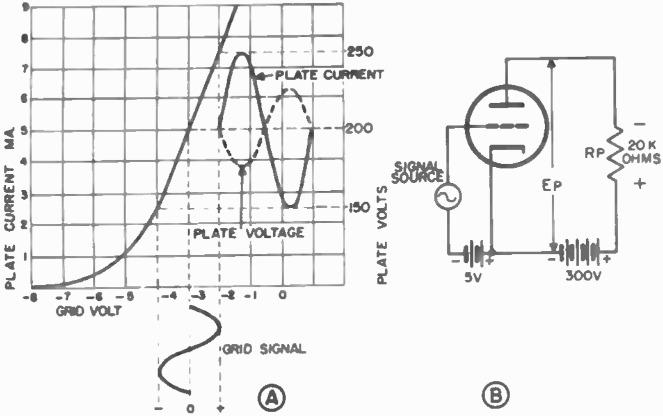


Fig. 9.—Curves showing how amplification takes place.

20. Power Vs. Voltage Amplification.—In voltage amplifiers, the voltage amplification secured is of primary importance. For this reason, they are designed to give the maximum output voltage for a given input voltage. To accomplish this, tubes having large amplification factors are used in combination with large values of plate load resistance.

Power amplifiers are designed for the purpose of delivering power to a load. An example of a power amplifier is the output stage of a receiver which delivers power to the loudspeaker. Since voltage amplification is not important in power amplifiers, tubes having large amplification factors are not necessary; instead tubes having large mutual conductances are employed. The load impedance is chosen for maximum power transfer to the load. This occurs when the load impedance is equal to the plate resistance of the tube. In most applications, the load impedance is made approximately twice the plate resistance to minimize the distortion which occurs in the amplifier. Power amplifiers are usually transformer coupled to the load as shown in Figure 10. In such a circuit, the loudspeaker usually has an impedance of a few ohms while the optimum load impedance for the tube is several thousand ohms. The transformer makes it possible to satisfy the conditions of the amplifier circuit with respect to output impedance, at the same time making it possible to transfer maximum power to the loudspeaker.

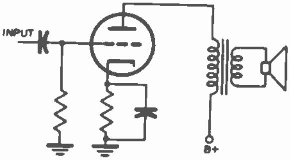


Fig. 10.—Transformer coupled power amplifier.

21. Plate Efficiency.—In a power amplifier, the a-c power delivered to the load originally came from the d-c plate supply. The d-c power from the plate supply is transformed to a-c by the amplifier. Not all of the power consumed by an amplifier is transformed to useful output; thus, the plate efficiency of an amplifier is always less than 100%. The plate efficiency of a power amplifier is equal to the power output in watts divided by the product of the average d-c plate current and the average d-c plate voltage. It is expressed by the formula:

$$\textit{plate efficiency}\ (\%) = \frac{Po}{Ep \times Ip} \times 100$$

22. Power Sensitivity.—Two terms are commonly used when referring to the amplifying ability of power amplifiers. The term **power amplification** is used to refer to the amplification of a power amplifier when the grid circuit of the amplifier absorbs power. **Power amplification** is the ratio of the power output to the power consumed in the grid circuit.

When a power amplifier is operated so that its grid is always negative, its grid circuit does not absorb power. When referring to the amplifying ability of such an amplifier, the term **power sensitivity** is used. **Power sensitivity** is the ratio be tween the power output of an amplifier and the square of the a-c grid voltage required to produce it. It is expressed by the formula:

$$\text{Power sensitivity} = \frac{Po}{Eg^2}$$

Where: Po = *power output in watts*
Eg^2 = *rms input signal volts*

23. Interelectrode Capacitance.—Two conductors separated by a non-conductor form a capacitor. An examination of a vacuum tube will show that this condition is satisfied by the plate and the grid, by the grid and the cathode, and by the cathode and the plate. While the capacitors formed by these elements might seem to be too small to effect the operation of the tube, the opposite is true. In many applications, interelectrode capacitance has important effects on the operation of vacuum tube circuits. The grid-plate capacity has the greatest effect, and an additional element has been added to many vacuum tubes to minimize this capacitance.

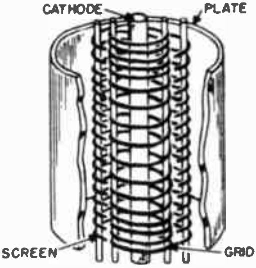


Fig. 11.—Construction of tetrode vacuum tube.

24. Tetrode.—The construction of a tetrode vacuum tube is shown in Figure 11. This type of tube is essentially the same as the triode except for the addition of a second grid called the screen grid. The screen grid is similar to the control grid in construction and is located betwen the control grid and the plate. The screen grid acts as an electrostatic shield between the grid and the plate, greatly decreasing the grid-plate capacitance. It also prevents the positive field surrounding the plate from attracting electrons from the cathode; thus no plate current can flow through the tube. To overcome this difficulty, a positive potential is applied to the screen. This positive potential attracts electrons from the cathode to the screen. By the time these electrons reach the screen, their velocity is high enough to carry most of them through the openings in the screen. Once through the screen, they may be attracted by the positive charge on the plate. Since some of the electrons do strike the screen, current flows to the screen grid.

To act as an effective shield, the screen grid must be connected to the cathode. Since a positive charge must be placed on the screen to permit the tube to operate, it is not possible to connect the screen directly to the cathode. This problem is solved by providing a low impedance path, in the form of a by-pass capacitor, for the frequency at which the tube is operating.

The addition of the screen grid has another effect on the tube which is useful particularly in tubes designed for use as audio frequency power amplifiers. The screen makes possible large values of plate current flow with comparatively low plate voltage as compared to the triode. This is true because the screen accelerates the passage of the electrons from the cathode to the plate. Consequently screen grid tubes have higher power sensitivity than triodes because a triode must have a very low amplification factor in order to permit high plate current at comparatively low plate voltage.

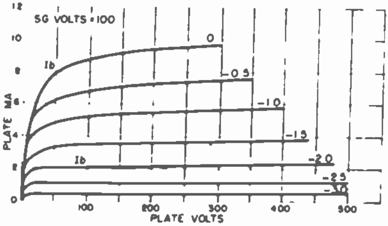


Fig. 12.—Plate characteristic curves of a pentode.

25. Secondary Emission.—When electrons, traveling from the cathode to the plate, reach the plate, they strike it with sufficient force to dislodge electrons from the plate. The dislodged electrons are thrown out into the space between the elements of the tube. In a triode, these electrons are immediately drawn back to the plate by its positive charge. In screen grid tubes this is not always the case. Some of the dislodged electrons may be attracted to the screen by its positive charge. As a result, current will flow from the plate to the screen. This effect does not occur when the plate potential is considerably above that of the screen. It begins as the plate potential is reduced and increases rapidly as the plate potential approaches that of the screen. The net result of secondary emission in a tetrode is to reduce the permissible plate voltage swing. For this reason, the tetrode has been largely superseded by the pentode.

26. Pentode.—In the pentode, a third grid has been added to overcome the effects of secondary emission. This grid is referred to as the suppressor grid. It is located between the screen grid and the plate. The suppressor grid is connected to the cathode, making it negative with respect to the plate. It therefore repels the secondary electrons forcing them to fall back to the plate. It does not effect the electrons traveling from the cathode to the plate because they have a velocity great enough to carry them through the suppressor grid structure.

Figure 12 shows the plate characteristic curves of a typical pentode. These curves indicate that the plate current of a pentode is almost independent of plate potential except at comparatively small values of plate potential. The curvature in the low plate potential region is due to the fact that the plate does not have sufficient attraction to prevent some electrons which have passed through the screen from being attracted back to the screen. Note that the curved portion of the characteristic occurs when the plate voltage is considerably less than the screen grid voltage. Th pentode is characterized by high plate resistance and amplification factor. Amplification factors in excess of 1000 and plate resistances greater than one megohm are obtainable in this type of tube.

Fig. 13.—Grid structure of a variable-mu tube.

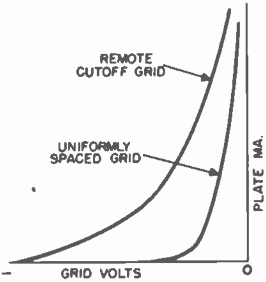


Fig. 14.—Grid voltage, plate current curve of sharp and remote cut-off tubes.

27. Variable-Mu Tubes.—It is possible, by using a nonuniform grid structure to design a tube which will possess a variable amplification factor. The grid of such a tube is constructed as illustrated in Figure 13.

Note that the grid wires are closer together near the ends of the grid than they are at the center of the grid. In an ordinary tube the grid wires are all evenly spaced.

With an evenly spaced grid structure if the grid voltage is gradually reduced, a value will be reached at which plate current will cease to flow, as shown in Figure 14. The point on the grid-voltage, plate-current curve at which this takes place is called the cut-off point, and such a tube is called a sharp cut-off tube.

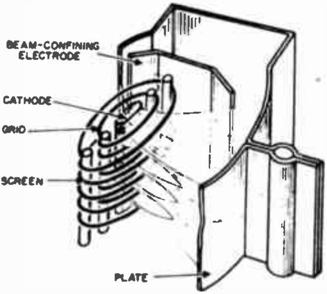


Fig. 15.—Construction of a beam power pentode.

When the nonuniform grid structure previously discussed is used, the plate current will not cease as suddenly as it does in a sharp cut-off tube; instead it will decrease gradually and in a more linear manner as the grid voltage is decreased. For this reason, such a tube is often referred to as a remote-cut-off tube. The remote-cut-off or variable mu tube operates in this manner because as the grid voltage is reduced, electron flow first ceases through the ends of the grid where the grid wires are close together. As the voltage is further decreased, more and more of the grid structure is closed to the passage of electrons; thus, the effectiveness of the grid in controlling the flow of plate current is less as the grid becomes more negative, because less of the grid structure is still effective. This results in a variation in the amplification factor of the tube.

Variable mu tubes have the advantage of being able to handle large grid signal amplitudes before plate current is cut-off or their grids are driven positive.

28. Beam Power Tubes.—The construction of a beam power tube is illustrated in Figure 15. The tube contains a cathode, control grid, screen grid, plate and two beam forming plates. The openings in the control and screen grids are aligned so that electrons may travel through them in straight paths. This type of grid construction tends to confine the flow of electrons to a number of sheet-like paths extending from the cathode through the openings in the grids to the plate. The beam forming plates are connected to the cathode and further concentrate the electron paths. As a result of this concentration of electrons in the region between the screen and the plate, a high-density space charge is created which suppresses secondary emission at the plate. The beam forming plates are so placed that they provide suppressor action in the areas not covered by the space charge.

This type of construction has the advantages of high power sensitivity, high power output, and high efficiency. Because of these advantages, the beam power tube has largely replaced other types in a-f and r-f power amplification applications.

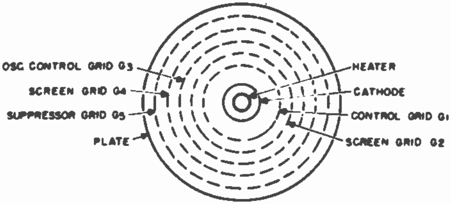


Fig. 16.—Electrode positioning in a heptode.

29. Multi-element Tubes.—Several special tube types using more than three grids have been designed. Among them are: the hexode, in which four grids are used; the heptode, in which five grids are used; the pentagrid converter, in which five grids are used; and the octode, in which six grids are used. The major use of all of these tubes is as frequency converters and mixers in superhetrodyne receivers.

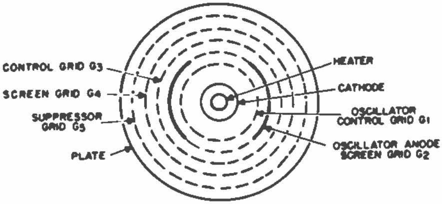


Fig. 17.—Electrode positioning in a pentagrid converter.

Figure 16 illustrates the electrode positioning of a heptode. Grids 2 and 4 are screen grids, grid 5 is the suppressor grid, grid 1 is a control grid to which the received signal is applied, and grid 3 is a second control grid to which the local oscillator voltage is fed. In the 6L7, a typical heptode, the number 1 grid gives a variable mu characteristic, while the number 3 grid has a sharp cut-off characteristic.

The pentagrid converter is essentially the same as the heptode except for the addition of collector plates to its number 2 grid as shown in Figure 17. This tube is used as a converter by connecting grids 1 and 2 in an oscillator circuit. Grid number 2 acts as the plate of the oscillator and grid 1 is the oscillator grid. The received signal is applied to grid 3. Grid 4 is a screen grid and grid 5 is a suppressor grid.

30. **Multi-Unit Tubes.**—For purposes of economy and to save space, a large number of multi-unit tubes have been designed. Such tubes are capable of performing the functions of two and sometimes three separate tubes. Among the types that are frequently encountered are dual diodes dual triodes, triode pentodes, twin-diode pentodes, diode-triode pentodes, etc.

Section 3

RESISTORS

1. Resistors are circuit elements used to reduce or limit the current flowing in a circuit, or to produce a required voltage drop. Resistors may be classified as fixed, adjustable and variable. They are rated according to their resistance and their ability to dissipate power. Values used in radio circuits range from a fraction of an ohm to ten or more megohms, and from less than one watt to over a hundred watts.

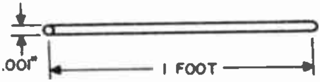


Fig. 1.—One mil foot.

2. **Specific Resistance.**—The specific resistance of a material is the resistance of a conductor, made of the material, one foot long with a cross-sectional area of one circular mil, as shown in Fig. 1. The resistance of a copper conductor one foot long with a cross section of one circular mil is 10.55 ohms at 0 degrees centigrade, and therefore the specific resistance of copper is 10.55 at 0 degrees centigrade. Table 1 shows the specific resistances of common materials. The resistance of a conductor can be found, when the specific resistance of the material of which it is composed is known, from the formula:

$$R = p\frac{l}{A}$$

Where p is the specific resistance of the material, l is the length in feet and A is the cross-sectional area in circular mils.

3. **Temperature Coefficient of Resistance.**—The resistance of a conductor changes with changes in temperature. The amount of change which takes place depends among other things upon the material used in the conductor. The resistances of some materials change more than others with varia-

tions in temperature. The term used to indicate this characteristic of materials is "temperature coefficient of resistance". It is usually expressed as the change in resistance in ohms per degree centigrade, of a conductor, of given material, one foot long having a cross-sectional area of one circular mil, Table 1 gives the temperature coefficients of common materials. Resistors are made of materials having low temperature coefficients in order to minimize changes in resistance with changes in temperature.

MATERIAL	SPECIFIC RESISTANCE AT 0 DEG. *	TEMPERATURE CCEFFICIENT IN OHMS/DEG. *
SILVER	9.75	0.004
CCPPER	10.55	0.004
ALUMINUM	17.3	0.0039
IRCN	61.1	0.0062
LEAD	114.7	0.0041
MANGANIN	290.0	0.00002
CCNSTANTIN	294.0	0.00002
NICHROME	650.0	0.00017

*CENTIGRADE

4. **Resistance Wire.**—Table 1 shows that copper has one of the lowest specific resistances. It is for this reason that copper is widely used in conductors when a minimum of resistance is desired. Other materials, having comparatively high specific resistances, are used when it is desired to introduce resistance into a circuit. Those materials most suitable for use in resistors combine comparatively high specific resistance with low temperature coefficient and high working temperature. The materials used in resistors are in most cases alloys of metals, formulated to obtain characteristics nearer to those of an ideal material. Nichrome has one of the highest permissible operating temperatures and is used in resistors with high power ratings. Manganin and constantan are used in precision resistors because these materials have temperature coefficients which approach zero.

5. **Skin Effect.**—When direct current is passed through a conductor, the flow of current is uniformly distributed throughout the cross section of the conductor. Such is not the case when an alternating current is passed through a conductor. The alternating current tends to concentrate near the surface of the conductor, greatest current flow being at the surface with a gradual decreasing in current flow as the center of the conductor is approached. This phenomena is referred to as skin effect. It is due to the magnetic field set up in and around a conductor when a current passes through it. The effect on a conductor or resistor is to increase its effective resistance.

Skin effect increases with frequency and resistance. It is negligible at frequencies below 100 kc. Above this frequency it may be minimized by proper design.

6. Wire-Wound Resistors.—A wire-wound resistor consists of resistance wire wound on a suitable form. The material used in the form or core of the resistor depends upon the rating and purpose for which the resistor is intended. Among the materials used are mica, bakelite, ceramics and glass fiber. The exteriors of most wire-wound resistors are coated or covered to protect the windings.

Several types of wire-wound resistors are shown in Fig. 2. The type shown at A is usually wound on a mica, fiber or ceramic coated metal strip. Low power types are wound on mica, bakelite or fiber strips and the windings are left uncovered. Medium-power types are wound on bakelite or fiber strips. The windings are covered with bakelite which is in turn covered with metal. Another type of construction, which is suitable for high power types, consists of a ceramic or asbestos covered strip used as a winding form. The winding of this type is usually protected by a ceramic coating or asbestos and metal covering. Low power flat strip resistors are often provided with taps used to provide filament centertaps, etc. High power types are used as power supply bleeders, filament dropping resistors in receivers, and with taps as voltage dividers.

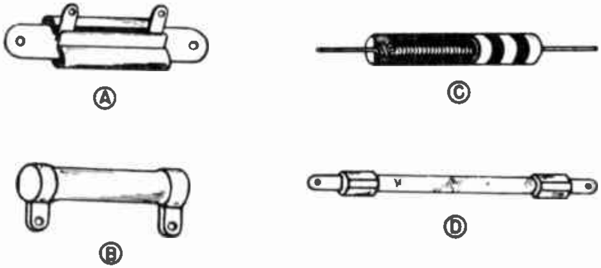


Fig. 2.—Wire-wound resistors.

The type shown at B is made with ratings of from a few watts to several hundred watts. The resistance wire in this type is usually wound on a tubular ceramic form. After winding, the resistor is coated with a vitreous-enamel or cement coating. Resistors of this type are made with and without tape. In addition, a strip along the body of the resistor is often left uncoated to permit contact between the winding and the adjustable sliding contact. This type of resistor is used for the same purposes as the strip type.

C shows a bakelite moulded wire-wound resistor. This type is made in ratings of from ½ to 2 watts. The winding is on a glass fiber core which is moulded in bakelite. Wire leads are provided as an integral part of the resistor.

The resistor shown at D is a flexible type. It consists of a glass fiber core and resistance winding with a braided glass fiber or textile covering. Flexible resistors are made in power ratings up to 5 watts.

7. Composition Resistors.—Composition resistors are those in which the resistance material consists of conducting particles mixed with a filler and a binder. Variation in resistance is obtained by varying the proportions of the conducting and filling materials. Composition resistors are made in wattages of from a fraction of a watt to several watts.

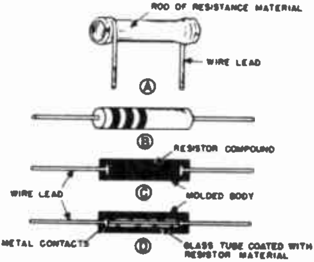


Fig. 3.—Carbon resistors.

Fig. 3A shows an uninsulated composition type resistor referred to as a "carbon resistor". The resistance material is pressed or molded into a rod which forms the body of the resistor. Wire leads are wrapped around and soldered to the ends of the rod to provide connections. Since no insulation is provided, care must be taken when this type of resistor is used to void contact with other parts of the circuit or chassis.

Fig. 3B shows an insulated carbon resistor. The resistance material is enclosed in a molded bakelite case. A cross section of the construction of this type is shown at C.

Fig. 3D is a cross section of a metalized composition resistor. In this type, the resistance material consists of a metalized film on a piece of small diameter glass tubing. The resistance element is enclosed in a molded bakelite case and provided with wire leads.

8. Radio-Frequency Characteristics of Resistors.—All resistors exhibit some inductance and capacitance in addition to their resistance. The equivalent circuit of a resistor thus takes the form shown in Fig. 4. Inductance is present when current flows through a resistor just as it is when current flows through any conductor. Capacity is present between the terminals and leads as well as between parts of the resistance material.

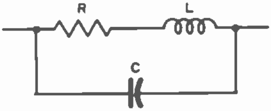


Fig. 4.—Equivalent circuit of a resistor.

As a result of the inductance and capacitance present in a resistor, its effective resistance at high frequencies is not the same as its direct current resistance. The change which takes place depends partially upon the design and upon the materials used, resulting in an increase in resistance, with frequency, for types of resistors in which inductance predominates and a decrease in resistance for types of resistors in which capacitance predominates.

In wire-wound types inductance predominates, and as a result, the effective resistance of these units increases with increasing frequency. In addition to the increase due to inductance, a further increase results from skin effect. To minimize inductance effects in wire-wound resistors, the resistance wire used should have a high ohmic value per foot to make the length of wire required as short as possible. Inductance is also decreased by winding the resistor so that adjacent turns carry current in opposite directions. This practice tends to cancel the magnetic fields around adjacent turns. Several winding methods which result in decreased inductance are shown in Fig. 5.

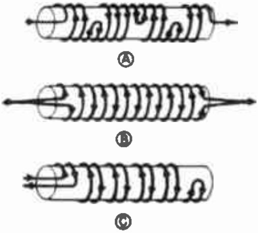


Fig. 5.—Non-inductive wire-wound resistors.

In carbon resistors resistance decreases with frequency. This decrease is brought about by the capacitance between conducting particles in the resistance material. The filler and binder in the resistance material act as dielectric materials increasing the capacitance to further decrease the resistance. These effects are greater for high resistance units than for low resistance units, being negligible for those of less than 100,000 ohms. Skin effect is also present in carbon resistors but the increase in resistance it tends to create is far less than the decrease due to capacitance effects.

Metalized film resistors also decrease in resistance with increasing frequency, although the change is a good deal less than that which takes place in an equivalent carbon resistor. This improvement is due to the fact that the thin film of resistance material used has a much higher specific resistance than the resistance material in carbon resistors. In addition less filler material is present to act as a dielectric and the potential difference between conducting particles is lower. Skin effect is less in metalized film resistors because the conductor is in the form of a thin hollow tube. In this type of conductor, the current distribution can vary but little with changing frequency.

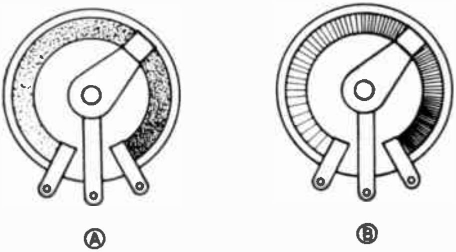


Fig. 6.—Composition and wire-wound variable resistors.

9. Noise.—When current passes through a composition resistor, the voltage drop across the resistor is not absolutely constant. Very small changes in potential occur. These variations are due to changes in contact between the conducting particles in the resistance material. These tiny voltage variations across a resistor are referred to as "noise". The amplitude of the noise generated in a resistor varies with the size and composition of the resistor. Because of this noise composition resistors are not always suitable for use in the first stages of high gain amplifiers and other equipment.

10. Variable Resistors.—Both wire-wound and composition variable resistors are manufactured. A wire-wound variable resistor consists of a flat strip over which the resistance wire is wound. The strip is formed into an arc around the pivot point of a rotating slider arm which rides on the edge of the resistance element as shown in Fig. 6B. Higher power types are wound on preformed ceramic cores. In applications where a taper is required, that is a variation in the resistance change per degree of rotation over different portions of the resistor, the winding space between turns or the depth of the form is varied.

Composition type variable resistors are made in low wattages. They consist of circular bakelite or fiber forms coated with resistance material as shown in Fig. 6A. A rotating arm moves a sliding contact, usually consisting of a number of fine wires, along the surface of the coated form. Composition variables are more economical than wire-wound types and are available in much higher resistances and greater variety of tapers. The composition variable is not adaptable to the higher power dissipations and is generally not as durable or as free from noise as is the wire-wound type.

Section 4

CAPACITORS

1. A capacitor is a circuit element consisting of two conducting surfaces separated by an insulator. The functions of a capacitor are, to store electrical energy and to permit the flow of alternating current while blocking the flow of direct current. Capacitors are usually rated in terms of their electrical capacity, in microfarads or micromicor farads, and the maximum potential difference which can be placed across them without damage and/or their maximum recommended working voltage consistent with long life.

2. **Dielectric Materials.**—The insulating material placed between the plates of a capacitor is called the dielectric. The dielectric of a capacitor may be a vacuum, a gas, a liquid or a solid. Air is the only gas in wide use as a capacitor dielectric.

MATERIAL	DIELECTRIC CONSTANT	POWER FACTOR IN % AT 1 MC.
BAKELITE (PAPER BASE)	5.5	3.5
BAKELITE (MICA FILLED)	5-6	0.7
CELLULOSE ACETATE	6-8	3-6
FIBER	4-7.5	5
GLASS (CROWN)	6.2	
GLASS (FLINT)	7	0.4
GLASS (PYREX)	4.5	0.2
LUCITE	2.5-3	
MICA (CLEAR INDIA)	6.5-7.5	0.02
MYCALEX	6-8	0.3
POLYSTYRENE	2.4-2.9	0.03
PORCELAIN	6.5-7	0.6
STEATITE	6.1	0.3

TABLE 1

Among the liquids that are used are linseed oil, castor oil and a number of special oil compounds. Ceramics, plastics, mica and paper are among the solid dielectric materials used.

When a gas or a liquid is used as the dielectric of a capacitor, some solid materials must be used to support the plates. A small portion of the dielectric of a gas or liquid dielectric capacitor is therefore solid dielectric material.

3. **Dielectric Constant.**—Dielectric constant is the ratio of the capacitance of a capacitor having a given dielectric material, to the capacitance of the same capacitor with air as a dielectric. The use of a solid or liquid dielectric results in a capacitance several times that obtained with air, because the dielectric constants of solid and liquid insulators are greater than unity. Table 1 shows the dielectric constants of a number of common insulating materials.

Fig. 1.—Representaton of an imperfect capacitor as a perfect capacitor with series resistance.

4. **Capacitor Losses.**—When a capacitor is discharged, it does not return all of the energy required to charge it. Some of the charging energy is lost in the capacitor. The loss occurs mainly in the dielectric although there are several other contributing factors.

The losses which occur in a capacitor may be represented as the result of a resistance connected in series with the capacitance as shown in Fig. 1. When a.c. passes through a perfect capacitor the current leads the voltage by 90 degrees. When a.c. passes through a capacitor having losses, or a perfect capacitor in series with a resistor, the current will lead the voltage somewhat less than 90 degrees. The phase angle thus gives an indication of the losses of the capacitor. It is common practice to indicate the power losses of a capacitor by giving its power factor or the cosine of the phase angle. Another method used to indicate the losses of a capacitor is to give the value of resistance which must be placed in series with an equivalent perfect capacitor to cause the same loss as that of the capacitor in question.

Power factor is also used to indicate the suitability of insulating materials for use as capacitor dielectrics. The power factor of a dielectric indicates the losses it will introduce in a capacitor in which it is used. Table 1 shows the power factors of a number of common insulating materials. The power factor of a capacitor or dielectric is not constant but changes with temperature, humidity and operating frequency. As a result, many insulating materials which are suitable for use at low frequencies do not make good dielectrics at high frequencies.

5. **Air-Dielectric Capacitors.**—Air-dielectric capacitors consist of two assemblies of parallel metal plates. The two sets

of plates are intermeshed but do not touch. The spacing between them is maintained by solid insulating supports. Most air-dielectric capacitors are variable. This is accomplished by mounting one set of plates on a rotatable shaft. When the shaft is rotated, the portion of the plates which is intermeshed is decreased or increased.

Air is an almost perfect dielectric, having practically zero power factor. The losses of this type of capacitor are therefore very low. Those that are present are due to resistance in the conducting plate assemblies and to the solid insulating material used to support the assemblies.

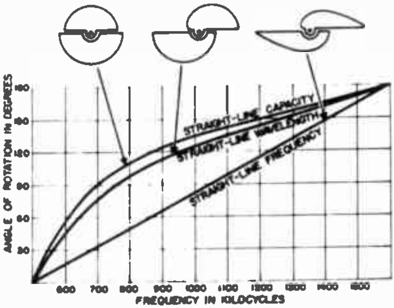


Fig. 2.—Plate shapes and frequency versus angle of rotation for variable capacitor types.

There are three types of variable capacitors: those which give a constant variation in capacitance per degree of rotation; those which produce a constant variation in frequency per degree of rotating; and those which produce a constant variation in wave-length per degree of rotation. They are referred to respectively as straight-line capacitance, straight-line frequency and straight-line wave-length capacitors. The shapes of the plates used to obtain these characteristics are shown in Fig. 2.

Variable air capacitors are manufactured in capacities of from a few micromicrofarads to several hundred micromicrofarads. They are used in the tuned circuits of receivers and transmitters to permit adjustment and variation of resonant frequency.

6. Paper Capacitors.—Paper capacitors consist of two strips of foil separated by several layers of paper as shown in Fig. 3. The foil strips and the paper insulation are wound together to form a compact capacitor. Copper or aluminum tabs are fastened to the foil strips to provide connections. A tab is usually provided for each turn of each plate to reduce the inductance and resistance of the capacitor.

The paper used in this type of capacitor must meet a number of rigid specifications. The type generally used is specially prepared pure linen paper. To improve its characteristics as a dielectric, the paper is wax or oil impregnated. Higher voltage units are often oil-impregnated and oil-filled. Paper capacitors are mounted in cardboard or metal containers. They are manufactured with pig-tail lead, lugs or with plug-in bases. They are used in power supply, a-f and low r-f circuits.

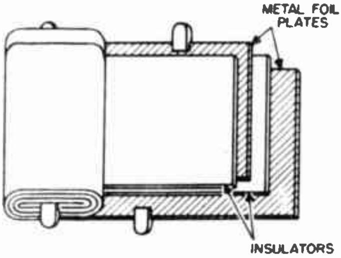


Fig. 3.—Construction of paper capacitors.

7. Mica Capacitors.—Mica capacitors consist of two sets of metal foil plates separated by thin sheets of mica as shown in Fig. 4A. Mica is widely used in radio capacitors because of its excellent dielectric properties, high breakdown voltage, and because it can be split into sheets of definite thickness. Tabs are connected to each metal foil plate to provide connection. The unit is then molded in a bakelite covering and provided with lugs or pig-tail leads. Mica capacitors are characterized by their low losses and long useful life. An improved mica capacitor, called a silvered mica capacitor, has plates which consist of silver plating on the mica dielectric. This type has a very low temperature coefficient of capacity.

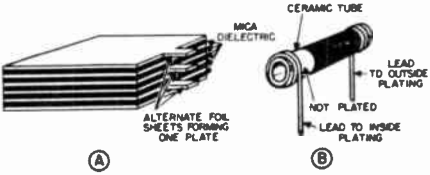


Fig. 4.—Construction of mica and ceramic capacitors.

8. Ceramic Capacitors.—This type of capacitor consists of a ceramic dielectric, usually in the form of a hollow tube, silver plated on the inside and outside as shown in Fig. 4B.

The inner plating serves as one electrode and the outer plating as the other. The sliver plating is often covered with a copper plating to which the leads are soldered.

Ceramic capacitors may be manufactured to secure definite, positive or negative temperature coefficients. It is also possible to secure zero temperature coefficient capacitors with this type of construction. Their stability and low power factor make ceramic capacitors particularly useful in high frequency circuits.

9. **Elecrolytic Capacitors.**—The construction of an electrolytic capacitor is shown in Fig. 5. It consists of two aluminum foil plates. Between the plates is an electrolyte. The surface of one plate is covered with an insulating film formed by action of the electrolyte and the plate when a positive voltage is applied to it. The film acts as the dielectric of the capacitor and the coated foil acts as one plate. The electrolyte acts as the other plate, the second piece of aluminum foil serving as a means of contact with it.

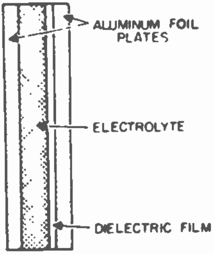


Fig. 5.—Construction of an electrolytic capacitor.

Electrolytic capacitors are polarized. That is, one plate serves as a positive electrode and the other as a negative electrode. The plate on which the film is formed is the positive plate and must never be operated at a negative potential. If it is, the film will be destroyed and the capacitor will break down. From these facts, it is evident that electrolytic capacitors can only be used in circuits in which the a-c potential is superimposed on a d-c potential of greater amplitude.

The electrolyte may be a liquid, paste or semi-dry solid material. Capacitors with liquid electrolyte are referred to as wet electrolytics. In this type, the film covered plate is suspended in a metal can and supported by a small amount of solid insulating material. The can is filled with electrolyte and serves as the container and the negative electrode.

Electrolytic capacitors in which the electrolyte is a paste are referred to as dry electrolytics. Absorbent paper or textile cloth is saturated with electrolyte and placed between aluminum plates to form a so-called dry electrolytic capacitor.

In manufacture, the film on the positive plate is formed by submersing the plate in a chemical solution and applying a positive potential to it. After the capacitor has been assembled, a positive potential is applied to the film covered plate to assure the formation of a film of uniform thickness.

The capacitance of an electrolytic capacitor is dependent upon the area of the positive plate and the thickness of the dielectric film. For a given plate area, an increase in the thickness of the film results in an increase in breakdown voltage and a decrease in capacitance. The positive plate of modern electrolytics is usually etched. Etching increases the surface area of the plate making it possible to construct capacitors with higher ratings for a given physical size.

Section 5

TRANSFORMERS AND CHOKES

1. **Inductors.**—Inductors are circuit elements used to introduce inductive reactance into circuits. An inductor is essentially a coil of wire wound around a core of air, a magnetic metal, or a nonmagnetic metal. A core of magnetic metal will give a greater inductance, for a coil of given size and number of turns, than will an air core; while the use of a nonmagnetic metal will give less inductance than that obtained with an air core.

Inductors are used in the resonant circuits of receivers and transmitters, in power supply, r-f and a-f filters, in interstage coupling circuits, etc.

2. **Q.**—If a perfect inductor is placed in a circuit and current is passed through it, a field will build up around the inductor. Power will be taken from the circuit to build up this field. If the voltage in the circuit were reduced to zero, the field around the coil would collapse and most but not all of the energy originally required to create the field would be returned to the circuit. The energy not returned to the circuit is dissipated due to losses in the inductor. The losses of an inductor are the result of several factors and may be represented as a resistance in series with a perfect inductor of the same inductance as the inductor in question. The resistance of the resistor is such that it will cause a loss equivalent to the losses of the inductor in question. The losses of an inductor may be expressed in terms of the ratio of its inductive reactance to its equivalent series resistance. This ratio is referred to as the Q of the inductor. Since the losses in a coil vary with frequency, the Q of a coil is not the same for all frequencies.

3. **Inductor Losses.**—The wire with which an inductor is wound has resistance. This resistance is the most important factor contributing to the losses of the inductor. Losses due

to resistance increase with frequency because skin effect results in a concentration of current near the surface of the wire. Skin effect is negligible at low frequencies, but at high frequencies it can be an important factor. Other factors which contribute to inductor losses are: the dielectric properties of the coil form and surrounding objects; eddy currents set up in the core and surrounding objects if they are conductors; hysteresis in the core and surrounding objects if they are magnetic metals. Losses occur as a result of the dielectric properties of the coil form because of the distributed capacitance of the inductor. Distributed capacitance is the capacitance which exsists between different parts of an inductor; that is, between turns, between the terminals and leads, etc.

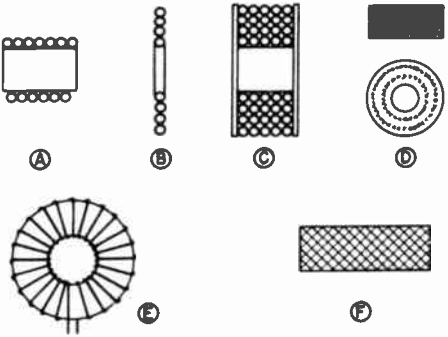


Fig. 1.—Types of coil windings.

The core and surrounding objects serve, to some extent, as the dielectric of these capacitors, and the dielectric losses which result contribute to the losses of the inductor.

4. Types of Coil Windings.—Many types of coil windings have been devised to secure desired characteristics. Several of them are shown in Fig. 1. A is a simple single layer solenoid. This type is used when small amounts of inductance are required. B is a flat or pancake coil. This type is seldom used singly, instead several coils are connected in series. C is a multi-layer coil used when a high inductance is necessary. D is a universal wound coil which is characterized by compactness and good Q. E is a toroid wound coil. This type is wound in one or more layers and is essentially a coil bent so that its ends meet. This configuration results in cancellation of the external field, a characteristic which is useful in many circuits. F is a honeycomb wound coil. This type of winding gives comparatively low distributed capacitance.

5. Receiver Coils.—Small size and high Q are the general requirements of the coils used in receiver tuned circuits. At frequencies above the broadcast band (1500 kc.), the coils used in the resonant circuits of radio receivers are single layer solenoids with air cores. Since comparatively small values of inductance are required, single layer solenoids are sufficiently compact. In addition, it is possible to secure relatively high Q ratios with this type of winding. Bakelite and ceramic forms are used in most cases, while self-supporting windings are often used in very-high and ultra-high frequency circuits.

At broadcast band frequencies, single layer solenoid, universal, spiral and other types of windings are used. At these frequencies, the single layer solenoid is large enough to make the more compact windings desirable when size is a factor. At frequencies below 500 kc. the single layer solenoid is too large and more compact types of windings are used exclusively.

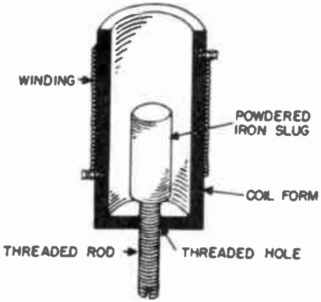


Fig. 2.—A powdered-iron-slug tuned coil.

6. Powdered Iron Cores.—While solid or laminated magnetic metal cores are not satisfactory for use at radio frequencies, powdered iron or alloy cores have proved very useful. This type of core consists of finely ground iron or alloy particles mixed with a bakelite filler and an insulating varnish binder and pressed into the form of a cylindrical slug. This construction insulates the iron particles from one another and reduces eddy current losses. Powdered iron cores are used to secure compact coils with high Q and to provide a means of varying the inductance of a coil. Variation in inductance is accomplished by mounting the iron slug so that it can

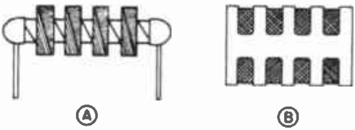


Fig. 3.—Radio-frequency choke coils.

be moved in and out of the coil along its axis. The construction of a slug tuned coil is illustrated in Fig. 2. A threaded rod is imbedded in the slug. The rod passes through a threaded hole in the closed end of the coil form. Turning the rod causes the slug to move in or out of the coil, producing a variation in the overall permeability of the core of the coil and subsequent change in inductance.

7. **Radio Frequency Chokes.**—Radio-frequency chokes are inductors used in r-f circuits to suppress the flow of r-f current while offering low resistance to the flow of a-f and direct currents. In order to secure a high inductance and minimize distributed capacity, choke coils are wound as shown in Fig. 3. The choke at A consists of several universal wound coils mounted on an insulated form and provided with pigtail leads. A second type of construction illustrated at B consists of a round, slotted form. The winding consists of a number of pies wound in the slots of the form.

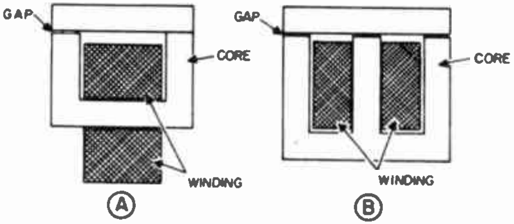


Fig. 4.—Core and shell type chokes.

Chokes for use in the v.h.f. and u.h.f. regions are usually simple space or close wound single layer solenoids. Radio-frequency chokes are manufactured in inductances of a fraction of a millihenry to more than 100 millihenries.

8. **Power-Frequency Chokes.**—Power-frequency chokes are used in rectifier type power supply filter circuits. They are manufactured in inductance values of from 5 to 30 henries. Fig. 4 illustrates the two common types of construction. A is called the core type and B is called the shell type. When the current through an iron core choke is gradually increased, a point is reached when an increase in current through the choke will not produce a corresponding increase in flux density in the core. This effect is called "saturation". When it occurs there is a rapid decrease in the permeability of the core and the inductance of the choke. This change in inductance with increasing current is undesirable in power supply chokes. The effects of core saturation are eliminated in power supply chokes by leaving a small gap in the core as shown in Fig. A. The reluctance of the gap is greater than the core, and it prevents the flux density in the core from reaching the saturation

point of the core material. With small values of current, the inductance is lower than it would be without the gap; however, throughout the current range for which the choke is designed, the inductance is almost constant and is higher than it would be without the gap.

9. Power-Supply Transformers.—This type of transformer is used to increase or decrease power line voltages in order to secure the various potentials required to operate electronic equipment. Such transformers consist of two or more windings on a laminated iron core. The cores used are of the core or shell type, although the core type is no longer very popular. Fig. 5 illustrates the construction of a shell type power transformer. The primary is generally wound nearest the core on a fiber form. The secondaries are wound over the primary. As many as four or five secondaries are often used. Enamel covered wire is generally used for winding power transformers. Wax impregnated paper serves as insulation between winding layers while Empire Cloth is used to insulate primary and secondary windings from one another.

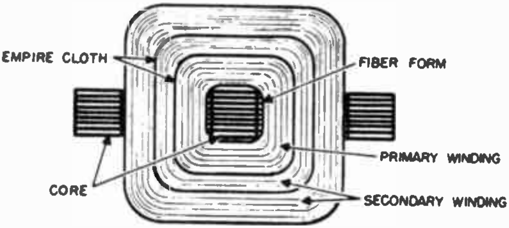


Fig. 5.—Construction of shell type transformer.

10. Audio-Frequency Transformers.—Audio-frequency transformers are similar to power transformers except that they are designed to transform impedances and must operate over a wide range of frequencies. They are used as interstage coupling devices and to match the outputs of amplifiers to transmission lines, loudspeakers, etc. A large number of primary and secondary turns and special grades of steel and alloys are used to secure the high primary and secondary impedances required.

Section 6

SWITCHES AND DRY RECTIFIERS

1. **Switches.**—Although switches are not circuit elements, they are important parts of almost all electronic equipment and must have adequate electrical and mechanical characteristics in order to perform properly. Switches are used to open and close circuits, to change circuits, and to substitute, add or remove circuit elements in all types of electronic equipment. Among the mechanical requirements of switches are resistance to corrosion and similar deterioration, proper wiping action to minimize wear on contacts and ability to withstand long use. Electrically, a switch should have low contact resistance, high insulation resistance, low dielectric loss and low capacity between contacts. Manufacturers usually state the lives of switches in terms of the minimum number of cycles of operation before signs of failure occur. These ratings range from 10,000 to more than 250,000 cycles. 10,000 to 50,000 cycles is regarded as satisfactory life for such applications as home radios and television receivers.

Mechanically, switches may be classified as lever, rotary, push-button, and slide action. Lever acting switches are usually made in two and three position types, although some are available with as many as eight positions. They are used in power and audio circuits and in many special applications. Lever action switches are manufactured in both low and high current types. The rotary switch is probably the most versatile and widely used type of switch. One type of rotary switch mounts on the back of variable resistor controls and is opened and closed when the control is at the extreme left end of its rotation. This type is very popular as a line switch in radio and television receivers where it is usually combined with the volume control.

Another type of rotary switch, referred to as a wafer switch, is especially suitable for use in r-f circuits. It consists of a flat piece of insulating material with lugs and contacts arranged around its outside edge as shown in Fig. 1. A shaft passes through a hole in the center of the wafer. Mounted on the shaft, but insulated from it, are one or more switch segments. Long contact clips make contact with the switch segments. Tabs on the segments make contact with shorter clips only when the tabs are rotated to the proper positions. The circuit path is from a long clip through the switch segment to a short clip. Wafer switches are manufactured in from two to 12 positions mounted singly or in gangs of as many as six sections operated by the same shaft.

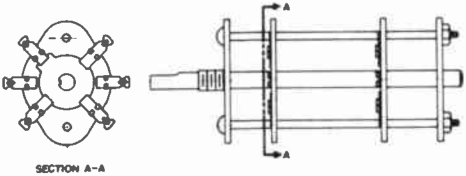


Fig. 1.—Wafer switch.

One of the most important uses of ganged wafer switches is in band-changing assemblies in all-wave receivers and in channel selecting assemblies in television receivers. They are characterized by low losses, low contact resistance, and long life. In addition, desired distances between wafers can be easily obtained and wafers may be shielded from one another without difficulty.

Ganged push-button switches are widely used as station selectors in home and automobile receivers. They are available in a wide variety of switching arrangements. They are not as suitable for use in very high frequency circuits, as are rotary wafer switches.

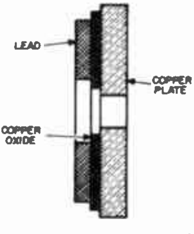


Fig. 2.—Copper-oxide rectifier.

2. **Copper-oxide Rectifiers.**—The operation of the copper-oxide rectifier is based upon the fact that if one side of a copper plate is covered with a cuprous-oxide layer, the oxide will permit current to flow from the copper to the oxide but not from the oxide to the copper. Figure 2 illustrates the construction of a copper-oxide rectifier disc. It consists of a washer-like disc of copper, one side of which is covered with

a layer of oxide. A lead disc is placed in contact with the oxide. Several of these assemblies are stacked to form a rectifier. They are mounted on an insulating rod run through the holes in their centers.

Copper-oxide rectifiers are manufactured in a wide range of sizes with disc diameters of a small fraction of an inch to several inches. They are characterized by very long life, fairly good efficiency, poor voltage regulation, and the ability to operate under high voltage-overloads for short periods without damage. Their permissible temperature rise, in operation, is low.

Copper-oxide rectifiers are found in a wide variety of applications. Among them are, in battery chargers, in bias and loudspeaker field supplies and as instrument rectifiers.

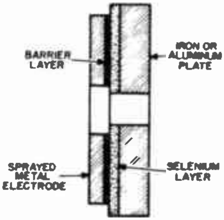


Fig. 3.—Selenium rectifier.

3. **Copper-sulphide Rectifiers.**—The copper-sulphide rectifier is similar in construction to the copper-oxide rectifier except that copper sulphide and magnesium discs are used. For given voltage and current ratings, it is smaller and lighter than the copper-oxide type. It is capable of withstanding higher operating temperatures and has better voltage regulation than the copper-oxide rectifier. Its efficiency is poorer and its life shorter than copper-oxide units. Because the discs must be assembled under comparatively high pressure, it cannot be manufactured in small sizes. These characteristics limit it to use in home battery chargers and other low cost equipment.

4. **Selenium Rectifiers.**—The construction of a selenium rectifier is illustrated in Fig. 3. It consists of an iron or aluminum plate on which a thin film of selenium has been deposited. The selenium is then heat treated to produce a crystaline structure, after which it is sprayed with metal. Finally, a chemical process forms a barrier layer between the sprayed metal electrode and the selenium. Units are used separately or in series to secure higher operating voltages.

The selenium rectifier operates satisfactorily at higher temperatures than does the copper-oxide rectifier and is smaller and lighter for comparable voltage and current ratings. Its efficiency and life are equivalent to those of copper-oxide units. The voltage rating per disc is higher than that of copper-oxide discs. Recent developments have further increased the voltage ratings of selenium discs, bringing greater flexibility and wider use of these units. Selenium rectifiers are used in plate and bias supplies for receivers and other small electronic equipment, in battery chargers, relay circuits, etc.

Section 1

BASIC CIRCUITS

All radio circuits are made up of circuit elements which are basic units. These basic circuits, are entities both in physical arrangement and function.

All work in radio requires the understanding of the basic electronic circuits. This Section has been specially prepared by the RADIO DATA BOOK staff to make available the circuits which properly combined make complete radio equipments.

The arrangement in which the basic circuits are presented has practical use as its objective. Every effort has been made to classify and discuss each circuit in the most practical manner. In doing this, the use of the circuit has been kept foremost in mind.

This Section follows the discussions on components and fundamentals because it is necessary to have an elementary knowledge of these subjects in order to be able to follow the theory of each basic circuit as presented herein.

Following the basic circuits Section we have presented the systems and accessories discussions. It is felt that familiarity with the basic circuits presented here will enable the reader to follow the systems discussion with greater understanding.

COLD CATHODE RECTIFIER

The cold cathode rectifier is suitable for power supplies in which the current drain is relatively low. It makes use of the fact that ionized gas will carry an electric current in only one direction. As shown in Fig. 1. the rectifier is connected in series with the AC power source and the load. The action is similar to that of a vacuum tube rectifier of a selenium rectifier.

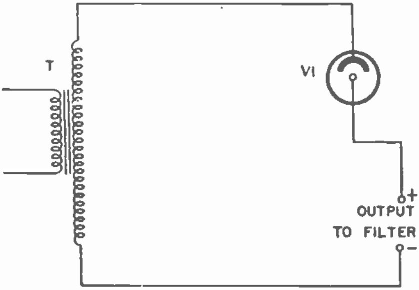


Fig. 1.

Some gas is placed in the envelope of the tube when it is manufactured. In use, the gas ionizes when sufficient voltage is applied between the plate and cathode. Electrons will only flow from cathode to plate, thus producing the necessary rectifying action. The cathode of the rectifier is heated by the bombardment of the ions in the gas and this liberates the electrons necessary for conduction through the tube.

The cold cathode rectifier tube first appeared as the old "HB" type, which was frequently used in B eliminators designed for battery-operated receivers. It is now typified by the OZ4 tube type.

A requirement of the cold cathode rectifier is that the gas in the tube must be ionized, at all times during operation. There is a minimum current below which ionization will not be sustained. The rectifier circuit must provide some means to keep the current drain above this minimum whenever external power drain is intermittent. The most convenient way to maintain the minimum current is through the use of a bleeder resistor across the output.

Applications.—Cold cathode rectifiers find their widest use in low-drain receiver power supplies. The fact that no filament supply is needed makes them ideal for mobile equipment, and portable receivers and transmitters often employ them.

Advantages.—The cold cathode rectifier circuit is simple and easy to construct and no filament supply is needed.

Limitations.—The cold cathode rectifier has a limited allowable current drain and a minimum current must be maintained so the gas in the tube will remain ionized.

Variations.—The diagram shows the half-wave connection; full wave arrangements are also used.

Tube Types Used.—HB, OZ4, OZ4G.

HALF WAVE RECTIFIER

The half wave rectifier makes use of the fact that electrons can flow from cathode to plate in a vacuum tube and not in the opposite direction. This principle is used to change alternating current or voltage to direct current or voltage. The fundamental circuit is shown in Fig. 2.. Whenever the polarity of the source voltage is such that the plate becomes positive with respect to the cathode, the tube conducts and current flows through the load resistance R. Since the current can only flow one way through the circuit, it is *pulsating DC* and produces a pulsating direct voltage across R. The ripple is filtered out of this voltage by means of filter condenser C. Fig. 3. shows the wave form of source and rectified output voltages.

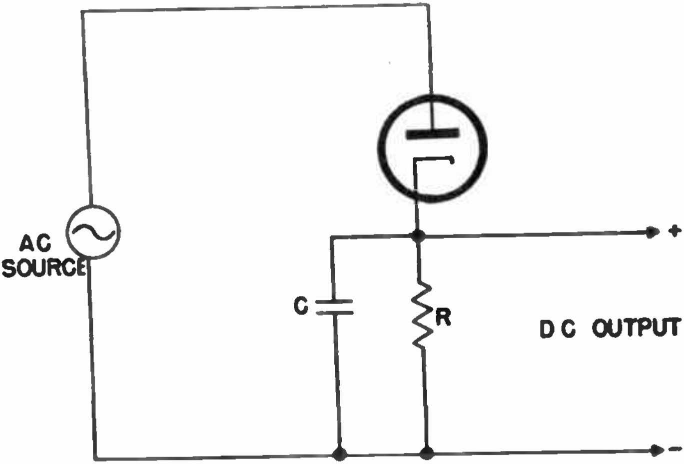


Fig. 2.

R and C are symbolic of load resistance and filter capacity respectively and in practice are replaced by one of the various types of power supply filters (see RC and LC filter basic circuits).

The name "half wave rectifier" is derived from the fact that DC output is supplied during half of the cycle of the source voltage only. The fundamental ripple frequency is therefore always the same as the frequency of the source.

Applications.—The most common application of the circuit is in the AC-DC type of broadcast receiver. Since no center tap is needed on the source voltage, the circuit permits the elimination of a power transformer. Because of this economy factor, the circuit is generally found in units of the less expensive type. The half wave rectifier is also frequently found in signal generators, frequency meters, monitors, code practice sets, signal tracers, FM converters and a wide variety of small electronic equipment.

Fig. 3.

Advantages.—Compactness and economy due to the elimination of power transformers are the principal advantages of the half wave rectifier circuit.

Limitations.—The fact that the ripple is the same as the power frequency makes filtering much more difficult than in the case of systems which have a higher ripple frequency (full wave). The ripple is a higher percentage of the DC output voltage than in other types. Another limitation is the fact that the negative DC output lead (B minus) is common to one side of the power line, making this lead "hot" with respect to pipes, radiators and other grounded objects when the source polarity is such that B minus is the ungrounded side of the power line.

Variations.—The half wave rectifier is used either with direct power line connection or from the secondary of a power transformer. The fundamental principle is also applied in the diode detector and in VTVM circuits, AC meters using vacuum tubes, etc.

Tube Types Used.—35Z5, 35Z4, 35Z3, 25Z5, 81. Dual diode tubes are also occasionally used as half wave rectifiers with their plates connected in parallel.

FULL WAVE VACUUM TUBE RECTIFIER

The full wave rectifier makes use of the fact that current will only flow in one direction through a vacuum diode tube. It is used to provide DC power for receivers and similar equipment. Two tubes are used (or a dual diode). One tube conducts on each half of the input power cycle. The circuit (Fig. 4.) is characterized by its use of a center-tapped power source, the use of two diodes, and common connection of their cathodes.

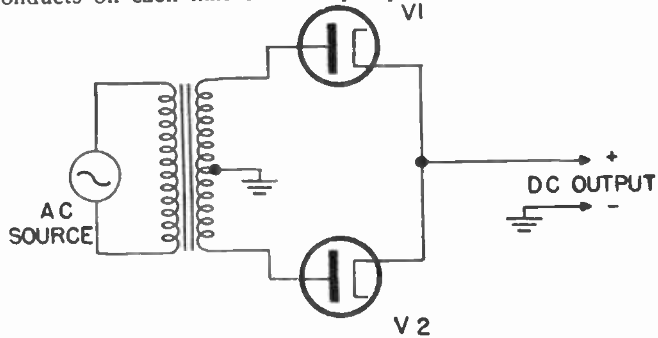


Fig. 4.

When the plate of VI becomes positive, electrons flow as shown, through V1, the upper half of the transformer secondary, the ground, the load and back to V1. When the plate of V2 becomes positive, a similar action takes place as shown by arrows. There is a pulse of DC current through the load (output circuit) during each half cycle of the source frequency.

The fact that only two diodes are used with a common cathode makes the circuit convenient for power supplies in both transmitters and receivers. The diodes are often combined in a single envelope and called a full wave rectifier tube.

Applications.—The full wave rectifier is widely used in radio receivers. Although half wave rectification is sometimes cheaper, the advantage of the full wave circuit in hum elimination and ease of filtering makes it desirable in most receivers. Radio transmitters frequently make use of this circuit in power supply units. It is encountered in almost all types of equipment which operate from AC power lines.

Advantages.—Advantages of the full wave rectifier circuit are a ripple frequency twice that of the power source, and a reasonably simple circuit. The filter requirements are much less than for a half wave rectifier due to the higher ripple frequency.

Limitations.—The full wave rectifier circuit requires the use of a center-tapped source. Its output voltage is equal to half the source voltage.

Tube Types Used.—Diode and dual diode rectifiers such as 866, 872A, 80, 6X5, 5Y3, 5Y4, etc.

BRIDGE RECTIFIER

The bridge rectifier circuit is distinguished by the fact that four separate rectifier elements are used, connected in a manner most easily shown as a diamond, or square, and arranged to conduct in the directions shown in Fig. 5.. The input is fed into two opposite corners and the output is taken from the other two corners.

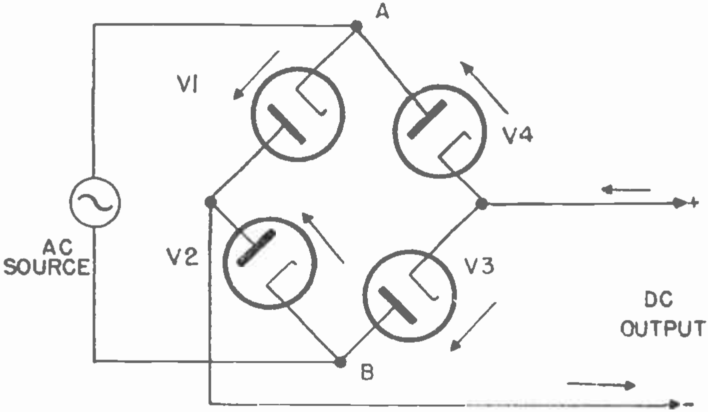


Fig. 5.

The operation of the bridge circuit allows both halves of the power cycle to be used in the rectifying process. Electrons will flow through the tubes only in the directions indicated by the arrows. When point A becomes positive, V2 and V4 conduct; and when point B becomes positive, V1 and V3 conduct. Current always flows through the output circuit in the same direction. The ripple in the output thus has twice the frequency of the power source.

The bridge type rectifier gives twice the DC voltage output of a conventional full wave rectifier and does not require a center-tapped transformer.

Applications.—Wherever it is desired to use a transformer with an untapped secondary, or to make use of the full secondary voltage, the bridge rectifier is useful. Its most frequent use is in transmitter power supplies, in which high voltages and full wave rectification are desired without the use of a double voltage secondary.

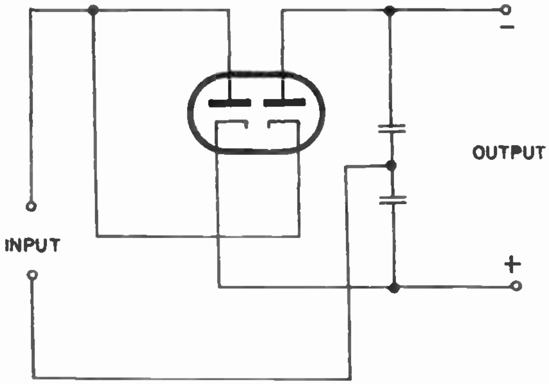
Advantages.—The main advantage of the bridge rectifier is that the full transformer (if one is used) secondary voltage can be utilized and no secondary (or power source) center tap is necessary.

Limitations.—Four rectifier tubes are needed except when dual diodes with separate cathodes and sufficient voltage ratings are available.

Tube Types Used.—Half wave rectifiers such as 866, 872A, etc.

VOLTAGE DOUBLING RECTIFIER

The voltage doubler is a rectifier whose DC output potential is approximately twice that of its AC input. A definite identifying characteristic is the fact that the diode cathodes are never joined as in other power supplies using parallel rectifiers.



Ⓐ FULL WAVE
Fig. 6A

The full-wave doubler circuit is shown in Fig. 6A. Operation is as follows:

1. When the input terminal C becomes positive, diode D1 conducts until C2 becomes charged with the polarity as shown.
2. When the input terminal D becomes positive, diode D2 conducts, charging C1 with the indicated polarity.
3. The capacity of these condensers is large enough to hold a charge between charging pulses.
4. The output voltage is obtained across C1 and C2 in series. The output voltage is, therefore, the sum of the voltages on the condensers and approximately twice the voltage of an ordinary half-wave rectifier.

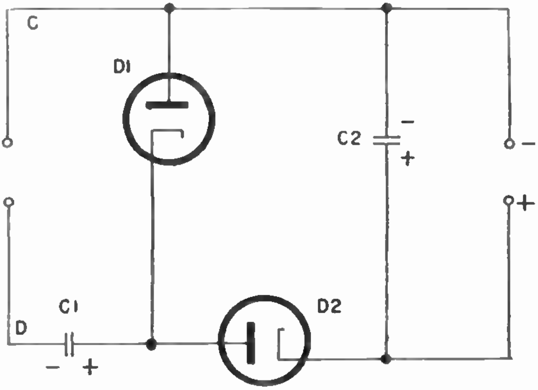
This is a full-wave doubler because two charging pulses are fed to the output for each power cycle. The ripple frequency is, therefore, twice the frequency of the power source.

The half-wave circuit is shown in Fig. 6B. Operation is as follows:

1. When input terminal C becomes positive, diode D1 conducts and charges C1 with polarity as shown. C2 does not charge at this time.
2. This places a voltage on the plate of D2 equal to the charge on C1 plus the voltage on input terminal D. When D is negative, it subtracts from the voltage on the plate of D1, stopping D2 from conducting.

3. When the plate of D2 becomes positive, it conducts and C2 becomes charged with a voltage equal to approximately twice that of C1. This is the output voltage.

This circuit is a half-wave doubler because the ripple frequency is equal to the power frequency.



B HALF WAVE

Fig. 6B

Applications.—The voltage doubler circuit is used in low priced power supplies. It is used with high filament voltage rectifiers in receivers designed to operate from both AC and DC sources. Use of high filament voltage tubes is made to permit the elimination of the filament step-down transformer used in AC sets. Although primarily used in connection with receivers, the voltage doubler circuit is often found in control equipment and in transmitters. In these uses, it is limited to applications involving a relatively low current drain and requiring simplicity and compactness.

Advantages.—The voltage doubler circuit has the advantage of simplicity approaching that of the AC-DC power supply. At the same time, it allows elimination of the power transformer necessary in AC receivers. It provides a DC voltage output approximately twice the voltage obtained from AC-DC supplies and is almost as simple and compact.

Limitations.—The voltage doubler circuit requires a dual diode rectifier tube which has a separate cathode for each section. Available current drain is limited and regulation is poor. The high capacity condensers used with the rectifier (C1 and C2) do not provide the necessary filtering. Additional condensers must be used in a filter in order to provide pure DC output.

Variations.—Half-wave and full-wave.

Tube Types Used.—Any dual diode rectifier with separate cathodes and insulation for the peak circuit voltage developed.

MULTIPLIER RECTIFIER

Fig. 7. shows a typical voltage multiplier rectifier circuit. Two voltage doubler sections are combined to produce a voltage quadrupling action. The operation of the circuit is as follows:

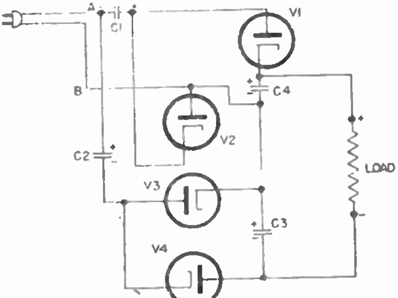


Fig. 7.

1. When the line polarity is such that point B is positive, a surge of current flows through V2 and C1, charging C1 with a DC voltage of the polarity shown. This voltage is about equal to the peak value of the AC source voltage.
2. When the plate of VI is positively charged, current is drawn through V1 and C4, charging C4 with a voltage of the indicated polarity.
3. The voltage applied to the plate of V1 is equal to the line voltage plus the DC voltage already developed across C1. On peaks it is thus equal to twice the peak value of the source voltage. The DC voltage across C4 is therefore twice the voltage across C1.
4. The same action also take place in the duplicated circuit of V3, V4, C2, and C3, producing a "doubled" voltage across C3.
5. C3 and C4 are connected in series across the load. The output voltage (DC) is therefore the sum of the voltages across these two condensers and four times the output of a simple half wave rectifier.

Applications.—Voltage multiplier rectifiers are occasionally found in low cost receivers in which the current drain is very low and the voltage must be higher than that afforded by ordinary rectifiers.

Advantages.—The main advantage of the multiplier rectifier is that higher DC output voltages can be obtained without the use of a transformer.

Limitations.—The multiplier circuit requires a large number of rectifiers and high capacity condensers for proper operation.

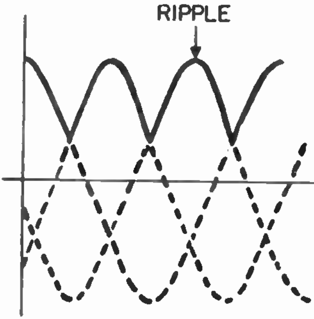
Variations.—Any multiple of the line voltage may be produced by proper arrangement of components. Multiplication as high as twelve has been found practical.

Tube Types Used.—Any power rectifier diodes or dual diodes.

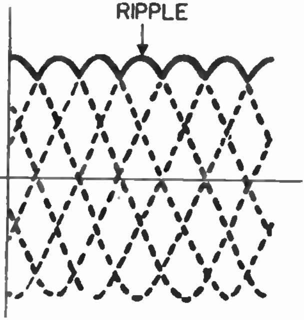
MULTI-PHASE RECTIFIER

Multi-phase rectifiers are frequently used in the power supplies of transmitters. The frequency of the ripple voltage present in the output of a multi-phase rectifier is equal to that of a corresponding single-phase rectifier multiplied by the number of phase of the source. Because of the higher ripple frequency, economy is effected in the filter section of the power supply.

Multi-phase transformers can be arranged in various way to produce the desired effects as to output voltage, current, and ripple frequency. These arrangements are very numerous. Several representative circuits are given on the following pages to illustrate the principle of operation. The diagram below shows the wave form of pulsating DC output for typical three-phase rectifiers.



3Ø HALF WAVE



3Ø FULL WAVE

Applications.—Multi-phase rectifiers are used in high voltage power supplies for transmitters. They are also used in converter power supplies for running DC motors and other equipment from the AC lines. Applications in which very well filtered DC voltage is required are the most frequent. The relatively high ripple frequency makes these rectifiers well adapted to pure DC supplies.

Advantages.—The advantage of multi-phase rectifiers is the ripple-frequency which is higher than that of single-phase rectifiers. Smaller values of filter components can thus be used to obtain equivalent filter effect. This represents a considerable economy in the construction of high power rectifiers. Load current is distributed so that only a fraction of it is carried by each tube and transformer secondary winding. Greater rectifier efficiency is obtained making the multi-phase rectifier very desirable for higher powers.

Limitations.—Multi-phase rectifiers require a power source of the proper number of phases. Special transformers are also necessary.

Variations.—Variations consist of the eight circuits shown and a number of others which are less frequently encountered.

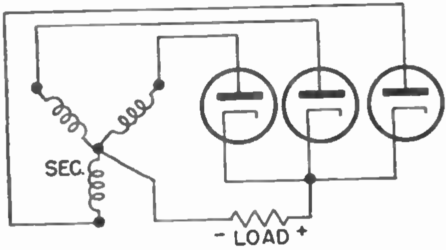


Fig. 8.

The three-phase half-wave rectifier is usually arranged in the delta-wye connection as illustrated in Fig. 8.. The secondary windings are joined at a common point which usually becomes the negative output lead. The voltages are 120 degrees out of phase with each other and each is connected to a rectifier. There are thus three DC pulses for every cycle of the power frequency.

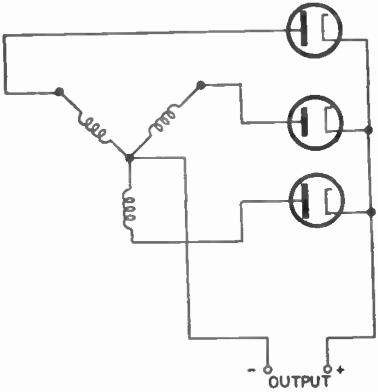


Fig. 9.

The three-phase full-wave rectifier uses a delta-wye connection as shown in Fig. 9.. The secondaries are joined to a common point on one end. Their voltages are 120 degrees apart and each one is connected to the plate of one rectifier tube and the cathode of another tube. In this way DC pulses flow on both positive and negative halves of the power cycle of each winding. The ripple frequency is thus six times that of the power source.

The double three-phase rectifier uses two wye-connected secondaries as shown in Fig. 11.. A centertapped inductor, L, which is connected between the two common points, is called a "balance coil." The legs of one wye are connected so as to contain voltages 180 degrees out of phase with those of the other wye. The ripple is thus six times the frequency of the power source since this is effectively a six phase supply.

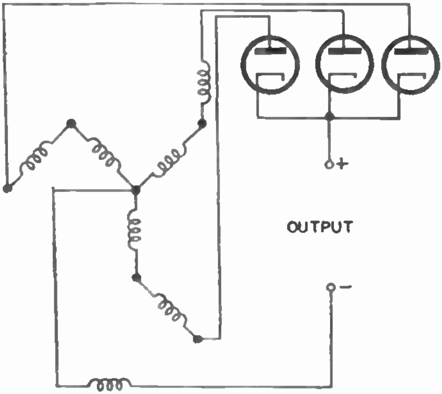


Fig. 10.

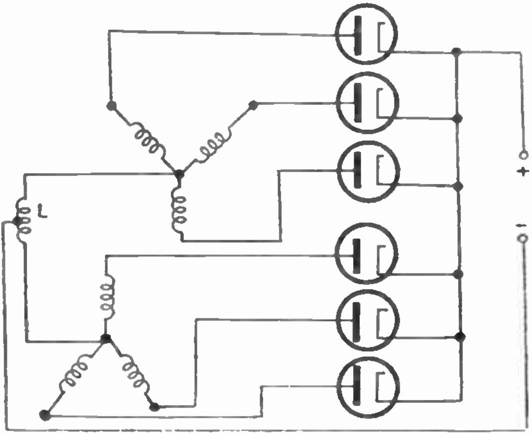


Fig. 11.

The three-phase broken star rectifier results from connecting each leg of a wye in series with another winding 60 degrees out of phase with it. (See Fig. 10..) The peak voltage of each rectifier is thus higher than for other three-phase arrangements.

Ripple voltage is three times the frequency of the power source.

The six-phase star (Fig. 12.) is arranged by connecting two out-of-phase windings of each phase in series so that they create two secondary phases for each primary phase (if a three-phase source is used). The ends of all the windings are tied together at a common point. As shown, it is usually the negative terminal of the DC output. The ripple frequency is thus six times that of the power source since the supply constitutes a six-phase arrangement.

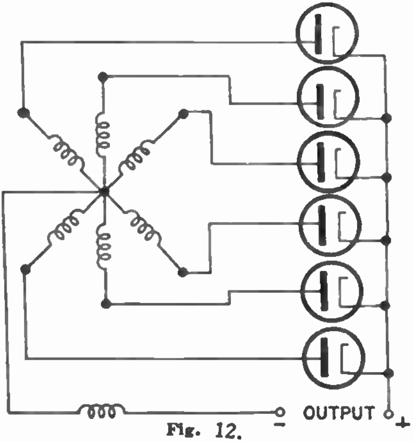


Fig. 12.

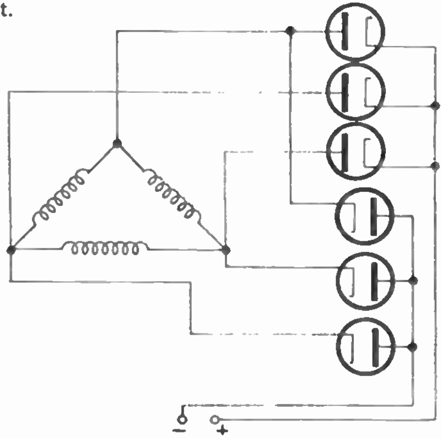


Fig. 13.

The three-phase delta full-wave arrangement is shown in Fig. 13.. Both primary and secondary transformer windings are connected in delta. Each vertex of the secondary delta is connected to the cathode of one rectifier and the plate of another rectifier. The rectification is, therefore, full wave and the ripple, accordingly, is six times the power frequency. The delta connection can also be used for half-wave rectification.

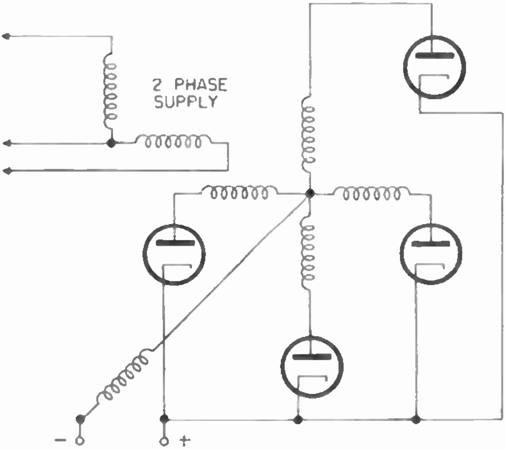


Fig. 14.

A typical rectifier using a two-phase supply is the four-phase star type shown in Fig. 14.. Two secondaries are coupled to each primary winding and phased to form the star pattern. The voltages at the points of the secondary star are spaced 90 degrees. Each point is connected to a rectifier plate, and the ripple frequency is thus four times the power frequency.

GRID CONTROLLED RECTIFIER

When negative grid voltage on a gas diode is reduced to less than cut-off value, plate current flows. From this point on, the grid loses control and will not stop plate current flow no matter how much bias is applied. This current flow is stopped, however, when the plate instantaneous voltage becomes zero or negative. On a subsequent plate voltage cycle an increased grid bias on the tube prevents conduction until a later instant in the cycle, reducing the DC output.

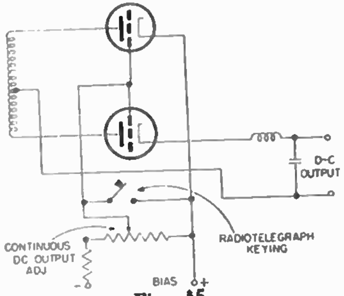


Fig. 15.

The most important use of the grid controlled rectifier is the control of the voltage output of a power supply. Fig. 15. shows a typical circuit. A bias is applied to the rectifier grids. By adjustments of this bias, the characteristics of the circuit can be set so that there is no output, or so there is only output when the instantaneous power voltage exceeds a certain value. In this way, the current or voltage output can be adjusted without inserting any device in the power leads themselves.

Applications.—Grid controlled rectifiers are used in power supplies, particularly high power units for transmitters. They are also employed in keying circuits for telegraph transmitters and in control applications. Generally, in high voltage and current uses, the tubes are called grid controlled rectifiers. Low current types, used primarily for control work, are referred to as thyratrons, or gas-filled triodes.

Advantages.—The grid controlled rectifier has the advantage that relatively high power circuits can be controlled by adjustment of a low power bias supply. Instantaneous overload cutoff can be built into the circuit.

Limitations.—Once the bias in a gas triode has caused the tube to *fire* (conduct) the grid loses control of the circuit. This limits the circuit to control applications in which subsequent interruption of the plate current need only occur when the plate voltage is zero or negative. A separate bias supply must be provided, with insulation for the full rectifier output potential.

Variations.—Power type and control type.

Tube Types Used.—2050, 2051, 2A4G, 884, KY21, etc.

IMPEDANCE COUPLED AMPLIFIER

The impedance coupled amplifier shown in Fig. 16 is distinguished by the use of an inductance (L) in the plate circuit (and sometimes another inductance in the grid circuit) instead of the resistor used in the resistance coupled circuit.

The input voltage from the previous stage appears across the input terminals and is impressed on the grid of tube VI.

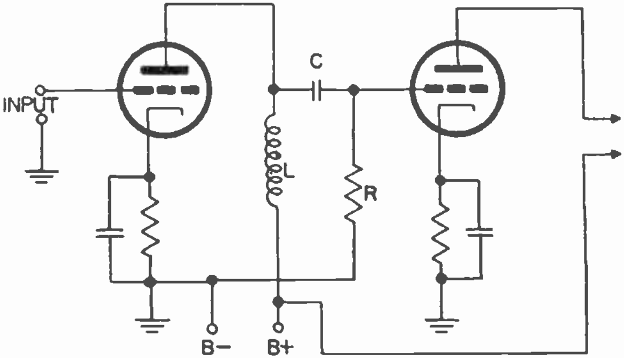


Fig. 16

This signal grid voltage produces in VI a signal plate current which flows through plate inductor L producing a voltage drop which is the amplified output of the stage. Current flowing through resistor R2 provides bias voltage for VI. This bias voltage is filtered by condenser C1.

Since the DC resistance of inductor L is much less than its AC impedance, a higher DC potential is applied to the plate of VI without decreasing the impedance of the load to the signal.

Applications.—The impedance coupled amplifier is used occasionally for audio frequency amplification and more frequently in broad band RF amplifiers.

Advantages.—The impedance coupled amplifier has the advantage over transformer coupled amplifiers in that only one inductance is used and, in RF applications, tuning is not required. Compared to resistance coupling, a much lower voltage drop is suffered in the plate load impedance. Higher signal output can be obtained than with resistance coupling.

Limitations.—The impedance coupled amplifier is subject to variations in plate load impedance due to distributed capacitance and unwanted resonance effects. The load impedance usually varies with frequency making the design of a high fidelity (broad band) amplifier difficult.

Variations.—Arrangements in which the inductor is in series with a resistor are used for broad band RF amplifiers in television receivers. Special filter coupling may be used for broad band (video) characteristics.

Tube Types Used.—Any triode, tetrode, or pentode for AF. RF amplifier pentodes for RF.

RECEIVER RF AMPLIFIER

The RF amplifiers used in receivers evolved from original neutralized triode types, (neutrodyne, synchrophase, etc.) to the almost exclusive use of the modern, high transconductance, low capacitance pentode. Although transformer coupling is employed in most cases, there has been a tendency toward resistance coupling in receivers operating in the broadcast band. (See resistance coupled RF amplifier listing.)

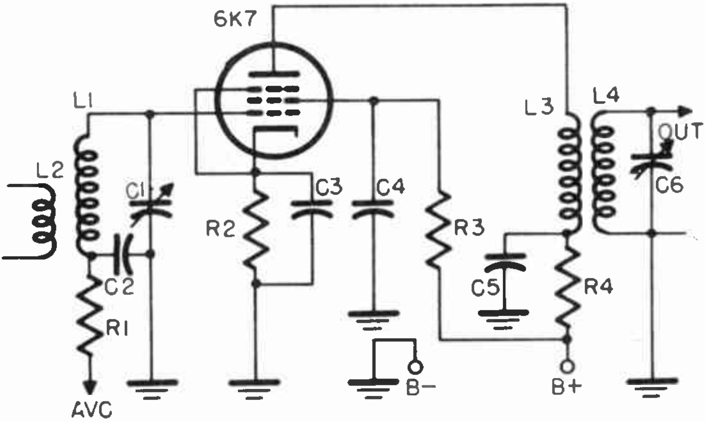


Fig. 17

The transformer coupling is usually of the untuned primary and tuned secondary type as illustrated in Fig. 17, although in intermediate frequency amplifiers, double tuned transformers are generally used. The other RF circuits in a receiver are tuned in synchronism (gang tuned) with the grid input tuning L1-C1 to give high amplification only to the desired signal and high attenuation to all others. Only grid circuits are tuned in RF stages. This accomplishes the dual purpose of allowing the rotors of the tuning condensers to be grounded (with primary tuning, they would be at the high potential) and keeping the total number of tuning condenser sections within practical limits. In IF amplifiers where only initial alignment is necessary, both coils are tuned.

Fig. 18 shows the resistance coupled RF stage found in some receivers. Nearly all modern superheterodynes use AVC. The AVC voltage is obtained from the second detector and fed back to the bottom of the grid coil L1 and thence to the grid. Grid bias is then a combination of the fixed value from the cathode resistor and the AVC voltage which varies with the strength of the incoming signal.

Applications.—RF amplifiers are in superheterodyne or tuned radio frequency receivers to amplify the incoming signal before either detection or mixing takes place. They are also used with double-tuned transformers as intermediate frequency amplifiers in superheterodyne receivers.

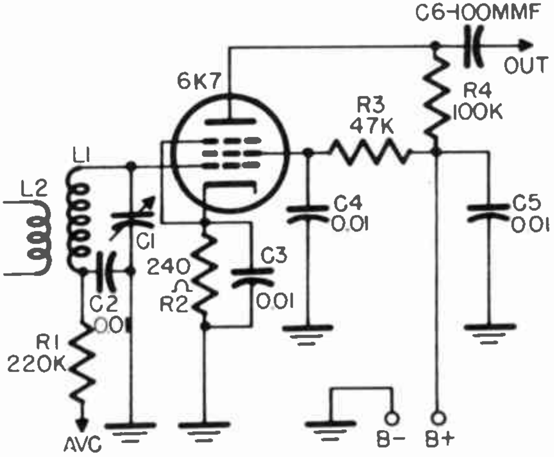


Fig. 18

Advantages.—This circuit provides the highest gain obtainable from the various types of RF amplifiers. This is due to the fact that resonant circuits are used to build up the RF voltage by providing a high impedance plate load and grid input.

Limitations.—Due to the high stage gain obtained, great care must be used to provide sufficient shielding between grid and plate circuits. This is particularly true when high frequencies are used and wiring and other stray capacities become an important factor. Another limitation is that each time a new frequency is used, the circuits must be retuned. Only a narrow band of frequencies can be amplified at one time.

Variations.—The circuit is used with single or double tuned transformers, resistance or impedance coupling, balanced circuits and neutralized triodes.

Tube Types Used.—Any RF amplifier pentode. Examples: Remote cut-off for use with AVC: 1T4, 6SK7, 7A7, etc. Sharp cut-off, cannot be used with AVC: 1I4, 6SJ7, 7C7, etc.

CATHODE FOLLOWER

The cathode follower circuit is shown in Fig. 19. It differs from that of other amplifiers in that the output is connected across the terminals of a cathode resistor R, or cathode impedance, Z, instead of across a plate impedance element.

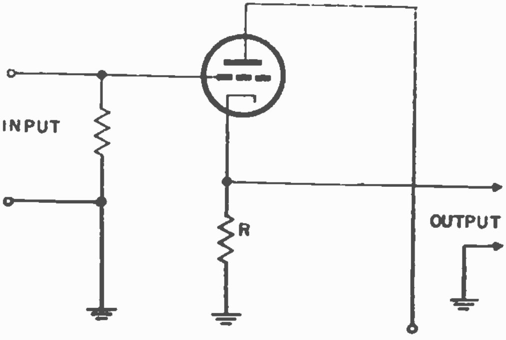


Fig. 19

The input signal is applied between grid and ground as in other amplifiers, but the output resistance is placed in series with the cathode to ground lead instead of the plate lead. Since the cathode return is also part of the grid-cathode circuit, the output across R is opposed by a part of the input voltage. Negative feedback is thus established and plays an important part in the operation of the cathode follower. Because the cathode circuit has a much lower impedance than the plate circuit, low impedance loads can be efficiently matched.

Applications.—The cathode follower is frequently used to match low impedance loads of various kinds. It is easily adapted for the purpose of matching an RF amplifier to a low impedance coaxial line. This application is often found in high frequency work. Although the voltage gain can never equal unity, good power amplification is obtainable. The circuit is frequently used in video power amplifiers.

Advantages.—A definite advantage of this circuit, especially at high frequencies, is that one side of the output can be grounded, and a low impedance line can be matched. The negative feedback present results in:

1. Low phase distortion.
2. Flat amplitude response.
3. Greater impedance at the input terminals.
4. Low output impedance with high power gain.

Limitations.—No voltage gain is derived from the cathode follower circuit, since the output voltage can never quite equal the input voltage.

Variations.—The output impedance can be raised somewhat by placing the load and cathode resistor in series with each other or by using a choke in the cathode.

Tube Types Used.—Any triode, tetrode, or pentode.

LIMITER AMPLIFIER

The limiter amplifier greatly resembles an ordinary IF stage, (Fig. 20) except that a grid leak is used and voltages are adjusted so that saturation takes place above a certain specified input signal level.

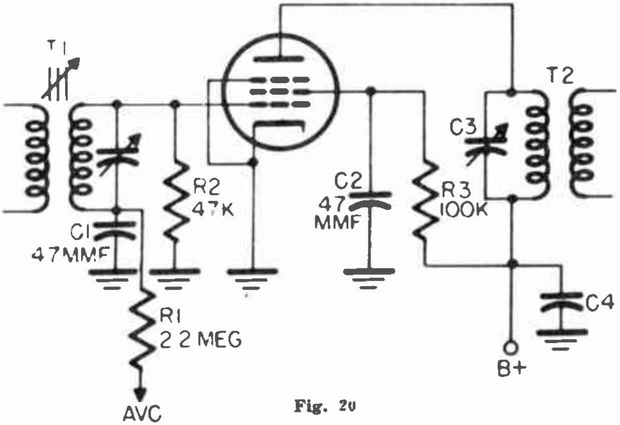


Fig. 20

Limiting action is secured by two means. One of these takes advantage of the properties of the remote cut-off pentode. An increasingly stronger signal produces an increasingly greater current through R2 and a correspondingly greater voltage drop across it. This voltage is applied to the tube as grid bias. Increasing the grid bias on a remote cut-off pentode reduces the amplification of the tube, thus giving a limiting effect.

The other limiting action is secured by using plate and screen supply potentials low enough to permit reasonably strong signals to saturate the tube. This gives a "clipping" effect which removes the amplitude modulation.

Applications.—The limiter amplifier is used to remove amplitude modulation or noise voltage fluctuations from the IF signal in an FM receiver.

Advantages.—It provides efficient amplitude limiting while passing freely a desirable range of frequencies for FM detection.

Limitations.—It does not provide amplification of the passed frequencies so that the FM detectors used with it usually have quite low level output.

Variations.—Time constant circuits may be used in the grid coupling to minimize shock effects in the limiter output resulting from random noise voltages.

Tube Types Used.—Sharp cut-off pentodes operated with low grid voltage swing are preferred although most low power tubes having one or more grids can be used.

RF AMPLIFIER—TRANSMITTING

The transmitting RF amplifier is distinguished by a tuned circuit, L-C, in the plate circuit and a tuned circuit, resistance coupling, or impedance coupling in the grid circuit. If a triode or a tetrode with high grid to plate capacity is used, neutralization is required as illustrated in Fig. 21 and 22.

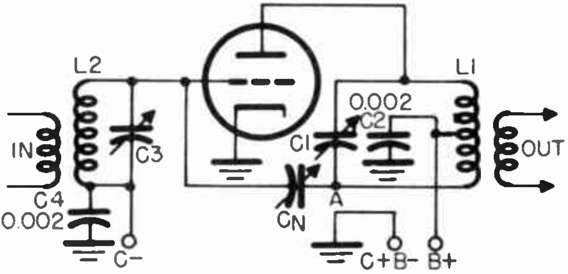


Fig. 21

RF voltage, known as "excitation," is coupled from the previous RF amplifier or oscillator and impressed on the grid. This RF voltage produces an RF current in the plate circuit. Since the combination L_1-C_1 is tuned to the same frequency, a relatively large RF voltage appears across it. Neutralization is necessary to equalize for RF energy fed back to the grid through the grid to plate capacity of the tube. This is done in (Fig. 21) by dividing the plate coil into two parts so that point A has an RF voltage above ground which is opposite in phase to the voltage on the grid. This voltage is then fed back to the grid through neutralizing condenser C_N and the positive feedback is neutralized. For high efficiency, the stage should be operated Class C.

In Fig 21, the neutralizing voltage is obtained from a grid coil.

Another arrangement of an RF amplifier, is shown in Fig. 22 in which the grid circuit is tuned. Here the grid coil is tapped and "grid neutralizing" is used. Usually link coupling is used between the plate coil of the previous stage and this grid coil.

Applications.—The transmitting RF amplifier is used in transmitters of the m.o.p.a. and crystal control types. It is used as an isolating amplifier or as a power amplifier.

Advantages.—The transmitting RF amplifier, if properly adjusted, can produce good voltage and power amplification of RF signals. It is also useful for isolating modulated RF stages from previous stages.

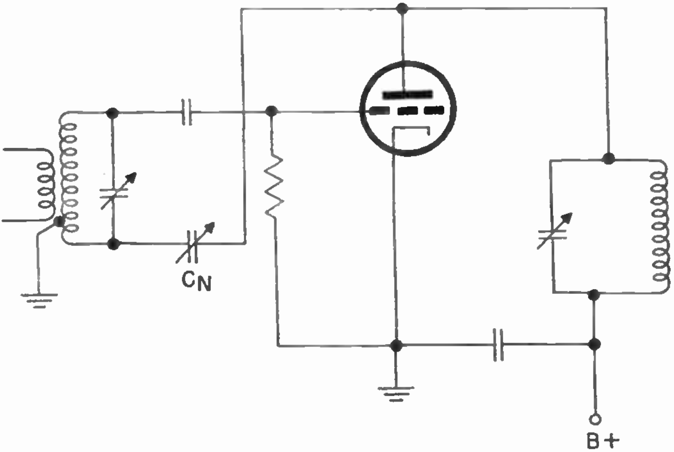


Fig. 22

Limitations.—The transmitting RF amplifier must be carefully tuned and neutralized to produce good results. High amplification can only be obtained over a very narrow frequency range without readjustment.

Variations.—Some often used are:

1. Tuned circuit at the grid.

2. Push-pull operation.

3. Pentodes and low C_{gp} tetrodes requiring no neutralization.

4. "Loaded" tuning circuits to give broader band amplification.

5. Plate and grid traps to accentuate or eliminate certain frequencies.

6. Parasitic suppressors in plate or grid leads.

7. Harmonic amplification by resonating plate to proper frequency.

Tube Types Used.—Any triode, tetrode, or pentode.

GROUNDED GRID AMPLIFIER

As implied by its name, the grid of the tube in a grounded grid amplifier goes directly to ground. A tuned circuit is placed in the cathode lead and acts as the input circuit. The circuit is shown in Fig. 23.

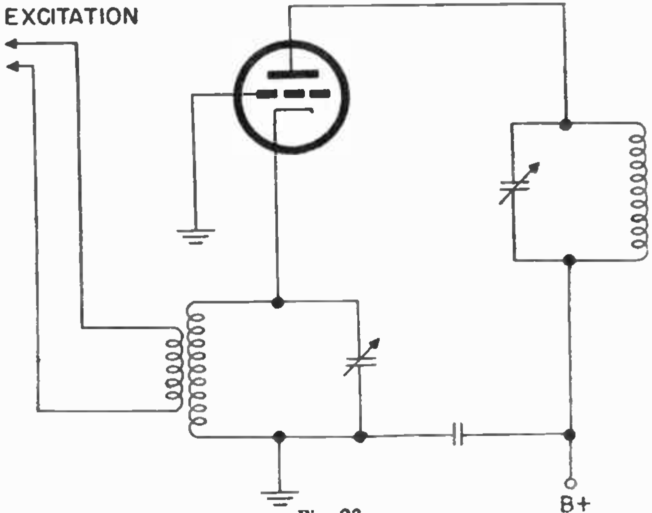


Fig. 23

The cathode instead of the grid is run at RF potential above ground. Amplification is thus produced in the usual way from grid circuit into plate circuit.

The circuit is always neutralized because any feedback energy going from plate to grid is directly grounded.

The input voltage is in series with the output voltage so that driving power combines with plate power in the output of the amplifier.

Applications.—The grounded grid amplifier finds its most frequent use in transmitters. This type of operation gives complete neutralization at all frequencies. It is particularly useful at high frequencies where it is desirable to operate with the grid at ground potential.

Advantages.—The grounded grid amplifier enables triode tubes to be used at high frequencies without the addition of neutralizing circuits.

Limitations.—The grounded grid amplifier has poor isolation qualities because the input voltage is effectively in series with the output voltage. This factor also reduces the gain of the stage.

Tube Types Used.—Any amplifier tube, preferably one designed for low input inductance at VHF (grid ring or multi-grid leads).

PUSH-PUSH DOUBLER

The push-push doubler circuit is distinguished by the fact that two tubes are used. See Fig. 24. The grids of these tubes are fed 180 degrees out of phase with each other and the plates are connected together to one end of the tuned circuit.

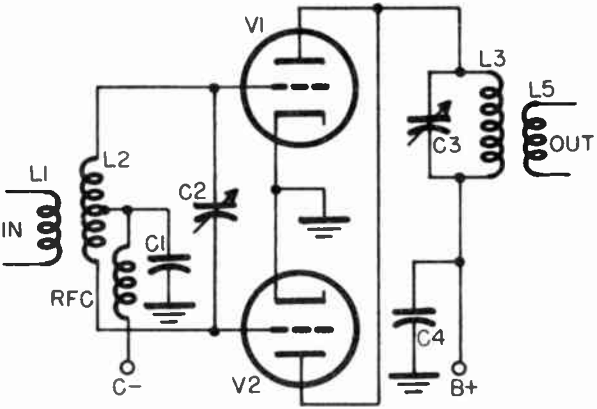


Fig. 24

On one half of the input cycle, the grid of VI becomes more positive than the grid of V2. At this moment, a pulse of increased plate current flows in V1. On the next half of the cycle, the grid of V2 becomes positive and a pulse of increased plate current flows through V2. There are thus two plate current pulses for every cycle of the input voltage, and the stage acts as a frequency doubler.

Because of this action, the output circuit contains second harmonic signal and the plate coil and condenser are tuned to that frequency. The efficiency is considerably better than ordinary single-ended doubler operation.

Applications.—The push-push doubler circuit is used in transmitters. It makes a very effective frequency doubler and is more efficient than doublers of the ordinary type.

Advantages.—The push-push doubler is one of the most efficient producers of second harmonic output.

Limitations.—The circuit cannot be used as a fundamental amplifier or to produce odd harmonics.

Tube Types Used.—Any triodes, tetrodes, or pentodes.

VIDEO AMPIFIER

Video amplifiers are distinguished by the use of resistance coupling. Besides the resistances, inductances called "peaking coils" are included. These are necessary to extend the response curve through the wide video frequency range.

The response of simple resistance coupling falls off at high and low frequencies. The drop in low frequencies is due to the increase in the reactance of the coupling condenser. This effect is compensated for by the combination of C1 and R3. This combination has negligible impedance at high frequencies because of the shunting effect of C1. At low frequencies, the combination impedance becomes high, adding to the plate circuit impedance and the gain.

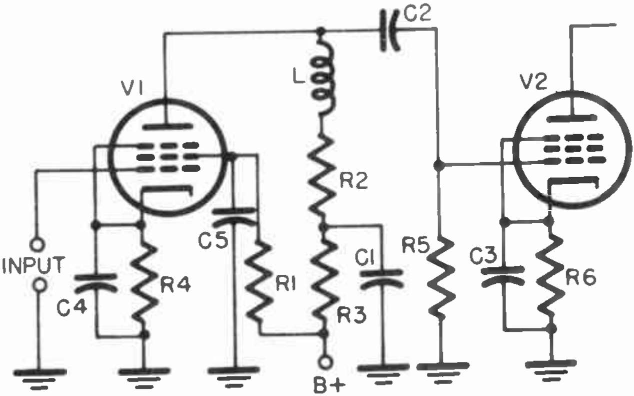


Fig. 25

High frequency equalization is provided by the use of an inductance L. Two methods are frequently used. Fig. 25 shows the shunt peaking method. L is chosen to resonate with the sum of input, output and stray capacitances, at a frequency a little above the highest frequency to be amplified. This builds up the amplification at the high end of the range where a decrease in gain would otherwise take place. Fig. 26 shows the series peaking method in which L resonates in series with the output capacitance of tube V1 and the input capacitance of the tube V2. The gain of video amplifiers is normally required to be flat from near zero cycles per second to several megacycles per second. Television receiver video amplifiers should be flat to 3.5 or 4 mc to amplify all the intelligence transmitted. The gain per stage is usually of the order of 2 to 5 even with the best high gain tubes.

Applications.—The video amplifier finds its greatest use in home television receivers. The impulses necessary to reproduce a picture are of a wide range of frequencies and certain harmonic components. Standard television signals contain video components up to 3.5 to 4 mc. Amplification must be fairly flat through the whole range in order to prevent picture distortion. Another use of video amplifiers is in radar receivers, which often require a frequency range greater than normal television video.

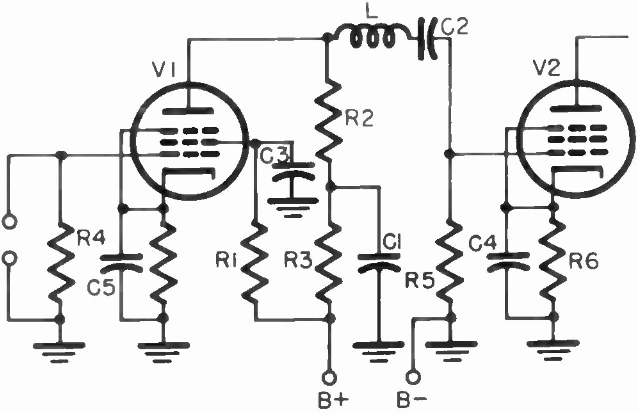


Fig. 26

Advantages.—The video amplifier does not have any particular advantages which are inherent in its design. The circuit was developed to meet the requirements of video amplification. If the proper compensating components are used, a flat response from near zero to a number of megacycles per second can be obtained. As the frequency range increases, a sacrifice in gain is necessary.

Limitations.—The video amplifier obtains its wide frequency range at a sacrifice in gain. Video amplifiers therefore have very low gain compared to similar audio frequency amplifiers. With an increase in pass band width, there is also a corresponding increase in noise level.

Variations.—Combinations of shunt and series peaking are used in a variety of video amplifier circuits. Coupling is sometimes accomplished by means of π and T filters.

Tube Types Used.—Tetrodes and pentodes are usually used; examples: 6V6, 6L6, 6AG5, etc.

RESISTANCE COUPLED AMPLIFIER

The resistance coupled audio frequency amplifier is shown in Fig. 27. It is distinguished by a coupling condenser (C1) between the plate of one tube and the grid of the next and resistors from the plate to B plus and from the grid to ground.

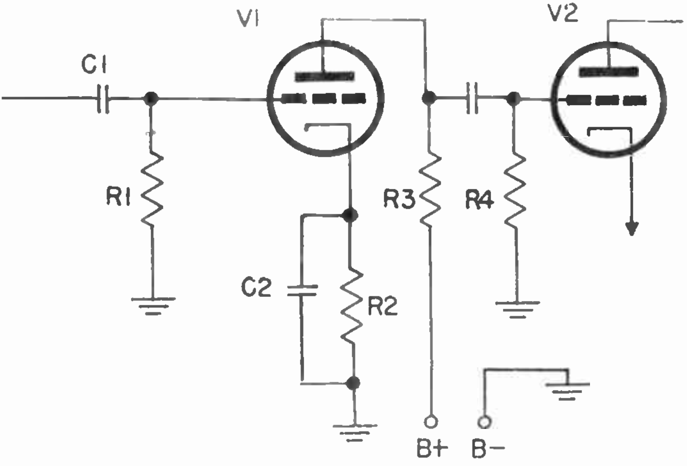


Fig. 27

The audio frequency signal from the previous stage creates an AF voltage drop across R1, which is applied to the grid of V1. This AF grid voltage produces an AF plate current in V1 which creates a signal voltage across plate resistor R3. The voltage across R3 is the amplified output of V1. DC grid bias is provided by cathode resistor R2 through which plate current returns to the cathode. Condenser C2 bypasses the signal fluctuations which appear across R2. The AF output of V1 is coupled by condenser C3 to grid resistor R4 and to the input grid of the succeeding stage.

Because of the fact that only resistors and coupling condensers of negligible reactance are used, the resistance coupled amplifier has an extremely good frequency response. The reactance of C3 at audio frequencies must be small compared to the impedance of R4 for good amplifier response.

Fig. 28 shows the push-pull version of the resistance coupled amplifier.

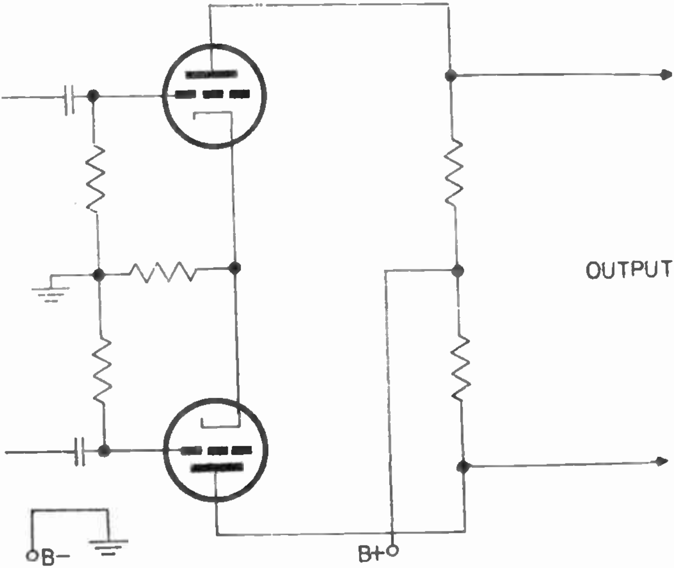


Fig. 28

Applications.—The resistance coupled amplifier is almost universally used as a voltage amplifier in receivers, record players, and PA systems, audio amplifiers in general and in some RF amplifiers for special use.

Advantages.—The resistance coupled amplifier has the advantage of excellent frequency response without the resonance distortion often found in transformer coupled amplifiers. It is simple and inexpensive to construct.

Limitations.—The gain of the resistance coupled amplifier is much lower than impedance or transformer coupled types. The resistance coupled amplifier is relatively inefficient as a power amplifier.

Variations.—Part of the coupling resistors may be bypassed to give a falling response characteristic if compensation or equalization of the amplifier's frequency response is desired. The coupling condenser may be so proportioned as to give increasing response at the higher amplified frequencies.

Tube Types Used.—Any triode, tetrode, or pentode.

TRANSFORMER COUPLED AMPLIFIER

The AF transformer coupled amplifier is distinguished by the use of an iron core transformer as a coupling circuit between tubes.

Fig. 29 shows the single-ended circuit.

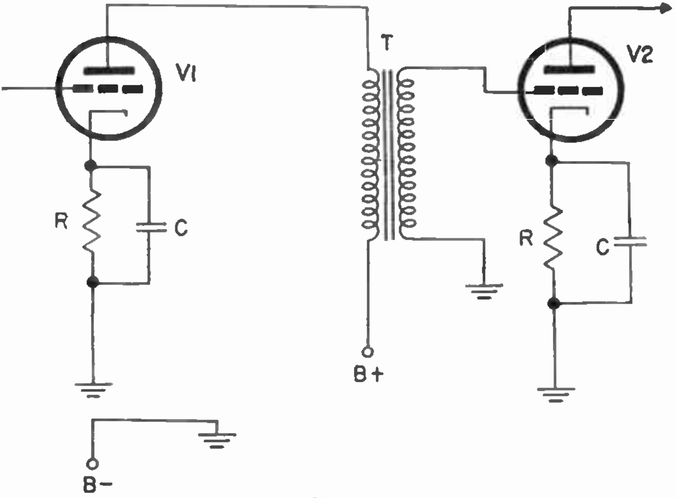


Fig. 29

A signal from a previous stage or circuit is applied to the grid of tube VI. This signal voltage produces plate signal current in the primary winding of transformer T, the secondary of which connects to the grid of V2. The transformers used often have a step up ratio as high as 3 or 5 to 1 and the gain of each stage is increased accordingly. DC grid bias is provided by resistor R, through which plate current returns to the cathode. Condenser C bypasses signal fluctuations which appear across R.

In Fig. 30 is shown the push-pull transformer coupled amplifier. As shown, transformers must be center-tapped. If the amplifier is well balanced, a bypass condenser across R3 is not necessary.

Because of the resonances present in audio transformers, the extra gain realized from them is accompanied by deviation from flat frequency response. Coupling transformers must be designed for the plate and load impedances they are to match and also for the signal level they transfer.

Applications.—The transformer coupled AF amplifier is used in audio frequency amplifiers in receivers, speech amplifiers and PA systems. As a voltage amplifier, it has been largely replaced by the resistance coupled type using high gain tubes.

Advantages.—The advantages of the transformer coupled amplifier are circuit simplicity and the possibility of high gain when a step up transformer is used.It also provides phase inversion where a center-tapped secondary connects to push-pull grids. It further provides correct matching of widely different tube and load impedances.

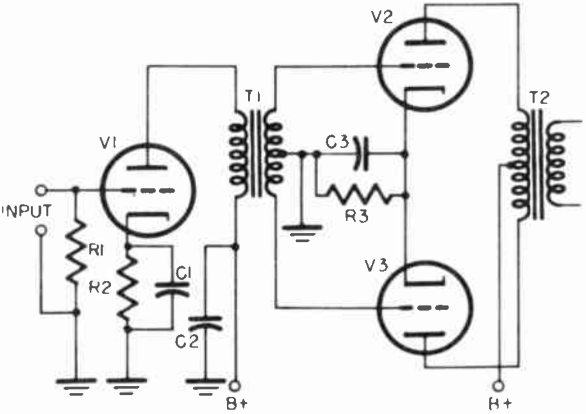


Fig. 30

Limitations.—The transformer coupled amplifier is subject to the resonance effects resulting from the inductances and distributed capacities of transformer windings, making it difficult to get uniform wide band amplification. Transformers are more expensive than R-C elements.

Variations.—When air core tuned transformers are used, the circuit becomes an RF amplifier. Powdered iron core transformers are used for RF amplifiers, and especially IF amplifiers.

Tube Types Used.—Any triode, tetrode or pentode.

DIRECT COUPLED AMPLIFIER

The direct coupled amplifier (see Fig. 31 is a resistance coupled amplifier whose grid is connected directly to the plate of the previous stage rather than through the conventional coupling condenser. Careful arrangement of voltages is necessary since the isolating effect of the coupling condenser is lost.

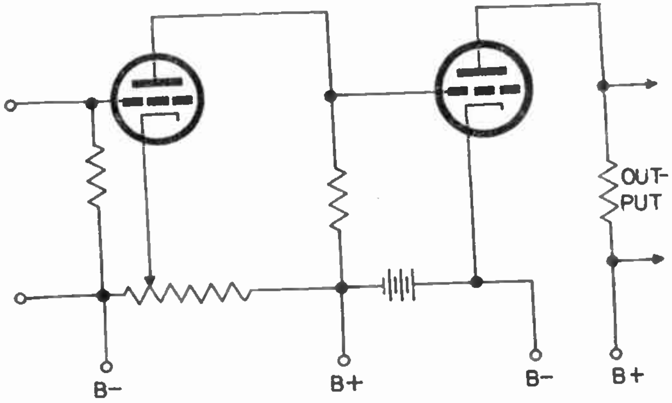


Fig. 31

While the removal of the coupling condenser usually found in AF amplifiers reduces the coupling reactance to zero at all frequencies, it also introduces another problem. Since grid and plate are directly connected, the DC plate potential of the previous stage is placed on the grid of the amplifier.

The direct coupled amplifier is particularly suited to low frequency operation because the reactance effect of a coupling condenser is not present. For this reason, the circuit is often referred to as a "direct current" amplifier, although it is also suitable for AC signals.

Two plate power supplies are usually necessary in order to keep the grid, plate and cathode potentials properly proportioned without a coupling condenser. This dual power supply arrangement is illustrated in Fig. 31. One arrangement, known as the "Loftin White" amplifier, uses only one power supply source and taps the various voltages from a bleeder. This circuit is shown in Fig. 32.

Applications.—The direct coupled amplifier is used for amplifying very slow voltage changes (direct current amplifier) and for AC signals. It is found in servo-mechanisms very frequently and in relay control mechanisms, slow variation control functions, seismographic and vibration amplifier work, etc.

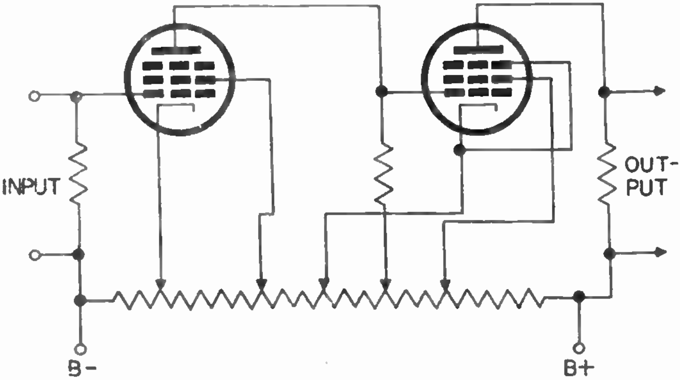


Fig. 32

Advantages.—For equipment requiring the use of very low frequencies (0-1000 cps) the direct current amplifier provides a very flat response and negligible phase distortion.

Limitations.—The direct current amplifier tends to be very unstable because of the plate supply voltage variations. This is due to the fact that very slow changes in voltage can be amplified. Due to lack of grid blocking, great care must be exercised in proportioning circuit voltages.

Variations.—As mentioned above, a circuit which makes use of one, instead of two, power supplies is the "Loftin White" arrangement in which all voltages are obtained from a bleeder resistor as illustrated in Fig. 32. Balancing systems utilizing two tubes per stage, and negative feedback circuits are used for stabilizing direct coupled amplifiers.

Tube Types Used.—Any triodes, tetrodes, or pentodes.

PUSH-PULL AMPLIFIER

The push-pull amplifier is distinguished by the use of two tubes whose grids either connect to the ends of an input transformer secondary or are coupled respectively to the two plates of a preceding push-pull stage or phase inverter. (See Fig. 33.) The plates of a push-pull amplifier are usually connected to the ends of the primary of an output transformer or to other interstage transformer.

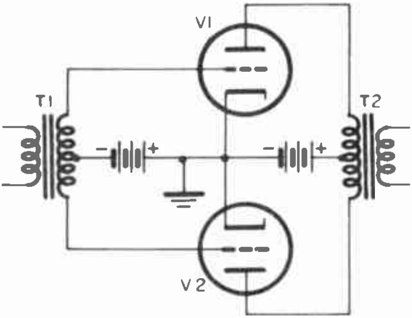


Fig. 33

The signal is fed to the grids so that there is a phase difference of 180° between the grid voltages. This phase relation is produced either by a transformer or a phase inverter. These grid voltages produce plate currents which are 180° out of phase with each other.

The balanced nature of the circuit causes even harmonic distortion to be cancelled, giving an improvement in quality over single ended amplifiers. Plate voltage is supplied to the center tap of the primary of the output transformer.

Applications.—The push-pull amplifier is used for amplification of both RF and AF signals. Its harmonic cancelling property makes it useful in both applications.

Advantages.—The push-pull amplifier cancels second, and higher order even harmonics, of the signal being amplified, thus creating little harmonic distortion. Another advantage is the fact that the DC plate currents flow through the output transformer primary in opposite directions (away from the center). This causes the DC magnetizing effects of the two halves on the core to balance each other, preventing saturation. The out-of-phase plate currents cancel each other minimizing coupling effects to other stages. Greater power level and efficiency are obtained with low distortion when properly adjusted, compared to single ended stages.

Limitations.—The push-pull amplifier requires two tubes and must have a balanced driving source and a center-tapped output transformer. For greatest output and efficiency, complete tube and circuit balance is required.

PHASE INVERTERS

A number of different types of phase inverter circuits are used. Although they are the same in purpose, they differ considerably and are therefore treated here as separate circuits. Four representative types which work on different basic principles as follows are:

Fig. 34.—180 degree phase shift between grid and plate voltages of a tube.

Fig. 35.—180 degree phase shift between grid and screen voltages in a tube.

Fig. 36.—180 degree phase shift between grid and cathode voltages in a tube.

Fig. 37.—180 degree phase shift between the voltages at the ends of an inductor with center tap grounded.

It will be noted that resistance coupling is used in all of these circuits except the last which uses impedance coupling.

Phase inverters became practical with the advent of high gain amplifier tubes. Previously, the gain resulting from the transformer "step-up" was an important factor. It was impractical to substitute a phase inverter for a push-pull transformer because of the relative loss ingain. Modern high gain tubes make amplification in the coupling circuits unnecessary and allow full use of the excellent frequency response of resistance coupling.

Another feature of these circuits is that negative feedback can often be simultaneously introduced as an integral part of the inverter circuit.The diagram of Fig. 149 with the dash line connection and Figs. 150 and 151 all provide negative feedback as part of the inversion process.

Applications.—Phase inverter circuits are used in audio and video amplifiers in which a single-ended stage is to be coupled to a push-pull stage without the use of an interstage transformer. Most high fidelity audio amplifiers and public address systems use phase inverters. They are also used extensively in all types of receivers.

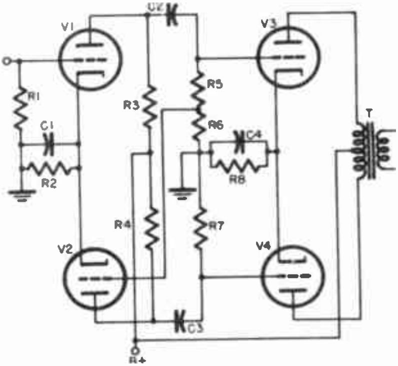
Advantages.—Advantages of phase inverters are:

1. They allow resistance coupling between single ended and push pull stages.
2. A large, heavy interstage transformer is replaced by a few small components.
3. Phase inverters are less expensive.
4. Negative feedback can be incorporated as part of the circuit.

Limitations.—Phase inverters must produce a balanced output to keep distortion to a minimum. The circuits are often critical in this respect and must be carefully designed.

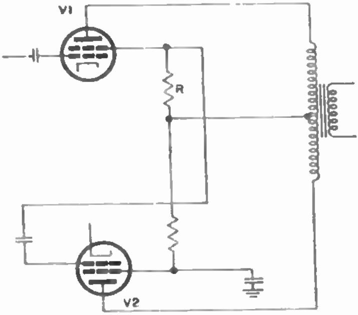
Variations.—The four representative ones shown and several others working on the same principles.

Tube Types Used.—Any audio frequency amplifier tubes, except in Fig. 35, which requires screen grid tubes.



PHASE INVERTER I Fig. 34.

In the circuit of Fig. 34. the input signal is applied to the grid of VI. It is then amplified in the usual way and appears at the grid of V3. The grid resistor of V3 is divided into two parts. That part of the signal appearing across R6 is fed to the grid V2, then amplified and applied to the grid of V4. Since the grid voltage of V4 has passed through one more tube than the V3 grid voltage, the two voltages are 180 degrees out of phase as required.



PHASE INVERTER II Fig. 35.

The circuit of Fig. 35. applies the principle that the signal voltage appearing across an unbypassed screen resistor is 180 degrees out of phase with the grid voltage of the same tube. The input voltage is applied to VI. The out-of-phase signal is fed from the screen of V1 to the grid of V2.

PHASE INVERTER III

The circuit of Fig. 36 works on the principle that the unbypassed cathode signal voltage is in phase with the grid signal voltage. The ground end of R thus has a voltage with respect to cathode which is out of phase with the grid voltage of V1. This out of phase voltage is effectively applied to the grid of V2 since this grid is grounded. The grid voltages are thus 180 degrees out of phase as required.

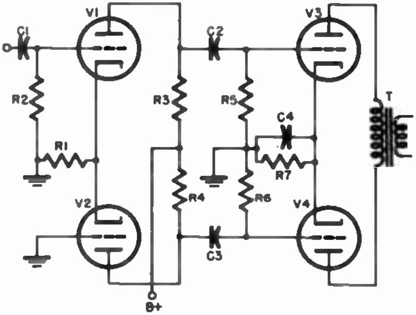


Fig. 36.

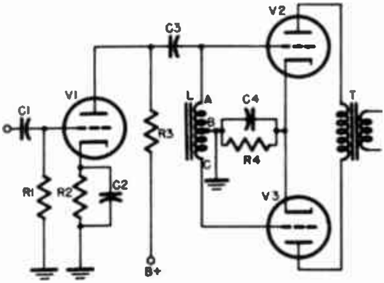


Fig. 37.

PHASE INVERTER IV

The circuit of Fig. 37. uses inductor L to produce the necessary 180 degree phase relation. The input signal voltage is amplified through V1 in the usual way, using portion AB of L as a load impedance. This signal then appears at the grid of V2. Signal fluctuations in AB induce voltages of opposite phase in the CB portion of L. This out-of-phase voltage is applied to the grid of V3, thus accomplishing the required signal phase inversion between V2 and V3.

NEGATIVE FEEDBACK (UNBYPASSED ELEMENTS)

Negative feedback is used in audio amplifiers. When audio frequency voltage is fed back the input of an amplifier distortion generated in the amplifier is canceled. Sufficient feed back will give more equal amplification of all frequence response.

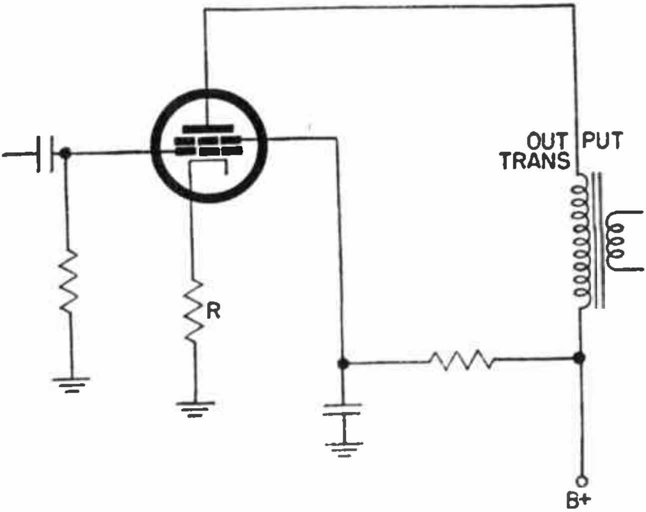


Fig. 38.

One method of obtaining this feedback is to omit the bypass condensers normally used on the cathode resistor and/or the screen resistor. (See Fig. 38. and 39.) Removing the bypass allows a signal voltage to build up across the resistor. As the grid voltage becomes more positive, the plate current increases. As the plate current increases, the voltage drop across the cathode resistor (Fig. 38.) also increases, making the grid more negative with respect to the cathode, and opposing the original grid voltage change. The effect of the unbypassed screen (Fig. 39.) is similar, but to a lesser degree. As screen current increases, current is drawn away from the plate. The plate and screen voltages are thus out of phase. The unbypassed screen acts in opposition to the signal (control) grid in producing plate current change.

Applications.—Negative feedback resulting from unbypassed elements is used in audio frequency amplifiers to reduce distortion. The characteristics of beam power tetrodes and pentodes are not as linear as those of triodes. Feedback is used in amplifiers using these tubes to compensate for any distortion resulting from their use. Thus the relatively high power sensitivity of beam tubes can be utilized without prohibitive distortion. Negative feedback can be used in all types of amplifiers of considerable gain to reduce distortion noise, and hum voltages, and to improve their frequency response.

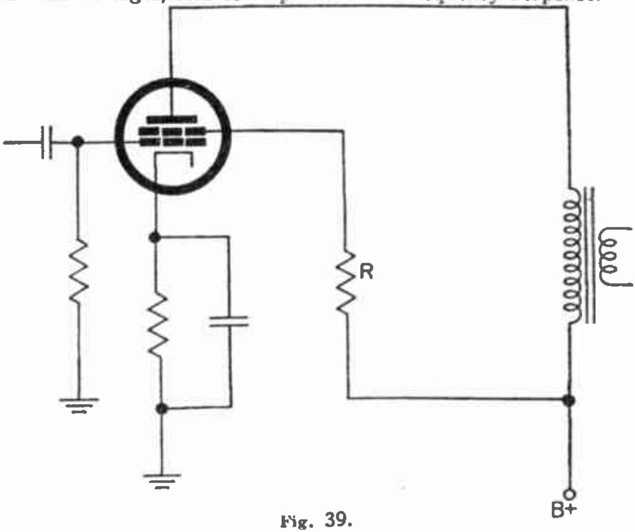


Fig. 39.

Advantages.—Negative feedback has the advantage that distortion tendencies inherent in the amplifier are compensated for by the feedback action. The distortion of the output signal is fed through the output stage(s) in negative phase, thus compensating for the original distortion. The unbypassed element method of obtaining negative feedback is simple and easy to arrange; it actually eliminates the bypass condenser, a component normally used in amplifiers.

Limitations.—As with resistive and impedance networks used to provide the path for negative feedback voltages, the phase shift of signals of extreme frequencies may be such as to constitute positive feedback and produce regeneration or oscillation of the amplifier. For this reason, the amplifier gain should be automatically reduced at extreme frequencies by suitable dividing or shunting networks to prevent such positive feedback from occurring.

Variations.—Screen and cathode application of negative voltages. Also current feedback from the load impedance to an earlier amplifier stage. Voltage or current signal can be fed back three or four stages in amplifiers if phase shift is small over the useful frequency range. Cathode followers have inherently high negative feedback and negligible phase shift.

NEGATIVE FEEDBACK (RESISTIVE)

Negative feedback is used in audio amplifiers. When some of the audio frequency voltage in the output is fed back to a previous stage in negative phase to the original signal voltage appearing there, two advantages result. First, distortion which is generated in the output stage cancels itself out. Second, if sufficient feedback is used, the output of the amplifier can be made independent of input frequency. This means essentially flat frequency response over the entire frequency range of use.

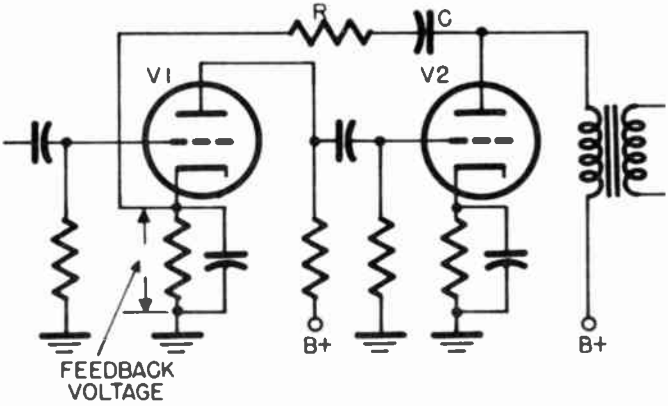


Fig. 40.

One method of obtaining this feedback is the resistive method. Fig. **40.** shows an arrangement useful when two-stage feedback is desired. In Fig. **41.** is shown a method suitable for negative feedback in one stage.

In the arrangement of Fig. **40.**, C is used as a blocking condenser and usually is made large enough to have negligible reactance at all frequencies amplified. Resistor R and the cathode resistor of V1 thus act as a voltage divider. The ratio of cathode resistance to the sum of the two resistances is the feedback ratio.

Because the feedback voltage is 180 degrees out of phase with the signal voltage at the cathode of V1, the feedback is negative. If condenser C is chosen to have an appreciable reactance at low frequencies, the feedback is less at these frequencies and "bass boost" will result.

Fig. **41.** shows another form of resistive feedback in which the feedback traverses only one tube. The feedback resistor and R form a voltage divider. The portion of the plate signal appearing across R is introduced into the grid circuit in negative phase.

Applications.—Negative feedback is widely used to stabilize audio frequency amplifiers. It is used for this purpose in public address systems and high fidelity amplifiers for AM and FM receivers and record players. It is found most frequently in amplifiers designed to take advantage of the high power sensitivity of beam power tubes. The feedback compensates for distortion which often results from the non-linear characteristics of tetrode and pentode power tubes. In high fidelity systems, a *selective* feedback circuit is often used to make the response curve favor the high frequencies or other portions of the spectrum.

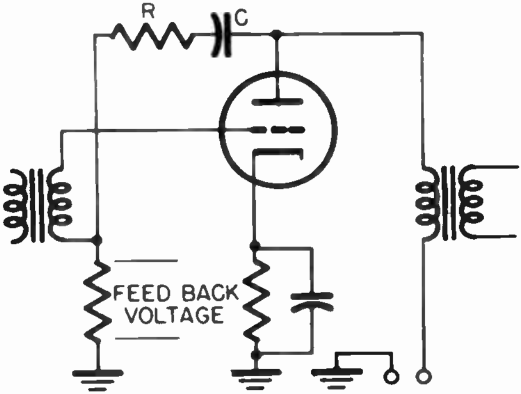


Fig. 41.

Advantages.—The advantages of resistive negative feedback are:

1. Reduction of harmonic distortion.
2. Reduction of hum and other noises introduced in the feedback stages.
3. It permits the use of beam tetrodes and pentodes as power stages with a minimum of distortion.
4. The use of resistors as feedback elements eliminates frequency discrimination.
5. Gives higher fidelity or wider amplifier response.

Limitations.—Feedback reduces the gain of the amplifier and makes it necessary to allow for this in the design. It may cause oscillation or instability at extreme frequencies.

Variations.—There are feedback circuits which utilize capacitive and unbypassed elements. Sometimes voltage is fed back three or more stages.

NEGATIVE FEEDBACK (CAPACITIVE)

Negative feedback is used in audio frequency amplifiers to reduce the distortion content of the output and provide uniform amplitude response. This circuit (Fig. 42.) is the capacitive method for providing negative feedback. Output audio frequency voltage is coupled to a lower level point in the amplifier which has a negative phase with respect to the output.

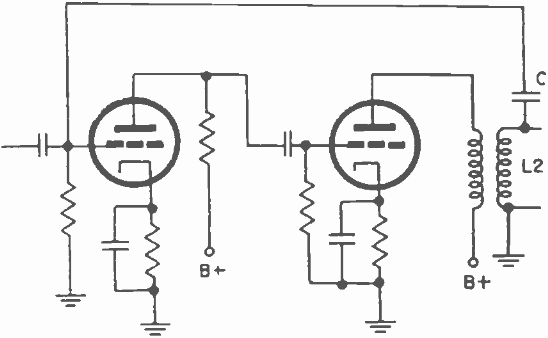


Fig. 42.

One side of L2, the output transformer secondary, is connected to ground. The other side of L2 is, therefore, above ground by an amount equal to the audio potential across the secondary. This audio potential is fed through condenser C back to the grid of the second previous stage. The signal at this grid is 180 degrees out of phase with the feedback voltage which is accordingly negative.

Because the feedback opposes the incoming signal, the gain of this type of amplifier is considerably less than that of units not using feedback. This sacrifice is made worth while because of the lowering of distortion which results. In practice, when negative feedback is to be used, an amplifier is designed to have extra amplification to make up for the loss in gain.

Applications.—This method of negative feedback is used in the audio amplifiers in high fidelity receivers and PA systems. It is frequently used in connection with pentode output tubes which normally have a greater tendency toward distortion than triode output tubes.

Advantages.—The capacity coupled feedback system is simple and easy to install. It greatly improves the quality of audio reproduction possible from an amplifier.

Limitations.—Negative feedback obtained by this circuit or any other circuit reduces the gain of the amplifier. At extreme frequencies, the feedback may become positive due to phase shift in the system and thereby cause oscillation.

Variations.—Other systems used to obtain negative feedback are the resistive method and the unbypassed element method.

ARC OSCILLATOR

The arc oscillator is distinguished by two electrodes connected to a power source and an associated oscillatory circuit as shown in Fig. 43.

Oscillation is provided by virtue of the fact that an electric arc has a negative resistance characteristic. When the arc current increases, the voltage drop decreases. Since the internal resistance of the arc is very low, a series resonant circuit, L-C, is used rather than the more common parallel resonant circuit. The arc oscillator is not suitable for frequencies much above 200 kc and the output has a large percentage of harmonic content. For these reasons, the arc oscillator is rapidly becoming obsolete as a radio transmitter. There are still a number of arc transmitters used for ship-to-shore communication; but these will undoubtedly be replaced by vacuum tube types in the near future.

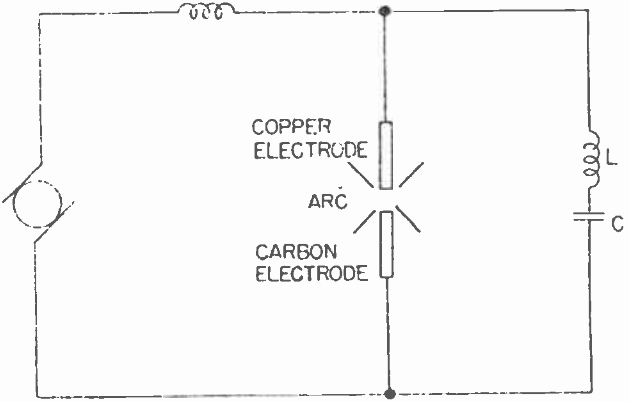


Fig. 43

Applications.—The arc oscillator's use is now confined primarily to ship-to-shore installations which were made some time ago and are to be replaced soon by vacuum tube transmitters.

Advantages.—Considered in the light of modern progress, there are few advantages in the use of an arc oscillator. The equipment is rather simple in nature and adjustment is not difficult.

Limitations.—There are many important limitations to the arc oscillator circuit which account for the fact that, although still used, it is rapidly becoming obsolete. Most installations are continued only until new vacuum tube equipment is economically feasible. The biggest limitation is the inherent instability of the circuit. The arc itself is never really stable, and its characteristics are continually changing. Even under the best of conditions, a high percentage of harmonic distortion is present in the output wave fundamental and the modulation.

SPARK OSCILLATOR

The spark type oscillator is composed of a spark gap connected in series with a parallel resonant circuit (L-C). A low frequency source of power produces a voltage across C which builds up until the gap breaks down and a spark is produced.

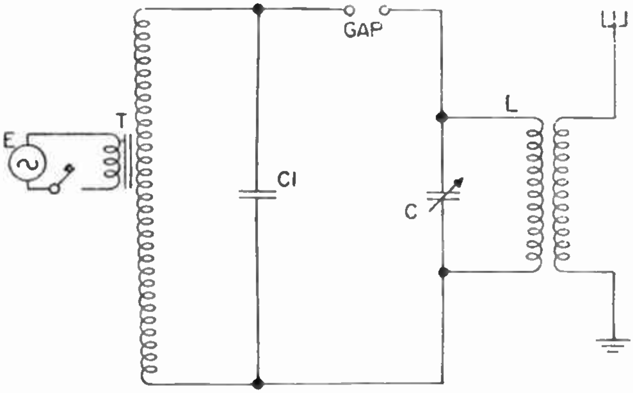


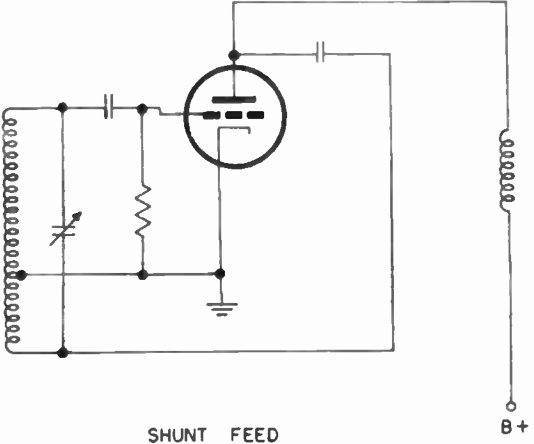
Fig. 44

This discharge causes RF oscillations to be set up in the L-C combination. These oscillations gradually die down until the next power cycle peak causes the gap again to break down and start another cycle. The circuit is shown in Fig. 44.

The damping effect and other factors cause the spark oscillator to produce a broad signal with high harmonic content. Much interference is usually caused and for this reason the spark transmitter is becoming obsolete. It is still used for ship-to-shore communications although all units will undoubtedly be replaced by vacuum tube types in the near future.

HARTLEY OSCILLATOR

The Hartley is one of the simplest self-excited oscillators. Its distinguishing feature is the tapped coil used to obtain the feedback necessary for oscillation. The circuit is shown in Fig. 45) and 46. The coil is connected between the plate and the grid. The tap, usually located nearer to the grid end is connected either directly, or through a condenser, to the cathode of the oscillator tube. A blocking condenser is used to isolate the high positive DC voltage on the plate from the negative DC voltage on the grid. The RF grid current flows in the lower section of the coil while the RF plate current flows in the upper section of the coil. The phasing of the plate and grid currents in the coil is such that positive feedback to the grid is obtained and oscillation is made possible.



SHUNT FEED
Fig. 45

Since, in the basic Hartley, the plate is a primary element of the oscillator (differing from its function in the electron coupled Hartley) the plate current must be kept to a minimum if greatest stability is desired. Generally, the basic Hartley, and other oscillators in which the plate is a primary element, are used when power requirements are relatively low or when stability is not a primary factor.

Both shunt (Fig. 45,) and series (Fig. 46) feed are illustrated to demonstrate the detailed circuit changes necessary to change from one to the other. Shunt feed is well adapted to applications in which it is desirable to keep the tuned circuit at ground potential. This is accomplished only at the expense of using a well designed RF choke in the B plus lead. Series feed eliminates the need for this choke but requires that the tuned circuit be at a high DC potential (plate voltage) above ground.

Applications.—The Hartley oscillator does not depend on the grid-plate capacity of the oscillator tube for feedback and will, therefore, work well with almost any type of triode, tetrode, or pentode. It is usually found in its basic form in triode circuits. Most frequent applications of the basic Hartley circuit are:

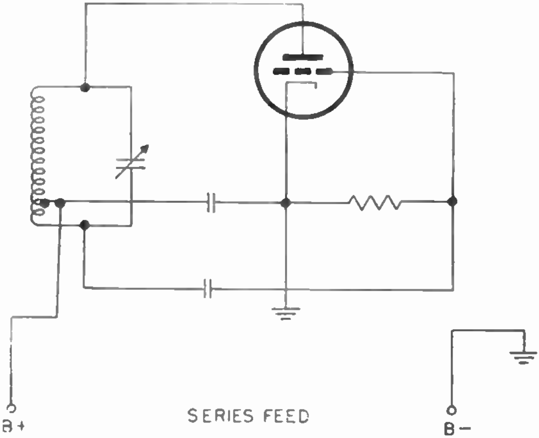


Fig. 46

1. Superheterodyne local oscillator.
2. Transmitter master oscillator.
3. Audio oscillator.
4. Signal generator (RF and AF).
5. Code practice oscillator.
6. Frequency meter.

Advantages.—The main advantage of the Hartley oscillator circuit is its simplicity. A minimum number of parts are needed and only one coil winding is necessary. Although the feedback ratio will change with frequency, this effect is not critical. Once the tap has been properly adjusted, good operation is obtainable over a wide range, although the output power will vary to some extent.

Limitations.—One of the limitations of the basic Hartley oscillator circuit is the fact that the coil must be tapped. This makes it necessary to change three connections when changing from one frequency band to another, compared with two for some other circuits (such as the Colpitts). Coupling between the two sections of the coil changes with frequency, causing the feedback ratio to vary over a tuning range.

Variations.—Shunt or series feed are variations of the Hartley circuit as illustrated in the diagrams. If the point of RF ground potential is moved from the cathode to the plate, the "grounded plate" Hartley circuit results. Another variation is the electron coupled Hartley oscillator.

Typical Tubes Used.—Any triode, tetrode, or pentode, or in triode section of 6K8, 12K8, 6J8, or 6J7.

PUSH-PULL HARTLEY

The push-pull Hartley oscillator circuit is distinguished by the fact that a coil with three taps is connected between the respective plates of the two oscillator tubes (see Fig. 47). The center tap is at ground potential to RF and is connected to B plus. The other taps are connected through blocking condensers (C1 and C2) to the grids as shown.

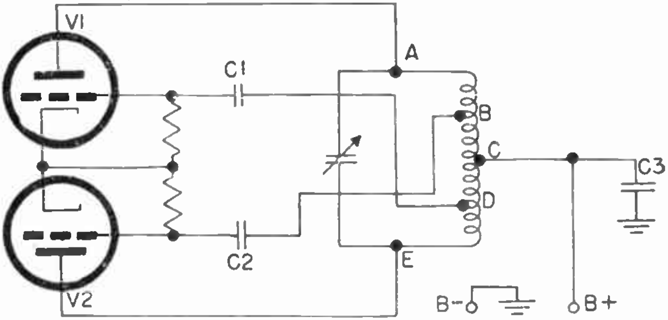


Fig. 47

Section A-D of the coil acts as the V1 oscillator coil; it is connected between the plate and grid of V1 and the tap C is coupled to the cathode. (C1, C2, and C3 have negligible reactance at the frequency used.) RF grid current flows in the C-D section of the coil and RF plate current flows through the A-C section of the coil. V2 operates in the same fashion as V1, D-C being the grid coil section and E-C the plate coil section. The phasing of the grid and plate currents flowing in the coil is such that positive feedback to the grids is obtained and oscillation is made possible. The currents flowing through V1 and V2 are 180° out of phase with each other and produce a total RF voltage across A-E equal to twice the RF voltage across each tube.

Applications.—The principal use of the Hartley push-pull oscillator is as a master oscillator in transmitters and as a generator in RF heating units.

Advantages.—The Hartley push-pull oscillator has the advantage that second harmonic distortion is canceled in the output. It also uses fewer components than other push-pull types.

Limitations.—The Hartley push-pull oscillator requires a coil with five leads—three taps and the two ends. Being a balanced circuit, the rotor of the tuning condenser cannot be grounded unless the split stator type is used. These factors make this oscillator type unsuitable for applications in which band-switching and ganging (most receivers) are required.

Variations.—Shunt feed is possible but not practicable since two RF chokes and plate blocking condensers would have to be added to the circuit shown.

Tube Types Used.—Any triodes, tetrodes, or pentodes.

GROUNDED PLATE HARTLEY

The grounded plate Hartley, shown in Fig. 48, is a variation of the basic Hartley circuit. This circuit is changed to the more familiar fundamental Hartley by moving the ground and B minus connections to the cathode and placing an RF choke in the B plus lead. The grounded plate Hartley circuit is distinguished by the fact that the coil is connected between grid and ground, and the cathode is connected to a tap on this coil. The plate has no load impedance, but connects directly to B plus.

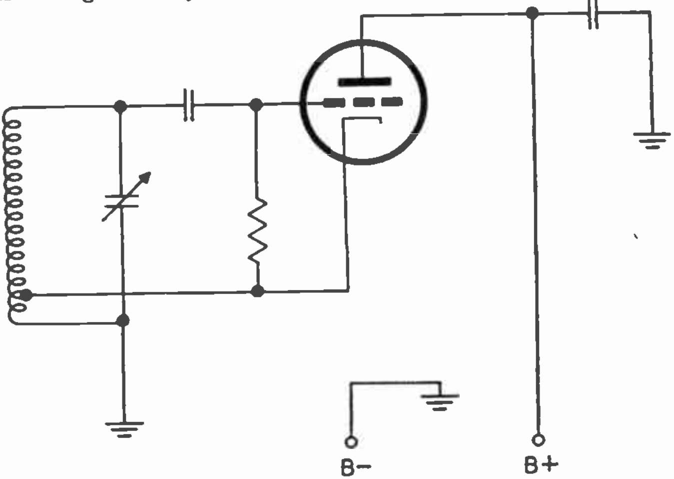


Fig. 48

The plate runs at ground potential to RF; there are thus RF voltages above ground on the cathode and the grid. For this reason, output cannot be taken from the plate, but must be coupled from the grid or cathode elements. When used as a local oscillator in a superheterodyne receiver, output is usually taken from the cathode, as ample voltage is usually available there and loading effects are small because of the low impedance of this part of the circuit. A variation of the usual circuit is shown in Fig. 49. This variation shows the use of a series grid leak and plate DC dropping resistor.

Applications.—The principal uses of the grounded plate Hartley are as the local oscillator and as a beat frequency oscillator in superheterodyne receivers. It will also occasionally be found in signal generators, frequency meters, etc. The RF grounding of the plate minimizes instability due to plate current heating effects in the coil, but also limits the output since the coil does not carry the RF plate current, and the amplifying property of the tube is not used. Since there is no RF voltage on the plate, output must be tapped off at the cathode or the grid, or inductively coupled from the coil. In some cases, a load resistor is added in the plate circuit, making it possible to build up an RF voltage on the plate. Although power output is reduced, better stability results from the limiting effect of the series resistor. Output is then coupled from the plate through a condenser.

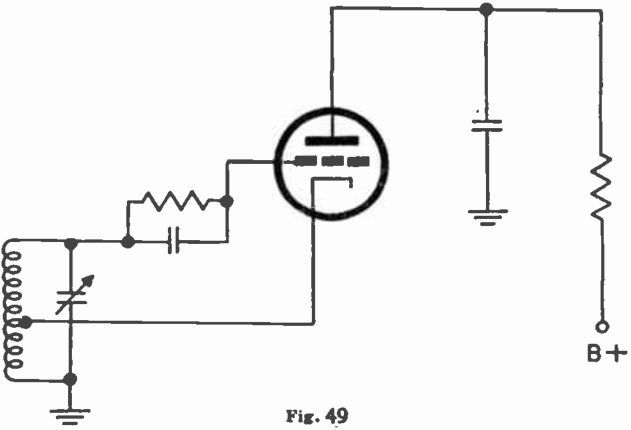


Fig. 49

Advantage.—The main advantage of the grounded plate Hartley circuit is that the plate, which carries the most current, is at ground RF potential. Direct heating effects in the plate circuit and loss of RF into the plate supply are thus minimized.

Limitations.—The power output of the grounded plate Hartley circuit is relatively low because the amplifying property of the tube is not used as fully as it is in other types. The circuit does not lend itself very well to band switching because the coil is tapped and three connections are necessary in the switching process instead of two as in some other types. The tap on the coil must be carefully adjusted to give best results and the turns ratio may change from band of band because of changes in distributed capacity.

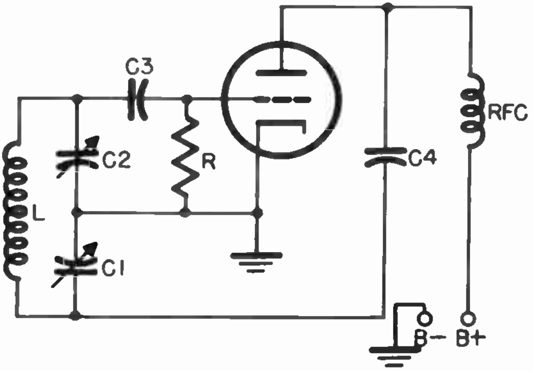
Variations.—If a screen grid tube is used, and the screen grid is substituted for the plate, an electron coupled Hartley oscillator is created.

A load resistor is sometimes added in the plate circuit. This plate resistor allows an RF voltage to build up on the plate. The resistor is in series with the feedback circuit and reduces the output power and, if too large, can stop oscillation. It also gives a stabilizing action by limiting feedback.

Typical Tubes Used.—Any triode or multi-element tube connected as a triode or with screen bypassed to ground can be used. As described above, multi-element tubes can be connected as the electron coupled variation.

COLPITTS OSCILLATOR

The Colpitts oscillator obtains the feedback necessary to support oscillation by dividing the tuned circuit into two parts, as shown in Figs. 50 and 51. This division is accomplished by means of a capacitive voltage divider made up of C1 and C2 in series, shunted across the coil L. It will be noticed that the principle involved is the same as that used in the Hartley circuit except that it is the capacity which is tapped instead of the coil. The RF voltage across C1 is the plate portion and the RF voltage across C2 is the grid portion. The feedback ratio is therefore dependent on the ratio of the two capacitances. The smaller capacity has the larger RF voltage across it since its reactance is greater. Because the *ratio* of the reactances does not change with frequency, a constant feedback ratio over a tuning range can be maintained providing the reactance ratio is not disturbed. The ratio can be kept constant by adding a separate variable condenser or by making C1 and C2 parts of a split stator condenser. The separate tuning condenser method is desirable in applications in which great stability is desired because C2 can be made a large fixed capacitance. This large capacitance, is then shunted across the grid to cathode capacitance, making the effects of the latter on the frequency of oscillation negligible.

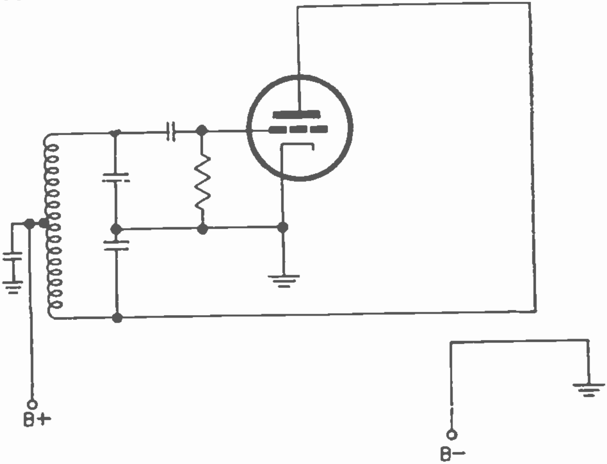


SHUNT FEED

Fig. 50

Shunt feed is shown in Fig. 50 and series feed is shown in Fig. 51, but the former type is almost always used. Series feed is usually not practical because it necessitates tapping the coil. Tapping the coil nullifies one of the most important advantages of this circuit since it adds another coil connection to be switched in multi-band applications.

Applications.—Some of the most important applications of the Colpitts circuit are:



SERIES FEED
Fig. 51

1. Local oscillator in superheterodyne receivers.
2. Signal generator RF oscillators.
3. Master oscillators for transmitters.
4. Grid dip meters, Q meters and other test equipment. The constant feedback ratio over a tuning range makes the Colpitts very well suited to use in instruments and equipment where constant output is desirable.

Advantages.—Constant feedback ratio over a tuning range, thus improving the output vs. frequency characteristic. One coil, without any taps, is used, facilitating switching or the use of plug-in coils. A large fixed capacity (C2) can be shunted across the grid to cathode internal capacity, thus minimizing frequency shift due to applied voltage change.

Limitations.—To make full use of its advantages, the circuit requires two more condensers than are generally used (C1 and C2 besides the tuning condenser). C1 and C2 may be varied for tuning purposes; but unless a gang condenser is used, the ratio will change, altering the feedback and the output. Frequency stability is similar to that of the Armstrong oscillator.

Typical Tubes Used.—Any triode, tetrode, or pentode, or the triode section of multi-element tubes as the 6K8, etc.

Variations.—Electron coupled Colpitts, series feed (seldom used) The Colpitts principle is also used in the ultraudion oscillator which uses tube capacities for C1 and C2.

ARMSTRONG OSCILLATOR

The Armstrong oscillator obtains the feedback necessary to support oscillation by means of the transformer formed by coils L1 and L2. (Figs. 52 and 53)

The amount of feedback is determined by the degree of coupling between L1 and L2. The degree of coupling depends upon the physical position and the number of turns used in each coil. Grid bias is obtained in Fig. 52 (series feed) by means of a series grid leak; in Fig. 53 by the shunt type of grid leak. In practice the series feed arrangement (Fig. 52) is preferred because the RF choke is not critical, and, in fact, can often be eliminated.

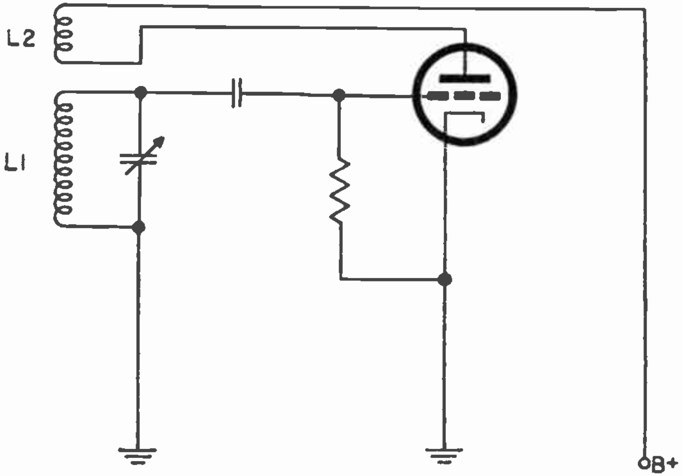


Fig. 52

The two separate coil windings of the Armstrong oscillator add a slight complication. But the two-winding arrangement is very flexible and allows careful adjustment of feedback.

Applications.—This circuit is widely used in superheterodyne receivers as a local oscillator and is particularly common in all wave receivers. There are a number of other widely diversified uses including most RF oscillator applications, except those where a minimum of coil leads are desired. In many applications, such as signal generators, frequency meters, etc., the advantage of being able to adjust feedback overcomes the disadvantage of many coil leads. It is therefore frequently found in these units.

Advantages.—Since the feedback ratio can be varied by either changing the number of turns in L2 or by changing its proximity to L1, feedback adjustments are more easily made than in other types of oscillators.

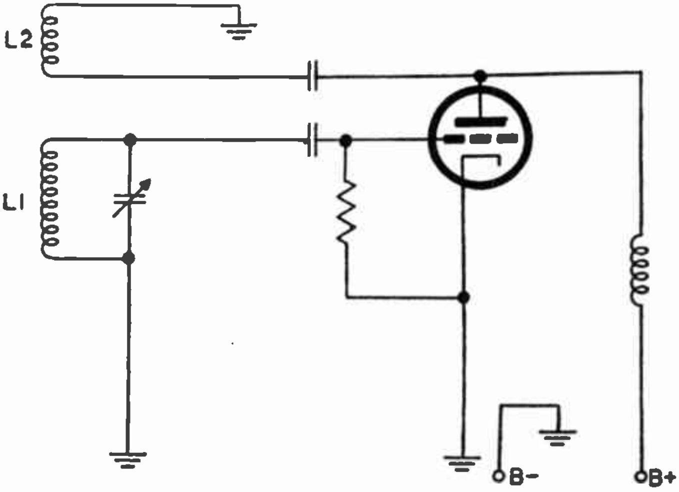


Fig. 53

Limitations.—The use of four connections on the coil makes it inconvenient to switch coils or make compact inductances of the plug-in type for multi-band use, etc. Frequency stability is subject to component temperature variations and direct load reaction in the tuned circuit.

Variations.—Electron coupled circuits sometimes use the Armstrong oscillator arrangement in the grid-cathode-ground section. (See electron coupled Armstrong basic circuit.) Another common use is as a regenerative detector.

Tube Types Used.—Any triode, tetrode, or pentode, or the oscillator section of converter tubes such as the 6K8, etc.

ELECTRON COUPLED HARTLEY

The electron coupled Hartley oscillator is distinguished by the coil connected between the grid and ground (through blocking condenser C3) and with a tap connected to the cathode of the tube. A screen grid tube must be used and the plate load impedance may be a tuned circuit as shown in Fig. 54 or an RF choke or resistor.

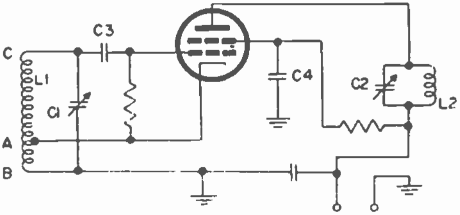


Fig. 54

The screen-grid of the tube acts as the anode of the primary oscillator circuit, and is coupled back to the bottom of the coil through condenser C4 and ground. Oscillator RF grid current passes through section A-C of the coil, while oscillator RF screen current flows through section A-B. The phasing of the screen and grid currents is such that positive feedback to the grid is obtained and oscillation is made possible. Grid voltage variations resulting from this oscillation vary the electron stream and the RF voltage appears in an amplified form at the plate.

Since the plate is not part of the primary oscillating circuit plate load, applied voltage variations do not affect the operating frequency nearly as much as in oscillators in which the plate is a primary element.

Applications.—The Hartley electron coupled oscillator circuit is used as:

(a) Master oscillator in transmitters.
(b) Local oscillator in superheterodynes.
(c) Signal generator RF oscillator.
(d) Heterodyne frequency meter.
(e) Beat frequency audio oscillator.

Advantages.—The Hartley electron coupled oscillator is much more stable than the basic Hartley type. Harmonic output can be obtained by tuning C2-L2 to the desired harmonic.

Variations.—The electron coupled principle can be used with other oscillator circuits connected to the grid, screen and cathode combination. (See Colpitts and Armstrong electron coupled circuits.) The circuit may be used with an RF choke or a resistor in the plate circuit if fundamental frequency output only is desired.

Limitations.—Requires tapped coils for tuning which are not as easily switched for band changing as are circuits using untapped coils.

Tube Types Used.—Any tetrode or pentode.

ELECTRON COUPLED COLPITTS

The electron coupled Colpitts circuit is distinguished by the grid coil L1 connected across dividing condensers C3 and C4 in series as shown in Fig. 55. The common terminal A of these two condensers connects to the cathode of the tube. The cathode DC return is provided by RF choke RFC.

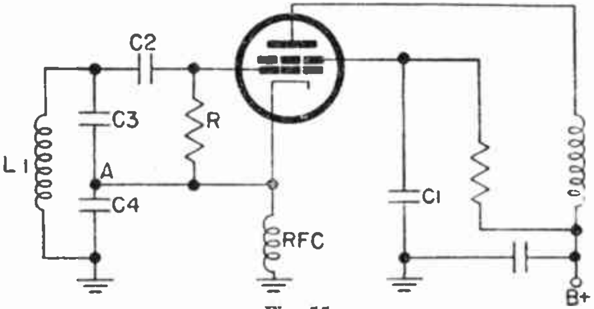


Fig. 55

Condensers C3 and C4 divide tank circuit L1-C1 into two parts. Oscillator RF grid current flows through C3 and oscillator RF screen current flows through C4. The phasing of the screen and grid currents is such that positive feedback to the grid is obtained and oscillation is made possible. Grid voltage variations resulting from this oscillation vary the electron stream and the RF voltage appears in an amplified form at the plate.

Since the plate is not part of the primary oscillating circuit, plate current and plate thermal and loading variations do not affect the operating frequency as much as in oscillators in which the plate is a primary element.

Applications.—The Colpitts electron coupled oscillator is used as a master oscillator in transmitters and occasionally as a local oscillator in superheterodyne receivers and in signal generators. The necessity for extra tank condensers (C3 and C4) and the RF choke RFC make the electron coupled Colpitts less popular than the electron coupled Hartley.

Advantages.—The Colpitts electron coupled oscillator is much more stable than the basic Colpitts due to the isolation between the plate and the primary oscillation circuit. In addition, it allows placing rather large capacitances (C3 and C4) across the interelectrode capacitances of the tube, thus reducing the effect which heating usually has upon the operating frequency of an oscillator.

Limitations.—The Colpitts electron-coupled circuit requires the use of dividing condensers C3 and C4 and the RF choke RFC.

Variations.—Other basic oscillator circuits may be used in the grid-screen-cathode section of the electron coupled circuit.

Tube Types Used.—Any tetrode or pentode.

ELECTRON COUPLED ARMSTRONG

The electron coupled Armstrong circuit shown in Fig. 56 is distinguished by separate grid and screen coil windings (L1 and L2). The grid coil is tuned. Either a tuned circuit (L3 and C3) or some fixed impedance such as an RF choke or resistor is connected in the plate circuit.

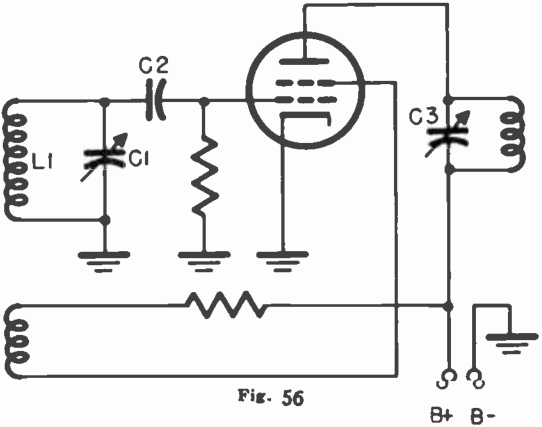


Fig. 56

By transformer action, screen current fluctuations are coupled from L2 back to L1 and the grid. The phasing of these currents is such as to produce positive feedback and oscillation is made possible. Grid voltage variations resulting from this oscillation vary the electron stream and the RF voltage appears in an amplified form at the plate.

Since the plate is not part of the primary oscillating circuit, plate current and plate thermal variations do not affect frequency stability nearly as much as in oscillators in which the plate is a primary element.

Applications.—The Armstrong electron coupled oscillator is occasionally used as a master oscillator in transmitters but finds its most frequent use as a local oscillator in superheterodyne broadcast receivers.

Advantages.—The Armstrong electron coupled oscillator is much more stable than the basic Armstrong circuit due to the isolation between the plate load and the primary oscillation circuit.

Limitations.—The electron coupled Armstrong circuit has the disadvantage of having two separate coil windings in the primary oscillating circuit, making coil switching more cumbersome than in other types.

Variations.—Other basic oscillator circuits may be used in the grid-screen-cathode section of the electron coupled circuit. (See electron coupled Hartley and Colpitts circuits.)

Tube Types Used.—Any tetrode or pentode.

PUSH-PULL TPTG

The push-pull tuned-plate tuned-grid circuit is distinguished by the fact that two separate tuned coils are used; one is connected between the plates of the two tubes, the other between the grids of the two tubes (V1 and V2) as shown in Fig. 57.

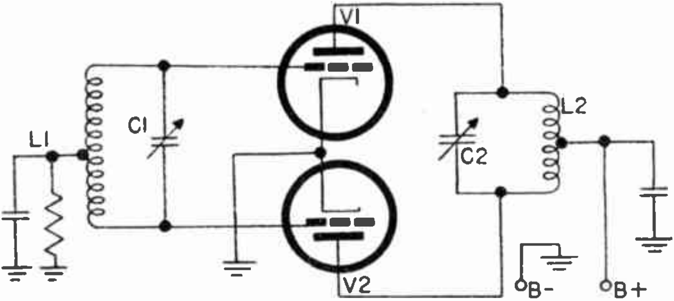


Fig. 57

The tuned circuits L1-C1 (grids) and L2-C2 (plates) are resonated at the same frequency. The RF energy in the plate circuits is fed back to the grids and re-amplified. Positive feedback is thus established and oscillation produced. The internal capacitance of the tube (C_{gp}) provides the necessary coupling between the grid and plate circuits.

Since in this oscillator the plates are primary elements of the oscillator (differing from electron coupled oscillators) the plate current must be kept to a minimum if greatest stability is desired.

Applications.—The principal use of the push-pull TPTG oscillator is as a master oscillator in transmitters and as a generator in RF heating units. The fact that two circuits must be adjusted simultaneously and the fact that the rotors of the variable condensers cannot be grounded without the use of split stators make the push-pull TPTG circuit unsuitable for use as a local oscillator in superheterodynes.

Advantages.—The TPTG push-pull oscillator has the advantage that second harmonic distortion is canceled in the output. More output is obtained than with a single tube circuit.

Limitations.—In the push-pull TPTG oscillator two separate tuned circuits must be adjusted, making ganging and tracking with other circuits impractical. This problem is further heightened by the fact that the rotors of the variable condensers cannot be grounded unless the split-stator type is used. Proper tracking of plate and grid circuits for good efficiency is difficult.

Variations.—Shunt feed is possible but not practicable since two RF chokes and plate blocking condensers must be added to the circuit shown.

Tube Types Used.—Any triodes, tetrodes or pentodes.

REVERSED FEEDBACK OSCILLATOR (TUNED PLATE)

The reversed feedback tuned plate oscillator shown in Fig 58 obtains the feedback necessary to support oscillation from the transformer action (coupling) between L2 and L1. The RF current in the plate circuit creates an RF voltage in the grid circuit in such phase that it builds up oscillation. As in the Armstrong oscillator, the feedback is dependent on the coupling between L1 and L2 and the number of turns in each. As in other oscillators using inductive coupling, the feedback varies with the frequency.

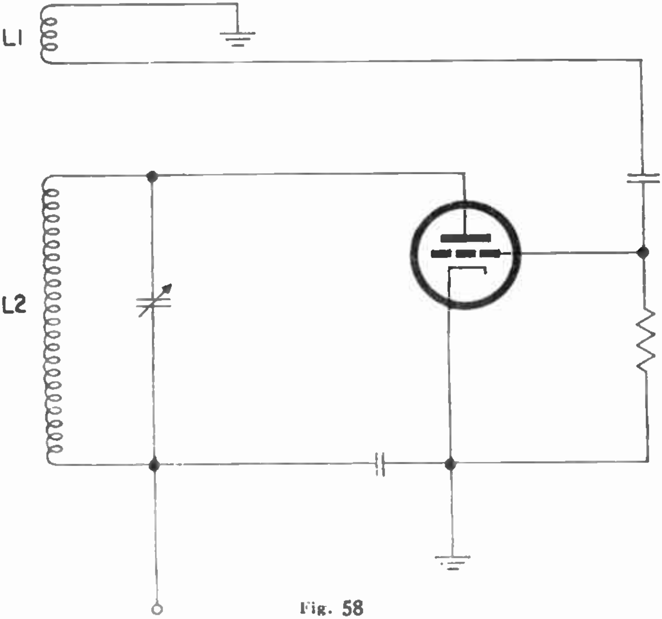


Fig. 58

The reversed feedback oscillator is similar to the Armstrong type. The difference is that in the reversed feedback oscillator, it is the plate circuit instead of the grid circuit which is tuned. DC plate voltage can be removed from the coil by using shunt feed, in which case the blocking condenser C is connected between the plate and the top of the tuned circuit. The high voltage is then applied through an RF choke directly to the plate.

Fig. 58 shows the series feed arrangement and Fig. 59 shows the shunt feed 'arrangement. In Fig. 58, the grid to ground bias method is used and Fig. 59 uses a series grid leak. Either bias method can be used in either circuit.

Applications.—The reversed feedback oscillator is occasionally found in superheterodyne receivers, RF signal generators, and transmitter master oscillators. The applications of the reversed feedback oscillator are identical to those of the Armstrong oscillator. Since the Armstrong has a number of significant advantages, it is used more often.

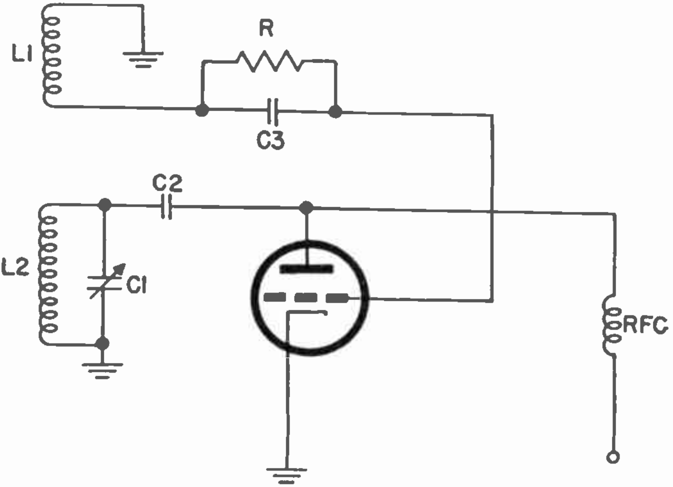


Fig. 59

Advantages.—The feedback in this oscillator circuit is easier to adjust than in most types because it is a function of both the number of turns in L1 and L2 and the proximity of the two coils.

Limitations.—The tuned circuit is at high DC potential unless shunt feed is used. If shunt feed is used, a good RF choke is needed in the plate circuit. There are four coil connections, making switching and construction of plug-in coils more difficult. Frequency stability is subject to component temperature variations and direct load reaction in the tuned circuit.

Variations.—The reverse feedback circuit can be used in an electron coupled oscillator although the Armstrong type is usually preferred.

Tube Types Used.—Any triode, tetrode, or pentode, or the oscillator section of frequency converter tubes such as 6K8, etc.

TUNED PLATE TUNED GRID (TPTG) OSCILLATOR

Proper tuning requires two controls unless a gang condenser is used. With series feed, the gang condenser must have electrically separated rotors to prevent the shorting of the high voltage to ground. If shunt feed is used, both rotors may be grounded. In the ganging process, variations in the distributed capacity from coil to coil and the effective inductance of each may introduce some tracking problems.

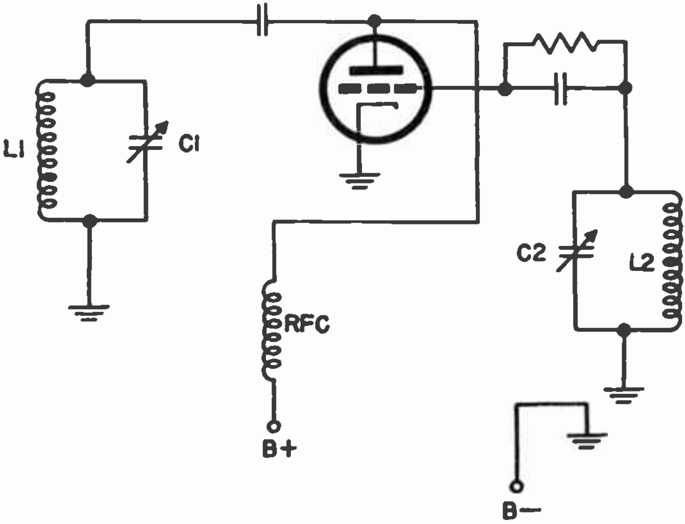


Fig. 60

The TPTG circuit can be used with either series or shunt feed as illustrated in Figs. 60 and 61. In Fig. 60, bias is obtained by a grid to ground resistor, while in Fig. 61, a series grid leak is used. Either method may be used with both circuits.

The TPTG oscillator utilizes the grid to plate capacity of the oscillator as a means of obtaining feedback. The circuit is similar to that of a transformer coupled RF amplifier with the difference that in the latter, oscillations are prevented by neutralization. Tuned circuits L1-C1 and L2-C2 are resonated at the same frequency, which is the operating frequency. RF voltage feedback from the plate circuit, through the grid to plate capacity, to the grid circuit supports oscillation.

Applications.—The principal use of the TPTG oscillator is as a master oscillator in transmitters. Self-excited oscillator-transmitters have made considerable use of it in the past, and its principle has been adapted to crystal control in which form it is widely used. The inconvenience of two tuning condensers makes the TPTG oscillator impractical for such uses as superheterodyne local oscillator, signal generators, frequency meters, etc.

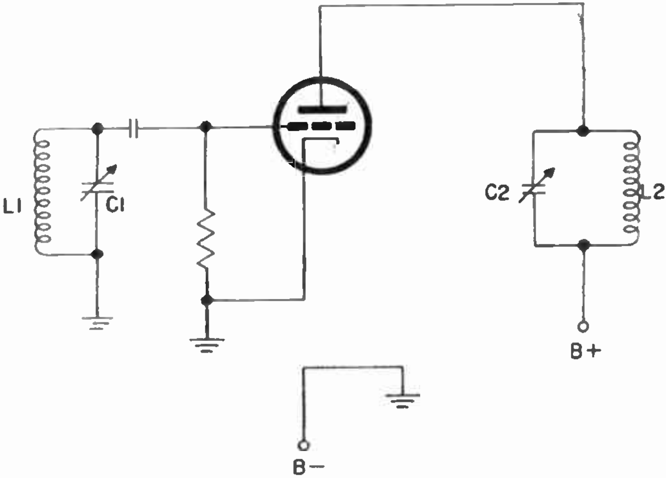


Fig. 61

Advantages.—The TPTG oscillator circuit has the advantage of great flexibility of tuning. Because both plate and grid circuits can be tuned, optimum feedback and frequency conditions can be obtained, with resultant gain in output and stability.

Limitations.—TPTG oscillators are inconvenient to tune because of the two circuits which must be resonated. At relatively low frequencies when a multi-element tube is used, it is often necessary to add another condenser between plate and grid to increase the feedback capacity.

Variations.—The fundamental principle of the TPTG oscillator is also used in a crystal oscillator and the TNT type in which the grid coil is tuned by its distributed capacity instead of an external condenser.

Tube Types Used.—Triodes are most adaptable, because their high plate to grid capacity provides more feedback necessary for oscillation.

TNT OSCILLATOR (TUNED NOT-TUNED)

The TNT oscillator has a tuned circuit in the plate resonated by means of condenser C1. The grid circuit contains a coil (L2) which is self resonant to the same frequency as that of the plate circuit; that is, it is tuned to resonance by the distributed capacity in the coil, together with the input capacity of the tube. The feedback path is through the grid to plate capacity of the tube. Since the L/C ratio of the grid circuit is high (distributed capacity is relatively low), the Q of this circuit is low. The grid tuning is, therefore, broad enough to permit the plate circuit (which should have a high Q) to be tuned over a considerable range of frequencies without serious loss of feedback. The range of efficient operation can be detected by a broad dip in plate current and rise in grid current as the plate circuit is tuned.

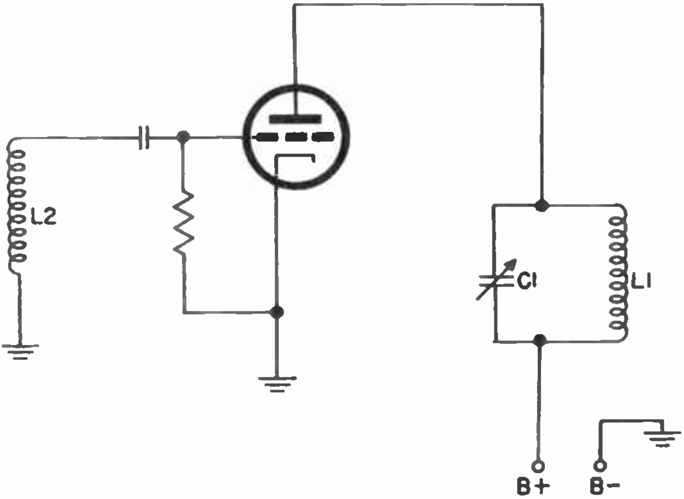


Fig. 62

The grid circuit tuning cannot be made broad enough to provide efficiency over the frequency range necessary in most superheterodyne receivers, signal generators, etc. The TNT circuit is best adapted to fixed frequency operation or uses in which frequency range used is small.

The TNT circuit may be used with either series or shunt feed as illustrated in Fig. 62 and 63. In Fig. 62, bias is obtained through the use of a grid to ground resistor; and in Fig. 63, a series grid leak is used. Either method may be used with both circuits.

Applications.—The TNT oscillator is limited to applications which are either of the fixed frequency type or require only small tuning variations. As such, its main use is as a master oscillator in transmitters.

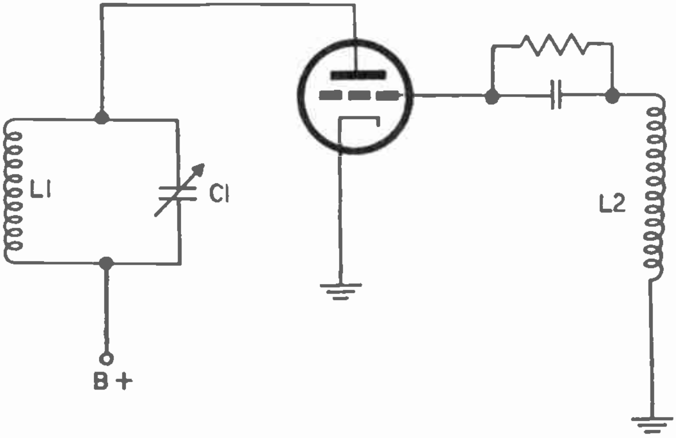


Fig. 63

Advantages.—In applications requiring a small tuning range, the TNT has the advantage that only two coil connections are necessary (for switching or plug-in). The grid circuit acts as a frequency guide in tuning since the oscillator plate current will only dip when the plate circuit is tuned to the grid resonant frequency. Only a single tuning condenser is required.

Limitations.—Frequency tuning range of the TNT oscillator is limited by the broadness of the grid circuit which, for good efficiency, is not sufficient to cover the range used in receivers, signal generators, frequency meters, etc. The frequency stability characteristics of this oscillator are not outstanding due to the low grid tuning capacitance used.

Variations.—Shunt feed is illustrated in the diagram. Series feed can also be used. For series feed, the blocking condenser C is moved to a point between the bottom of the coil and the cathode. B plus is then connected to the bottom of the coil and no RF choke is necessary. The TPTG oscillator is the same circuit except that an extra condenser is added to tune the grid coil. The conventional crystal oscillator uses the same principle by substituting a quartz crystal for the grid coil (see crystal oscillator).

Tube Types Used.—Any triode, tetrode, or pentode.

MEISSNER OSCILLATOR

The Meissner oscillator can be distinguished from other oscillator circuits by its use of a separate tuned circuit which is inductively coupled to the tube elements. This tuned circuit, L1-C1, controls the frequency of oscillation. The amount of coupling between L1 and the other coils L2 and L3 determines the feedback ratio which effects oscillation.

RF plate current, flowing in L2 produces RF current in the tuned circuit L1-C1. The current in L1 in turn induces a voltage across L3, which is applied to the grid. The feedback path is thus established. Since the resonance of L1-C1 allows only the resonant frequency to feedback, the frequency of oscillation is controlled by this circuit.

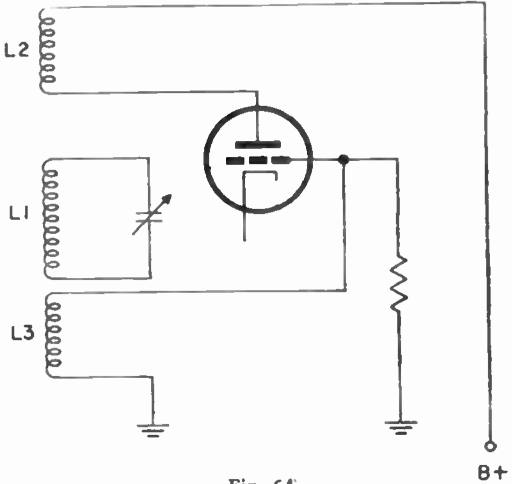


Fig. 64

The Meissner circuit is of note particularly because capacitive coupling between the resonant circuit and the tube elements is practically eliminated. In this way, variations in output with changes in frequency are limited.

The Meissner circuit may be used with either series or shunt feed as illustrated in Figs. 64 and 65. In Fig. 64, bias is obtained through the use of a grid to ground resistor; and in Fig. 65, a series grid leak is used. Either method may be used with both circuits.

Fig. 66 shows the electron coupled version of the Meissner in which the screen acts as the anode and energy is delivered to the plate load through the electron stream.

Applications.—The Meissner circuit is suitable for uses in which a wide range of frequencies must be covered. It is used as a local oscillator in superheterodyne receivers and is applicable to use in signal generators.

Advantages.—The principal advantage of the Meissner oscillator circuit is the fact that no capacitive coupling is used between the tuned circuit and the tube. Frequency stability is good. There is no DC voltage on the tank circuit.

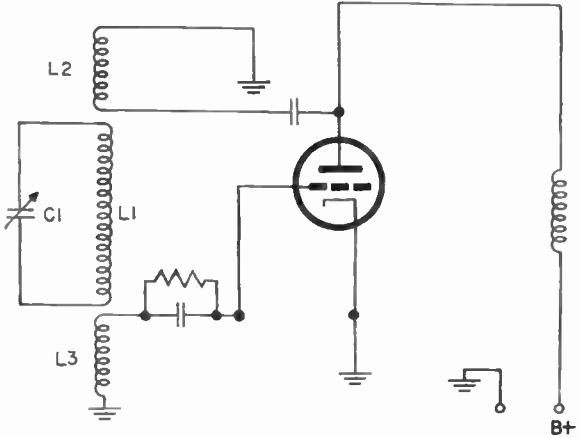


Fig. 65

Limitations.—The Meissner oscillator circuit is somewhat limited in application by the fact that three separate coil windings are needed, making it less flexible for coil changing and band switching.

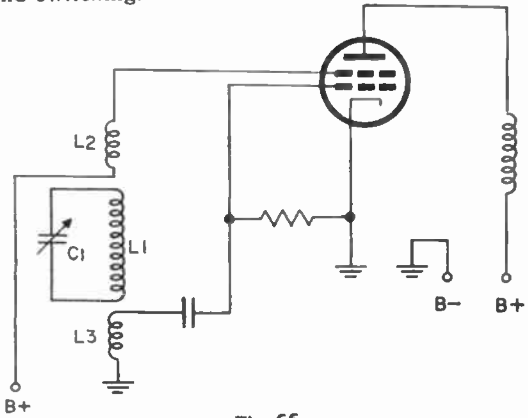


Fig. 66

Variations.—Can be used in electron coupled circuit as shown in Fig. 66.

Tube Types Used.—Any triode, tetrode, or pentode.

ULTRAUDION CIRCUIT

The ultraudion circuit (Fig. 67) has the distinguishing characteristic that there is no visible division between grid and plate portions of the coil L1. This circuit has no coil tap such as does the Hartley or capacity divider as does the Colpitts.

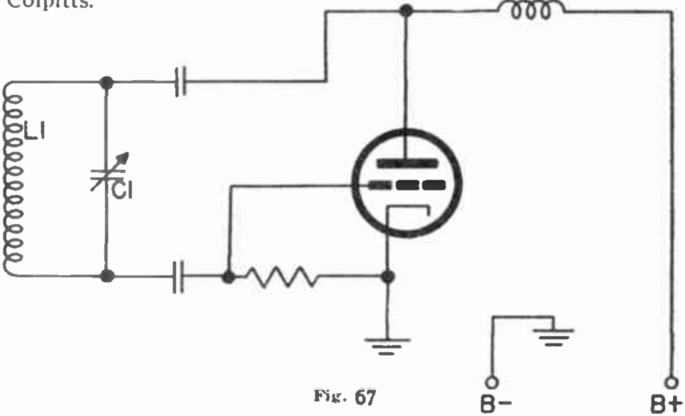


Fig. 67

In the ultraudion, the grid to cathode and the cathode to plate capacitance form a divider which performs the same function as do the dividing capacitors used in the Colpitts circuit. In other words, the operation is exactly the same as the Colpitts circuit except that the dividing capacitances are the interelectrode capacitances of the tube plus stray capacitance in the wiring.

This makes the feedback ratio entirely dependent upon the characteristics of the tube and the stability subject to all the heating effects in the tube elements. Adjustment of feedback is only possible by addition of another condenser between grid and cathode or plate and cathode, or both.

Applications.—Because of the lack of control over feedback ratio and stability, the ultraudion has very few practical uses.

Advantages.—The advantage of the ultraudion circuit is that it is simple and requires comparatively few components since it uses interelectrode capacitances in place of external components.

Limitations.—With the ultraudion oscillator it is not possible to control (even in design) the feedback ratio and therefore it is very difficult to obtain good efficiency. Stability is also very difficult to obtain because the feedback ratio is determined by tube constants alone and is subject to variations due to tube heating.

Variations.—The addition of external capacitances to supplement interelectrode capacitances produces the Colpitts circuit.

Tube Types Used.—Any triode, tetrode or pentode.

KLYSTRON OSCILLATOR

The Klystron oscillator is distinguished by the use of two resonant cavity assemblies (C and D) connected by what is called a "drift tube" E. Most components of the circuit are part of the mechanical construction of the tube. (Fig. 68)

The Klystron tube is known as the "velocity-modulated" type and works on the principle of alternately bunching and thinning the electrons in the cathode stream. Electrons from cathode A are focused and accelerated by electrode B and pass through the grids G1 and G2 of resonator C. The electrons passing through these grids when the grids are positive are accelerated; those passing through on the negative half of the cycle are slowed down, thus the "bunching" effect is produced. The bunches of electrons pass through the grids G3 and G4 of "catcher" resonator D, producing on it the output electric field within chamber D signal voltage. Some of this output is fed back to the buncher cavity C and grids G1 and G2 by feedback link F, and oscillation is supported.

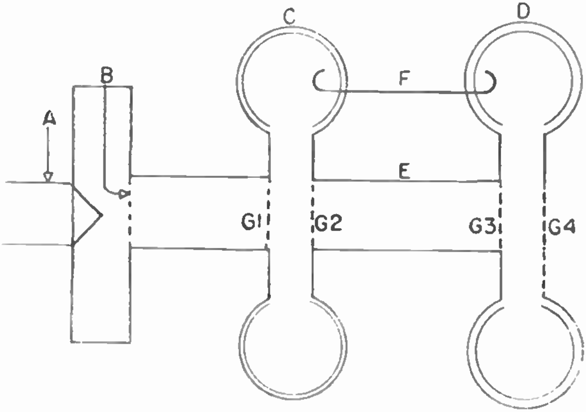


Fig. 68

Applications.—The Klystron oscillator is able to produce stable microwave RF energy with relatively good efficiency.

Limitations.—The Klystron oscillator has cavity resonators fastened to the tube. These resonators are onlv good for use at one frequency except for some types which include flexible resonators which give a small frequency variation. The size of the resonators involved limits the tube to use at frequencies in the microwave region. Oscillation is possibly only at certain tube element potentials as a function of physical dimensions.

Variations.—Variable resonators are provided on some Klystrons.

Tube Types Used.—Klystron tube types according to operating conditions desired.

NEGATIVE RESISTANCE MAGNETRON OSCILLATOR

The negative resistance magnetron oscillator is distinguished by the fact that a magnetron must be used in conjunction with a coil which surrounds the tube. A tuned circuit is used and connected as shown in Fig. 69. The coil surrounding the tube is energized by passing DC current through it. A magnetic field is thus produced in the magnetron. The behavior of electrons in a magnetron in combination with the effect of the magnetic field causes a negative resistance to develop across the anodes of the tube. This negative resistance supports oscillation, the frequency of which is controlled by the tuned circuit.

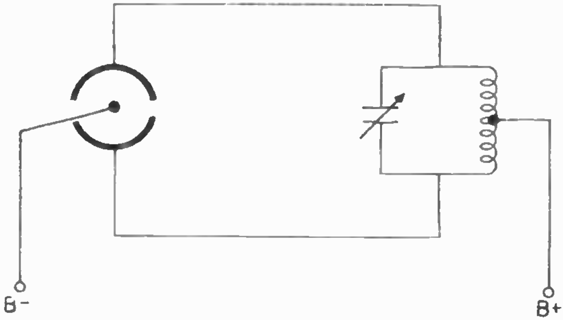


Fig. 69

This magnetron oscillator is different from the magnetron electron oscillator in that the latter can only operate on frequencies determined by the geometry of the tube.

Good efficiency can be obtained at high frequencies providing good high impedance components are used and the magnetic field is of the proper value. This type of oscillator is being used to generate energy at frequencies as high as 600 mc.

Applications.—It is used in pulse signalling systems, radar and U.H.F. relay links where its operating frequencies are appropriate.

Advantages.—The magnetron oscillator can generate RF power of the order of hundreds of watts in its optimum frequency range. Its frequency is quite stable, and is easily varied. Its output is variable according to the anode potential used and may be easily supplied, through coupling, to other circuits.

Limitations.—The magnetron has good efficiency over but a comparatively limited frequency range. Its operation is affected by magnetic fields in the vicinity.

Variations.—Multi-anode magnetron circuits and multi-electron chamber types associated with the magnetic and electrode structures.

Tube Types Used.—Any magnetron of suitable rating and physical characteristics for the service desired.

ELECTRONIC MAGNETRON OSCILLATOR

The electron type magnetron oscillator consists of a magnetron tube with a magnetic field and a tuned circuit connected to the anodes. The circuit is shown in Fig. 70.

Electrons emanating from the cathode at the center of the magnetron tube take a curved path and spin around in the area between the cathode and the anodes. If the tuned circuit is adjusted to the proper frequency, the gyrations of the electrons cause changes in the anode potentials of that frequency.

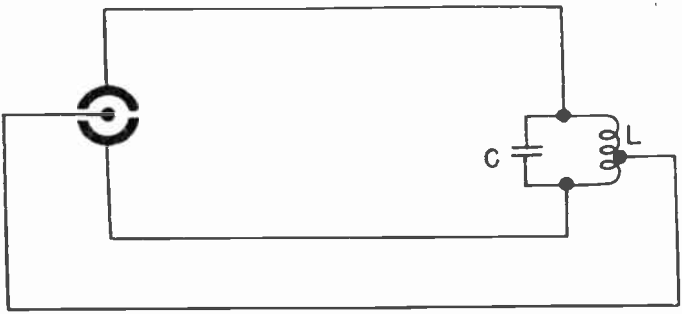


Fig. 70

The frequency of oscillation is determined primarily by the geometry of the magnetron tube. Most magnetrons are designed so that they operate efficiently somewhere in the range between 20 and 100 centimeters. Rather high power can be obtained from such oscillators and as much as 200 watts has been obtained at a frequency of 60 cm.

Applications.—It is used to generate RF energy in pulse signalling systems, radar and U.H.F. relay links where its operating frequencies are appropriate.

Advantages.—The electronic magnetron oscillator can generate considerable RF power of the order of hundreds of watts in its optimum frequency range. Its frequency is quite stable. but it is easily tunable and continuous. Its output is variable according to the anode potential used and may be supplied, through coupling, to other circuits. It tunes at discrete points due to tube geometry and magnetic field.

Limitations.—The electronic magnetron has good efficiency over a comparatively limited frequency range (more restricted than that of the negative resistance magnetron oscillator).

Variations.—Multi-anode magnetron circuits and multi-electron chamber types associated with the magnetic and electrode structures.

Tube Types Used.—Any magnetron of suitable rating and physical characteristics for the service desired.

BARKHAUSEN OSCILLATOR

The Barkhausen oscillator differs from other oscillators in that a *positive* DC voltage is placed on the grid and a *negative* DC voltage is placed on the plate. External tuned circuits are never used since they have no effect on the frequency of oscillation. Fig. 71 shows the circuit.

The positive voltage on the grid draws the electrons toward it. When these electrons reach the grid, however, they pass between the narrow wires and proceed toward the plate. They are soon turned back by the plate's negative charge to return through the grid and start the cycle again. The frequency of oscillation is determined by the geometry of the tube elements and the plate and grid voltages. External circuit constants have only a minor effect on the frequency.

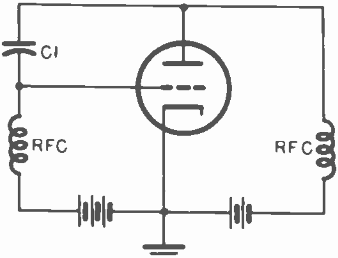


Fig. 71

The Barkhausen circuit overcomes transit time difficulties in ordinary tubes and makes it possible to use these tubes at frequencies above the normal range for negative grid circuits. Care must be taken that grid dissipation is not excessive.

Applications.—The Barkhausen oscillator is used in experimental setups to generate limited amounts of very high radio frequency energy.

Advantages.—The advantages of the Barkhausen oscillator lie mainly in its abiilty to generate extremely high frequency energy with a tube of normally low frequency ratings. This makes the circuit adaptable for use in experimental microwave generators.

Limitations.—The Barkhausen oscillator has very limited power output and efficiency. This is due to the inefficient method of generating oscillations and the fact that the grid at which most of the power is dissipated has a low dissipation rating.

Variations.—The circuit is sometimes rearranged so as to eliminate the RF choke in the grid circuit and place a condenser between cathode and grid. Magnetron oscillators use the same principle of operation.

Tube Types Used.—Any triode can be used, but types with cylindrical elements and magnetrons are particularly useful. RF energy of a wavelength of a few centimeters is easily obtainable with magnetrons.

CRYSTAL OSCILLATOR

The crystal oscillator in its fundamental form is one which uses a crystal connected from grid to ground and a plate tuned circuit which resonates at the crystal frequency.

The circuit (Fig. 72) is fundamentally a tuned-plate tuned-grid oscillator except that a crystal is used as the grid tuned circuit. Positive feedback is provided by the grid to plate capacity of the tube. At very low RF frequencies or when pentodes are used, it is often necessary to use an external capacity connected between the plate and the grid to provide sufficient feedback.

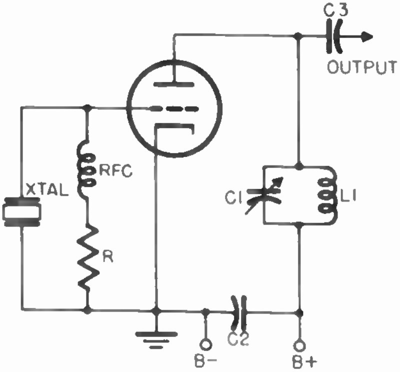


Fig. 72

The crystal oscillator circuit shown is useful because of its simplicity and the fact that the components necessary are not as critical as those found in more elaborate types of crystal oscillators. Output can be obtained on the crystal frequency only.

Applications.—The principal use of the simple crystal oscillator is in transmitting equipment. It is particularly adapted to crystal controlled RF units in which frequency multiplication is not necessary.

Advantages.—The main advantages of the crystal oscillator circuit are its simplicity and the fact that components and operation are not critical.

Limitations.—The simple crystal oscillator cannot be used as a self-contained multiplier as is the case with the tritet oscillator. When the grid to plate capacitance is high (as with triodes) there is danger of injury to the crystal due to excessive feedback unless the power is kept quite low.

Variations.—None.

Tube Types Used.—Any triode, tetrode or pentode of low power commensurate with the frequency and size of the crystal used. Triodes oscillate most easily but tend to give the highest crystal currents.

PIERCE OSCILLATOR (CRYSTAL CONTROLLED)

The Pierce oscillator uses a crystal as a feedback path between the grid and plate circuits of the tube. Fig. 73 is the electron coupled version of the Pierce circuit; the feedback is between the grid and the screen which acts as the anode. The RF generated is then coupled through the electron stream to the plate circuit. Fig. 74 shows the basic Pierce circuit in which the plate acts as the anode. This circuit is not as popular as that shown in Fig. 73 because with equal output the crystal current is greater. This is due to the fact that the crystal is connected to the plate instead of the screen. In both versions, the crystal acts as a series resonant circuit, offering a very low impedance to the resonant frequency and a very high impedance to all others. In this way, only the energy of the desired frequency can be fed back to the grid and the oscillation can occur only at this frequency.

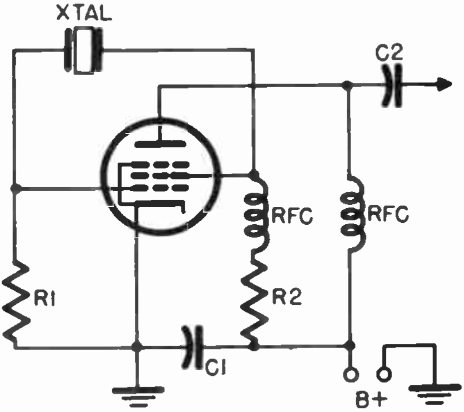
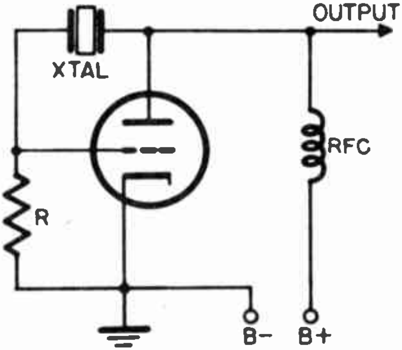


Fig. 73

One of the most important characteristics of the Pierce oscillator is the fact that there are no tuned circuits which require adjustment. If the components are properly chosen, crystals resonant at widely different frequencies will oscillate when placed in the circuit. Depending upon the value of screen voltage used, it is often best to use a blocking condenser between the screen and the crystal.

Applications.—The Pierce circuit is used in transmitters to minimize the number of tuning operations. Since there are no elements to be tuned in this oscillator, frequency changes can be made by simply changing crystals. Another common application is in crystal controlled signal generators used for alignment and calibration purposes.



B−

Fig. 74

Advantages.—The advantages of the Pierce circuit are its simplicity and compactness, and the fact that no tuning controls are necessary. A minimum of parts is needed for its construction. Because the frequency is controlled by the crystal used, frequency stability is much better than is obtainable with tuned L-C circuits.

Limitations.—Due to the fact that the Pierce circuit uses resistance components, the relative losses are higher than in circuits utilizing coils. In order to maintain the crystal current within safe limits and reduce heating and attendant frequency drift, the output of the oscillator must be limited. Since in the Pierce oscillator this means that output is limited to the order of a few watts, it can only be used where small output power is sufficient.

Variations.—The Pierce circuit can be used in either the electron coupled version (shown) or as a straight triode oscillator, in which case the plate, instead of the screen, is the anode. It is often desirable to isolate the crystal from the DC supply. Screen and plate voltages may be fed through RF chokes for higher efficiency. Plate tuning may also be used in the electron coupled arrangement to accentuate either the fundamental or a harmonic of the crystal frequency.

GRID-PLATE CRYSTAL OSCILLATOR

The grid-plate crystal oscillator is a crystal controlled electron coupled oscillator. The circuit is distinguished by its use of a cathode tuned circuit in which respect it is similar only to the "tritet" circuit. (See Fig. 75.)

The control grid, screen, and cathode are the elements of the primary crystal oscillator circuit and when the circuit L1-C1 is tuned to a frequency somewhat lower than that of the crystal, oscillations are produced. The frequency of these oscillations is controlled by the crystal. Energy is supplied to the plate load through the electron stream. The plate resonant circuit L2-C2 may be tuned to the fundamental (crystal frequency) or to a multiple (harmonic) of the crystal frequency.

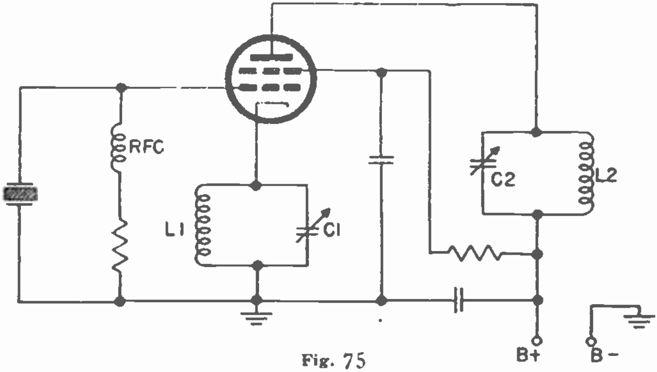


Fig. 75

The grid-plate crystal oscillator is well adapted to use as a frequency generator and multiplier for transmitters.

Applications.—The grid plate oscillator circuit is frequently used in transmitters as a combination RF generator and frequency multiplier. Its design allows crystal control and the ability to produce considerable amounts of power at harmonic frequencies.

Advantages.—The main advantages of the grid-plate circuit are its high harmonic output and the isolation of the crystal from the load.

Limitations.—With tetrodes having a relatively high plate to grid capacity, the grid-plate arrangement cannot be operated at full power output on the fundamental frequency. Feedback in this case can easily be sufficient to heat and fracture the crystal. Frequency stability is not as good as that obtainable with circuits in which the crystal alone determines the frequency. The operating frequency of the grid-plate oscillator is partially dependent upon the values of L1 and C1.

Variations.—Tritet oscillator.

Tube Types Used.—Any tetrode, or pentode.

TRITET OSCILLATOR

The tritet oscillator is an electron coupled oscillator with crystal control. The circuit has two main distinguishing characteristics, as shown in Fig. 76. One is the use of a quartz oscillating crystal between the control grid and the cathode of the tube. The other is a tuned circuit between the cathode and ground.

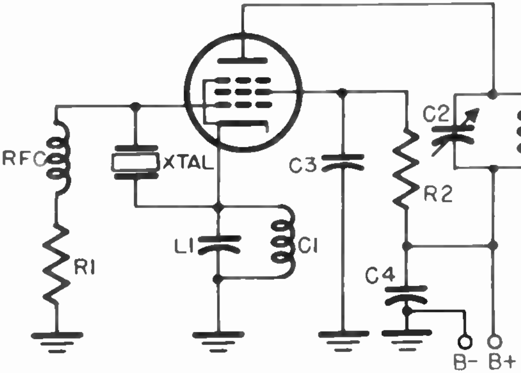


Fig. 76

The crystal and the tuned circuit L1-C1 are connected to the tube elements in a manner that produces oscillation. When the tuned circuit L1-C1 is tuned to a considerably higher frequency than that of the crystal, oscillations take place. These oscillations occur at the resonant frequency of the crystal. They also cause variations in the control grid potential, causing the RF signal to appear in amplified form in the plate circuit. The plate resonant circuit L2-C2 may be tuned to the fundamental (crystal) frequency or to a harmonic (multiple) of that frequency. The circuit is thus suitable for use as an RF generator and multiplier in one stage.

Applications.—The tritet circuit is frequently used in transmitters as a combination RF generator and frequency multiplier.

Advantages.—The main advantages of the tritet circuit are its high harmonic output and the isolation of the crystal circuit which it affords. For example, a 3 mc crystal can be used and good output obtained at 3, 6, 9, or 12 mc.

Limitations.—With tetrodes having a relatively high plate to grid capacity, the tritet arrangement cannot be operated at full power output on the fundamental frequency. Feedback in this case can easily be sufficient to heat and fracture the crystal. Frequency stability is not quite as high as that obtainable in circuits in which the crystal alone determines the frequency. Tuning of L1-C1 will shift the frequency slightly.

Variations.—Grid-plate crystal oscillator.

Tube Types Used.—Any tetrode or pentode.

PUSH-PULL CRYSTAL OSCILLATOR

The push-pull crystal oscillator circuit (Fig. 77) is distinguished by a center-tapped coil connected between the plates of the two tubes and a quartz crystal connected between the two grids. Since the circuit is balanced and both sides of the crystal are at an RF potential above ground, the DC grid return is through the two RF chokes RFC.

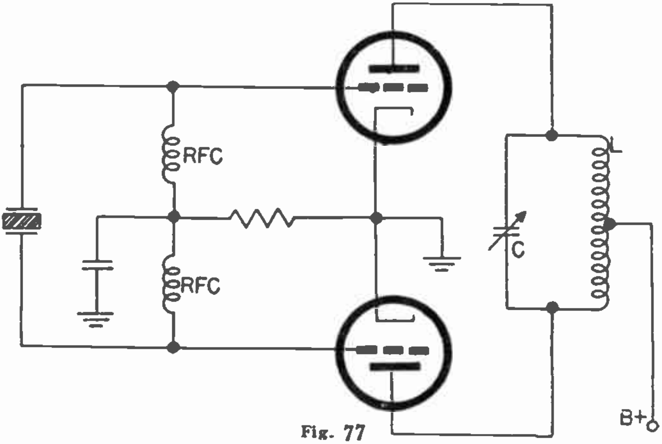


Fig. 77

The tuned circuit L-C is resonated to the crystal frequency. RF from the plates is fed back through the grid-plate capacity to the grids. This produces positive feedback and oscillation. The circuit thus acts as a TPTG oscillator (see elsewhere) with the crystal acting as the grid resonant circuit.

Because the crystal will only oscillate at one frequency, the oscillator frequency is controlled by the crystal and an order of stability normally unattainable by self-controlled oscillators results.

Applications.—The push-pull crystal oscillator is used as a master oscillator in transmitters in which the stability of crystal control and low harmonic content of push-pull operation are desired.

Advantages.—Due to the use of crystal control, this oscillator is much more stable than self-controlled types. The use of push-pull operation cancels out second harmonic energy and eliminates it from the output. Greater output is available compared to single tube types.

Limitations.—The rotor of the variable condenser cannot be grounded unless the split stator type is used.

Tube Types Used.—Any triode, tetrode or pentode. At low frequencies, when tetrodes or pentodes are used, external condensers connecting the plate and grid of each tube are often necessary because of low grid-plate capacity.

RC TUNED OSCILLATOR

The RC tuned oscillator is distinguished by the fact that two tubes are connected in cascade and that parallel and series RC circuits are connected to the grid of one tube (R1-C1 and R2-C2). The circuit is shown in Fig. 78.

This circuit is essentially a two-stage resistance coupled amplifier in which the output of the second plate (V2) is coupled back to the grid of the first tube V1 through the resistor-capacitor combination R2-C2. Because two tubes are used, this feedback is positive and oscillation is made possible. The lamp in the cathode of V1 must be chosen to match V1's cathode current. The frequency of oscillation is governed by the time constants of R1-C1 and R2-C2. Tuning is usually by variation of C1 and C2 which operate together and are generally ganged.

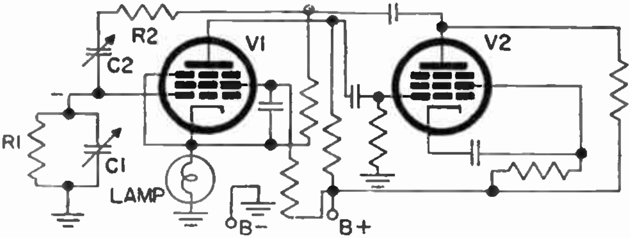


Fig. 78

The combination of the lamp in the cathode lead and the resistor R3 provides a negative feedback voltage, which controls the amplitude of oscillation. This control of amplitude is necessary to keep the distortion to a minimum, and reduces the effect of applied voltage variations on frequency and output.

The RC tuned oscillator is probably the most stable and distortion-free oscillator for producing audio frequency and low radio frequency signals.

Applications.—The RC tuned oscillator is used in highly stable and distortion-free audio frequency signal generators and other test equipment in which a signal of excellent wave form is needed.

Advantages.—The use of resistance coupling and amplitude control makes the RC tuned oscillator extremely stable in frequency and amplitude and capable of producing a very good wave form. A much wider frequency tuning range is available than with other types of audio oscillators.

Limitations.—Two tubes are required for the RC tuned oscillator and a relatively large number of resistors and condensers. Good design limits the tuning range to a frequency ratio of about 10 to 1 in the audio band.

Variations.—The RC tuned oscillator is a variation of the general type also represented by the push-pull negative resistance oscillator, except that in the RC tuned oscillator amplitude control is greater.

Tube Types Used.—Any triode, tetrode, or pentode.

PHASE SHIFT OSCILLATOR

The distinguishing characteristic of the phase shift oscillator is the use of a single tube in an RC circuit including a series of phase shifting RC meshes shown in the diagram as R1-C1, R2-C2, R3-C3. See Fig. 79.

This phase shifting network changes the phase of the signal from the plate in steps until it has been changd 180 degrees. It is then in phase with the grid voltage and is thus fed back to the grid positively to produce oscillation. For a given series of R and C values, there is a definite frequency at which the phase is reversed completely; this is the frequency at which oscillation takes place.

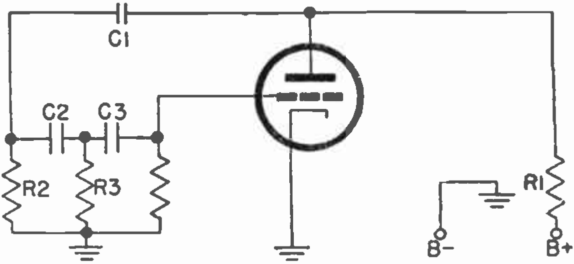


Fig. 79

The phase shift oscillator is probably the simplest of the RC oscillator types. Because of the large number of condensers in the frequency controlling RC network, the circuit is not adapted to use over a large tuning range.

Application.—The phase shift oscillator is very useful as a fixed frequency oscillator. As such, it is used to produce AF voltage in signal generators and other test equipment, code practice oscillators, electronic organs and other fixed frequency devices.

Advantages.—The phase shift oscillator has the advantage of simplicity over other RC oscillator types. Choice of the RC components allows an adjustment of frequency to any reasonable value. Excellent wave form and stability are obtainable in the audio frequency range. Only one tube is used. Narrow range tuning can be achieved, but calibration accuracy is relatively poor.

Limitations.—Because of the fact that a number of condensers (C1, C2, C3) or resistors (R1, R2, R3, R4) must be varied simultaneously, the phase shift oscillator is not adapted to operation over a tuning range. Operation on radio frequencies is not practical because of the losses involved with suitable phase shift components. Output is very low. The load affects the Q shift and therefore the frequency.

Variations.—More or less phase shifting resistors and condensers may be used in the phase shift oscillator. The minimum number to produce a complete 180 degree phase change is usually three sections as shown.

Tube Types Used.—Any triode, tetrode, or pentode.

MAGNETOSTRICTION OSCILLATOR

The magnetostriction oscillator is characterized by the use of a metal rod as a frequency controlling device. The circuit is shown in Fig. 80. The rod is placed in the grid and plate coils, which are placed so that there is no coupling, or mutual inductance, between them. The rod is made to have a magnetomechanical resonance at the frequency at which oscillation is desired.

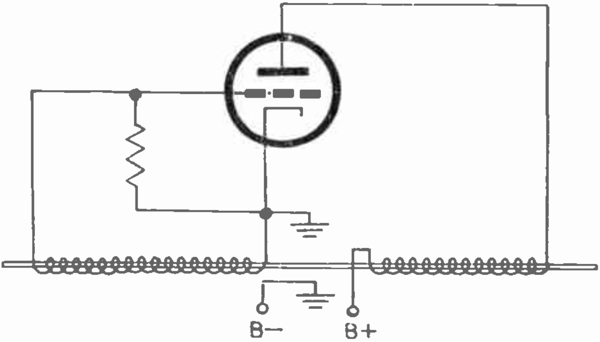


Fig. 80

Since there is no mutual inductance between the coils, oscillation does not take place until the rod is inserted in the coils. Then any electrical impulse in a coil magnetizes the rod causing it to alter its dimensions (magnetostrictive effect) and tend to vibrate mechanically. This mechanical vibration in turn induces a voltage in a second coil. Feedback and oscillation at the resonant frequency of the rod are thus established. Oscillation is very critical in frequency and is determined by the composition and dimensions of the material.

This circuit was developed and is used for generation of supersonic waves. The rod will radiate supersonic energy at its self-resonant frequency.

Applications.—The magnetostriction oscillator is used for generating and radiating supersonic waves in the frequency range from 15 kc to 4 mc or higher. Audio frequencies can also be generated in this manner.

Advantages.—The magnetostriction oscillator is simple in construction and is one of the few ways of creating and radiating supersonic energy efficiently. Tuning is very sharp as the magnetostrictive material has a very high effective Q.

Limitations.—Oscillation frequency depends entirely upon the physical properties and dimensions of the material and can be changed only slightly by external means. Production of the magnetostrictive materials for many desirabie frequencies is very expensive. Oscillator output is dependent upon the frequency (the amount of material used) to a great extent.

Tube Types Used.—Any triode, tetrode or pentode.

FRANKLIN OSCILLATOR

The Franklin oscillator, illustrated in Fig. 81, is composed of two tubes in cascade, resistance coupled, with the output of the second tube fed back to the grid of the first tube. A tuned circuit (L-C) is then added at the grid of the first tube, to lock the oscillations into its resonant frequency. This frequency is also affected by time constants C1(R1+R3) and C2(R2+R4).

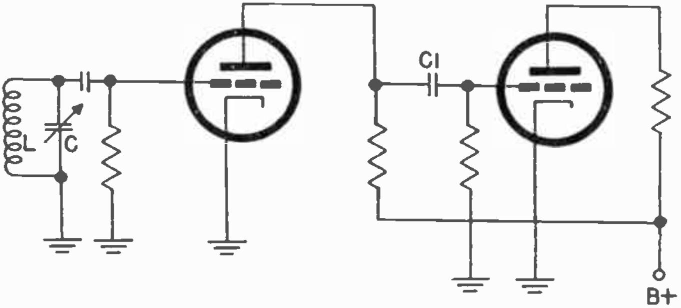


Fig. 81

The signal from the grid of V1 passes through V1 and V2, each tube adding a 180° phase shift. The signal is thus fed back to reinforce the original grid voltage and produce oscillation. This action is similar to that in a multivibrator but in this case a tuned circuit is added and the tubes are operated in such a manner as to produce a good wave form.

The tuned circuit L-C is usually coupled so loosely to the tube that the tube constants have little effect on the frequency of oscillation.

Applications.—The Franklin oscillator is used for general oscillator purposes in audio and the lower radio frequency ranges.

Advantages.—The Franklin oscillator circuit is a relatively simple RC oscillator and is controlled by an LC circuit giving good wave form and stability, especially at frequency steps corresponding to the time constants C1(R1+R3) and G2(R2+R4).

Limitations.—Oscillator frequency output and efficiency are not constant over a uniform frequency range due to the effect of the time constant circuits in absorbing energy, and in tending to determine frequency steps. Two tubes are required along with other components which make the circuit more expensive to construct than other oscillator types.

Variations.—The Franklin oscillator is one of a group of types which make use of a two stage amplifier to shift the phase sufficiently to produce positive feedback. Others are the push-pull negative resistance type and the multivibrator type.

Tube Types Used.—Any triodes, tetrodes or pentodes.

DYNATRON OSCILLATOR

The Dynatron oscillator (Fig. 82) is distinguished by the fact that the plate voltage is made lower than the screen voltage and a tuned circuit is usually connected in the plate circuit. Like the transitron, the Dynatron oscillator makes use of the negative resistance characteristic which a tube can be made to have through the use of the proper operating conditions. In these oscillators, the plate secondary emission is made to produce this negative resistance characteristic by operation with a screen voltage higher than the plate voltage.

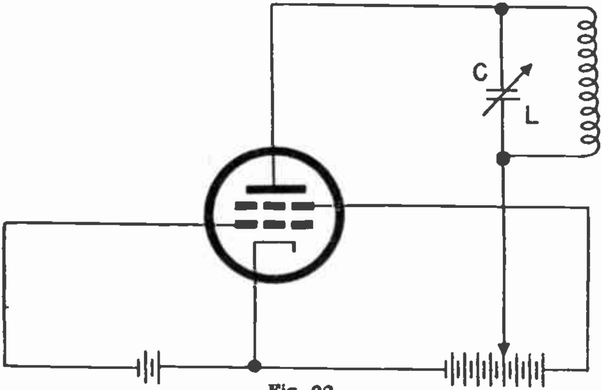


Fig. 82

The Dynatron oscillator is suitable for audio frequency and low radio frequency operation.

Applications.—Because of its relative stability compared with many other types and its adaptability to a wide tuning range, the dynatron has been frequently used in frequency meters and calibrators. It is suitable for an economical, low output signal generator covering the AF and low RF range. It is simple and easy to construct.

Advantages.—The main advantage of the dynatron oscillator is its simplicity. Although not as stable as some other oscillators, its stability is relatively good. Its stability is particularly good with respect to changes in applied voltages. Thus the power supply generally need not be regulated, making for lower cost equipment.

Limitations.—The Dynatron oscillator is not as stable as some other types of negative resistance oscillators as, for instance, the transitron. It is not suitable for high power applications. A rather limited range of tube operating voltages must be used to achieve the dynatron characteristic wth any particular tube type.

Variations.—The transitron and other negative resistance oscillators are simply variations of the same principle involved in the operation of the dynatron.

Tube Types Used.—Any tetrode.

TRANSITRON OSCILLATOR

The transitron oscillator (Fig. 83) can be recognized by the fact that a pentode is always used and the positive voltage on the screen is greater than that on the plate. A negative voltage is applied to the suppressor through the resistor R.

The transitron oscillator depends for its operation on the fact that when conditions are as described above, the tube offers a ***negative resistance*** to the tuned circuit. In other words, a decrease of screen voltage causes an increase in screen current and vice versa, due to the relative effect of the suppressor and screen grid fields.

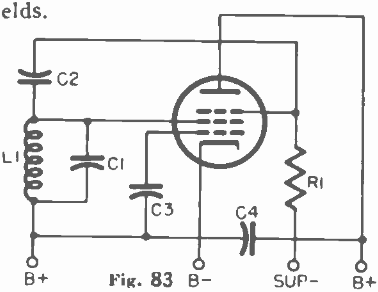


Fig. 83

The transitron, like other RC negative resistance oscillators, is well suited to use as an audio oscillator. It is similar to the dynatron oscillator but has more output and uses modern tube types.

Applications.—The transitron oscillator is used in audio oscillators designed as test equipment and in other AF generator applications such as modulated RF signal generators; also in telephone line amplifiers giving frequency correction.

Advantages.—The transition oscillator, like other RC oscillators, is relatively stable at audio frequencies because there are no resonant circuits. Its output is greater than that of the dynatron oscillator. A greater frequency range is possible than with LC tuned oscillators because the frequency is inversely proportional to capacity rather than the square root of capacity as in tuned circuit oscillators. The wave is clean and free of harmonics. An injected signal can easily be made to control the frequency. The circuit is simple and economical, using but a single tube.

Limitations.—Tube element voltages must be held within rather narrow operating limits for good operation. Operation is unstable with variable loading and requires a buffer stage for best results as an AF oscillator. Output varies with frequency unless $\frac{L1}{R1\text{-}C1}$ is maintained constant. To do this, two or three elements have to be varied simultaneously with frequency tuning. Thus it is impractical for use as a wide range oscillator. Operation can be obtained satisfactorily from 10 cps to 10 ms with proper adjustments.

PUSH-PULL NEGATIVE RESISTANCE OSCILLATOR (KALLITRON)

The push-pull negative resistance oscillator is distinguished by the fact that two tubes are used connected in cascade as resistance coupled amplifiers with the output of each plate coupled to the grid of the other tube. A tuned circuit is added between the two plates, as shown in Fig 84.

The signal on the grid of VI is amplified in the plate circuit, coupled through C1 to the grid of V2 and then appears at the plate of V2, whence it is coupled back to the grid of VI. Positive feedback is thus produced and the system oscillates. The frequency of oscillation is controlled by the tuned circuit L-C3 along with the time constants of C1 (R1 + R3) and C2(R2 + R4). The more nearly L-C3 resonates to the frequency or a harmonic of the frequency determined by the time constants of C1(R1 + R3) and C2(R2 + R4), the better the frequency stability and the better the output wave shape.

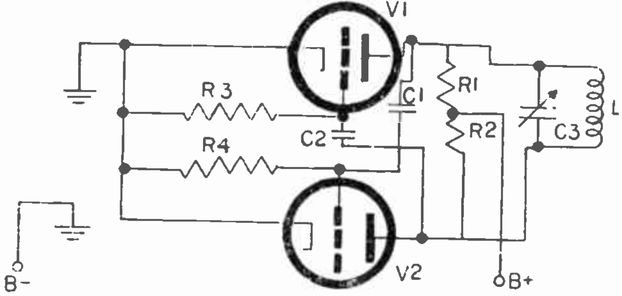


Fig. 84

Applications.—The push-pull negative resistance oscillator is used at audio and lower radio frequencies. As an audio oscillator, it is useful to provide a stable signal of good wave form.

Advantages.—Oscillation is most stable at frequencies which are harmonics of that determined by the time constants of C1(R1 + R3) and C2(R2 + R4). Thus, frequency steps can be chosen with the tuned circuit which are useful for frequency identification or measurement purposes.

Limitations.—Oscillator frequency output and efficiency are not constant over a uniform frequency range due to the effect of the time constant circuits in absorbing energy, and in tending to determine frequency steps. Also, two tubes are required along with other components which make the circuit more expensive than other oscillator types.

Variations.—The Franklin oscillator is a variation of the push-pull negative resistance type. The only difference between the two circuits is that the controlling L-C tuned circuit is balanced and connected between the plates on the push-pull type. The Franklin oscillator couples the tuned circuit

Tube Types Used.—Any triode, tetrode, or pentode.

MULTIVIBRATOR

The multivibrator circuit is an oscillator consisting of two tubes connected as resistance coupled amplifiers in cascade. This circuit is shown in Fig. 85. The output of the second tube, V2, is coupled back to the grid of the second tube, V1.

Because each tube introduces a 180° phase shift, any impulse starting at the grid of V1 and passing through the circuit will be reinforced by the voltage fed back from the plate of V2 to the grid of V1. This positive feedback builds up until the circuit oscillates. The frequency of oscillation is determined by the time constants formed by C1, R1, and R4, and C2, R2, and R3 which give the conduction time of each tube.

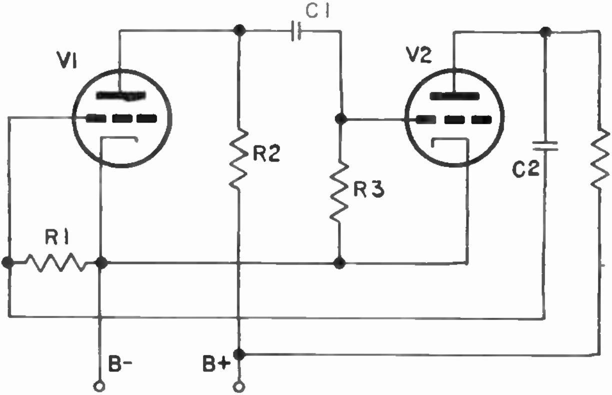


Fig. 85

The wave form of the signal produced by a multivibrator oscillator is very irregular and the output is thus rich in harmonics. It is also very easy to regulate, or "lock" the frequency of oscillation by means of a synchronizing signal injected into the circuit.

Application.—The large number of harmonics and ease of frequency synchronization account for a variety of uses of the multivibrator. One of the most important applications is its use in frequency measuring devices. Secondary RF frequency standards starting with a 100 kc oscillator and using a multivibrator to produce 10 kc marker points are quite common. Other uses include electronic counters and timers, frequency dividers, etc.

Advantages.—The multivibrator has two main advantages. First, its output is rich in harmonics (through the 100th and higher) and second, it can easily be controlled by an injected signal.

Limitations.—The distortion and the operating conditions of the multivibrator make it unsuitable as a primary signal source.

Tube Types Used.—Any triode, tetrode, or pentode.

BLOCKING OSCILLATOR

The blocking oscillator is a variation of the Armstrong tuned grid type. It is rearranged so that it can be locked into a synchronizing voltage fed into the circuit as shown in Fig. 86. The circuits are broadly tuned near the desired frequency (preferably lower) by means of the distributed capacity.

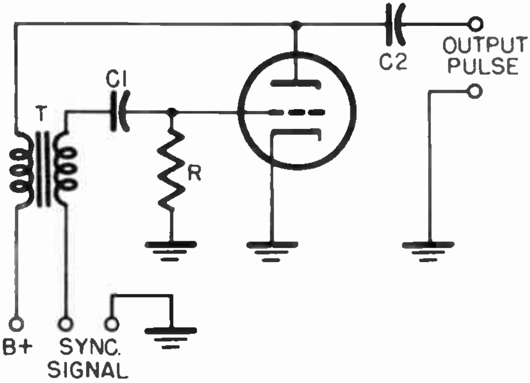


Fig. 86

Its purpose is to produce pulses in the output circuit as a result of a controlling voltage fed to the grid. The Q of the coils is very low due to the use of distributed capacity for tuning and the fact that very tight coupling is used. The grid leak R is made very high in resistance so that as soon as an oscillation starts, the resulting grid current causes a sharp cut-off in the wave form.

Because of these characteristics, the blocking oscillator is useful in television receivers for producing pulses or increments of high frequency oscillation which can be synchronized with the incoming signal and used to trigger the sweep circuits.

Applications.—The blocking oscillator is frequently used in television receivers for synchronizing with video pulses of the incoming signal. The circuits are made sufficiently broad to facilitate "locking" of the oscillations to the synchronizing pulses of the television signal.

Advantages.—The blocking oscillator is simple and easy to construct. If properly designed, it will easily "lock" itself to a synchronizing voltage fed into it.

Limitations.—Voltages and operating conditions must be adjusted carefully to produce desired type of oscillation.

Tube Types Used.—Any triode, tetrode or pentode.

GAS TUBE RELAXATION OSCILLATOR

The gas tube relaxation oscillator is distinguished by the use of a simple series RC circuit connected across a voltage source and a gas tube connected across the condenser. The circuit is shown in Fig. 87.

When the voltage is applied, current flows through resistor R and into condenser C, charging it gradually up to the "firing" voltage of the gas tube. When this firing voltage is reached, the gas tube suddenly becomes a short circuit and discharges the condenser C. The same cycle then starts again. The frequency at which this cycle occurs depends upon the values of resistance and capacitance used. Large condensers make for a lower frequency since they take longer to charge. Larger values of resistance make for a lower frequency by limiting current flow and thus increasing charging time.

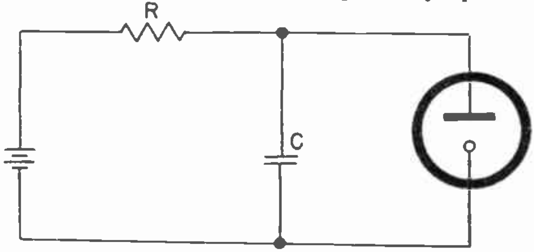


Fig. 87

The frequency of oscillation of a gas tube relaxation oscillator can be approximated by the expression:

$$f = \frac{1}{RC}$$

Applications.—The gas tube relaxation oscillator is used for generating audio frequency signals when wave form and stability are not important factors. One such application is tone generation in the less expensive type of signal generator. Another is as a very cheap sawtooth generator for oscilloscopes.

Advantages.—The main advantage of the gas tube relaxation oscillator is its simplicity and low cost, requiring only a resistor, a condenser, and a gas tube.

Limitations.—The gas tube relaxation oscillator is unstable and the wave form is distorted approaching a sawtooth shape as the source voltage becomes large compared to the firing voltage of the gas tube.

Variations.—The same principle is used with triode gas tubes in which the amplitude and frequency of oscillations are controlled by a bias on the grid.

Tube Types Used.—Neon bulbs, voltage regulators such as VR105, VR150, etc., and thyrations such as 884, etc.

SELF-RECTIFIED OSCILLATOR

The self-rectified type of oscillator is distinguished by the fact that AC power is fed into the plates by means of a transformer, the secondary of which is center tapped and connected to the cathodes of the tubes through a filter choke. The circuit is shown in Fig. 88. The plates and grids of the tubes are coupled to tuned circuit L-C in such a manner as to produce positive feedback and make RF oscillation possible.

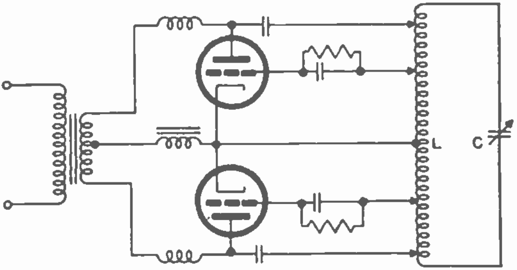


Fig. 88

The plates draw pulsating DC current; each tube conducting when its plate becomes positive. Filter choke L1 smoothes out these pulsations; and if the two halves of the circuit are well balanced, the ripple percentage will be fairly low.

The fact that AC power can be fed directly into the oscillator without a separate power supply makes this circuit adaptable to uses in which it is necessary to work with a minimum of power supply equipment and some ripple can be tolerated.

Applications.—The self-rectified RF oscillator is used mainly in shipboard transmitters and as a generator in RF heating units. It is very difficult to eliminate the ripple from the RF output and therefore this circuit is seldom used in radiotelephone or good CW transmitters.

Advantages.—This circuit has the advantage that it is simple and plate DC power is not required. As shown, it is of the push-pull type and the second harmonic content of the output is low.

Limitations.—Because of the fact that AC power and RF energy are applied to the same tubes, the self-rectified oscillator is inherently subject to hum ripple modulation which is difficult to remove completely. It has poor frequency stability characteristics.

Variations.—The self-rectified principle may also be used in connection with a single ended oscillator provided two tubes are used in parallel in the RF circuit and push-pull in the power rectifier section. AC can be applied directly between the center tap of the plate tank circuits and ground.

Tube Types Used.—Any triodes, tetrodes or pentodes. The tubes used are ordinarily of the transmitting type and must be capable of carrying the peak plate current and withstanding peak voltage of one-half of the secondary .

DIODE MIXER

The diode mixer circuit is distinguished by the fact that the incoming signal and the oscillator RF output are both applied between the plate and cathode of a diode vacuum tube. In receivers, the incoming signal is usually fed in through a tuned circuit or antenna coil. The oscillator voltage is fed into the mixer either capacitively or inductively bv coupling to the tuned circuit. The circuit is shown in Fig. 89.

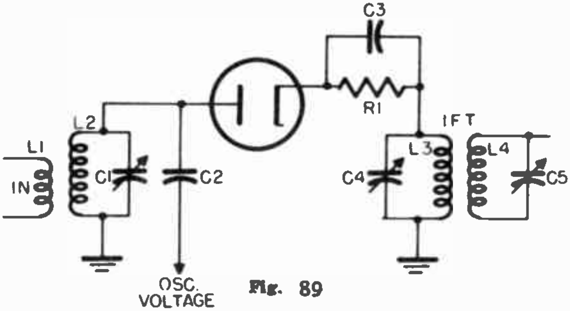


Fig. 89

The detection effect of the diode causes the sum or difference frequency currents to flow through R and build up a voltage across the IF transformer primary. This circuit in conjunction with an oscillator tube makes up the front end of a superheterodyne receiver. This type of detector finds its widest use at high RF frequencies where the loading and transit time effects of ordinary mixer tubes become excessive. Because the electron stream flows only to the plate and no other elements are present, the noise level of the diode mixer is quite low. The diode mixer is also suitable for mixing low RF and audio frequencies. In this application it is usually used because of its simplicity.

Applications.—The diode mixer is frequently used in high frequency receiving equipment. Its low transit time, loading effect, and capacity make it especially suitable for receivers operating on frequencies above 50 mc. The diode mixer is also used for mixing audio tones and low frequency RF signals in receivers and test equipment. This latter use is usually in equipment in which compactness is an important consideration.

Advantages.—The principal advantages of the diode mixer are low input capacity and transit time effects. These two factors make the loading on high frequencies less than that of other types of mixers. Although it requires filament voltage, no plate screen, etc., power must be supplied. The fact that the electrons need flow to only one element (the plate) causes the relative noise level of the diode mixer to be low.

Limitations.—No conversation gain can be obtained from a diode mixer and a separate oscillator is always required.

Tube Types Used.—6H6, 7A6, etc., also diode sections of multi-element tubes and tubes with all elements but cathode tied together.

CRYSTAL MIXER

The crystal mixer circuit is distinguished by the fact that the incoming signal and the oscillator RF output are both applied across a crystal detector. In receivers, the incoming signal is usually fed in through a tuned circuit or antenna coil. The oscillator voltage is fed into the circuit either capacitively or inductively by coupling to the tuned circuit. The circuit is shown in Fig. 90.

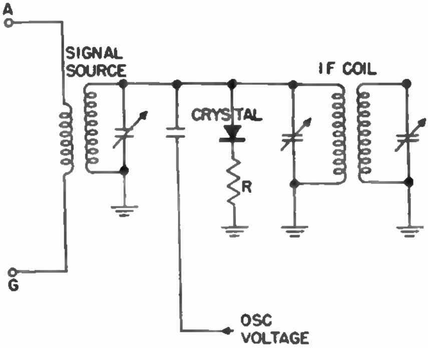


Fig. 90

The detecting action (non linear impedance) of the crystal causes the sum or difference frequency currents to build up a voltage across the primary of the IF transformer. The front end of a superheterodyne receiver can thus be constructed with the oscillator the only tube required. This type of detector is used mainly at high frequencies where the loading and transit time effects of ordinary mixer tubes become excessive. The crystal detector has negligible transit time effect and its capacitance is very low.

The crystal mixer is also suitable for mixing low RF and audio frequencies where it is sometimes used because of its simplicity and compactness.

Applications.—The crystal mixer is frequently used in high frequency receiving equipment. Its low transit time loading effect and capacity make it especially suitable for receivers operating at frequencies above 50 mc. The crystal mixer is also used for mixing audio tones and low frequency RF signals in receivers and test equipment. This latter equipment is usually of the type in which compactness is an important consideration.

Advantages.—The advantages of a crystal mixer are as follows:

1. Compactness
2. No filament or other external power required
3. Negligible transit time loading
4. Low capacity

Limitations.—A crystal detector is not very stable unless it is set for less than its maximum sensitivity. Commercial crystal detectors preset at the factory are adjusted for the best compromise. A separate oscillator is always required.

TRIODE MIXER

The triode mixer was one of the first mixer circuits used. It was employed in early superheterodyne receivers because multi-element tubes were not yet available. Although converter tubes have been developed to eliminate the use of a separate oscillator, the triode mixer is still desirable because of its low noise level compared to that of mixer circuits employing multi-element tubes. The triode mixer requires the use of another tube in a separate oscillator.

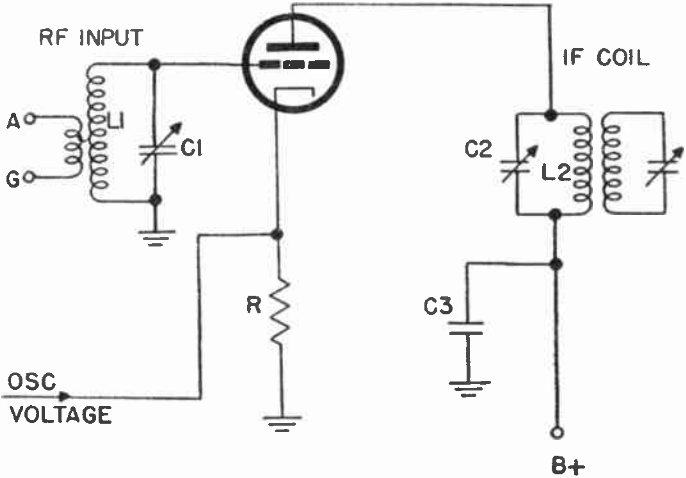


Fig. 91

Fundamentally the circuit is a triode connected as an amplifier with its grid circuit tuned to the frequency of the received signal. The plate circuit is usually the primary of the first IF transformer and is tuned to the intermediate frequency. Oscillator voltage is fed into the grid circuit. A number of methods have been developed to inject this oscillator voltage, two of which are shown here. Fig. 91 shows the cathode injection system and Fig. 92 the inductive system.

The non-linear characteristic of the grid circuit and of the amplification curves of the tube causes the difference or sum frequency to become available in amplified form in the plate circuit. The desired heterodyne is selected by the tuned primary of the IF coil.

Applications.—The triode mixer has been used in superheterodyne receivers of all frequency ranges. With the development of the more compact and efficient pentagrid converter for low frequencies, the tridoe mixer has found more favor in the high frequency region. Having a lower noise level and less loading effect than the pentagrid type the triode mixer competes with and is usually more desirable than the pentagrid type at frequencies above 50 mc.

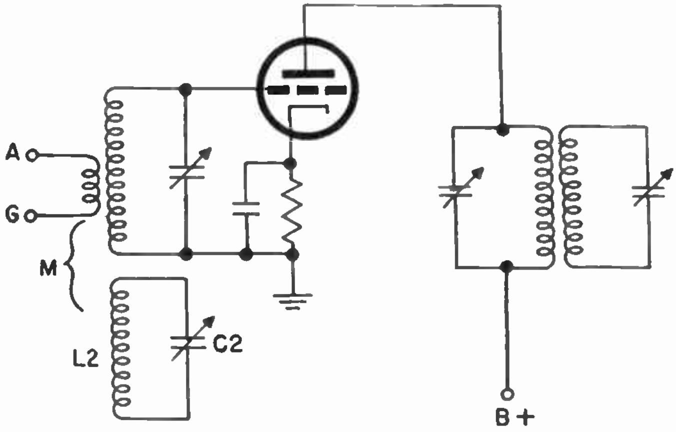


Fig. 92.

Advantages.—The principal advantages of the triode mixer are:

1. Low noise level (better signal to noise ratio).
2. Less loading effect than mixers employing multi-element tubes.
3. Less oscillator "pulling."

Limitations.—The gain of a triode mixer is less than that of multi-element types and therefore the conversion transconductance is lower.

Variations.—The variations of the triode mixer are mainly in the means of injecting the oscillator voltage. Two of these methods are shown here in Fig. 91 and Fig. 92. Others are illustrated in the basic circuits on injection methods.

Tube Types Used.—Any triode, preferably those with high perveance (g_m/C) for the higher RF range.

PENTODE MIXER

RF pentodes are used as mixers to gain the advantage of their efficiency at high frequencies. Good RF pentodes have relatively low input and output capacitances. They also have a high gm (transconductance). This combination makes for good amplification or conversion efficiency on high frequencies.

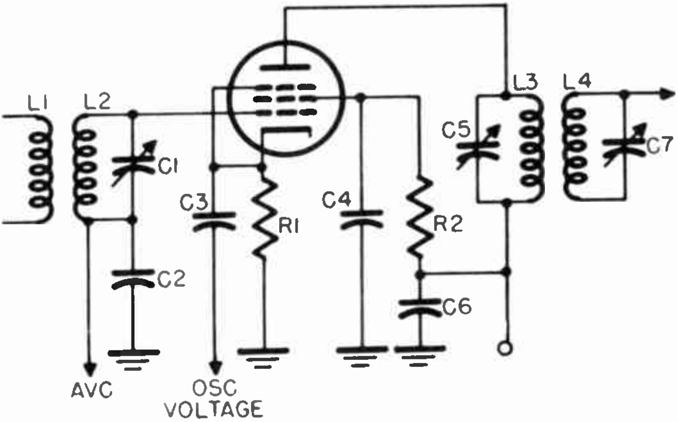


Fig. 93

Since the pentode of itself does not provide sufficient elements for a self-contained oscillator, a separate oscillator tube must be used.

Fundamentally the circuit is a pentode connected as an amplifier with its control grid circuit tuned to the frequency of the received signal. The plate circuit is usually the primary of the first IF coil and is tuned to the intermediate frequency. Oscillator voltage is fed into the grid circuit. A number of methods have been developed to inject this voltage, and two of them are shown in Fig. 93 and 94. Fig. 94. shows the cathode injection system and Fig. 94. the inductive system.

The non-linear characteristic of the grid circuit and the amplification curves cause the difference and sum frequency to be available in amplified form in the plate circuit. The desired heterodyne is selected by the tuned primary of the IF coil.

Applications.—The pentode type of mixer is used in various types of superheterodyne receivers to provide the non-linear medium necessary to mix the received signal and the local oscillator. The high gm of RF pentodes makes it useful at high frequencies. It gives good conversion efficiency.

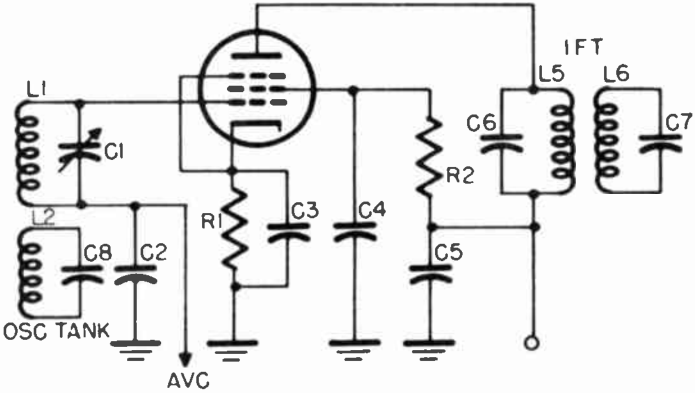


Fig. 94.

Advantages.—The advantages of the pentode mixer are mainly in the gain available at the higher frequencies. This gain is possible because in good RF pentodes the input and output capacitances are relatively low and the gm of the tube is very high. When these two things are true at the same time, the tube is said to have a high "perveance" and therefore gives greater gain.

Limitations.—Although the pentode mixer has a high gm, it has several important disadvantages:

1. The fact that there are five elements in the tube causes the noise level of a pentode mixer to be higher than that of a triode. The noise level is not as bed as in a pentagrid converter.
2. Since no extra grid convenient for injection is provided, coupling between oscillator and incoming signal is quite high. This leads to oscillator "pulling" much greater than if "electronic" mixing were used.

Tube Types Used.—Any Pentode.

BALANCED MIXER

The balanced mixer circuit is shown in Fig. **95.**

The input circuit to the grids is balanced and usually tuned, as shown, with a split stator condenser. Input from either an antenna and ground or an RF stage is fed in at points A and G. The bias resistor R is adjusted so that the tubes operate on the bend in the Eg-Ip curve in the same manner as a square law detector (see elsewhere). This provides the non-linear necessary to create the heterodyne (intermdiate) frequency. The intermediate frequency transformer is tuned to the heterodyne frequency and selects the intermediate frequency signal from the other signals appearing in the plate circuit. A second or heterodyning signal is coupled into the grid circuit such that it is superimposed on the first.

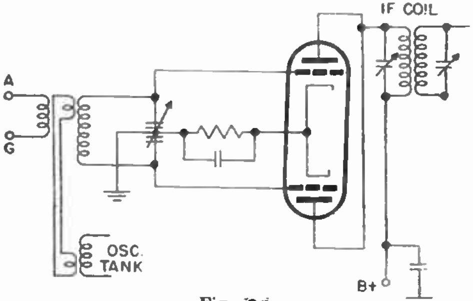


Fig. 95.

A separate oscillator is always necessary. The circuit arrangement places the grid to cathode input capacitances in series across the tuned circuit, reducing the effective capacity across the tuned circuit. This factor, and the fact that the circuit is balanced, make the circuit very well adapted to high frequencies.

Applications.—The balanced mixer finds its most frequent application in high frequency receivers. Because of the balanced nature of the input circuit and the low input capacitance, the circuit has less losses than most others when operating above 50 mc. The low capacity input characteristic makes the circuit adaptable to broad band applications and for this reason it is frequently found in television receivers.

Advantages.—The main advantages of the balanced mixer circuit are:

1. Balanced nature of input circuit
2. Low capacitance of input circuit

The push-pull balanced input circuit is well adapted to coupling to a balanced transmission line from an antenna or RF amplifier stage. The low input capacity reduces input loading effects and permits more efficient broad band operation.

Limitations.—The balanced mixer requires two tubes (or a dual triode) instead of one as in other mixers. This is in addition to a local oscillator requiring another tube.

Tube Types Used.—6J6, 6AL5, etc.

OFF TUNE DISCRIMINATOR

This discriminator circuit uses a three-winding IF transformer as shown in Fig. 96. The primary circuit L1-C1 is tuned to the intermediate frequency. One of the secondaries is tuned to a frequency higher than the intermediate frequency; the other to a frequency lower than it. Refer to Fig. 96. The operation of the off tune discriminator can be easily understood by assuming that L2-C2 resonate at a frequency higher than the intermediate frequency, and L3-C3 resonate at a frequency lower than it. As the signal at the output of the last IF amplifier deviates higher in frequency than the intermediate frequency, it approaches the resonant frequency of L2-C2 and goes further from the resonant frequency of L3-C3. This causes the rectified DC voltage across R1 to increase, that across R2 to decrease, and point A becomes positive with respect to ground. When the signal deviates lower in frequency, a similar process takes place making point A negative with respect to ground. Thus AF signal fluctuations corresponding to the frequency modulation previously imposed on the incoming signal appear across R3.

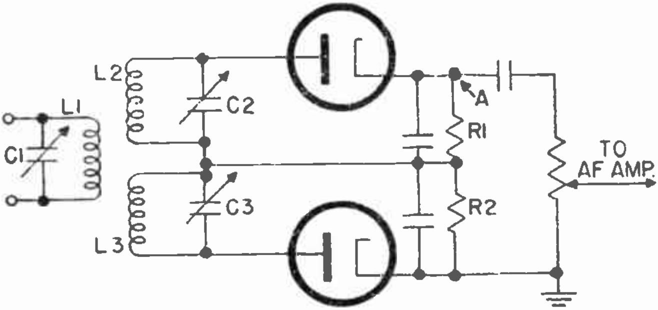


Fig. 96

Applications.—This type of circuit is occasionally found in FM receivers and in automatic frequency control circuits. Because it performs no better than simpler types, it is not used frequently.

Advantages.—It is comparatively easy to set the tuned circuits for a given deviation range since the resonant frequency of each secondary is set just outside the limits of frequency deviation in either direction. The Q of the tuned secondary circuits must be the same in order to produce a smooth linear curve between the two resonant peaks.

Limitations.—The off tune discriminator is not as frequently used as other types because of the expense of the three tuned circuits in the last IF coil.

Typical Tubes Used.—Any diode, but preferably a dual diode with separate cathodes.

PENTAGRID MIXER

The pentagrid mixer makes use of a tube containing five grids. The circuit is shown in Fig. 97.

The control grid (No. 1) is connected to the resonant circuit L1-C1, which tunes to the received signal. A signal voltage is thus applied to grid No. 1 and fed into the electron stream of the tube. Oscillator voltage is obtained from a separate oscillator circuit and fed to grid No. 3 through C2. The received signal and the oscillator signal are mixed in the electron stream (electronic mixing). The gm of tube is simultaneously varied by these two injected control voltages. Screen grids No. 2 and No. 4, are tied together and RF bypassed to ground through C3. These screen grids thus surround injection grid No. 3, shielding it and eliminating its capacity effects with other elements. This shielding prevents interaction (pulling) between incoming signals and the oscillator. The plate circuit contains the primary of the first IF coil which is tuned to the sum or difference frequency.

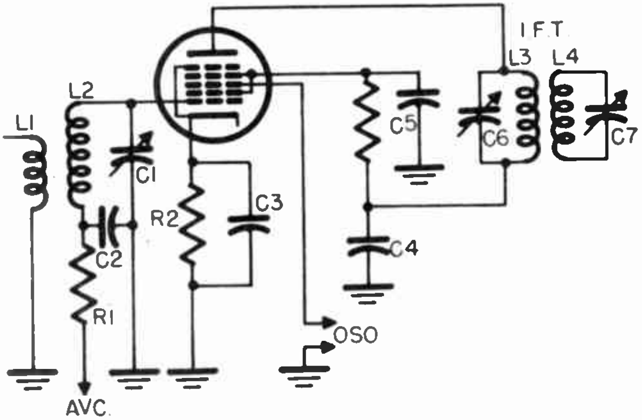


Fig. 97

Applications.—Because it is used with a separate oscillator, the pentagrid mixer is seldom found in small, inexpensive receivers. Generally the circuit is found in the more elaborate receivers and those designed for short waves. At high frequencies, where oscillator pulling tends to be most severe, the shielding grids 2 and 4 play an important part in improving stability. This type of mixer is also used in beat frequency AF signal generators.

Advantages.—The main advantage of the pentagrid mixer is the fact that the injection grid is shielded from the other elements in the tube. This shielding is accomplished by the screen grids (No. 2 and 4). The gain of the pentagrid mixer is high, resulting from the fact that it is used as a pentode and has a high gm.

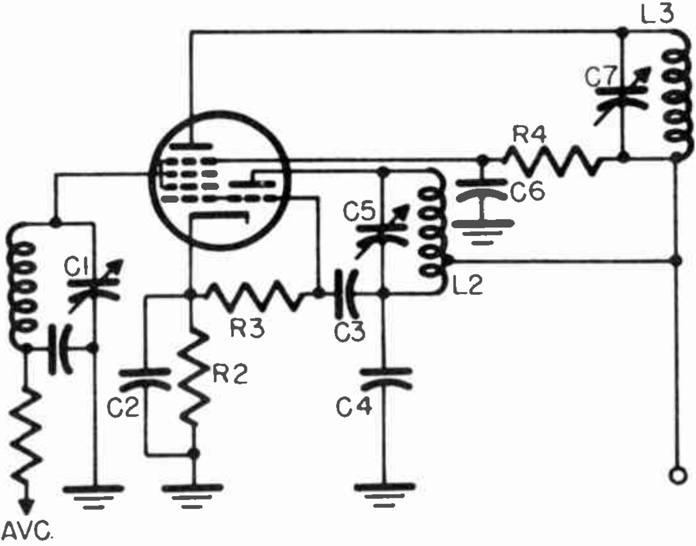


Fig. 98.

Variations.—A common variation of the pentagrid mixer circuit is similar to the 6L7 (used in Fig. 97) except that the anode and the grid of the oscillator are separated from the mixer electron stream. The oscillator grid is connected to the grid of the mixer inside the tube.

Limitations.—The pentagrid mixer requires a separate oscillator for conversion. This limits its use in small compact and inexpensive receivers. Being a multi-element tube, the noise level is higher than that produced in diode or triode mixers.

Tube Types Used.—6L7, 6L7G.

PENTAGRID CONVERTER

The pentagrid converter circuit shown in Fig. 99. is distinguished by two important features. One is the fact that separate grids are provided for the oscillator and the incoming signal respectively. The other is the fact that the signal grid (No. 4) is surrounded by two screen grids which shield it from the other elements in the tube. Grid No. 2, which is a third screen grid, is used as the anode of the oscillator.

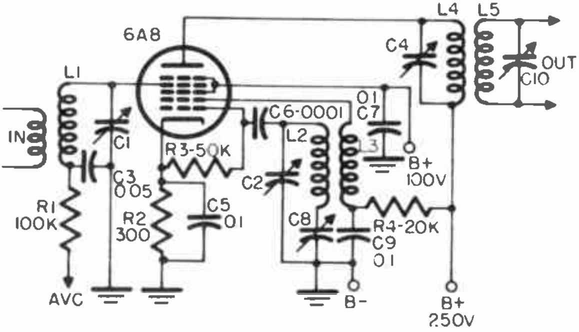


Fig. 99.

A signal is applied to points A and G from an antenna or an RF amplifier stage. Resonant circiut L1-C1 is tuned to this signal and builds up a signal voltage on grid No. 4. Screen grids 3 and 5 are operated at ground RF potential and thus shield the signal grid.

Grid No. 1 is the oscillator grid; grid No. 2 is the oscillator anode. These elements may be connected in any one of a number of ways to produce the necessary oscillation. Fig. 99. and 100 show the two main types of pentagrid converters. Fig. 99. shows a circuit using a 6A8 tube. In this circuit, grids 3 and 5 are screens, grid 2 is the oscillator anode. Fig. 100 shows another circuit as used with the 6SA7 tube. Here there is no element used for the oscillator anode alone, grids 2 and 4 being both screen and oscillator anodes. Grid No. 5 is a suppressor and is connected to the cathode. In either case, the oscillations cause the grid No. 1 potential to vary according to the oscillator radio frequency signal. These potential fluctuations cause the electron stream to vary at radio frequency. The signal grid (No. 4) also influences the electron stream according to the incoming signal. The two signals are mixed in the electron stream in a process referred to as "electronic mixing." The sum or difference heterodyne (IF) is extracted in the plate circuit by the tuned primary of the IF coil (L4-C4).

Applications.—The pentagrid converter circuit is one of the most popular types used in modern superheterodyne receivers. Since the tube includes both mixer and oscillator elements, it permits the use of a very compact converter section. This factor makes it popular in small low priced receivers. The shielding provided between the signal grid and other elements provides stability and efficiency appropriate to the best receivers as long as the frequency coverage is below 20 mc. The pentagrid converter is also used in test equipment of the type in which mixing is required.

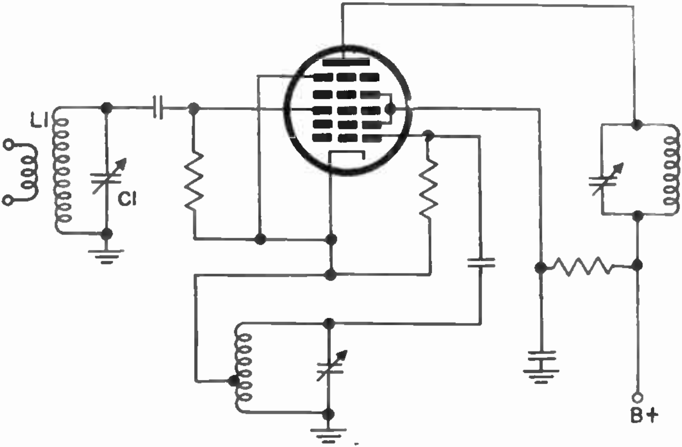


Fig. 100

Advantages.—The pentagrid converter circuit provides stable operation and good conversion gain on the lower frequencies, especially in the broadcast band. The interelectrode capacities are low enough not to interfere with operation below about 20 mc and "pulling" is minimized by the shielding of the signal grid.

Limitations.—The pentagrid converter is limited in its applications to frequencies below the 20 mc region. In the higher range, interelectrode capacities become excessive; and, despite the shielding effect of the screen grids, "pulling" usually becomes serious. The use of so many elements makes the noise level of this type of converter quite high.

Variations.—The pentagrid converter is similar to the pentagrid mixer, except that the latter uses a separate oscillator. The pentagrid converter differs from this circuit only in that it uses the screens as the oscilator anode and eliminates grid No. 2. A suppressor grid is added.

Tube Types Used.—6A8, 12AB, 6D8, 6A7 (Type A); 6SA7, 12SA7 (Type B).

TRIODE-HEXODE CONVERTER

The triode-hexode converter uses a tube containing a triode section and a hexode section in the same envelope. The triode is connected as an oscillator and the hexode is connected as a mixer. The two circuits are coupled inside the tube to provide oscillator voltage injection and electronic mixing.

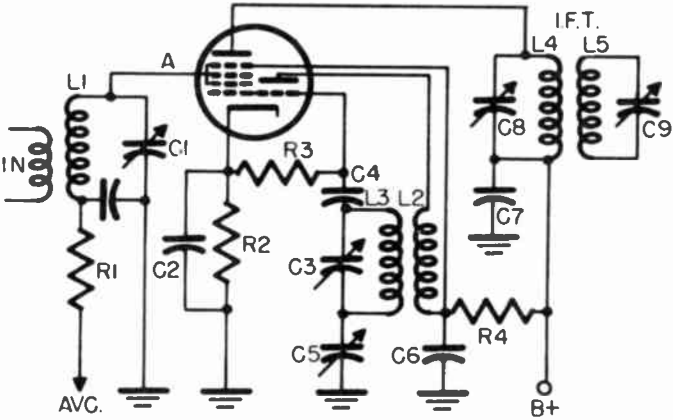


Fig. 101

The input circuit L1-C1 is tuned to resonance at the frequency of the incoming signal. This builds up a voltage on the signal grid (point A). The triode is connected as an Armstrong oscillator in Fig. 101 and as a Hartley in Fig. 102. Any standard RF oscillator circuit may be used.

The control grid of the oscillator and grid No. 1 of the hexode are connected together. The radio frequency voltage developed on the oscillator grid is thus fed into the electron stream of the hexode. The circuit is therefore practically the same as though separate tubes were used with oscillator grid and the mixer injection grid directly connected. This "separate tube" arrangement minimizes interaction between incoming signals and the oscillator frequency.

Because separate electron streams are used for oscillator and mixer, variations in mixer plate potential or grid bias voltages do not have as much effect on the oscillators frequency as they do in other circuits. For instance, in pentagrid converter circuits, AVC voltage is applied to the tube which contains the oscillator elements, causing plate voltage and current variations. The triode-hexode converter eliminates this trouble giving greater oscillator stability.

Applications.—The triode-hexode converter is used in superheterodyne receivers and in test equipment using superheterodyne circuits. The characteristics of the circuit are such as to favor operation on the higher frequencies, giving best performance in the "short wave" region from 2 to 50 mc. Interelectrode capacities are minimized through the use of two separate electron streams. This greatly reduces oscillator pulling and allows stable operation on frequencies far higher than the limits of good operation for pentagrid converters. The triode-hexode converter also has miscellaneous applications requiring two tubes with grids connected.

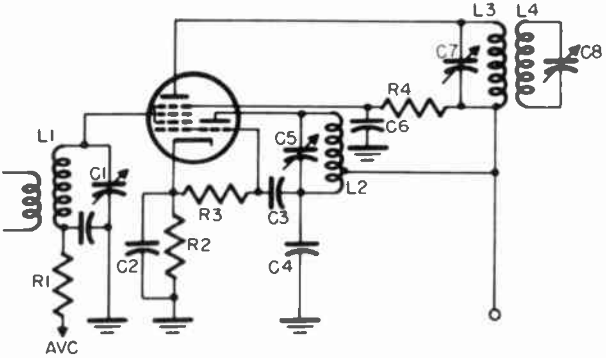


Fig. 102

Advantages.—The triode-hexode converter uses separate oscillator and mixer sections. This reduces the interaction between the oscillator and mixer sections and permits operation on higher frequencies than is possible with converters which are self-contained.

Limitations.—Although the triode-hexode converter uses two separate sections for the oscillator and mixer, one element is interconnected. This results in interaction between the incoming signal and the oscillator which at very high frequencies becomes appreciable.

Variations.—Any triode oscillator circuit may be used

Tube Types Used.—6K8. 12K8, etc.

RATIO DETECTOR

The ratio detector is distinguished by its use of an IF transformer with a center-tapped secondary (called a "discriminator transformer"), two diodes and a load circuit as shown in Fig 103 Its purpose is the detection of frequency

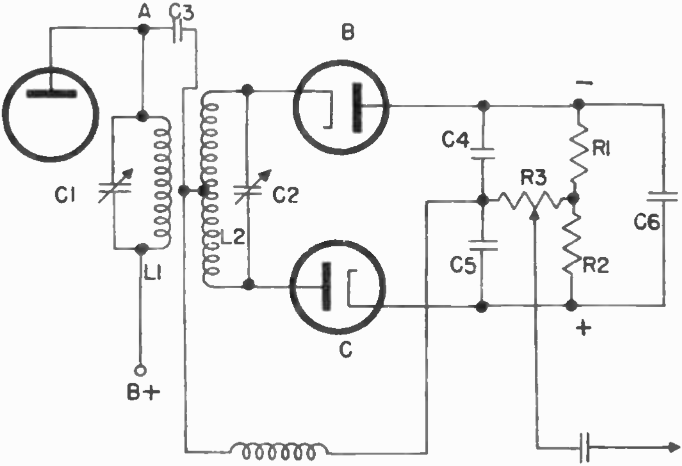
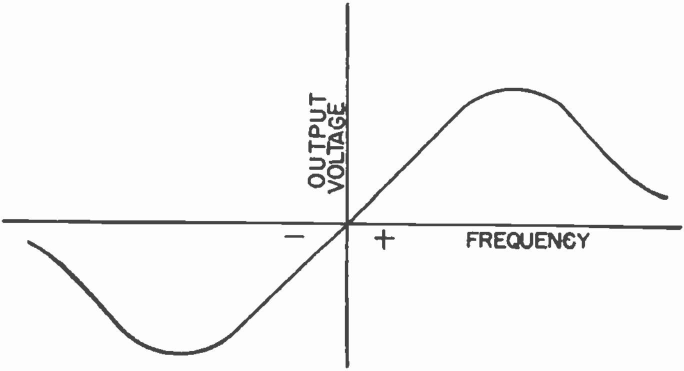


Fig. 103

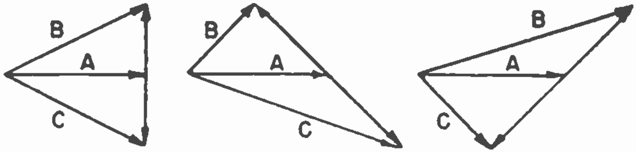
modulated signals. The circuit differs from the Foster-Seeley type in that the polarity of one diode is reversed.

The RF voltages applied to the diodes at B and C are the vectorial, or phased, sum of the primary voltages at A and the half of L2 connected to the diode involved. The phase relation is such that, as the frequency of the signal goes higher, RF voltage B grows larger and RF voltage C grows smaller; when the frequency deviates downward, C grows larger and B smaller. The rectified DC voltages across R1 and R2 are proportional to the AC voltages across the diodes to which they are connected. Because of the manner in which the diodes are connected, DC current will flow through R1 and R2 only when B is negative and C is positive. A DC voltage , proportional to the received signal and with the polarity shown, will appear across R1 plus R2. Condenser C6 is made large enough to filter out all but very slow fluctuations in the signal. Due to variations in the phasing of voltages B and C with carrier deviations, varying DC voltages appear across C4 and C5, producing a varying current in R3. This is the desired audio signal. The instantaneous sum of the voltages across C4 and C5 must at all times equal the fixed voltage across C6; in other words, the ratio of voltages C4 and C5 varies and not their sum. This fact prevents amplitude variations from affecting the output and gives the ratio discriminator its name. The response curve is the same as that of a Foster-Seeley discriminator (Fig. 104). The output voltage is that appearing across R3 or across C4 or C5.

Applications.—The ratio discriminator is widely used as a second detector in FM receivers.



DISCRIMINATOR CHARACTERISTIC



AT RESONANCE BELOW RESONANCE ABOVE RESONANCE

Fig. 104

Advantages.—The ratio discriminator has the inherent property of canceling amplitude variations in the received signal, thus eliminating the need for a limiter stage. The AM signal voltage canceling process is effective on signals of any strength and there is no ‘threshold” value of input signal below which no canceling is possible as there is with receivers using limiters.

Limitations.—An extra component is necessary in this circuit. Condenser C6 is necessary to keep the total rectified voltage E constant with rapid variations in the incoming signal. Although the ratio detector inherently discriminates against AM noise, its rejection ability is not as good as a well designed limiter-discriminator combination. Equal limiting is provided at very low signal levels but is not complete.

Variations.—The ratio detector is very similar to the Foster-Seeley discriminator. The main differences are reversal of one diode plate and cathode connections, inclusion of ratio condensers C4 and C5, and addition of residual condenser C6.

Typical Tubes Used.—Any two single diodes or any dual diode of the RF type.

FOSTER-SEELEY DISCRIMINATOR

The Foster-Seeley discriminator circuit is used to detect frequency modulated signals and does so by means of various phase shifts in voltages produced in its component parts as the incoming radio frequency signal deviates. The circuit is shown in Fig. 105 An IF transformer (generally called a "discriminator" coil) with a tapped secondary is used. The primary resonant circuit L1-C1 is made broad enough to have a flat response over the FM signal deviation band width; the secondary circuit L2-C2 normally has a relatively high Q to accentuate phase shift over the frequency deviation range from the center of the IF.

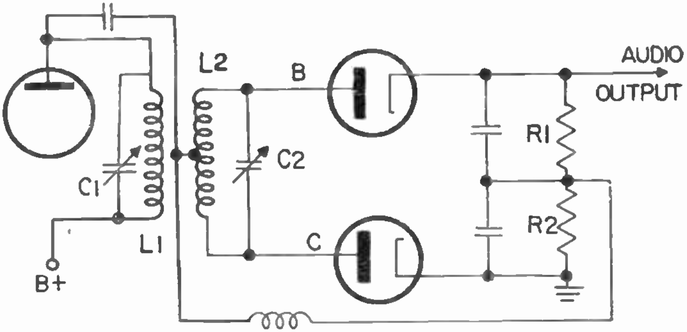


Fig. 105

The RF voltages applied to the plates of the diodes at B and C are the vectorial or phased sum of the primary voltage at A and the voltage appearing across the half of L2 connected to the diode involved. The phase relation is such that as the frequency of the signal goes higher, voltage B gets larger and voltage C gets smaller; when the frequency deviates downward, C gets larger and B smaller. The rectified DC voltages across R1 and R2 are proportional to the AC voltages on the diodes to which they are connected. With respect to ground, their polarities are opposed. The net result at point D is a voltage varying positively and negatively as the signal deviates about the center frequency.

Fig. 106 shows vectorially the phase relations involved.

Applications.—A large number of FM receivers use the Foster-Seeley discriminator as a second detector. In this application, it is preceded by a limiter because the detector itself does not discriminate against amplitude variations. This necessity for a limiter has tended to lessen its use in inexpensive receivers which utilize a ratio discriminator without a limiter. In addition, AM and FM receivers which include automatic frequency control (AFC) use their circuit to produce the reactance tube control voltage.

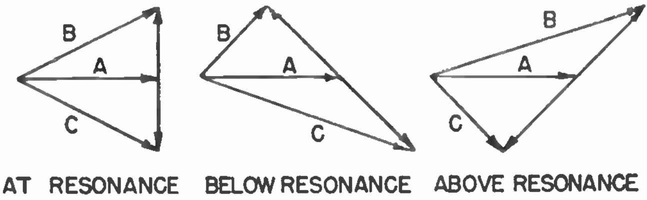


Fig. 106

Advantages.—The Foster-Seeley discriminator is relatively simple as far as number of parts and circuit arrangement are concerned, and gives high fidelity audio response. An average response curve (such as that shown in Fig. 107) remains quite linear with great deviation of the signal.

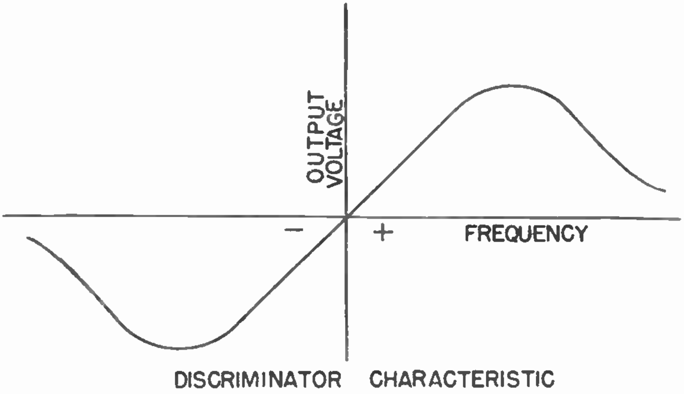


Fig. 107

Limitations.—The Foster-Seeley discriminator circuit is sensitive to AM as well as FM signals and must, therefore, be preceded by a limiter. It is also somewhat critical as far as choice of components is concerned, and must be carefully aligned to prevent distortion.

Typical Tubes Used.—Any RF diode such as 6H6, 6AL5, etc. Crystal detectors may also be used in place of vacuum tubes.

LOCK-IN OSCILLATOR DETECTOR

The lock-in oscillator detector is distinguished by the fact that a signal from the IF section of the receiver (FM) is fed into the signal grid of a pentagrid converter tube and a signal of a frequency which is a submultiple of the IF is produced in the plate circuit. A typical circuit is shown in Fig. 108 The plate and grid No. 3 oscillate at this submultiple frequency, which is usually one-fifth of the IF.

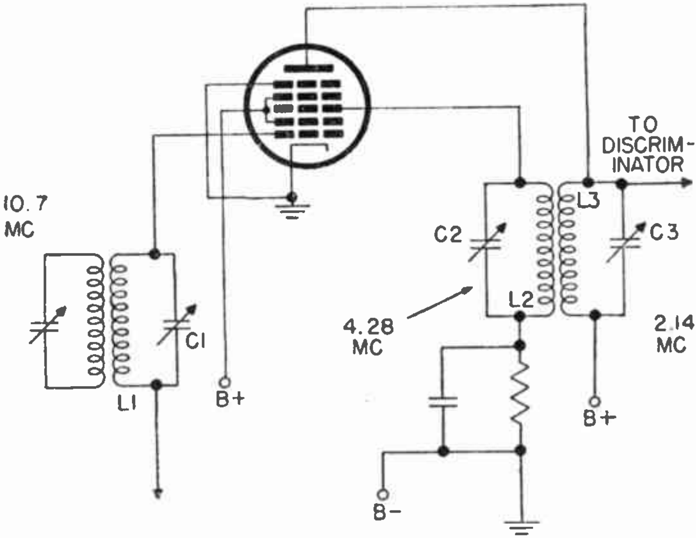


Fig. 108

The typical circuit shown operates as follows:

1. Plate and grid No. 3 oscillate at 2.14 mc, the resonant frequency of L3-C3.

2. L2-C2 is tuned to 4.28 mc, second harmonic of 2.14, thus accentuating other even harmonics.

3. Because of the action in 2, a considerable amount of the 4th and 6th harmonics are produced: 8.56 mc and 12.84 mc.

4. A 10.7 mc FM signal is fed in through L1-C1. This signal beats against the 8.56 mc and 12.84 mc harmonics, producing more of the 2.14 mc output signal.

5. The ±75 kc deviation of the incoming IF signal is reduced proportionately in the 2.14 mc signal to ±15 kc.

6. The 2.14 mc oscillator is "pulled" or "locked in" to follow this deviation. The signal is then passed on to a reduced range discriminator for final detection.

Because the lock-in oscillator can only be "pulled" by the strongest and nearest signal, great adjacent channel selectivity is afforded.

Applications.—The lock-in oscillator is used in FM receivers as a substitute for the limiter and as a partial detector. Although a narrow range discriminator is used, the lock-in oscillator reduces the frequency and deviation to make the discriminator more efficient.

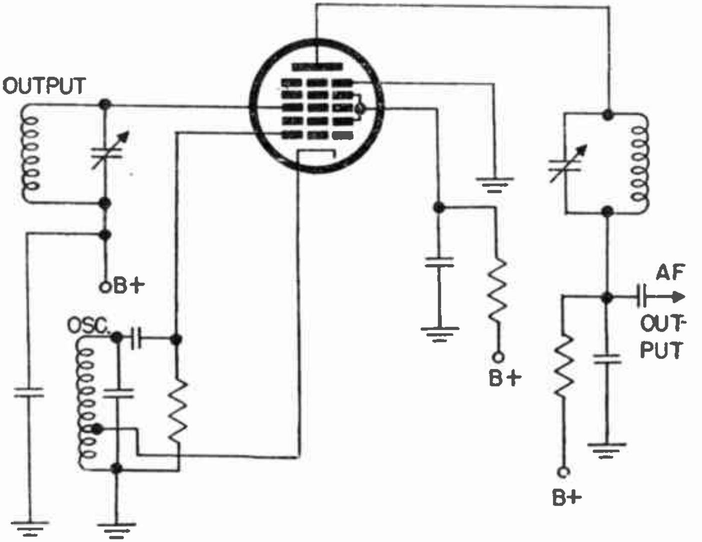


Fig. 109

Advantages.—The greatest advantage of the lock-in oscillator detector is its adjacent channel selectivity. Other types of limiter-detector arrangements leave a wide pass band open at all times, whereas the oscillator in this circuit responds only to the desired signal and is not influenced by weaker adjacent channel signals. There is also greater stability resulting from the transformation to a lower frequency signal in the discriminator.

Limitations.—The lock-in oscillator circuit for detection is a little more involved than ordinary limiter-discriminator arrangements. Several tuned circuits must be adjusted for proper operation and an oscillator is included.

Variations.—An important variation of this circuit makes use of the fact that the plate current of the tube varies in *amplitude* according to the deviation of the incoming signal. A resistor is placed in the plate circuit and audio output obtained from it as shown in Fig. 109

Typical Tubes Used.—Pentagrid converters or mixer tubes and separate oscillators.

CRYSTAL DETECTOR

The crystal detector makes use of the rectifying action of a galena, carborundum, germanium or other suitable type of crystal to detect an amplitude modulated signal. The tuned circuit (Fig. 110) resonates at the frequency of the incoming signal and builds up the RF voltage to a maximum. This RF voltage causes a current to flow through the crystal and earphones in series. Because of the rectifying action of the crystal, the current is pulsating DC. The bypass condenser, C2, is made small enough in capacity to filter out the RF pulsations and yet allow the desired audio signal to appear across the earphones. If an antenna and a ground are connected to points A and G respectively, the circuit becomes a self-contained radio receiver. The earphones may be replaced by a resistor or a choke so that output may be fed into an audio amplifier.

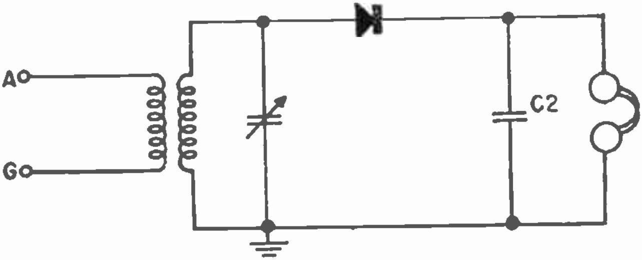


Fig. 110

Except for the extremely crude "coherer" detector, the crystal detector was the first used for detection of radio signals. Early crystal detectors were made of a mineral called "galena." A piece of this material was imbedded in a container; a small piece of wire, supported by a nearby binding post, made contact with the surface of the crystal. This wire, which had to be adjusted to a "sensitive" spot on the crystal, was referred to as the "cat-whisker." Later types were permanently adjusted by the manufacturer and various other materials were used. These materials were tungsten, carborundum, silicon, and germanium. Recent developments have greatly improved germanium crystals. They are light and compact, easily made in large quantities, and are very rugged in comparison to older types.

Applications.—In the early days of radio, the crystal detector was used almost universally. In spite of the fact that it has been largely replaced by vacuum tube detectors, the crystal detector continues to play an important role in modern radio. Some of the most important modern applications are:

1. In small "battery-less" and "tube-less" receivers used by experimenters and hobbyists.
2. In high fidelity receivers which use a crystal detector followed by a wide range audio amplifier.

3. As detectors in signal tracers.
4. As detectors in field strength meters and AF and RF measuring devices.
5. As a mixer in receivers and test equipment.

Advantages.—Crystal detectors are simple and have good quality characteristics. Their principal advantages may be summed up as follows:

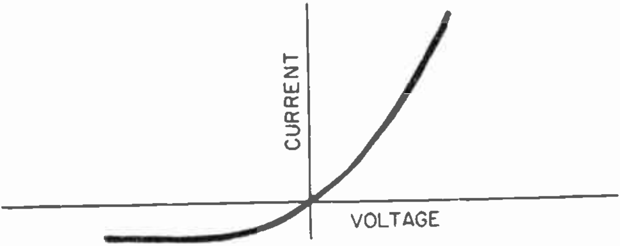


Fig. 111

1. Simple, compact, light in weight.
2. No power required except that of the incoming signal.
3. Instant starting, no filament heating time.
4. Linear rectification characteristic within a useful range. The quality of the detected signal is good.
5. "Transit time" effect, present in vacuum tubes, is very small in crystal rectifiers. This makes crystal detectors particularly useful at very high frequencies.
6. The capacity effect between the crystal terminals is normally very low, an important advantage at high frequencies.

Limitations.—The crystal detector gives no amplification of the incoming RF, or the detected AF signal. The output of the crystal detector is derived entirely from the incoming signal. The sensitivity of this detector circuit is therefore very low and a relatively strong signal is needed to produce usable output. For this reason, very elaborate antenna and tuning systems are needed for good reception at any appreciable distance from a broadcasting station. A stage or two of audio frequency amplification is also frequently necessary for use in bringing the low output up to a practical level.

Crystal detectors are capable of handling only very small amounts of power. Their operation is often affected by temperature changes. Rectification is not complete since some current can flow in the "backward" direction, as seen from the typical response curve shown in Fig. 111

Variations.—A number of types of tuning circuits have been used in crystal detectors to improve the sensitivity and selectivity of the circuit as a whole. If the crystal detector is used in conjunction with an oscillator, it will operate as an efficient mixer (see Crystal Mixer circuit). Another variation is the use of the crystal with a DC meter to produce an RF or AF voltmeter.

DIODE DETECTOR

The vacuum tube diode detector makes use of the fact that electrons will flow from the cathode to the plate of a vacuum tube and not in the reverse direction. The circuit is shown in Fig. 112 and Fig. 113 A tuned circuit L-C is used to build

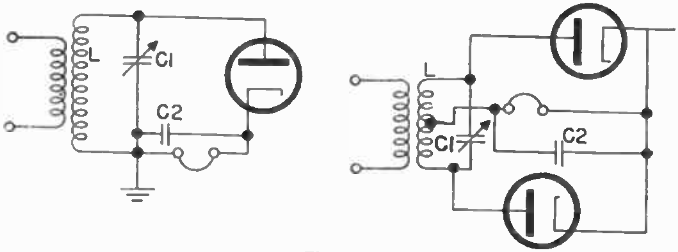


Fig. 112

up the incoming signal by resonating at its frequency. The resonant circuit voltage (amplitude modulated RF) is then applied to the plate and cathode of the diode vacuum tube. The rectifying action of the tube produces a pulsating direct current in the circuit. This current contains both RF and AF pulsations. The RF pulsations are bypassed around the earphones (load resistor if AF stages follow) by C2. C2 is chosen to have sufficient capacity to bypass the RF currents but not enough capacity to bypass the AF currents.

An antenna and a ground may be connected at A and G respectively to make the circuit a self-contained radio receiver. In superheterodyne receivers, the diode is universally used as a second detector. In this application, it is used with a load resistor and placed after the last IF stage as shown in Fig. 113

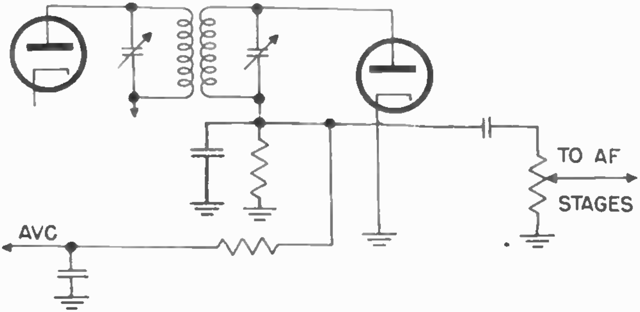


Fig. 113

Several different arrangements of load resistors are used to minimize loading and provide AVC voltage. In addition to load resistor R, there is usually an additional resistor between the top of R and the cathode to decrease loading of the tuned circuit.

Applications.—The most extensive application of the diode detector is as second detector in superheterodyne receivers. Its stability and the fact that it can handle very strong signals without appreciable distortion make it well adapted to the detection of the high level output of the IF section of the average superheterodyne receiver. Some of the other important applications are:

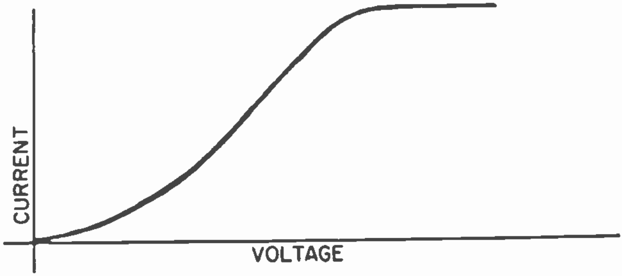


Fig. 114

1. Signal tracer detectors.
2. Vacuum tube voltmeters.
3. Field strength meters.
4. Noise limiters and clippers.
5. Automatic volume control rectifiers.

Advantages.—The main advantages of the vacuum tube diode detector are:

1. Ability to handle large signal voltages with a minimum of distortion.
2. Stability and good linearity over a wide range of amplitudes.

Limitations.—The vacuum tube diode detector is less sensitive than most other detectors. This low sensitivity is due to the fact that all the output is derived from the input signal. The audio frequency output is simply a rectified and filtered version of this input signal.

The diode detector distorts very weak signals. Reference to the diode characteristic curve (Fig. 114) will show the reason for this. The curved portion in the low voltage section of the characteristic causes the distortion on low levels, whereas operation at all times on a higher input level eliminates this distortion.

Variations.—The diode detector can also be used in the push-pull version shown in Fig. 112 Another variation is the noise limiter, or "clipper" which conducts and shunts a signal when it reaches certain peak values. FM discriminators are a variation of the diode detector.

Typical Tubes Used.—6H6, 6AL5, 6Q7, 6SW7, 6B8, etc. Or any triode, tetrode, or pentode may be used by connecting all elements except the cathode to the plate.

SQUARE LAW DETECTOR

The square law detector circuit shown in Fig. 115 is similar to an RF amplifier except that the bias resistor R is chosen so that the operating point of the tube is located on the "bend" or "knee" of the grid voltage-plate current curve.

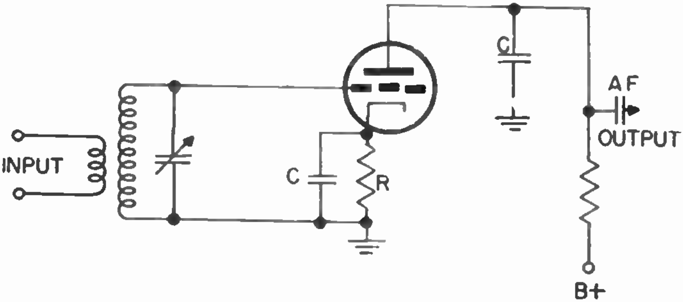


Fig. 115

The graph (Fig. 116) shows how detection is obtained. The non-linearity of the curve at the operating point causes positive halves of the RF cycles to produce greater plate current swings than the negative halves. Bypass condenser C filters out the RF pulsations, leaving the audio frequency variations in the output.

The name "square law" is derived from the fact that the rectified output is proportional to the square of the effective value of the applied signal. Since the efficiency of the square law detector is greatest when the signal is weak enough to permit operation on the curved portion of the grid voltage-plate current curve (Fig. 116), it is sometimes referred to as a "weak signal" detector.

The amplifying property of the tube is utilized in the square law detector, making the sensitivity much better than that of the diode or other non-amplifying types. The square law detector is, therefore, frequently used for low cost TRF receivers. Due to the fact that its operation depends on non-linearity of characteristic, normal use entails a considerable amount of distortion.

Applications.—The square law detector is used in low cost communication receivers in which considerable audio distortion is permissible in the output, or where principal reception is of CW signals. It is also used in vacuum tube voltmeters. This circuit makes the VTVM in which it is used quite sensitive. Variations due to non-linearity can be compensated for in the calibration of the meter scales. When two signals are heterodyned, the beat frequency can be detected by this circuit with little distortion. For this reason, the square law detector is used in beat frequency oscillators and other test equipment.

Advantages.—The most important advantage of the square law detector is its sensitivity resulting from use of the amplifying property of the tube. Because of this sensitivity, the circuit is useful in receivers employing a minimum number of tubes. The square law detector circuit is also useful as a mixer-detector since it gives a distortionless difference frequency when two signals are heterodyned.

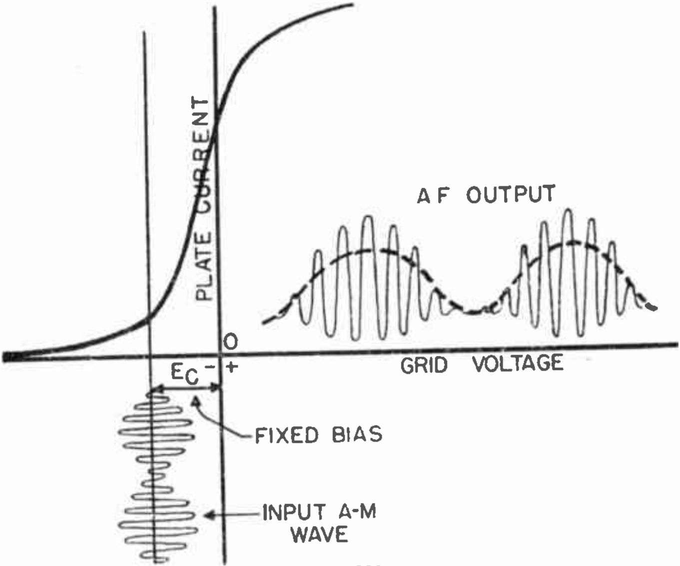


Fig. 116

Limitations.—The greatest limitation of the square law detector is the high percentage of harmonic distortion introduced in the output by the non-linear character of the operating curve. Another limitation is the fact that only weak signals can be handled with good results since the efficiency falls off rapidly when saturation is approached. Distortion also increases under these conditions.

Variations.—Since the distinguishing characteristic of the square law detector is its operation on the curved portion of the grid voltage-plate current curve, diodes and other detectors can be made to operate in this circuit.

Typical Tubes Used.—Any triode, tetrode, or pentode.

REGENERATIVE DETECTOR

The regenerative detector is one of the most sensitive so far devised. Its excellent sensitivity is secured by having detection take place in the grid circuit, amplifying the signal in the tube, and adding regeneration further to build up the signal. Fig. 117 shows the circuit. The grid, grid leak and condenser, the tuned circuit, and the cathode form a diode detector circuit which rectifies the incoming signal. The grid leak R1 acts as the diode load and rectified RF and AF pulsations appear across it. The RF, however, is filtered out by condenser C which is too small to bypass the audio signal. The audio signal appears across R1 and is applied to the grid, amplified by the tube, and appears in the plate circuit. L2 is coupled to L1 to feed the plate current variations back into the grid in a manner tending to increase the grid input signal. This process is allowed to continue until the circuit is almost ready to oscillate. At this point, sensitivity is greatest. Control of the regeneration is provided by R2 which varies the plate current. Variable coupling of L1 to L2 may also be used for regeneration control.

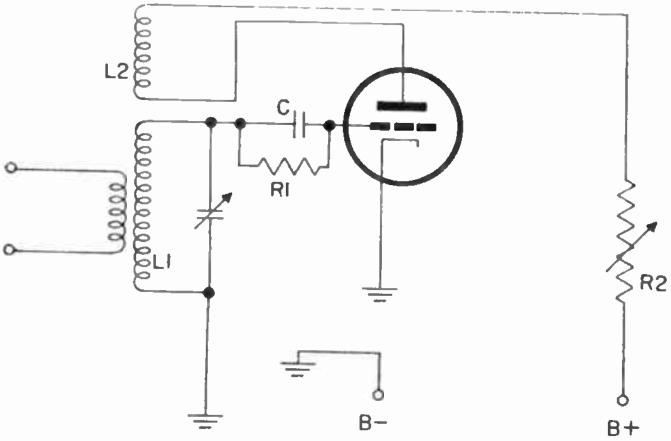


Fig. 117

A complete one-tube receiver is created by connecting an antenna and a ground to points A and G respectively and earphones to the AF output.

Applications.—The development of the superheterodyne receiver circuit obviated the necessity for a highly sensitive detector. The regenerative detector is therefore no longer in common use. The circuit is still popular among hobbyists and experimenters. It is the most efficient way to get good output from a one-tube receiver.

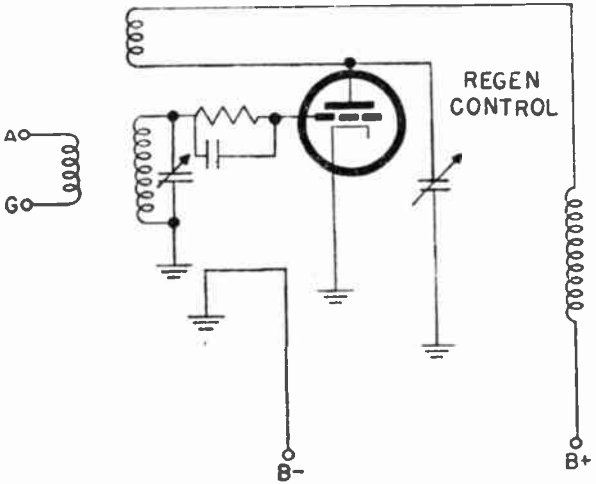


Fig. 118

Advantages.—Principal advantages are great sensitivity and flexibility of adjustment.

Limitations.—While very sensitive, the regenerative detector has very poor quality characteristics. It is easily overloaded by strong signals. Its selectivity varies with the adjustment of the regeneration control. When this control is near the oscillation point, the detector is very selective due to regeneration; otherwise it is quite broad.

Variations.—The most important variations in this detector are in the ways regeneration is controlled. Control can be secured by varying the plate potential as shown in the diagram, by varying the coupling between L1 and L2, or by placing a variable condenser or resistor across the "tickler" coil, L2 as shown in Fig. 118

Typical Tubes Used.—Any triode, tetrode, or pentode suitable for amplification at the frequency of operation.

SUPERREGENERATIVE DETECTOR

The superregenerative detector greatly resembles an ordinary Hartley or Dynatron RF oscillator. The difference lies in the fact that the values of the components used are so chosen that in the same circuit or in a separate circuit, low frequency RF oscillations also take place. These low frequency oscillations alternately put the high (received signal) frequency oscillator in and out of oscillation. The quenching (low) frequency is made just high enough to be inaudible. Passing the detector in and out of oscillation at such a rapid rate results in great sensitivity because the most sensitive point is that at which oscillation is about to take place. Figs. 119 and 120 show typical arrangements of self and separately quenched detectors.

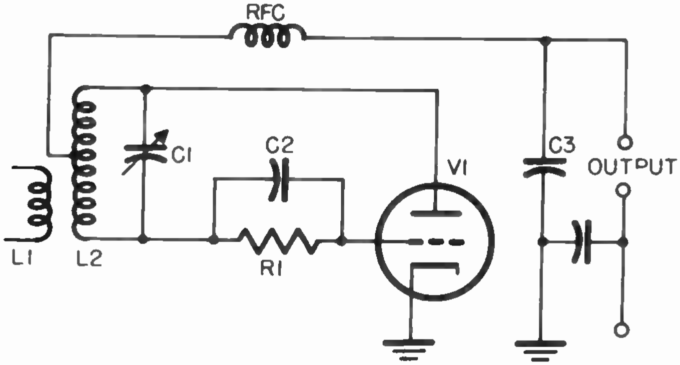


Fig. 119

The quench frequency is produced,

A. By proper choice of grid leak and plate blocking condenser.

B. By adjustment of the separate quench oscillator V2 and its circuit.

Applications.—The superregenerative detector makes a relatively simple and highly sensitive receiver for very high frequencies. For this reason, it is used extensively on very small or portable equipment designed for UHF and VHF work.

Advantages.—The main advantages of the superregenerative detector are its simplicity and extreme sensitivity. It is so sensitive that in one stage (detector itself) the thermal noise of the input circuit is strongly audible and manifests itself as a loud hissing noise, the familiar "superregenerative rush."

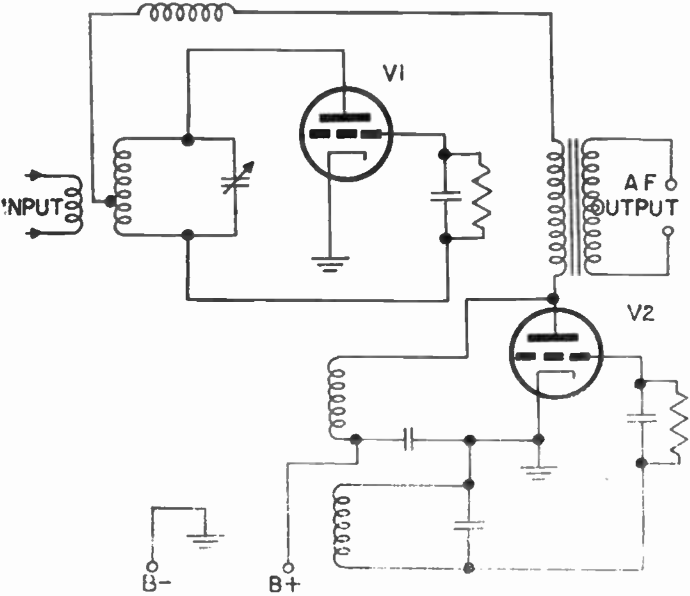


Fig. 120

Limitations.—The superregenerative detector is characterized by the following limitations:

1. Very poor selectivity; the pass band is usually 100 kc or more.
2. Very poor quality; the detection characteristic is not linear and peaks of modulation are often chopped off while the troughs are accentuated.
3. Thermal noise; the output of the detector contains the superregenerative "hiss" whenever a strong signal is not being received.

Variations.—The two main variations are the self-quenched and the separately quenched types.

Typical Tubes Used.—Any triode, tetrode, or pentode.

INFINITE IMPEDANCE DETECTOR

The infinite impedance detector is distinguished by the fact that the detected audio signal output appears across the cathode resistor R, as shown in Fig. 122 The input signal is fed to the grid in the usual way . The tuned circuit L1-C1 builds up the incoming signal and selects the desired frequency. The plate is connected directly to B plus. The cathode resistor R is shunted by an RF bypass condenser C2.

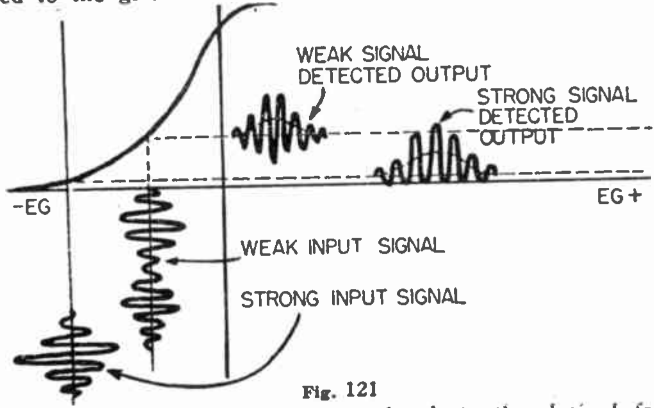


Fig. 121

Under "no-signal" conditions, the resistor R builds up a bias which keeps the grid potential near cutoff. It cannot reach cutoff because this would stop plate current flow which produces the bias.

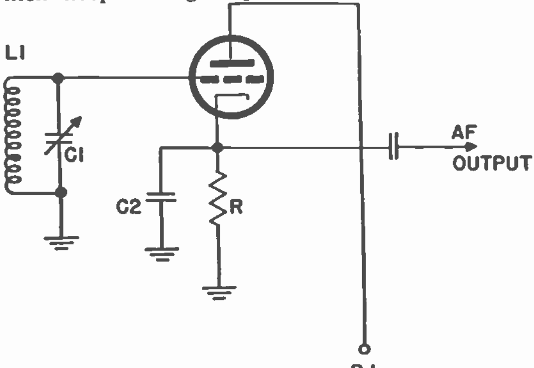


Fig. 122

When a signal (IF or RF) is applied to the grid rectified plate current pulses are produced. Rectification takes place because of the proximity of cutoff. The rectified plate current flows through the cathode resistor R and produces an audio frequency voltage across R. RF fluctuations are bypassed through C2. The output audio signal is then tapped off at the top of R as shown.

Resistor R is in series with the incoming signal. For this reason, the peak audio value must always be less than the peak envelope voltage of the incoming signal.

Applications.—The infinite impedance detector is useful in receivers and other applications where it is necessary to handle large RF carriers without input loading effects. Amplification cannot equal or exceed unity, so the circuit is not used where sensitivity is important. One of the most important specific uses is in high fidelity TRF AM broadcast receivers. A strong signal developed through several RF stages is handled well by the infinite impedance detector. The lack of loading effect on the tuned circuits at the input to the detector allows a high Q to be used with the resulting gain in selectivity and sensitivity. The circuit is occasionally used as a second detector in superheterodyne receivers because it is suitable for handling the high level IF signal.

Advantages.—Because the grid is kept at a negative voltage with respect to the cathode, no grid current flows in the infinite impedance detector. The input impedance to the detector is thus infinite giving the circuit its name. This is a definite advantage in that high Q tuned circuits may be used at the input and no loading effect is experienced. Very large input signals can be handled because of the dynamic nature of the circuit. Whenever a high input voltage peak drives the grid in the positive direction, the bias produced by cathode resistor R increases. The operating point is thus moved in a negative direction, preventing the grid from drawing current. A high peak audio output voltage can be obtained without overloading; in fact, its peak voltage can approach half of the B plus potential.

Limitations.—The infinite impedance detector has the disadvantage that no amplification of the signal takes place. The output resistor R is also in series with the input voltage and thus no gain is possible. The characteristics of this detector are, therefore, similar to those of the diode type, except that the infinite impedance type does not produce input loading like the diode type. The negative peaks of modulation will be clipped off if the modulation degree of the input signal becomes greater than the AC to DC impedance ratio of the load. This limiting percentage thus is:

$$\text{Mod}\ \% = \frac{(Z_R + Z_O)R}{Z_R Z_O}$$

in which $Zc = jX_c$ and $Z_R = R$

Due to the non-linear nature of the grid voltage-plate current curve at low levels, a high level signal is necessary to minimize distortion.

Typical Tube Types.—Any triode, tetrode, or pentode.

GRID LEAK DETECTOR

The grid leak detector accomplishes its detecting action in the grid circuit. Its circuit is shown in Fig. 123 The circuit comprising the grid, grid leak and condenser, tuned circuit and cathode acts as a diode detector. The tuned circuit voltage is built up at resonance and applied to the grid. The diode action of the grid and cathode causes pulsating current to flow through the circuit. The resistor R acts as a diode load and C filters out the RF variation leaving the AF signal voltage intact. The detected audio signal appears across R and is applied to the grid. It is then amplified in the tube to appear in greater amplitude at the plate. This is the same type of detector action used in the regenerative detector, except that here no regeneration is used.

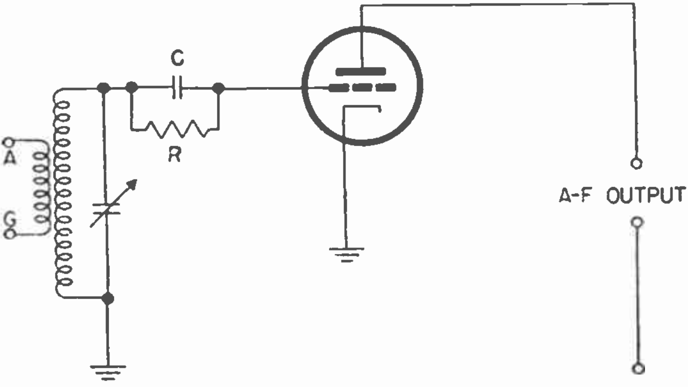


Fig. 123

A complete receiver can be made from the circuit by connecting an antenna and a ground to points A and G respectively and connecting earphones to the AF output.

Applications.—The grid leak detector finds its greatest use in TRF receivers in which greater sensitivity is needed than the diode detector affords. Since the TRF receiver has been almost entirely replaced by the superheterodyne, the grid leak detector is no longer in general use.

Advantages.—The main advantage of the grid leak detector is its relatively high sensitivity compared to the diode type. This increase in sensitivity is secured by taking advantage of the amplifying properties of the vacuum tube.

Limitations.—The grid leak detector does not have the extreme sensitivity of the regenerative type nor can it handle as large signal inputs without distortion as can the diode type.

Variations.—Addition of a tickler (plate) coil transforms the grid leak detector into a regenerative detector.

Typical Tubes Used.—Any triode, tetrode, or pentode.

HIGH PASS FILTER

The high pass filter in its simplest form consists of a resistor and a condenser connected as shown in Fig.124 The filter is designed to remove low frequency components from a signal or reduce them for equalization purposes.

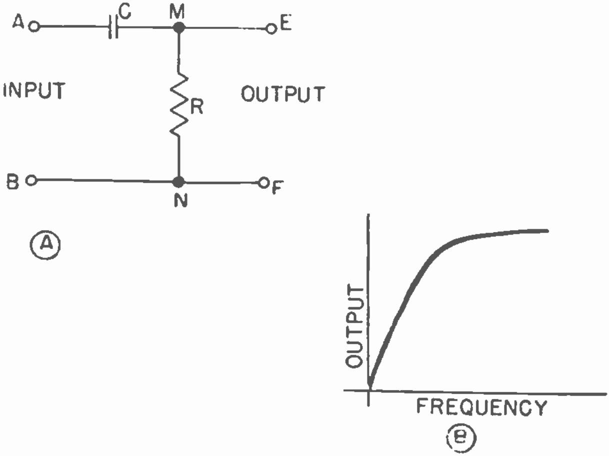


Fig. 124

The circuit, shown in Fig124A, can be considered as an AC voltage divider A-M-N. The input signal is applied at A-B across R and C in series. The output voltage is that appearing across R (M-N). At high frequencies the reactance of C is small compared to the resistance of R, and the output voltage is high, or nearly equal to the input value at A-B, because R represents almost the total impedance of the divider.

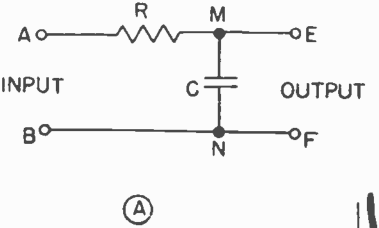
At low frequencies, the reactance of C becomes large compared to the resistance of R and only a small portion of the input appears at the output terminals E to F. Thus the circuit attenuates the signal increasingly as the signal frequency decreases.

One of the most important uses of the high pass filter is as a response modifying device for audio equipment such as microphones, phonograph pickups, and audio amplifier circuits which would otherwise have undesirable frequency response characteristics.

Fig124B shows a representative plot, or graph, of the current in a high pass filter with constant input as the frequency is varied. Use of an inductance in place of R will accentuate the high pass characteristic because the inductance itself has a lower impedance (greater shunting effect) to the lower frequencies.

LOW PASS FILTER

The low pass filter in its simplest form consists of a resistor and a condenser connected as shown in the figure. It is designed to remove high frequency components from a signal or reduce them for equalization purposes.



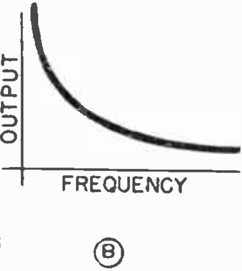


Fig.125

The circuit, shown in Fig. 125, can be considered as an AC voltage divider A-M-N. The input signal is applied at A-B and across R and C in series. The output voltage is that appearing across C (M-N). At high frequencies, the reactance of C is small compared to the resistance of R and the output voltage is low in relation to the input voltage.

At low frequencies, the reactance of C becomes large compared to the resistance of R, and most of the input voltage appears at the output terminals E to F.

Frequent uses of this circuit are as crystal pickup equalizers and de-emphasis circuits in FM tuners.

The graph, Fig. 125, shows a representative plot of the response of a low pass filter of this type, assuming a constant voltage input. Use of an inductance in place of R will accentuate the low pass characteristic; the inductance itself offers a higher impedance to high frequencies.

In the transmission of standard FM broadcast signals, high modulation frequencies are applied to the carrier with a greater degree of modulation than the lower modulation frequencies. This process is known as "pre-emphasis." The low pass filter described above is used to equalize the signal at the receiving end, this latter process being known as "de-emphasis." In this way, the high frequency noise arising from transmission and reception processes is suppressed as the signal frequency response returns to normal.

BAND PASS FILTER

The band pass filter in its simplest form is a condenser and inductance connected in parallel and arranged as shown in Fig.126A. It is designed to reject signals of all frequencies except the resonant frequency or a narrow frequency range around it.

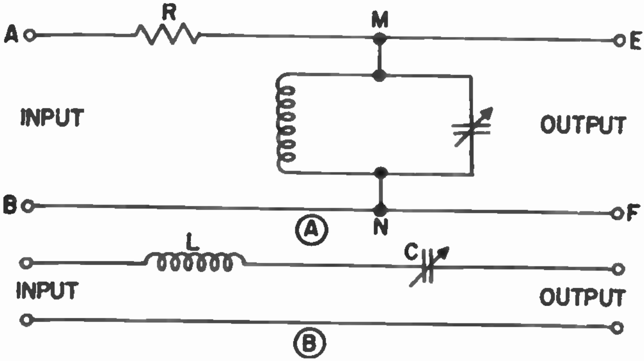


Fig. 126

This circuit makes use of the fact that a parallel tuned circuit exhibits a very high impedance at its resonant frequency and a relatively low impedance to all appreciably different frequencies. Signals at frequencies other than the resonant frequency are shunted (shorted) through the parallel circuit. Because of the high impedance at its resonant frequency, resonant signals are unaffected.

Resistor R is seldom used in practice, but is placed in this circuit to represent the internal resistance of the source. The whole circuit acts as a voltage divider with output tapped off at M-N of the leg A-M-N (R and L-C in series).

The band pass circuit is the most common in radio. Some of its applications are in receiver RF, IF, and oscillator circuits, wave traps, transmitter RF amplifiers, and in most circuits where frequency selection or frequency discrimination is desired.

Alternatively, the series resonant circuit may be used as shown in Fig.126B. With signal input of a frequency at or very near the resonant point of L and C, very little impedance is offered to the passage of the signal to the load resistance. At frequencies other than the resonant frequency, high impedance is offered by the L-C combination. The load resistance thus constitutes a voltage divider section in series with the L-C combination. Output voltage varies according to the relative impedance of the load and of L and C in series at the frequency used.

PI FILTER

The pi filter circuit derives its name from the fact that in schematic form its components are arranged so as to resemble the Greek letter π. It is this arrangement which distinguishes the circuit; the types of components used may be changed in any combination desired, giving different transmission characteristics.

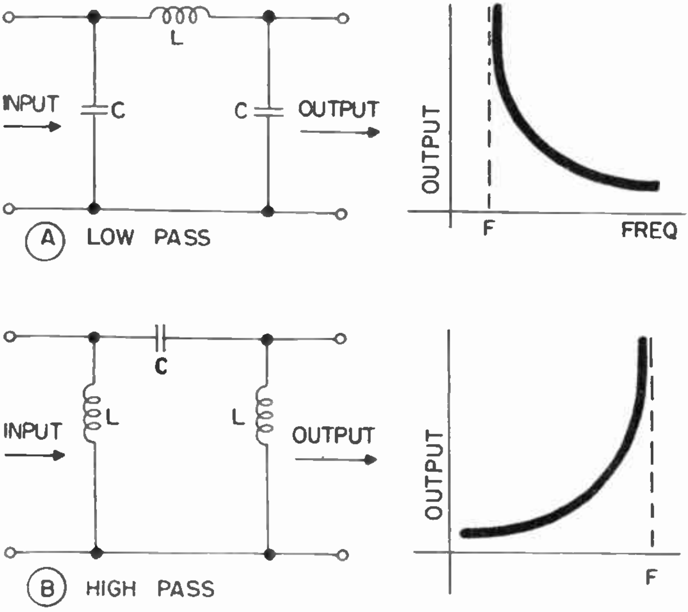


Fig. 127

The main uses of the pi circuit are:

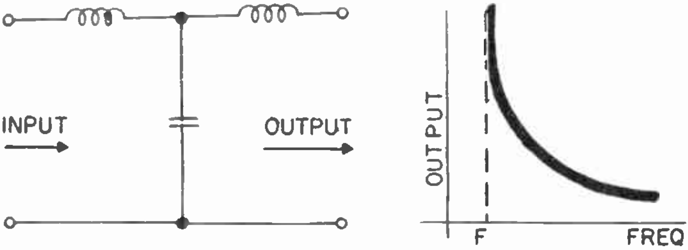
1. Impedance matching.
2. Equalization or filtering.

The circuit shown in Fig. 127A is a pi low pass filter. The graph shows the response of this circuit. Note that there is a "cut-off" frequency F below which there is no attenuation and above which the attenuation rises rapidly. In other words, the lower frequencies below F are allowed to pass through the filter, whereas frequencies above F are not allowed to pass

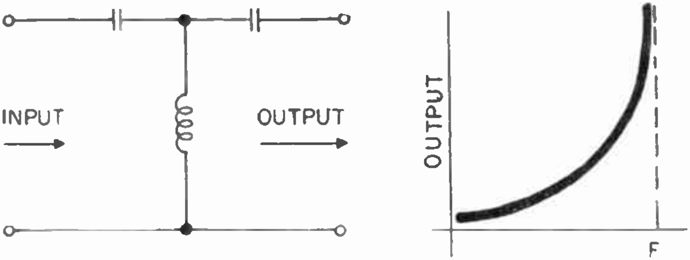
Fig. 127B shows another arrangement of the pi filter. This type has a high pass characteristic as illustrated by the graph.

T FILTER

The T filter circuit derives its name from the fact that in schematic form its components are arranged to resemble the letter T. The circuit is identified by the arrangement, not by the type of components. Use is made of resistors, condensers, and inductances in various positions.



Ⓐ LOW PASS



Ⓑ HIGH PASS

Fig. 128

Two main uses of the circuit are:

1. Impedance matching.
2. Equalization or selective filtering.

The example shown in Fig. 128A shows the T low pass filter and a graph of the response of the circuit. Note that there is a cut-off frequency F below which there is no attenuation and above which the attenuation rises rapidly.

Another variation is the T high pass filter in which condensers are used to replace the coils L and an inductance is used to replace C. The circuit and response are then as shown in Fig.128B.

DIVIDING NETWORKS

It is difficult to design a speaker which will reproduce all frequencies in the audible range. For this reason, high fidelity speakers are usually designed in two parts or sections. One part reproduces the low frequencies, the other part reproduces the high frequencies. For proper operation, the output of the amplifier used must be divided so that no highs are fed into the low frequency speaker and no lows into the high frequency speaker. This is necessary for efficient operation since energy fed into the wrong channel is wasted. Dividing networks are designed to separate the highs and lows and feed them into the proper speaker sections.

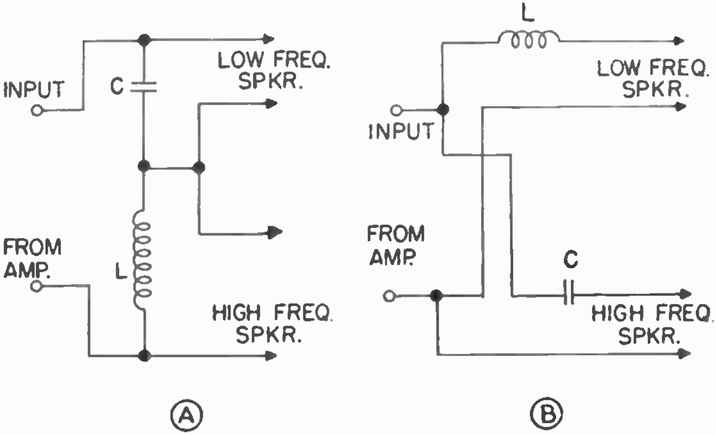


Fig. 129

Fig. 129 A shows the simplest form of dividing network. A voltage divider consisting of an inductance (L) and a capacitance (C) in series is connected across the amplifier output. The voltage division between the two elements changes with frequency as follows:

High Frequencies—Low voltage on C, high voltage on L.
Low Frequencies—Low voltage on L, high voltage on C.

The low frequency speaker is connected across the condenser and the high frequency speaker is connected across the inductance. The elements may be connected in series as shown in Fig. 129 B.

Fig. 130 shows another type of dividing network in which filters are used. L1-C1 and L2-C2 are low pass and high pass filters, respectively. This circuit has the advantage that attenuation at the cross-over frequency (dividing line between high and low frequencies) is much sharper.

Fig. 131 shows graphically the proper response curve for a dividing network.

Applications.—Dividing networks are used in audio amplifiers to divide the output power between the sections of dual speakers. The result is that all high frequencies are fed into the high frequency speaker and the lows into the low frequency speaker.

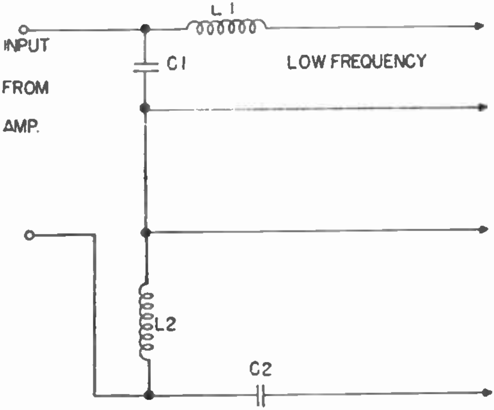


Fig. 130

Advantages.—The main advantage of a dividing network is efficiency of reproduction. The AF energy is fed to the circuit where it will be most efficiently reproduced, giving high fidelity with a proper load division between the reproducing elements.

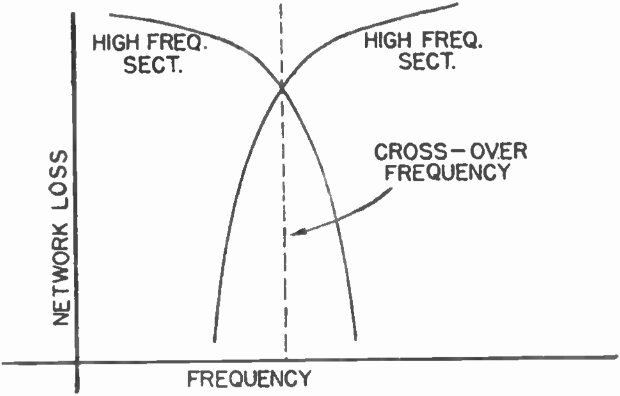


Fig. 131

Limitations.—The dividing network is only useful with amplifiers having a wide range, and with dual speakers which merit its use.

RESONANT FILTER

Resonant filters are used in power supplies for transmitters and receivers. In the resonant filter inductances and capacitances are used in pairs to form resonant circuits. These resonant circuits may be of the parallel or the series type and are tuned to the power frequency. They make use of the impedance characteristic at resonance.

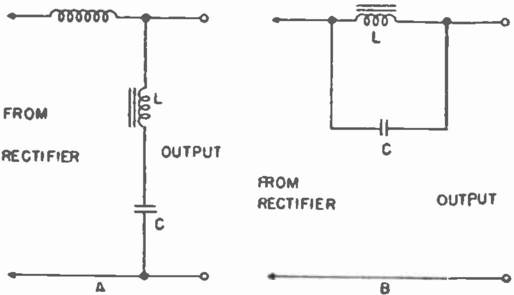


Fig. 132

Fig. 132A shows the series resonant type of filter. The input choke is often included to prevent too high a ripple current from being drawn through the resonant circuit. It is not always necessary. The choke coil L and the condenser C are designed to resonate at the power or ripple frequency. At the resonant power frequency, the combination has a very low impedance. Since the output power is drawn from across L and C in series, the ripple frequency is bypassed, or shorted out.

Fig. 132B shows the parallel resonant type of filter. Here L and C resonate at the power or ripple frequency and offer a very high impedance to the ripple current. If properly designed the choke coil will have a low DC resistance.

The circuits illustrated above use only one resonant circuit each. More than one resonant circuit is often used in the more elaborate types of power supplies.

Applications.—Resonant filters are used in power supplies (see Rectifier Circuits) for receivers and transmitters. Because the choice of components is rather critical, the applications are limited to a few types of equipment. High voltage, high power supply units make the most frequent use of resonant filters. In these supplies, filter components are very expensive and a substantial saving can be made by using a much smaller choke than is required with a non-resonant filter.

Advantages.—The resonant type of filter is lighter, more compact, and less expensive than a non-resonant filter of equivalent effectiveness.

Limitations.—The components in a resonant filter must be carefully chosen for rating, quality, and reactance value.

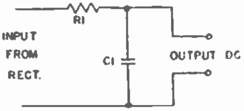
Variations.—More than one section is often used. Combinations of series and parallel types are sometimes found.

Tube Types Used.—Not restricted by circuit.

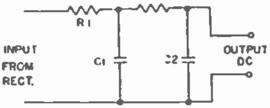
RC POWER FILTER

RC power filters are used with rectifier type power supplies to remove the "ripple" from their output. When AC is changed to DC by means of a rectifier pulsating DC is obtained. This pulsating DC contains an undesirable AC component, known as "ripple" which the RC filter is designed to eliminate.

The RC power filter eliminates ripple voltage from the output of an AC power supply by acting as a low pass filter whose cut-off frequency is below the power frequency.



Ⓐ SINGLE SECTION



Ⓑ TWO SECTION

Fig. 133

Figs. 133A and 133B show the single and two-section RC filters most frequently found in receiver power supplies. Both types are shown with resistor input which is usual, although condenser input is occasionally found. The principle of operation is as follows:

1. R1 and C1 form a voltage divider at the ripple frequency.
2. At this ripple frequency C1 has a negligible reactance compared to the resistance of R1.
3. Almost all of the ripple voltage appears across R1 and very little appears across C1 and the output voltage.

The same principle applies in Fig. 172 B except that the process is repeated in the R2-C2 combination. The efficiency of filtering is much lower than that of LC filters because for good filtering, R1 and R2 must have a high resistance and, therefore, considerable voltage drop occurs in them.

Applications.—The RC power filter is used in AC power supplies for receiver and transmitters. It is generally found in small supplies where current drain is small and where economy and compactness are important. It is also used to decouple the B plus from various stages in a high gain amplifier supplied by a common DC source.

Advantages.—The main advantages of the RC power filter are economy and compactness. Resistors are much cheaper and smaller in size than filter chokes.

Limitations.—The voltage regulation of an RC filter is poor because when R1 and R2 are made large enough for good filtering, they offer a high resistance to the DC current.

Variations.—Any number of filter sections may be used and resistors can be added in both power leads to produce a balanced combination.

Tube Types Used.—Not restricted by the circuit.

CHOKE INPUT FILTER

Filters are required in all rectifier type power supplies operating from an AC source when pure DC output is desired. Most radio equipment uses rectifier type power supplies. AC is changed to DC by means of rectifier whose output is pulsating DC. This pulsating DC contains an undesirable AC component, known as "ripple" which the filter is designed to eliminate.

The most efficient filters are those which contain inductance and capacitance. This is because a high ratio of reactance to DC resistance can be maintained. LC filters are classified as "choke input" or "condenser input" depending on which type of element is first encountered by the pulsating DC input from the rectifier. Filters are also classified by the number of sections (L-C combinations) used.

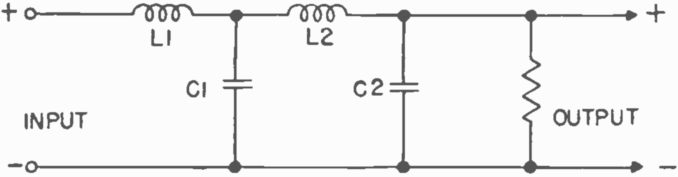


Fig. 134

The choke input filter shown in Fig. 134 is the most popular type. It uses two sections. The "input choke" L1 is often a "swinging choke." This name is used to distinguish this type of choke coil from the ordinary smoothing choke used at position L2. The swinging choke, L1, is made without a gap in its iron core, making it saturate easily when high current passes through it. As it saturates, its reactance decreases, compensating for the DC output voltage drop which occurs at heavy loads.

C1 and C2 form low reactance shunting paths for the ripple frequency. L1 and L2 have a high reactance to the ripple frequency, thus "choking" it from the output. The condensers do not shunt the DC at all, and the chokes represent a low DC resistance. The filter thus allows DC to pass through it but attenuates ripple frequency voltage greatly.

Applications.—Choke input filters are used in AC power supplies for receivers and transmitters. The use of choke input is especially applied to heavy current drain uses, especially those in which the load is intermittent or fluctuating.

Advantages.—The choke input filter has the advantage of good voltage regulation with heavy intermittent and fluctuating power loads. It also limits peak rectifier currents to a lower value than does a condenser input filter thus protecting the rectifier tubes.

Limitations.—The choke input filter requires a "swinging choke" whose inductance must fluctuate within certain limits as current drain varies. Any kind of an input choke reduces the output DC voltage below that which could be obtained with condenser input.

CONDENSER INPUT FILTER

The condenser input filter, shown in Fig. 135 uses two sections and is the filter most frequently used in radio transmitters and receivers. It is distinguished from choke input filters in that the pulsating DC does not have to pass through a choke coil before reaching the first filter condenser C1 (input condenser).

C1 and C2 form low reactance shunting paths for the ripple frequency. L1 has a high reactance to the ripple frequency thus "choking" it from the output. On the other hand, the condensers do not shunt the DC at all, and the chokes represent a low DC resistance. The filter thus allows DC to pass through it while it attenuates ripple frequency voltage greatly.

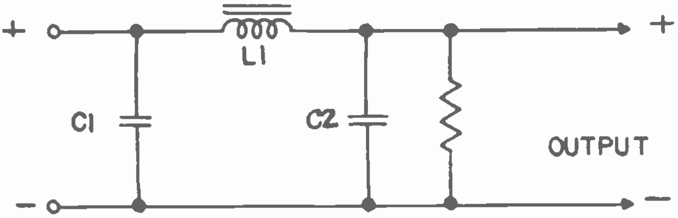


Fig. 135

Applications.—Condenser input filters are used in radio transmitter and receiver power supplies. The condenser input feature favors applications in which a relatively high voltage output is desired.

Advantages.—Condenser input filters have the advantage of producing a filtered DC output which is a high percentage of the peak value of the pulsating DC wave from the rectifier. In this respect, they are definitely superior to the choke input type. They are also cheaper since they do not require an input choke coil.

Limitations.—The condenser input type of filter is not adapted to heavy intermittent current drain applications because it lacks the controlling effect of the input choke. It also requires that the input condenser C1 have a higher voltage rating than the corresponding condenser in a choke input filter. Regulation due to current variation is not as good as with a choke input filter.

Variations.—Any number of sections (L-C combinations) may be used. Increasing the number of sections increases filter efficiency and cost and lowers the output voltage.

Tube Types Used.—Mercury vapor rectifiers should not be used with condenser input filters because of the danger of "flashback," due to the high peak currents drawn by the rectifier tubes.

CRYSTAL FILTER

The crystal filter is used to increase the selectivity characteristics of superheterodyne receivers. It is so arranged that the intermediate frequency signal must be coupled through a quartz crystal to the following stage, as shown in Fig. 136

This circuit makes use of the fact that a quartz crystal acts like a tuned circuit with a very high Q. The intermediate frequency signal is fed through the crystal to the grid circuit of the next stage. The crystal acts as a series resonant selective circuit allowing only signals of the resonant frequency through and producing a very high attenuation to signals of slightly higher or lower frequency.

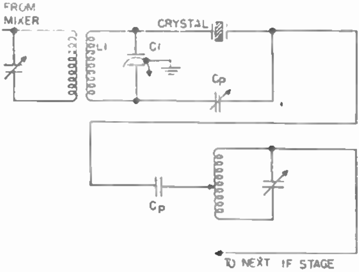


Fig. 136

Crystal filters nearly always include a phasing control, Cp. This control neutralizes the parallel capacitance of the crystal holder. The tuned circuit, L1-C1, is split by C1 so that the RF fed through Cp is 180 degrees out of phase with the RF on the crystal. Thus when Cp is equal to the parallel capacity of the crystal, phasing is complete and selectivity is best.

Applications.—Crystal filters are used in superheterodyne receivers, particularly those of the communications type, in which great adjacent channel selectivity is desired. Because of its sideband clipping action, the crystal filter is not often used for radio teelphone reception. It is primarily useful in receiving keyed CW signals.

Advantages.—Crystal filters make use of the high Q characteristics of the quartz crystal to provide a very sharp selectivity curve. With reasonable care, a band-pass characteristic as narrow as a few cycles can be obtained at a 455 kc intermediate frequency.

Limitations.—Crystal filters will not pass the full sidebands of radiotelephone signals.

Variations.—Several variations are used for providing variable selectivity. Variable selectivity controls usually consist of a rheostat in series or in parallel with a tuned circuit at the grid of the next stage. More than one crystal may be used in various network arrangements to gain desirable band pass characteristics. Piezoelectric crystals of suitable frequency, Q and temperature coefficient are used.

Section 8

A-M

RECEIVERS AND TRANSMITTERS

1. Amplitude Modulation.—One method of transmitting intelligence by means of radio waves is by amplitude modulation. Amplitude modulation is defined as the process of changing the amplitude of an r-f carrier wave in accordance with the intelligence to be transmitted. The radio frequency carrier portion of an amplitude modulated wave is of constant frequency and constant amplitude, as shown in Fig. 1A. An audio modulating frequency is superimposed on this carrier in a manner that causes the **amplitude** of the carrier signal to vary as illustrated in Fig. 1B, leaving the carrier frequency unchanged. The pattern shown in Fig. 1B is commonly referred to as a modulation envelope.

2. Side Bands.—An amplitude modulated wave is composed of a number of frequencies; the radio frequency of the carrier wave, the modulating audio frequency or frequencies, and combinations of these frequencies. These combination frequencies are called the side-band frequencies and are the result of mixing the radio frequency and the modulating frequencies. Whenever any two frequencies are mixed together, two new frequencies are produced. One of these is the sum of the two frequencies, and the other is the difference between the two original frequencies. Thus, for a modulating

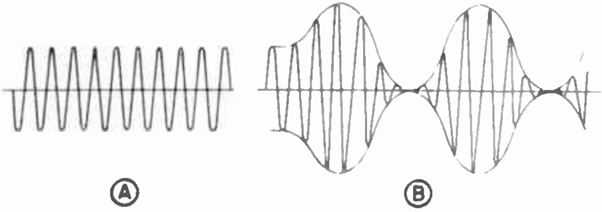


Fig. 1.—Unmodulated and amplitude modulated r-f carriers.

frequency of 500 cycles and a carrier frequency of 100 kilocycles, side-band frequencies of 99.5 kilocycles and 100.5 kilocycles are produced. If the modulating frequency is increased to 1000 cycles, side bands will be produced at 99 kilocycles and 101 kilocycles.

It is these side-band frequencies that carry the intelligence in an amplitude modulated wave. When an r-f carrier is modulated by many audio frequencies, such as occur in speech or music, the side frequencies consist of a band of frequencies above and below the carrier frequency. The width of this band is determined by the highest modulating frequency.

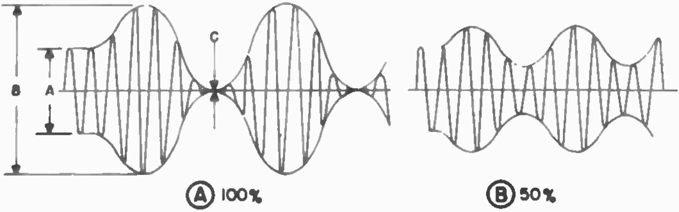


Fig. 2.—Wave envelopes for 100 percent and 50 percent modulation.

3. **Modulation Percentage.**—The degree of modulation of an amplitude modulated wave is expressed as a percentage of the amplitude deviation from the unmodulated value. A carrier wave is 100 percent modulated when the total amplitude variation from crest to trough is equal to twice the unmodulated amplitude. This is shown in Fig. 2A. The amplitude at A is the constant amplitude of the unmodulated carrier wave. When measured from positive crest to negative crest as at B, the amplitude is twice the unmodulated amplitude. At point C the amplitude is zero. The total variation is equal to twice the unmodulated amplitude of the carrier and the wave is 100 percent modulated. The modulation envelope shown in Fig. 2B is 50 percent modulated. In this instance, the total variation is equal to the unmodulated amplitude. Stated in terms of voltage, 100 percent modulation exists when the plate voltage of the r-f amplifier is made to rise to double its unmodulated value and to fall to zero.

The modulation percentage of a wave should always be as high as possible. The intelligence being transmitted is contained only in the side bands, and the greatest amount of power is contained in the side bands when 100 percent modulation is accomplished. If a final amplifier operating at a d-c plate supply voltage of 200 volts is plate modulated by an audio signal of 250 volts, a condition of overmodulation will exist. The percentage of modulation in this case is 125 percent. As the modulating voltage swings from zero to its maximum value and back to zero as shown in Fig. 3A, the plate voltage of the amplifier rises from 200 volts to 450 volts and falls back to 200 volts. All during this interval plate current will flow. During the next half cycle of audio modulating voltage, the audio voltage subtracts from the d-c plate voltage causing the plate voltage of the amplifier to fall to a value of —50 volts. During the period that the plate voltage on the amplifier is negative, no plate current flows. Thus the instantaneous peak value of the r-f waves, as shown in Fig. 3B, do not follow the amplitude variations of the audio modulating wave during the complete cycle and distortion results. High-order harmonics are produced as a result of overmodulation. These harmonics act in the same way as modulating voltages; they generate side bands which greatly widen the modulated carrier.

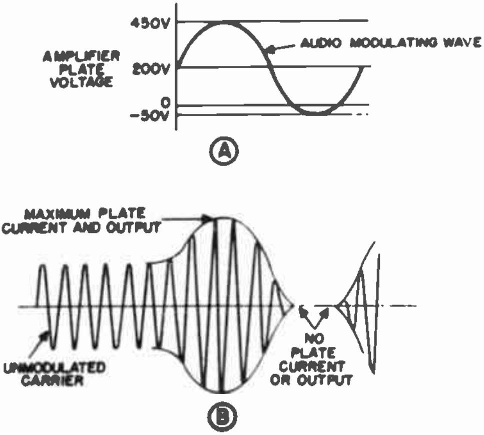


Fig. 3.—Overmodulation.

4. Power and Amplitude Relations.—In order to 100 percent modulate an r-f carrier with a single sine wave audio frequency, a modulating power equal to one-half of the r-f carrier power is required. Under this condition, the average power of the modulated carrier is equal to 1.5 times the unmodulated carrier power. The added power is divided equally between the upper and lower side bands. During the peaks of modulating signal, the amplitude of the carrier is doubled and the instantaneous peak power is equal to four times the unmodulated power.

When voice modulation is used, only the highest amplitude peaks can be permitted to modulate the carrier 100 percent. A large portion of the a-f speech components do not modulate the carrier 100 percent. Consequently, the power required for voice modulation is less than that required for modulation with a single frequency sine wave. It has been determined that a modulating power equal to approximately 25 percent of the unmodulated carrier power will result in 100 percent modulation during voice peaks.

5. Plate Modulation.—In plate modulation the plate voltage of an r-f amplifier is varied in accordance with the amplitude and frequency of the modulating signal. Plate modulation is the most efficient of the various types of modulation. In addition, a plate modulated transmitter is relatively easy to adjust. For these reasons, plate modulation is used to a greater extent than other types.

The most common method of accomplishing plate modulation is by transformer coupling between the modulator stage and the r-f amplifier. Figure 4 is a simplified schematic of a transformer coupled, plate modulated r-f amplifier. The output of the modulator stage is assumed to be a sine wave of 1000 c.p.s. and 400 volts peak-to-peak amplitude with the instantaneous polarity as shown in Fig. 4. The voltage induced in the secondary of T1 will subtract from the d-c supply voltage, applied to the plate of the r-f amplifier, during one modulating frequency half cyle, causing a reduced output from the stage. During the next half cycle of the audio wave, the polarities reverse and the audio voltage will add to the d-c supply voltage. The increased voltage on the amplifier causes a greater current flow in the stage and consequently a higher output. Since the amplitude of the r-f output is dependent upon the d-c plate voltage applied to the r-f amplifier, the continuous variation of the effective plate voltage by the modulating signal causes a continuous variation in the amplitude of the r-f output.

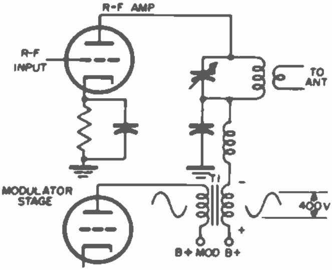


Fig. 4.—Plate modulated r-f amplifier.

Another method of plate modulating an r-f amplifier is by choke coupling. This system, commonly known as the **Heising constant current** system, is illustrated in Fig. 5. Plate voltage is applied to the modulator and the r-f amplifier through common audio choke coil L1. The audio voltage across L1 is in series with the d-c plate voltage and will alternately add to and subtract from the plate voltage applied to the r-f amplifier and modulator. The output of the r-f amplifier will therefore vary in amplitude in accordance with the modulating signal. When the signal applied to the grid of the modulator is swinging negative, current flow through the modulator tube decreases and plate voltage increases. The positive voltage across L1 adds to the d-c supply voltage and causes an increased current through the r-f amplifier. As the current through V1 decreases, the current through V2 increases and the total current through L1 remains practically constant. Thus, the name **constant current.** This system requires that the modulator tube V1 be operated as a class A amplifier. In order to attain 100 percent modulation, the r-f amplifier must be operated at a lower plate voltage than the modulator.

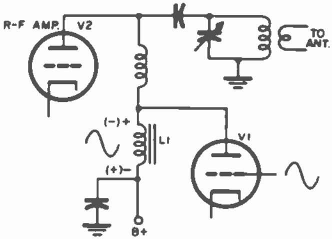


Fig. 5.—Heising constant-current system of plate modulation.

6. **Grid-bias Modulation.**—Another method of amplitude modulating a carrier is by varying the grid bias applied to an r-f amplifier. An example of this type of circuit is shown in Fig. 6. A modulation transformer (T1) is connected in series with the fixed grid bias source of the r-f amplifier. The audio signal induced in the secondary of T1 varies the d-c bias on the amplifier. This continuous variation of the bias causes the output of the r-f amplifier to vary at the audio rate. The modulator must be operated as a class A amplifier. Since little power is consumed and a comparatively small amplitude audio votage is required, this is not a disadvantage. The power outputs obtained with grid-bias modulation are gen-

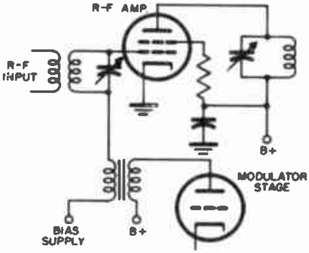


Fig. 6.—Grid-bias modulation.

erally less than one-fourth the output obtainable with plate modulation. In addition to low efficiency, it is difficult to obtain a high percentage of modulation using this method.

7. **Cathode Modulation.**—Cathode modulation is a combination of plate and grid-bias modulation. The carrier efficiency obtained with cathode modulation lies between that obtained with the grid-bias and plate modulating systems. The actual efficiency secured depends upon the proportion of plate modulation to grid-bias modulation. The audio power required and the permissible carrier efficiency increase as the plate modulation is increased in proportion to the grid-bias modulation. A simplified circuit for cathode modulation is shown in Fig. 7A.

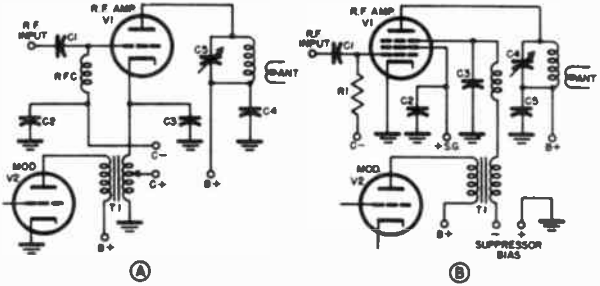


Fig. 7.—Cathode and suppressor-grid modulation.

8. **Suppressor Grid Modulation.**—In a pentode tube a variation in plate current can be produced by varying the voltage applied to the suppressor grid. An r-f amplifier employing a pentode tube can be amplitude modulated by returning the suppressor grid to a voltage source and varying this voltage at an audio rate. The audio signal can be introduced by

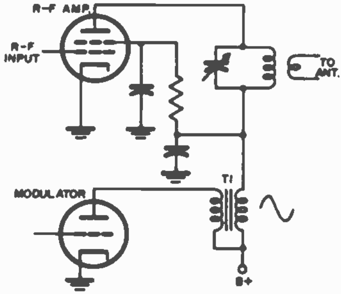


Fig. 8.—Plate and screen modulated r-f amplifier.

means of a modulation transformer as shown in Fig. 7B. This method is not widely used because it is difficult to obtain a reasonable modulation percentage with acceptable linearity.

9. Screen Grid Modulation.—Amplitude modulation of a tetrode r-f amplifier can be accomplished by applying the audio modulating signal in series with the screen grid and the d-c supply voltage. The variation of plate current with a change in screen voltage is linear over a very small range.

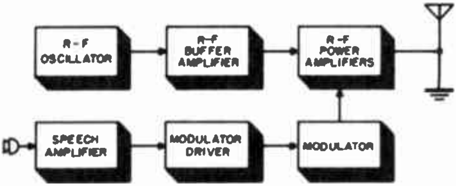


Fig. 9.—Block diagram of a-m transmitter.

It would be impossible to obtain a high degree of modulation with screen-grid modulation. In order to obtain a high degree of modulation, both the plate voltage and the screen-grid voltage of a tetrode r-f amplifier are varied. A simple circuit for this type of modulation is shown in Fig. 8. The audio voltage induced in the secondary of T1 varies the plate voltage and the screen-grid voltage without changing the ratio of the voltages with respect to each other.

A-M TRANSMITTERS

10. An amplitude-modulated transmitter consists of the r-f circuits which generate and amplify the carrier signal and the necessary audio circuits to provide modulation. Figure 9 is a simplified block diagram of an a-m transmitter. The r-f oscillator generates the carrier frequency. The output of the oscillator is applied to a buffer amplifier where it is amplified before being applied to the final power amplifier. The audio signal is amplified by the speech amplifier and then applied to the modulator stage. In the modulator stage, the audio signal is amplified to a power level suitable for application to the r-f power amplifier.

11. Speech Amplifiers.—The audio stages which precede the modulator are referred to as the speech amplifier. The speech amplifier usually consists of from one to three voltage-amplifier stages followed by a power-amplifier or driver stage. A typical three stage speech amplifier is shown in Fig. 10. It consists of a class A pentode voltage-amplifier, resistance coupled to a class A triode voltage amplifier whose output is resistance coupled to a class A power amplifier. This speech amplifier is suitable for driving class B modulators of up to

50 watts output. When greater modulator powers are required, the driver is usually a push-pull stage.

12. **Modulators.**—This stage supplies the power for modulating the r-f power amplifier. Many modulator arrangements are used depending upon the power, frequency response, and distortion requirements of the transmitter. In low power transmitters class A and class AB modulator stages are generally used. High power plate-modulated transmitters generally use class B modulators. The power output of a power ampifier used for plate modulation is usually equal to approximately 50 percent of the plate input of the modulated stage. The circuit of a class B modulator is shown in Fig. 11. It consists of input and output transformers and the modulator tubes. The output transformer is designed to match the impedance of the modulator plates to the load impedance presented by the r-f amplifier. The load presented to the modulator is equal to the plate voltage of the modulated stage divided by its plate current.

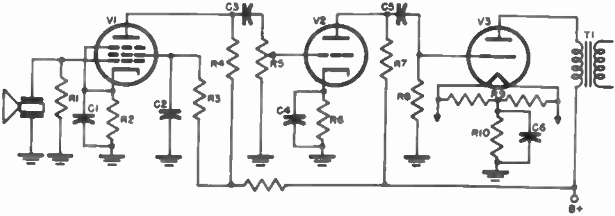


Fig. 10.—A three-stage speech amplifier.

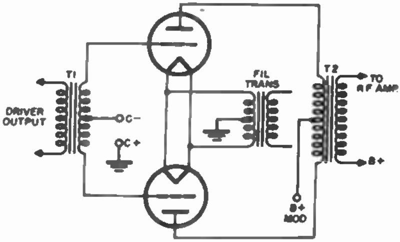


Fig. 11.—Class B modulator.

13. **Oscillators.**—The oscillator generates the r-f signal which is amplified and modulated in later stages of the transmitter. There are two general types of oscillators, variable-frequency or self-excited oscillators and crystal-controlled oscillators. Self-excited oscillators make it possible to operate the transmitter at any frequency in the tuning range of the oscillator and are used when flexibility is more import-

ant than frequency stability. Self-excited oscillators must be operated at low power levels, be provided with stable element voltages, and be lightly loaded to secure suitable frequency stability. In addition, circuit components must be carefully designed to minimize variation in circuit values with temperature change. Because of their better load isolation, electron-coupled oscillators are widely used as variable-frequency oscillators in transmitters.

When stability and the ability to operate on an exact predetermined frequency are important, crystal-controlled oscillators are generally used. In this type of oscillator, the frequency of oscillation is controlled by a piezo-electric plate. This plate is mounted between two metal electrodes. When pressure is applied to a plate of piezo-electric material, such as quartz, an electromotive force is generated. Conversely when a voltage is applied to the faces of a quartz plate, it distorts mechanically. If a quartz plate is mounted between suitable metal electrodes and placed in an oscillator circuit as shown in Fig. 12, it will control the frequency of oscillation. The crystal acts as a high Q resonant circuit. The frequency at which a quartz plate oscillates is determined by its dimensions and its orientation in the quartz crystal from which it was cut. While the resonant frequency of a good quartz plate is remarkably independent of temperature, some frequency change does occur with temperature variation. When the greatest possible stability is required, the crystal unit is mounted in a temperature control chamber. The temperature chamber maintains the crystal at a nearly constant operating temperature.

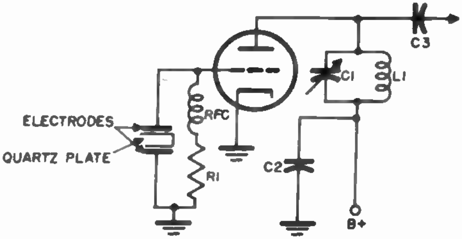


Fig. 12.—Simple crystal oscillator.

14. **Buffer Amplifiers.**—The frequency stability of an oscillator is somewhat dependent upon load conditions. If an oscillator must supply power and loading conditions change, the stability of the oscillator will suffer. To minimize the load on the oscillator and to isolate it from the power amplifier stages, a buffer amplifier is generally used in transmitters. An ideal buffer amplifier operates as a voltage amplifier, biased so that its grid does not draw current. Under these conditions, the oscillator is not required to supply power and

optimum load conditions are secured.

15. Interstage Coupling.—Two coupling methods, capacitive and link, are commonly used between transmitter stages. Capacitive coupling is illustrated in Fig. 13A. Capacitor C1 serves as the coupling and as a blocking capacitor preventing the plate supply voltage of the previous stage from reaching the grid of the amplifier. The amount of coupling is varied by changing the position of the tap on tank coil L1. Link coupling is illustrated in Fig. 13B. With this type of coupling, two coils, consisting of a few turns each, are tightly coupled to the plate and grid tank circuits. These coils are then connected by a suitable low impedance transmission line. The coils are located at the low potential points on the output and input tank coils. In Fig. 13B, where single tube circuits are employed, these are at the lower ends of the coils; while in Fig. 13C, where the amplifier is of the push-pull type, the coupling is placed at the center of the coil. Link coupling has several advantages. The circuits to be coupled do not have to be located close together; when used with push-pull circuits circuit balance is not disturbed, and it minimizes capacitive coupling which must be avoided in many circuit arrangements.

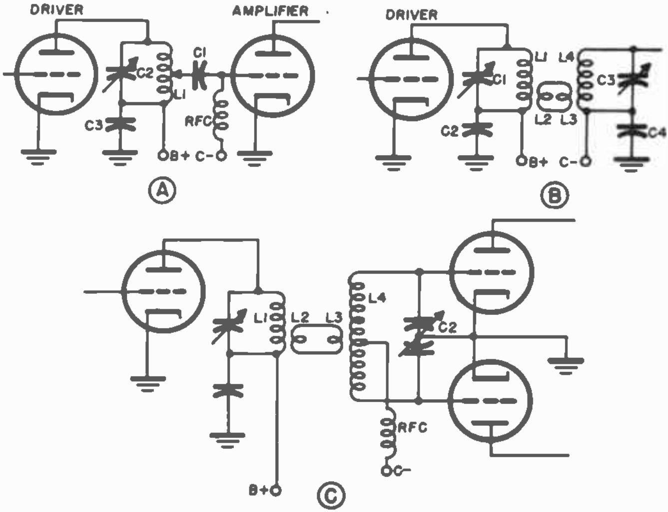


Fig. 13.—Interstage coupling circuits.

16. Frequency Multipliers.—It is not always possible or desirable to operate the oscillator of a transmitter at the transmitting frequency. In many cases, the oscillator is operated at a sub-multiple of the transmitting frequency. The oscillator frequency is then multiplied in suitable amplifier circuits to produce the transmitting frequency. An amplifier whose purpose is to produce energy at a harmonic of its input frequency is called a frequency multiplier. These circuits take advantage of the nonlinearity of the plate-current grid-voltage characteristics of vacuum tubes to produce harmonic energy. Two frequency multiplying circuits are illustrated in Fig. 14. In the circuit at A, a single tube is used. The plate tank circuit is tuned to a harmonic of the input frequency. To secure greatest efficiency, the plate circuit is operated at a much higher voltage than would be used with a straight amplifier, and the grid is biased at a voltage slightly beyond plate-current cutoff.

The circuit of Fig. 14B is called a push-pull frequency multiplier. In this circuit, the grids are connected in push-pull and the plates are paralleled. Thus for each half cycle of input voltage, a full cycle of output voltage is developed. This circuit will not operate at the oscillator frequency or at odd harmonics of that frequency. It is suitable for use at even harmonics only and its efficiency approaches that of a straight amplifier.

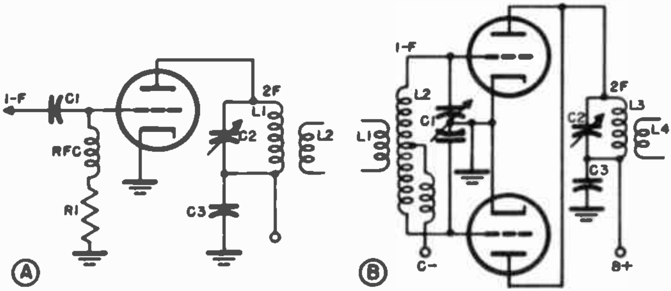


Fig. 14.—Frequency-multiplier circuits.

17. Neutralization.—When the grid and plate circuits of an r-f amplifier are tuned to the same frequency, some means must be provided to prevent the circuit from acting as an oscillator. In an amplifier with plate and grid circuits tuned to the same frequency, the feedback due to the grid-to-plate capacitance of the tube causes the circuit to operate as a tuned-plate tuned-grid oscillator. The effects of the feedback can be neutralized by providing an equal amount of feedback voltage 180 degrees out of phase with the grid-to-plate feedback. Several methods of accomplishing this are illustrated in Fig. 15. In A a center-tapped plate tank coil L1 is used. The plate supply voltage is applied to the center tap of L1 through an r-f choke, and bypass capacitor C3 is provided to place the center tap at ground potential with respect to r.f. The plate current of the stage flows through the upper half of L1 and the r-f variations in this current induce a voltage in the lower half 180 degrees out of phase with the r-f voltage in the upper half. Part of this out-of-phase voltage at the lower end of L1 is fed back to the grid through neutralizing capacitor Cn. This voltage opposes the feedback due to the interelectrode capacitance and prevents oscillation. The correct amount of feedback is obtained by varying the capacitance of Cn.

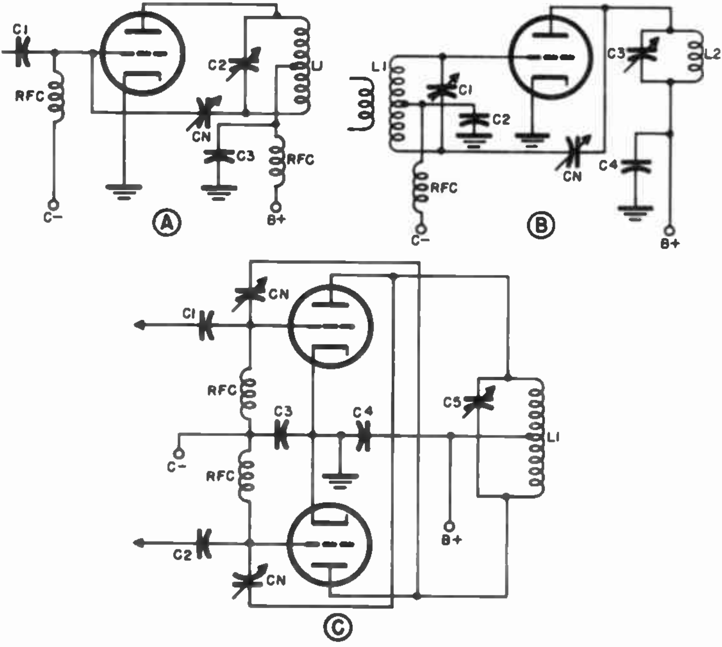


Fig. 15.—Neutralizing circuits.

In the circuit at B, a center-tapped grid coil is used instead of the tapped plate coil of A. Proper phasing of the feedback voltages is obtained by applying them to the opposite ends of the coil. The circuit at C is a push-pull amplifier with cross neutralization. The r-f voltages on the opposite plates of a push-pull stage are 180 degrees out of phase. By feeding r-f voltage from each plate to opposite grids, the effects of feedback due to interelectrode capacitance are eliminated.

18. Power Amplifiers.—Class B and C amplifiers are used in the r-f power amplifier stages of transmitters. Class A is not suitable because of its low efficiency. A class B amplifier is biased approximately at cutoff. Without excitation, the plate current is near zero. When excited by a sinusoidal voltage, the plate current flows in a series of half cycles. Push-pull amplifiers may be operated in class B in which case each tube conducts alternately. The class B amplifier is not as efficient as the class C amplifier and its use is generally limited to transmitters in which the modulated amplifier precedes the final power amplifier. In such a transmitter, considerable distortion would result if a class C amplifier were used.

Class C amplifiers are biased well beyond cutoff. Plate efficiencies as high as 90 percent may be obtained with this class of operation. When the final power amplifier is the modulated stage, it is usually operated in class C.

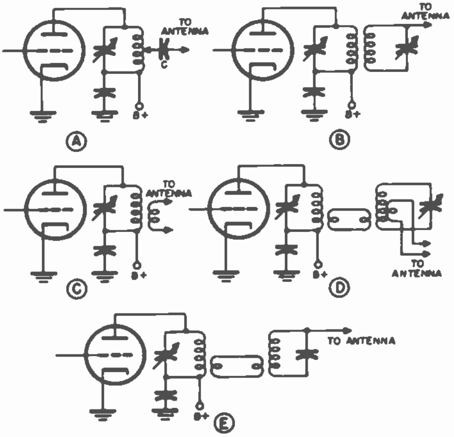


Fig. 16.—Antenna coupling circuits.

Triodes, screen-grid tetrodes and pentodes are used as power amplifiers. The screen grid tubes require less driving power and usually do not require neutralizing.

19. Coupling to the Antenna.—Several of the methods used to couple the antenna transmission line to the output of a final amplifier are shown in Fig. 16. A is called direct coupling. It is used to connect a single-wire or end-fed antenna to the output tank. To secure proper loading, the position of the tap is varied. The capacitor C prevents the high positive plate voltage from being applied to the antenna system. In B a tuned circuit is inductively coupled to the final tank circuit, and the antenna is attached to the tuned circuit. To minimize capacitive coupling, the antenna coil should be located on the final tank at a point of low r-f voltage. In C a half wave antenna, fed with a low impedance transmission line, is coupled to the transmitter by means of a link consisting of a few turns of wire tightly coupled to the final tank circuit. Link coupling may also be used as illustrated in D and E. In D a low impedance non-resonant line is link coupled to an antenna tuned-circuit which in turn is coupled to the final tank by means of a link. E is similar except that it is used to feed a single-wire-fed antenna.

A-M RECEIVERS

20. Superheterodyne Receiver.—A superheterodyne receiver is one in which the desired signal is mixed with a locally generated signal to produce an intermediate frequency signal. This intermediate frequency signal is then amplified and detected to produce the audio frequency. Figure 17 is a simplified block diagram of a typical superheterodyne receiver.

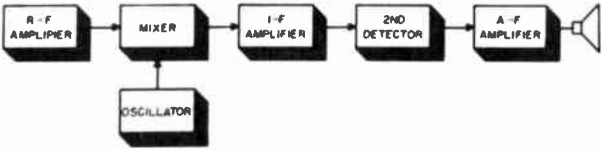


Fig. 17.—Block diagram of superheterodyne receiver.

The r-f amplifier stage receives the weak signal intercepted by the antenna, amplifies it and passes it on to the mixer. In the mixer stage, the received signal is heterodyned with the output of the local oscillator. The output of the mixer stage is an intermediate frequency signal which has the same modulation characteristics as the received signal. The i-f signal then passes through a number of amplifiers, referred to as intermediate-frequency amplifiers, whose output is applied to the second detector. This stage removes the i-f component from the signal, leaving the undistorted audio signal which is then amplified and applied to the loudspeaker.

21. Frequency Conversion.—The converter stage consists of the mixer and local oscillator. The purpose of the frequency converter is to produce an intermediate-frequency signal having the same modulation characteristics as the received signal. This is accomplished by generating an unmodulated r-f signal in the receiver and heterodyning it with the received signal. By this method, a third signal is generated, whose frequency is equal to the difference between the locally generated and incoming signal frequencies.

Two circuits are required to generate the i-f signal, an oscillator and a mixer. Tubes of special design have been developed so that both functions can be accomplished by one tube. Many receivers, however, employ separate mixer and oscillator tubes. A typical converter circuit using separate mixer and oscillator tubes is shown in Fig. 18. The r-f input is coupled to the mixer grid tuned-circuit, L2-C1, by means of coupling coil L1. This circuit (L2-C1) is tuned to the frequency of the incoming signal. The incoming signal builds up across L2-C1 and is applied to the mixer grid. V2 is connected in an Armstrong oscillator circuit. The oscillator operates at a frequency equal to the incoming-signal frequency plus the intermediate frequency. Output from the oscillator is coupled to the mixer grid through capacitor C2. The signal on the plate of the mixer tube is thus the result of both the incoming signal and the oscillator signal. Signals at the oscillator frequency, the received signal frequency, the difference frequency, and several others appear in the mixer output. Circuit L5-C8 is tuned to the difference frequency and this signal builds up to a high amplitude while other signals are largely eliminated.

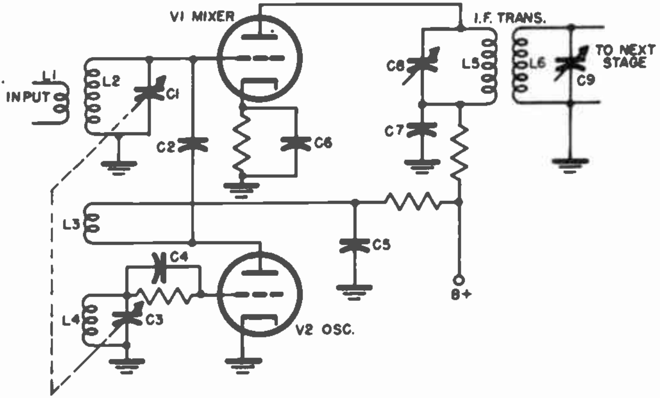


Fig. 18.—Converter stage using separate mixer and oscillator tubes.

Capacitors C1 and C3 are ganged so that when the mixer grid circuit is tuned to the frequency of an incoming signal, the oscillator is tuned so that its frequency remains equal to the incoming signal plus intermediate frequencies. 465 kilocycles is one of the most common intermediate frequencies. With this i.f. if the received signal is at a frequency of 1,000 kilocycles, the oscillator frequency must be 1,465 kilocycles. If the mixer is tuned to a new signal, at say 2,000 kilocycles, the oscillator must be changed to 2,465 kilocycles.

22. Oscillator Signal Injection.—In the converter described above, a capacitor is used to inject the oscillator signal into the grid circuit of the mixer. This arrangement is called capacitive injection. Two other methods of injecting the oscillator signal into the mixer circuit are shown in Fig. 19. In A inductive injection is used. The oscillator grid coil L4 is inductively coupled to the mixer cathode circuit by means of coupling coil L3. In B electronic injection is used. A pentagrid mixer tube is used in this circuit providing a separate grid for the oscillator signal. The incoming signal, applied to the control grid, and oscillator signal, applied to a second control grid, both act upon the electron stream through the tube, to produce the intermediate frequency in the plate circuit. The injection method illustrated in Fig 19A is superior to that of Fig. 18 in that it reduces interaction between the mixer and oscillator circuits. The circuit of Fig. 19B is superior to both of the others in this respect.

23. **I-f Amplifiers.**—The i-f amplifiers provide the selectivity and most of the voltage amplification of a superheterodyne receiver. One, two and sometimes three i-f amplifier stages are used. A typical i-f amplifier circuit is shown in Fig. 20. The input and output circuits are inductively coupled by means of i-f transformers T1 and T2. The primaries and secondaries of the transformers are tuned. Since the incoming signal is always heterodyned to the same intermediate frequency, the four tuned circuits are operated at the same frequency at all times. This makes it possible to design and adjust the circuits to obtain maximum gain and selectivity. The i-f transformers are mounted in small metal cans and are adjusted to the proper frequency by means of variable capacitors, as shown in the figure, or by means of movable powdered-iron cores. The capacitor-tuned type are often provided with fixed powdered-iron cores to increase gain and selectivity.

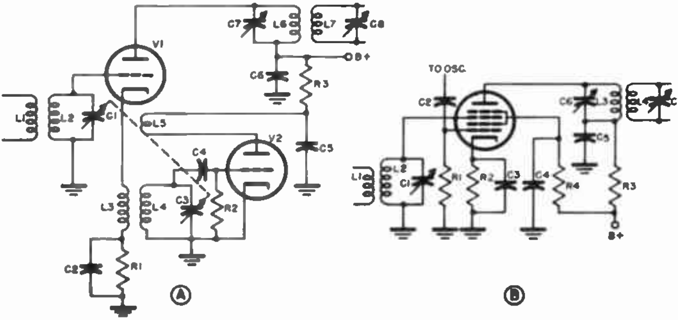


Fig. 19.—Inductive and electronic oscillator signal injection.

Because of the high gain of i-f amplifiers, coupling between input and output circuits must be kept to a minimum. This is accomplished by careful shielding and placement of parts and by providing suitable decoupling net works in plate, screen and grid circuits. Decoupling networks usually consist of a resistor and capacitor connected as shown in Fig. 20. R2-C5 is the plate decoupling network while R3-C6 provides screen decoupling.

24. **Selectivity and Image Rejection.**—The two most important factors influencing the choice of an intermediate fre-

quency are selectivity and image rejection. For several reasons it is possible to obtain greater selectivity as the intermediate frequency is lowered. Therefore, when maximum selectivity is desired, the intermediate frequency is made as low as possible consistent with other factors.

If the oscillator of a superheterodyne is tuned to 1,465 kilocycles and the intermediate frequency is 465 kilocycles, signals at 1,000 kilocycles (oscillator minus i.f.) and 1,930 kilocycles (oscillator plus i.f.) may be received by tuning the mixer to the desired signal. This is possible because both frequencies when heterodyned with the oscillator signal will produce the same difference frequency. In practice, the mixer is tracked so that it is always tuned to either the oscillator frequency plus the i.f. or the oscillator frequency minus the i.f. If the mixer frequency is equal to the i.f. plus the oscillator frequency, then the i.f. minus the oscillator frequency is referred to as the image frequency. If the mixer is tuned below the oscillator frequency, then the higher frequency is the image frequency. Regardless to which frequency the mixer is tuned, some signal energy will appear in the mixer output if a strong image frequency signal is present. This difficulty occurs because the mixer circuit is not selective enough to reject the image signal. Suitable image rejection is obtained by choosing an intermediate frequency high enough to provide sufficient separation between the received-signal and image-signal frequencies. As the i.f. is increased, the image frequency moves further away from the frequency to which the mixer is tuned and the image rejection increases. In the broadcast band and at somewhat higher frequencies, i.f.'s in the neighborhood of 465 kilocycles are satisfactory; while at higher frequencies, the i.f. must be increased to obtain suitable image rejection. Generally, it is necessary to make a compromise and choose a frequency somewhere between that which gives optimum image rejection and that which gives the greatest selectivity.

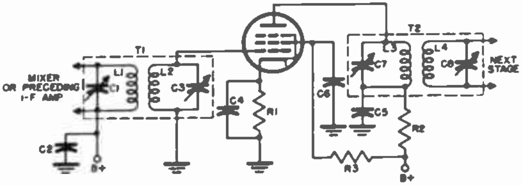


Fig. 20.—Pentode i-f amplifier circuit.

25. Crystal Filters.—When very high selectivity is desired, a crystal filter is included in the i-f circuits of the receiver. The crystal consists of a piezo-electric quartz plate mounted in a suitable holder and connected in the coupling circuit between two i-f amplifiers. Because the crystal has a very high Q and will respond to only a very narrow band of frequencies, it greatly increases the selectivity of the receiver. A typical crystal filter circuit is shown in Fig. 21. The crystal is in a bridge circuit consisting of the two halfs of L2, the crystal, and phasing capacitor C4. L2 is balanced to ground by the centertap. The capacitance of C4 is made approximately the same as the capacitance of the crystal holder. This eliminates the effects of the holder capacitance, and the crystal acts as a high Q series-resonant circuit. If the holder capacitance were not neutralized, it would act as a coupling capacitor and destroy the selectivity of the circuit.

C3 is used to adjust the resonant frequency of the input transformer secondary and acts as a selectivity control. Greatest selectivity is obtained when the secondary is tuned to the i.f. When broader response is desired, the secondary is detuned slightly.

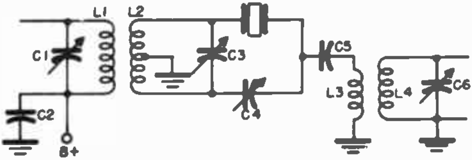


Fig. 21.—A crystal-filter circuit.

26. R-f Amplifiers.—An r-f amplifier is not necessary in a superheterodyne receiver and in fact many receivers do not include such a stage. However, the incorporation of an r-f amplifier greatly improves the performance of a receiver. The purpose of an r-f amplifier is to improve the image rejection and the sensitivity of the receiver. As explained in the paragraph on i-f amplifiers, the mixer stage does not have sufficient selectivity to completely reject strong signals at the image frequency. The r-f stage increases the image rejection by amplifying the desired signal. The image signal is not amplified and thus image interference is reduced. Some receivers use as many as three r-f stages to secure optimum image rejection in combination with an intermediate frequency low enough to permit high selectivity.

Considerable noise is generated in converter tubes. This noise is superimposed on the signal and appears in the output of the receiver. To be received, a signal must have an amplitude greater than the noise generated in the converter stage. An r-f amplifier increases the amplitude of the incoming signal before it reaches the converter stage. Since the converter noise remains constant, the additional signal amplification makes it possible to receive signals which would otherwise be lower than the converter noise level. Some noise is also generated in r-f amplifiers, and when such a stage is employed the absolute sensitivity of the receiver is determined by this noise. R-f amplifiers, however, generate much less noise than converters. The ability of an r-f stage to improve the sensitivity of a receiver is particularly important at frequencies above 10 megacycles. Below 10 megacycles, man-made noise is too great to make very high sensitivity useful.

A typical r-f amplifier circuit is shown in Fig. 22. It consists of a pentode tube with a tuned-grid circuit and an impedance load. Pentodes are generally used because of their high gain and low interelectrode capacitance. Because of their high gain, r-f amplifiers must be carefully shielded and decoupled to prevent oscillation.

27. Second Detector.—The second detector removes the i-f component from the signal and leaves the audio impressed upon the carrier at the transmitter. The simplest and most common type of detector is the diode detector shown in Fig. 23. Grid-leak detectors overload too easily for use in superheterodyne receivers. The plate detector is sometimes used but is not as popular as the diode detector because it is more difficult to obtain a.v.c. voltage from the former.

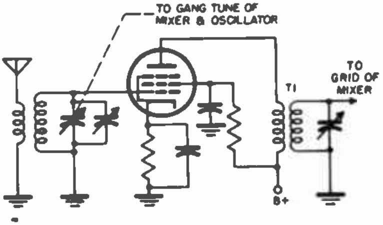


Fig. 22.—Typical receiver r-f amplifier.

28. Automatic Volume Control.—The function of a.v.c. is to maintain constant output from a receiver when the amplitude of the incoming signal changes. This is accomplished by rectifying part of the received signal, at the output of the i-f amplifier, and developing a voltage across a suitable resistor. The magnitude of the voltage is proportional to the amplitude of the incoming signal. By using remote-cutoff tubes in the r-f and i-f stages of the receiver, this voltage may be applied to their grids, as bias, to vary the gain of the receiver inversely as to signal strength.

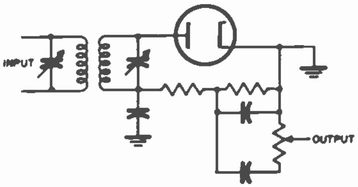


Fig. 23.—Diode-detector circuit.

A typical a-v-c circuit is shown in Fig. 24. V1 operates as a conventional diode detector. V2 is the a-v-c rectifier. Signal voltage is fed from the detector plate to the plate of V2 through coupling capacitor C6. The rectified signal current produces a voltage across the diode load resistor R5. Since the current flow through R5 is from the diode plate to ground, the upper end of R5 is negative with respect to ground. This negative voltage is applied to the grid circuits of the r-f and i-f amplifiers through a filter and individual decoupling networks. An increase in the amplitude of the incoming signal increases the a-v-c bias and reduces the gain of the receiver to maintain constant output. If the signal amplitude decreases, the a-v-c bias decreases and the receiver gain is raised. R6 and R7 form a voltage divider operating from the receiver high voltage supply. The voltage divider places a positive potential on the cathode of the a-v-c diode. This potential delays the development of a-v-c voltage until the signal reaches a predetermined minimum value. On weak signals, there is no a-v-c bias and the receiver operates at full gain.

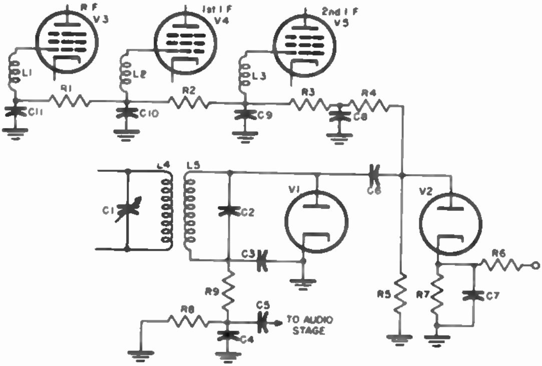


Fig. 24.—Automatic-volume-control circuit.

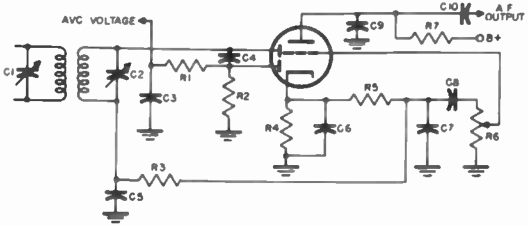


Fig. 25.—Combined a.v.c., second detector and first audio amplifier stage.

Many receivers employ the circuit of Fig. 25. Here the second detector, a-v-c rectifier, and the first audio amplifier are combined in one tube. The upper diode is the signal detector. The lower diode, which acts as the a-v-c rectifier, is coupled to the detector plate through capacitor C4. A rectified voltage is developed across R2 and applied to the r-f and i-f grid circuits through a filter consisting of R1 and C3. The cathode current of the audio amplifier section produces a bias voltage across R4 which delays a-v-c action until the incoming signal is great enough to develop a voltage exceeding the bias.

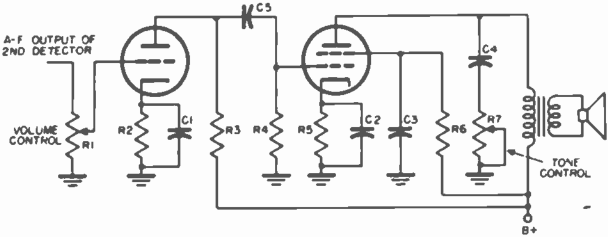


Fig. 26.—Two-stage a-f amplifier.

The filters, R1-C3 in Fig. 25 and R4-C8 in Fig. 24 play an important part in the operation of these circuits. The filters remove audio-frequency variations from the a-v-c voltage. Their time constants must be long enough to remove all audio fluctuations but not so long as to prevent the a-v-c voltage from following rapid changes in input signal amplitude.

29. Audio-frequency Amplifiers.—The a-f stages of a receiver amplify the output of the second detector and raise it to a sufficiently high level to drive the loudspeaker. This is usually accomplished in two stages. The first stage is a voltage amplifier and the output stage is a power amplifier, as shown in Fig. 26. Both stages are operated as class A amplifiers and are biased by means of a cathode resistor and bypass capacitor. Potentiometer R1 acts as a volume control, permitting variation in the portion of the signal voltage applied to the grid of the voltage amplifier. A series resistor-capacitor network, R7-C4, makes it possible to vary the amplitude of the high frequencies in the audio output.

When more power output is required, the output stage usually employs two tubes operated in push-pull. With this arrangement, a third stage is required. This stage is either a transformer-coupled driver or a phase inverter.

30. Cathode-ray Tuning Indicators.—The tuning eye, or "magic eye", is a cathode-ray type of tuning device that may be used to simplify tuning of receivers and other equipment. It consists of a miniature cathode-ray tube and a triode amplifier in the same evacuated glass envelope. The usual circuit arrangement is shown in Fig. 27. A rod-like common cathode is mounted vertically and surrounded by a funnel-shaped anode that tapers downward. The inner surface of this anode, or target electrode, is chemically treated so that it glows when struck by the electrons emitted by the heated cathode, producing the familiar ring of light visible at the end of the glass envelope. Between the cathode and target is a vertical wire known as the ray-control electrode. If this electrode is at the same voltage as the target, the glow will be a continuous ring. However, if the voltage is less positive than that of the target electrode, a field is set up that repels electrons flowing from the cathode to the target. Thus, the part of the target in line with the ray-control electrode will be dark, the extent of the dark area depending upon the voltage difference between the target and the ray-control electrode. In a typical circuit, the control grid of the triode section is connected to the a-v-c line in the receiver. Without a signal there is no a-v-c voltage and no bias on the control grid (G1) of the triode section of the indicator. This results in a high anode current in the triode section and, therefore, a high voltage across resistor R1 (usually about 1 megohm). Thus, the voltage at the ray-control electrode is considerably less positive than that at the target, and a wide shadow angle is obtained. As the signal increases, the negative a-v-c voltage increases and the control grid G1 becomes more negative. This results in less anode current in the triode section and a smaller voltage drop across resistor R. The difference in the voltages at the ray-control electrode and the target electrode is less, and the shadow angle becomes smaller. Thus, as a

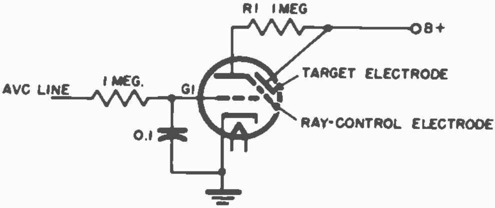


Fig. 27.—Cathode-ray tuning indicator circuit.

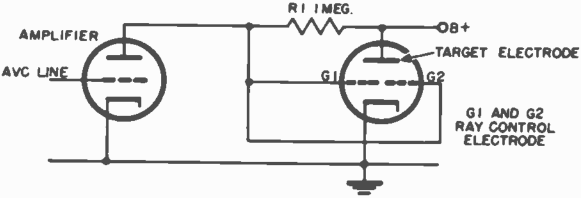


Fig. 28.—Dual shadow cathode-ray tuning indicator.

station is tuned in, the dark portion of the ring becomes smaller.

A dual magic-eye indicator is shown in Fig. 28. Its operation is similar to that of the single type except that it employs an external d-c amplifier. The cathode-ray section uses two ray-control electrodes and two shadow angles are produced. These shadows will be symmetrically opposite if the ray-control electrodes are connected together. Two dissimilar patterns are obtained if the ray-control electrodes are connected to separate circuits.

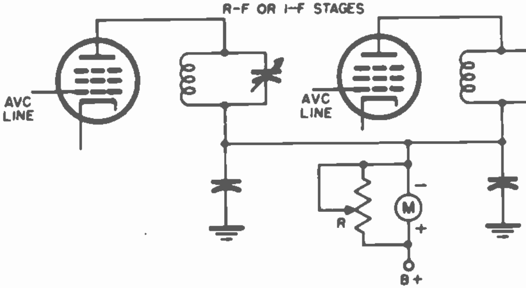


Fig. 29.—Plate current signal-strength meter.

31. Signal-strength Meters.—A plate-current signal-strength meter circuit is shown in Fig. 29. A milliameter is connected in the plate lead of several of the r-f or i-f tubes to whose grids a-v-c voltage is applied. As the signal strength increases, the a-v-c voltage becomes more negative and the plate current through the meter decreases. Resistor R is adjusted so that the milliameter reads full-scale with no signal (highest plate current). This point is called "zero signal". Thus, the meter indicator moves counterclockwise with increasing signal. In many commercial receivers, the meter is mounted in an inverted position, so that the pointer will move to the right with increasing signal strength.

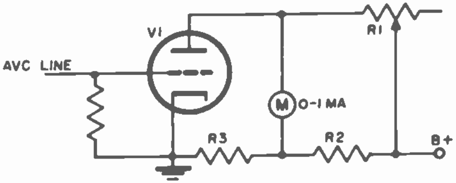


Fig. 30.—Bridge type signal-strength meter.

A bridge type signal-strength meter is shown in Fig. 30. V1 is used to amplify the a-v-c voltage. The current through R1, M, and R3 tends to cause the meter needle to move to the right, while the current through R2, M, and the tube tends to make the needle move to the left. At zero signal, these currents are made equal by adjusting the resistance of R1. The operation of this circuit is based on the fact that a change in grid bias will cause a variation in the d-c plate current of the tube. As the received signal amplitude increases, the a-v-c voltage becomes more negative. This voltage is applied to the grid of V1 and the d-c plate current decreases. Thus, the meter needle moves to the right with increasing signal strength.

32. Automatic Frequency Control.—Automatic-frequency-control circuits are used in many superheterodyne receivers to compensate for intermediate-frequency drift. This drift may be due to such factors as small changes in oscillator or carrier frequency. It is compensated for by automatically adjusting the oscillator frequency.

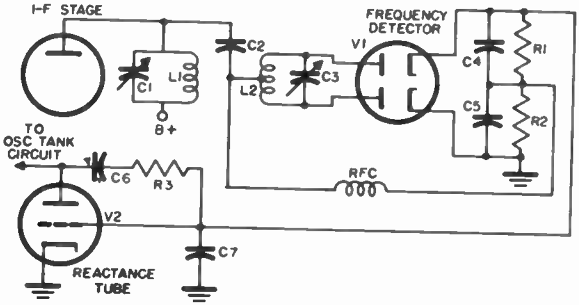


Fig. 31.—Automatic-frequency-control circuit.

An a-f-c system consists of two basic parts, a frequency detector and a variable reactance circuit. Fig. 31 shows a typical circuit. The discriminator is of the Foster-Seeley type and is excited by the i-f signal from the final i-f amplifier stage. The discriminator output is a d-c voltage whose polarity depends upon whether the intermediate frequency has deviated above or below its correct value, and whose magnitude is proportional to the amount of deviation. This d-c voltage is applied to the control grid of the reactance tube, which is connected across the tank circuit of the local oscillator. The effective reactance this tube offers to the oscillator varies with the grid bias. A deviation in the intermediate frequency from its proper value causes a change in the d-c grid voltage of V2, which produces a change in the reactance presented to the local oscillator. This change in reactance is such that the oscillator is automatically adjusted to bring the intermediate frequency back to its correct value.

33. **Diode Noise Limiters.**—Noise limiters are used to minimize the effects of noise superimposed upon the signal. Their main purpose is to suppress noise impulses of high amplitude and short duration. They are not effective against other types of noise.

The circuit in Fig. 32 is used in conjunction with an infinite-impedance second detector. In the detector output signal, the noise voltages are positive. The positive noise pulses and the signal are applied to the cathode of the diode limiter. The plate of the diode is positively biased with respect to the cathode. The value of the bias is slightly greater than the received signal and therefore the diode conducts the signal to the audio amplifier. When a noise, whose amplitude exceeds the positive bias, occurs, the cathode becomes more positive than the plate and the diode does not conduct. Thus, the pulse is not passed on to the audio amplifier. The positive bias on the plate of the diode can be adjusted, for different signal levels, by means of R1.

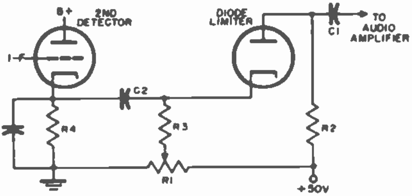


Fig. 32.—Series-diode noise limiter used with an infinite-impedance detector.

Figure 33 illustrates a diode noise limiter for use with a diode second detector. In the output of the diode detector, the signal and noise voltages are negative. The output of the second detector is applied to the plate of the diode limiter, whose plate is positively biased with respect to its cathode. The signal voltage does not exceed this bias and is therefore passed on to the audio amplifier. Noise pulses which exceed the bias are not conducted and do not reach the audio stage.

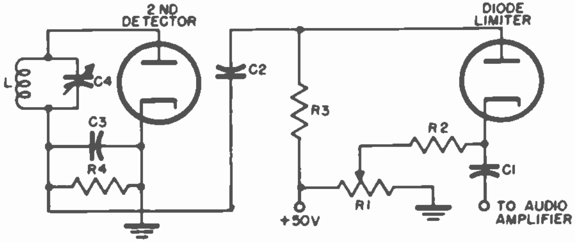


Fig. 33.—Series-diode noise limiter used with diode detector.

34. I-f Noise Silencer.—A noise silencing circuit which operates in conjunction with an i-f amplifier is shown in Fig. 34. Its basic action is to decrease the gain of the i-f stage during noise pulses and thus silence the receiver.

The i-f signal is applied to the control grids of both the noise-silencer V3 and the noise-amplifier V1. The signal is amplified by V1 and applied to full-wave noise-rectifier tube V2. When a noise pulse occurs, it is rectified and a negative voltage is developed across R5. This negative voltage is applied to the third grid of V3 where it produces a reduction in the gain of the amplifier which silences the receiver for the duration of the noise pulse. Adjustment for the desired signal level is made by means of potentiometer R1, which varies the bias and gain of the noise-amplifier V1.

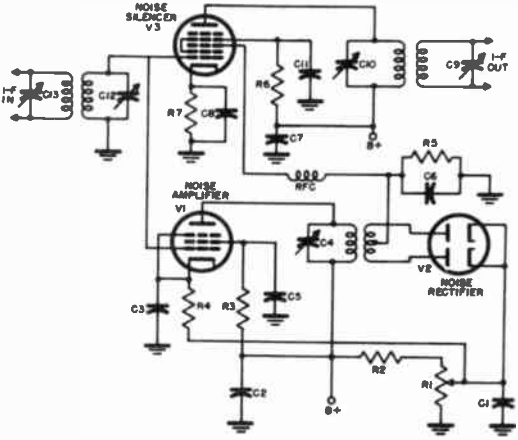


Fig. 34.—Intermediate-frequency noise silencing circuit.

The center-tapped rectifier in the noise-rectifier circuit minimizes r-f feedback from the noise-rectifier to the noise-silencer stage. The time constant (R5-C6) of the rectifier load circuit is small; if it is too large, the "silencing" will be effective for a period greater than the duration of noise pulses.

35. C-w Reception.—Continuous wave signals may be received with a superheterodyne receiver if an additional oscillator is provided. This oscillator, called a beat frequency oscillator or "b.f.o.", is coupled to the second detector circuit. The intermediate-frequency and b-f-o signals are mixed in the second detector and the difference-frequency signal obtained. For example, if the intermediate frequency is 456 kilocycles, the b.f.o. is tuned to approximately 455 or 457 kilocycles. Thus, an audible (1,000 c.p.s.) beat signal is produced in the second detector output. The oscillator signal is not in the audible range.

A typical b-f-o circuit is shown in Fig. 35. The oscillator is of the Hartley type. The frequency of the tuned circuit is variable over a narrow range, by means of trimmer capacitor C1, in order to allow the operator to obtain a suitable beat note after the c-w signal has been tuned in. An increase in stability is obtained by the use of a high gain tube, such as a tetrode or pentode, rather than a triode. A tapped load resistor in the oscillator plate circuit is often used to adjust the amplitude of the b-f-o output to correspond with that of the received signal. This arrangement permits enough b-f-o signal to be produced to give the desired beat with strong signals and also permits the b-f-o output to be decreased when receiving weak signals, to reduce hiss.

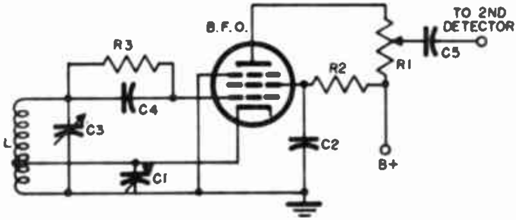


Fig. 35.—Beat-frequency-oscillator circuit.

Section 9

FREQUENCY MODULATION

1. **General.**—Modulation is a process in which the amplitude, frequency, or phase of an r-f carrier is varied in accordance with the intelligence to be transmitted. In amplitude modulation the amplitude of the r-f carrier is varied in time, in accordance with the a-f or other signal to be transmitted. Amplitude modulation has several disadvantages. One of them is its susceptibility to noise. Such noise is the result of atmospheric disturbances and man-made electrical equipment, such as automobile ignition systems and electric motors. Since this noise is amplitude in character and is present over the whole radio frequency spectrum, it is received amplified and detected with the desired signal. To overcome this disadvantage, some other method of modulation in which amplitude variation is not employed must be used. One such method is frequency modulation.

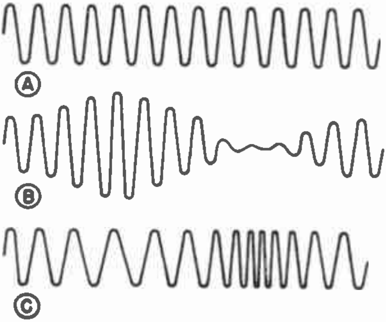


Fig. 1.—Amplitude and frequency modulated carriers.

2. **Frequency Modulation.**—In frequency modulation, the frequency of the r-f carrier is varied in accordance with the a-f or other signal to be transmitted. Amplitude and frequency modulation are compared in Fig. 1. A shows an unmodulated carrier, B shows an amplitude modulated carrier, and C shows

a frequency modulated carrier. In the a-m carrier the frequency remains constant and the amplitude varies during modulation, while in the f-m carrier the amplitude remains constant and the frequency varies during modulation.

The principle parts of a simple frequency modulated transmitter are shown in Fig. 2. It consists of a self-excited oscillator with a capacitor type microphone shunted across its tank circuit. Output from the oscillator is fed to a frequency multiplier which in turn drives a power amplifier operating at the desired transmitting frequency. When sound strikes the diaphram of the microphone, the diaphram is compressed and released in accordance with the amplitude and frequency of the sound waves. The microphone is essentially a capacitor. Since the capacitance of a capacitor is partially dependent upon the distance between its plates, the movement of the diaphram results in a variation in the capacitance across the oscillator tank circuit. This variation in capacitance causes the frequency of the oscillator to change. When the diaphram is depressed, the oscillator frequency is lower than when the diaphram is at rest, and when the diaphram is released the oscillator frequency is higher than the resting frequency. Since the position of the diaphram varies with the sound waves striking it, the changes or swings in oscillator frequency follow the frequency of the sound waves. The higher the frequency of the sound waves reaching the microphone, the more rapid will be the swings in oscillator frequency. Thus if a 100 cycle sound wave is impressed upon the microphone, the frequency of the oscillator will swing above and below its original frequency 100 times per second, while a 400 cycle sound wave will result in 400 frequency swings per second.

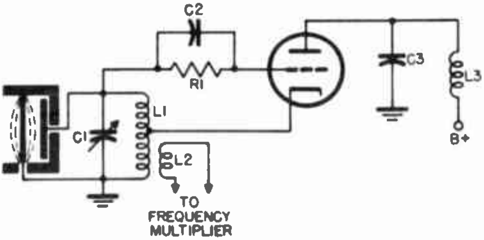


Fig. 2.—A simple frequency-modulation system.

3. **Deviation.**—If in the simple frequency-modulated transmitter described above, sound waves of a certain intensity cause the transmitter frequency to swing 10 kilocycles either side of its resting frequency, doubling the intensity of the sound waves will increase the frequency swing to 20 kilocycles either side of the resting frequency. Assuming the resting fre-

quency of the carrier to be 10 megacycles, the transmitter frequency would swing between 10,010 kilocycles and 9,990 kilocycles while doubling the sound intensity would cause it to swing between 10,020 kilocycles and 9,980 kilocycles. The amount of carrier frequency swing either side of the center or resting frequency of the carrier is referred to as its deviation. The maximum permissible deviation is determined by the width of the band assigned for station operation. In frequency modulated broadcasting, this is limited to 75 kilocycles either side of the carrier center frequency.

In amplitude modulation, 100 percent modulation occurs when the amplitude of the carrier varies from zero to twice its unmodulated value. In frequency modulation, 100 percent modulation occurs when the frequency deviation is equal to a predetermined maximum.

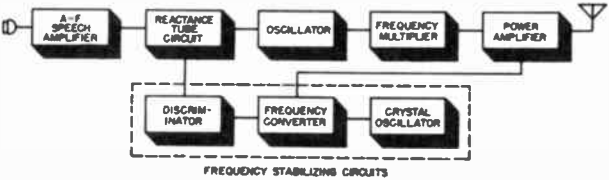


Fig. 3.—Block diagram of a reactance-tube modulated f-m transmitter.

4. Reactance-Tube Modulation.—In the simple frequency modulated transmitter previously described, a mechanical-electrical arrangement was used. In actual practice, electronic systems are always used. One such electronic frequency-modulating system utilizes a reactance-tube to vary the frequency of the transmitter. Fig. 3 is a block diagram of a reactance-tube modulated transmitter. It consists of a self-excited oscillator, usually a Hartley circuit, with a reactance tube circuit connected across its tank. In a reactance-tube circuit, the tube acts as a reactance, either capacitive or inductive. The modulating voltage supplied by the audio amplifier is applied to the reactance tube and causes its reactance to vary in accordance with the intelligence to be transmitted. Since the reactance tube is connected across the tank circuit of the oscillator, the oscillator frequency is made to vary in a like manner. The output of the oscillator is passed through a series of frequency multipliers. Here its frequency is increased to the desired transmitting frequency. Each time the oscillator frequency is doubled, the deviation is doubled. The output of the frequency multiplier is applied to a power amplifier which feeds the signal to the antenna. To stabilize the frequency of the oscillator, the output of the power amplifier is compared with the frequency of a crystal oscillator in order to produce a correcting voltage for application to the reactance-tube circuit.

One type of reactance-tube circuit is illustrated in the simplified schematic of Fig. 4. V1 is the reactance tube and V2 is the oscillator. The plate of the reactance tube is coupled to the oscillator tuned circuit through capacitor C5. C2 feeds r-f voltage to the phase splitting network consisting of R2 and Cs. Cs is the input capacitance of the reactance tube plus stray capacitance to ground. R2 is chosen so that the reactance of Cs is negligible in comparison to its resistance. The r-f current is therefore almost in phase with the r-f voltage through R2-Cs. Under this condition, the voltage across Cs lags the voltage across the oscillator tuned circuit by almost 90 degrees. As a result of this 90-degree lag in voltage at the reactance-tube grid, the plate current of V1 lags the voltage across the oscillator tuned circuit by 90 degrees. Consequently, the reactance-tube acts in the same manner as would an inductance connected across the oscillator tuned circuit. It increases the frequency of the oscillator. The plate current through V1, and hence the frequency of the oscillator, varies with changes in the signal voltage on the grid of V1. The signal voltage at the grid is supplied by an audio amplifier.

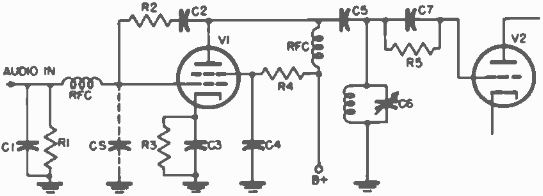


Fig. 4.—Reactance-tube modulator circuit.

5. **Phase Modulation.**—In some frequency modulated transmitters the frequency-modulated signal is produced indirectly through phase modulation. In phase modulation, the instantaneous phase angle of the modulated signal is varied with respect to the phase of the unmodulated carrier. During a change in phase, the instantaneous frequency of the modulated signal is also changing. Consequently, during phase modulation both the instantaneous phase angle and the instantaneous frequency of the r-f signal are varied. In phase modulation, the amount of frequency change or deviation produced varies with both the amplitude and frequency of the modulating signal. In frequency-modulation the frequency swing must be the same for all modulating frequencies; changing only with the amplitude of the modulating signal. If means are provided for eliminating the frequency variations of the phase modulated wave, produced by changes in the modulating frequency, the final r-f signal will be equivalent to a frequency-modulated signal.

A block diagram of an indirect frequency-modulation transmitter is shown in Fig. 5. It consists of a crystal controlled oscillator followed by a phase-shifting circuit. The output of the speech amplifier passes through a distortion network which changes the frequency response characteristic of the audio system. As a result of this net work, the response of the speech circuits decreases with increasing frequency. In this manner, the increase in deviation with frequency, which occurs in the phase modulator, is compensated for and the output of the transmitter is a frequency-modulated wave.

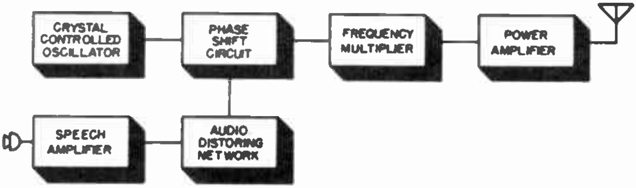


Fig. 5.—Block diagram of a phase modulated f-m transmitter.

The output of the distortion network is applied to the phase modulator. In the phase modulator, phase changes are produced whose frequency and deviation correspond to the frequency and amplitude of the audio signal. The output of the phase modulator passes through a series of frequency-multiplying stages. These stages multiply the frequency and deviation of the modulated signal. A power amplifier following the frequency multipliers increases the power of the modulated signal to a value suitable for transmission.

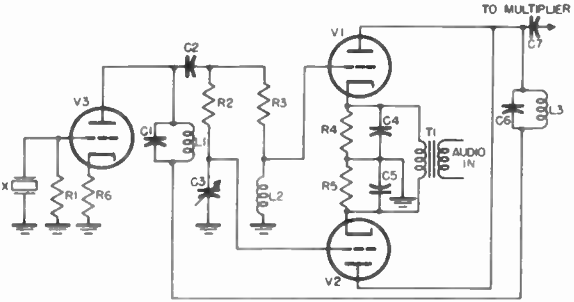


Fig. 6.—A simple circuit for producing phase modulation.

The circuit of a simple phase modulator is shown in Fig. 6. In this circuit, the output of a crystal oscillator is applied to a tuned circuit through a phase-shift circuit. Two voltage divider circuits R2-C3 and R3-L2 are coupled to the oscillator plate tuned circuit through capacitor C2. In each of these circuits, the resistance is equal to the reactance. Consequently, the r-f voltage at the junction of R3-L2 leads to the r-f plate voltage of the oscillator by 45 degrees while the r-f voltage at the junction of R2-C3 lags the oscillator r-f plate voltage by 45 degrees. These voltages are applied to the grids of V1 and V2 respectively. The plate currents produced in V1 and V2 are of the same amplitude and of equal but opposite phase. Therefore when combined, they produce a current which is in phase with the oscillator r-f plate current.

The audio modulating voltage is applied to the cathode of V1 and V2 through transformer T1. When a modulating signal is present, the cathodes of V1 and V2 go alternately negative and positive with respect to ground. When the cathode of V1 is positive and the cathode of V2 is negative, the plate current of V1 decreases and the plate current of V2 increases. Under this condition, the combined plate currents produce a current which lags the oscillator r-f plate voltage. When the cathode potentials reverse, the resultant plate current leads the oscillator r-f plate voltage. In this manner, the r-f current through tuned circuit C8-L3 is shifted in phase in accordance with the audio modulating signal. The output of the phase-shift stage is capacity coupled to the first multiplier.

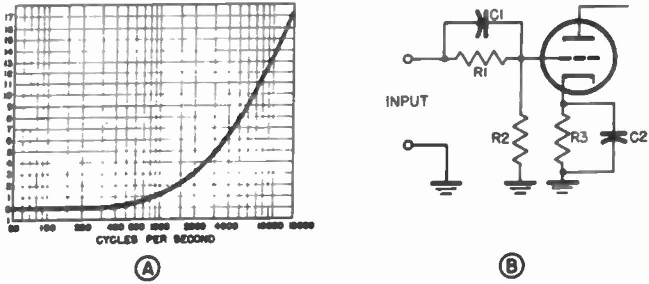


Fig. 7.—Pre-emphasis circuit and standard response curve.

6. Pre-emphasis and De-emphasis.—In the transmitter, in transmission and in the receiver, a certain amount of noise is inadvertently added to the frequency-modulated signal. This noise is almost all at the high audio frequencies and is most troublesome in wide range systems, such as are intended for use with f-m broadcasting. To minimize the effects of the noise, the amplitude of the high audio frequencies is increased with respect to the low audio frequencies. This is accomplished by a pre-emphasis filter located in the audio section of the transmitter. A typical circuit and the pre-emphasis response curve which is produces is shown in Fig. 7. Proper choice of values for R1 and C1 produces the pre-emphasized response curve. When the relative amplitude of the high audio frequencies is increased, all noise which is superimposed on the signal, after the filter, remains at the same amplitude; consequently, the ratio of the audio signal to the noise is considerably improved.

The signal, when it arrives at the receiver, is not suitable for reproduction, as a result of the pre-emphasis it received before transmission. To restore the proper balance between the high and low frequencies, a second filter called a de-emphasis filter is used. This filter is usually located in the input to the first audio amplifier. It reduces the amplitude of the high frequencies to their original relative amplitude and at the same time reduces the noise amplitude in a like ratio. Thus the improved signal-to-noise ratio is retained. A typical de-emphasis filter is shown in Fig. 8. Proper choice of R1 and C1 produces the desired response curve.

It might be supposed that pre-emphasis of the high frequencies before transmission would lead to overmodulation. Overmodulation does not occur because the high audio frequencies, before pre-emphasis, are normally of much lower amplitude than the low audio frequencies.

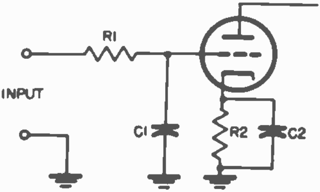


Fig. 8.—De-emphasis network.

7. **Frequency-Modulation Receivers.**—Receivers for frequency modulation are of the superhetrodyne type and are somewhat similar to ordinary amplitude-modulation superhetrodynes. Block diagrams of the two most widely used f-m receivers and an a-m superhetrodyne are shown in Fig. 9. All three receivers employ r-f amplifiers, mixer stages, oscillators, and i-f amplifiers. The most important difference between a-m and f-m receivers is in the detector circuit. A number of f-m detectors have been developed. The ratio detector used in the receiver at B removes the audio signal from the carrier and at the same time rejects amplitude impulses which may accompany it. The receiver at C employs a discriminator detector to remove the audio signal from the carrier. This detector is sensitive to amplitude impulses and in order to eliminate them before detection, a limiter stage must be provided. The limiter removes all amplitude fluctuations from the carrier before it is applied to the detector.

8. **R-F Amplifier.**—R-f amplifiers are used to secure improved signal-to-noise ratio, higher gain and selectivity and improved image rejection. Improvement in signal-to-noise ratio is secured in an r-f amplifier because considerable noise is generated in converter stages and the addition of amplification before the converter increases the signal amplitude

without increasing the noise. The tubes used in r-f amplifiers must have high mutual conductance, low interelectrode capacitance, high input resistance and must generate as little noise as possible. Because of the high frequencies at which these circuits operate, short leads, careful shielding and high quality insulation must be used.

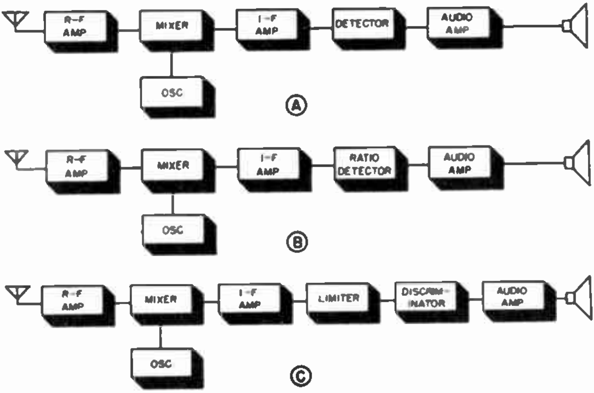


Fig. 9.—Block diagrams of f-m and a-m superheterodynes.

A typical r-f amplifier circuit is shown in Fig. 10. The antenna transmission line is coupled to the input coil by means of a separate winding. This is required to match the high input impedance of the stage to the comparatively low impedance of the transmission line. Most receivers are designed to match a 300 ohm line. To pass the complete f-m signal, the r-f amplifier must respond to a wide band of frequencies. This is accomplished by using low Q coils. The low Q broadens the response curve of the amplifier.

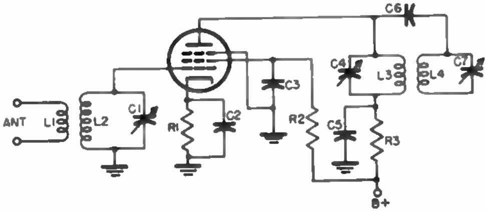


Fig. 10.—Typical r-f amplifier circuit.

9. **Mixer-Oscillator.**—Frequency-modulation receivers generally use separate mixer and oscillator tubes although in some cases these functions are combined in one tube specifically

designed for this application. The circuits employed are similar to those found in a-m receivers with modifications to make them more suitable for use at high frequencies. The difficulties encountered in using a combined mixer-oscillator stage stem from interaction between the mixer and oscillator which becomes troublesome at high frequencies and results in oscillator pulling and instability. These difficulties are largely avoided by using separate tubes and loose oscillator-mixer coupling.

It is much more difficult to minimize oscillator drift at the frequencies used for f-m broadcasting than it is at a-m broadcasting frequencies. Heating, humidity and B-supply voltage variations all contribute to oscillator drift. The effects of changing humidity are minimized by coating circuit components with moistureproofing materials, and by permitting a certain amount of temperature rise in the area surrounding critical components. Heating causes drift because it expands parts of critical components which results in increased capacity. It is minimized by using insulation materials wth low temperature coefficents and by shunting tuned circuits with negative temperature coefficient capacitors to counteract the increase in capacity taking place in other components. The effects of B-supply voltage variations are minimized by careful decoupling of the various circuits in the receiver.

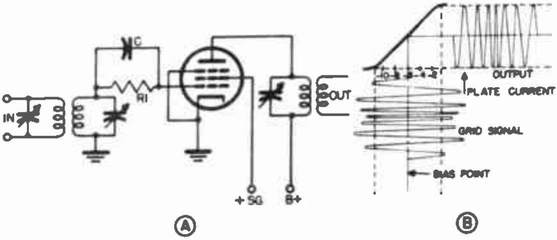


Fig. 11.—Limiter circuit and how limiting is accomplished.

10. **I-F Amplifiers.**—The i-f amplifiers used in f-m receivers employ conventional amplifier circuits. To a major extent, they determine the overall gain and selectivity of the receiver. Two stages of amplification are generally used in which three double-tuned transformers are employed. To secure the required broad band response, the Q of the i-f transformer windings is made comparatively low. In addition, one or more of the transformers is often overcoupled to broaden its response. The i-f frequency used in most modern f-m broadcast receivers is 10.7 mc. This high i-f gives excellent image-frequency interference rejection.

11. **Limiters.**—In receivers using discriminator type detectors some means must be provided to remove amplitude varia-

tions from the received signal before it is applied to the detector stage. The function of the limiter is to remove noise pulses and to restore uniformity to the signal over the pass band. A simplified limiter circuit is shown in Fig. 11A. A sharp cut-off tube is used. The plate and screen voltages applied to the tube are much lower than those normally applied to an amplifier and no fixed bias is provided. Bias is obtained by placing a capacitor and resistor in the grid return of the tube. Under these operating conditions, a grid signal of comparatively low amplitude will drive the tube to saturation on positive peaks and to cut-off on negative peaks.

This action is illustrated in Fig. 11B. When the input signal to the limiter has sufficient amplitude all the negative and positive peaks are clipped and the signal at the plate of the limiter has a constant amplitude. If the signal is not of sufficient amplitude, only partial limiting will take place. Resistor R1 and capacitor C1 play an important part in the operation of the limiter. During the positive cycles of input voltage, the grid of the tube draws current, loading the input tuned circuit and providing a diode clipping action. During this period, current flows through resistor R1 and capacitor C1 is charged. During the negative portion of the input-signal cycle C1 discharges through R1 developing a negative bias on the grid which is inversely proportional to the amplitude of the input signal. When the amplitude of the input signal increases, the negative bias on the tube becomes more negative. Thus the bias on the tube is automatically controlled by the amplitude of the input signal. The time constant of R1-C1 is chosen so that it is long enough to maintain substantially constant grid bias during the negative portions of the i-f signal applied to the stage. However, the time constant is short enough to permit an increase in bias when sudden amplitude impulses occur.

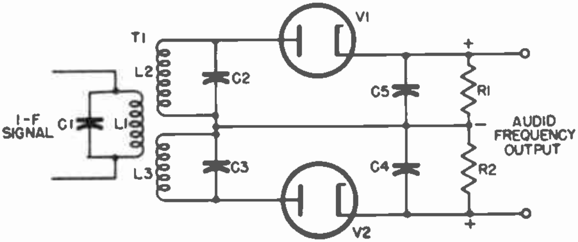


Fig. 12.—Circuit of a double-tuned discriminator.

In many receivers two limiter stages are used to secure improved limiter action.

12. The Discriminator.—The discriminator circuit of Fig. 12 illustrates one way in which the audio modulation may be removed from the frequency-modulated carrier. The r-f signal is coupled to the discriminator plates by means of transformer T1. The secondary of the transformer consists of two windings, L2 and L3, tuned by means of capacitors C2 and C3. Tuned circuits L2-C2 and L3-C3 are resonated at different frequencies, one above the frequency of the received signal and the other below. The frequencies to which the resonant circuits are tuned are equal to the carrier center frequency plus the maximum r-f carrier deviation and the carrier center frequency minus the maximum r-f carrier deviation. For f-m broadcast reception one tuned circuit is tuned to the carrier center frequency plus 75 kc. and the other to the carrier center frequency minus 75 kc. Fig. 13 illustrates the response curves of the tuned circuits as indicated by the voltages at the plates of the diodes. When a frequency-modulated signal is applied to the input of the circuit, the instantaneous voltages on the diode plates vary as the signal swings each side of the center frequency. If L2-C2 is resonant above the carrier frequency, the voltage on the plate of V1 will be higher than the voltage on the plate of V2 when the carrier swings higher in frequency than its center frequency. When the carrier swings lower in frequency than its center frequency, the voltage on the plate of V2 will be higher than the voltage on the plate of V1. When the carrier frequency is above its center frequency and the voltage on the plate of V1 is higher than the voltage on the plate of V2, the current through V1 is greater than the current through V2; consequently, the voltage developed across R1 is greater than the voltage developed across R2. The resistors are connected so that the voltages developed across them are of opposite polarities. As a result, the voltage difference from the top of R1 to ground is equal to the voltage across R1 minus the voltage across R2. Under the conditions described above, the voltage at the output is positive. When the carrier swings below its center frequency, the voltage developed across R2

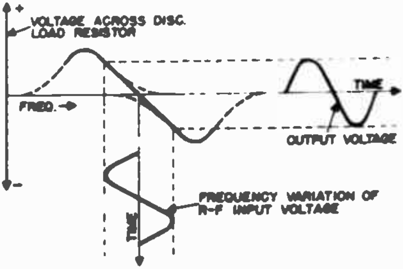


Fig. 13.—Response curves of discriminator tuned circuits.

is greater than that across R1, and the voltage at the output of the circuit is negative in polarity. Thus as the carrier swings above and below its center frequency, it produces a voltage in the output of the discriminator which varies in amplitude and frequency in accordance with the modulation of the f-m carrier.

Section 10

TELEVISION

1. Television is the electrical transmission and reception of transient visual images in sufficiently rapid succession to produce, in the observer, the illusion that he is witnessing the events occurring at the transmitter. The television system currently in use is essentially a cathode-ray television system since it makes use of a cathode ray tube to pick up the scene to be transmitted, and another cathode ray tube to reproduce the image at the receiver.

2. **Scanning.**—At the transmitter the scene to be televised is focused onto a photosensitive plate (mosaic) in the camera tube. The image thus created on the mosaic is explored, in a systematic manner, by the electron beam produced by an electron gun mounted in the tube. The electron beam explores a very small area or spot of the image at a time. This process of exploring the image to be transmitted is referred to as scanning. The method used in the present television system is called horizontal linear scanning.

In horizontal linear scanning the electron beam traverses the entire area of the image starting at the upper right-hand corner of the mosaic. The beam moves horizontally across the image at a constant speed until it reaches the left-hand edge. As the beam moves across the mosaic, it also moves down slowly. Upon reaching the left-hand edge, the beam is moved rapidly back to the right-hand edge of the image. It then moves across the image again scanning a second line. This action is repeated until the entire area of the image is traversed as shown in Fig. 1. As the electron beam moves across the image, the camera tube generates a succession of electrical impulses whose amplitude varies as the beam scans image areas of varying brightness.

At the receiver an electron beam, produced by the electron gun mounted in the picture tube, is made to scan the screen of the tube, where it produces a small luminous spot. The scanning action in the picture tube is identical to, and in synchronization with, the scanning in the camera tube. The signal produced by the camera tube is applied to the picture tube where it varies the brightness of the luminous spot. In this manner the brightness values of the image on the camera tube mosaic are reproduced on the picture tube screen.

The scanning process is rapid enough to be completed in less than the period of persistance of vision of the human eye. Consequently the eye perceives a completed image.

3. Image Repetition.—Linear scanning makes it possible to transmit and reproduce still images. It does not provide for the transmission of moving images. This is accomplished by the reproduction of a succession of images, each one slightly different than its predecessor. The same technique is used in motion-pictures where 24 still pictures are projected each second. The interval between pictures is considerably less than the period of persistance of vision, when this repetition rate is used. The eye thus perceives one continuously changing image. At present a picture or frame repetition rate of thirty per second is used in television.

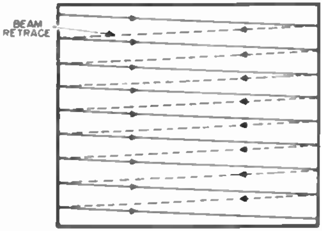


Fig 1.—Horizontal linear scanning pattern.

4. Interlaced Scanning.—Although the projection of 24 pictures per second is sufficient to create the illusion of continuous motion, it is not great enough to eliminate flicker. Flicker is a decernable change in light intensity as each successive picture is projected on the screen. In motion pictures, flicker is eliminated by projecting each picture or frame twice. This procedure doubles the number of projected images without increasing the number of still pictures required.

In television a similar technique called interlaced scanning is used. With interlacing, only half of the picture is scanned at one time. This is accomplished by leaving an unscanned space between each scanned line. The unscanned space between adjacent scanned lines is approximately equal to that of a scaned line. The half of the picture scanned in this way is called a field. When the first scanning field has been completed, the image is scanned again and the unscanned area between the previously scanned lines is explored to create a second field as shown in Fig. 2. Thus with interlaced scanning there are 60 fields for 30 frames. This effectively eliminates all flicker.

5. Aspect Ratio.—The ratio of the height of the received image to its width is known as its aspect ratio. The standard aspect ratio for commercial television broadcasting in this country is 3 to 4 as illustrated in Fig. 3.

6. Vertical Resolution.—Resolution is the ability of a television system to reproduce detail. It can be measured in both horizontal and vertical directions and expressed in the number of picture details or elements which may be reproduced. Vertical resolution is directly related to the number of scanning lines used since each scanning line can accommodate one picture element. In the present system, 525 lines are used; however the vertical resolution is not equal to this figure because not all scanning lines are utilized in the reproduced image. Some lines are lost during the interval it takes the electron beam to travel from the bottom of the picture back to the top, where it begins tracing a new field. The lines actually utilized in the image are referred to as active lines. Approximately 480 line vertical resolution may be obtained in practice.

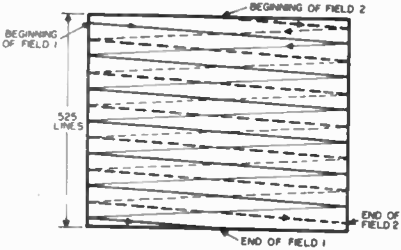


Fig. 2.—Interlaced scanning pattern.

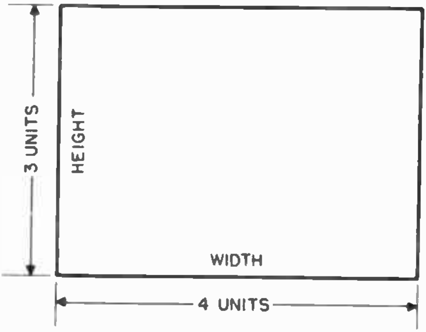


Fig. 3.—Outer margins of an image with 3 to 4 aspect ratio.

7. Horizontal Resolution.—The horizontal resolution of the reproduced image is expressed in terms of the number of picture elements or details which are accommodated in a horizontal distance equal to the height of the picture. This method of expression is used to simplify comparison of vertical and horizontal resolution.

Horizontal resolution is dependent upon the size of the spots scanning the image at the transmitter and reproducing it at the receiver. When the spots are sufficiently small, the bandwidths of the various amplifiers and of the television r.f. signal become the determining factors. Since the present standards limit the maximum video frequency which can be transmitted to approximately 4 mc., the maximum obtainable horizontal resolution is predetermined. The term resolution ratio is used to designate the comparison of horizontal and vertical resolutions.

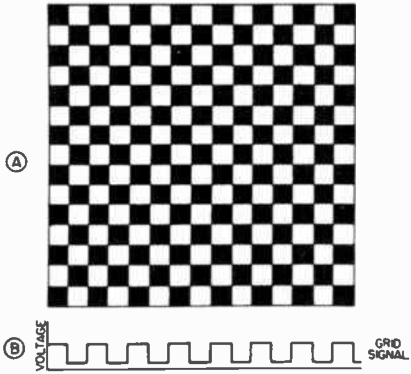


Fig. 4.—Checkerboard pattern and signal.

8. Picture Elements.—The number of picture elements in the reproduced image is directly related to the maximum video frequency which may be transmitted and passed by the various amplifiers in the television system. In Fig. 4 each black or white square is equivalent to a picture element. The signal produced by the camera as the electron beam scans the checkered pattern is shown at B. The signal passes through one cycle of change for each pair of picture elements. A scanning rate of 8,000,000 elements per second is thus equal to a video frequency of 4 mc. With a frame rate of 30 per second each complete image may have a total of 8,000,000 divided by 30 or approximately 270,000 elements. This number does not take into consideration the horizontal and vertical retrace periods which reduce the number of usable picture elements to approximately 200,000. In practice, images of approximately 160,000 elements are usually produced.

9. Brightness and Contrast.—The term brightness is used when referring to the average light intensity of the reproduced image. Contrast is the ratio of the light intensity of the darkest portion of the image to the intensity of the lightest portion of the image. The contrast ratio possible at the present state of the art is considerably less than 100 to 1.

10. Scanning Signals.—In order to produce the horizontal linear scanning motion illustrated in Fig. 2, sawtooth signals must be applied to the deflection coils of the camera and picture tubes. The configuration of a sawtooth waveform is illustrated in Fig. 5. Starting at point one the amplitude rises from a negative amplitude to a positive amplitude (point two). The rise in amplitude from point one to point two is at a constant rate. When point two is reached, the amplitude of the wave drops quickly to its original value.

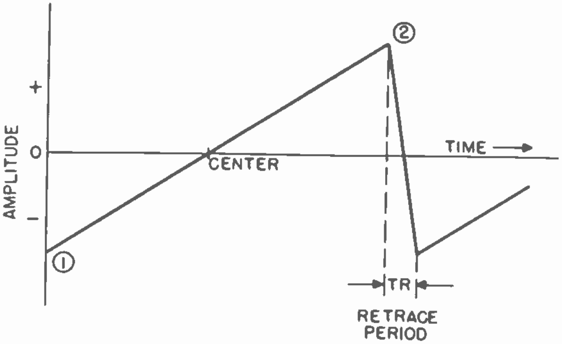


Fig. 5.—A sawtooth signal.

If a current of this wave shape is passed through the horizontal deflection coils of a picture tube, the luminous spot will travel from one side of the screen to the other, in a linear fashion. It will then return rapidly to the side from which it began. The time required for the spot to return is referred to as the "retrace period". It is represented by the letters TR in Fig. 5. Ideally the retrace period should be as short as possible and the rising portion of the wave as linear as possible.

Since one sawtooth cycle is required for each scanning line, the horizontal sawtooth frequency is equal to the product of the number of lines per frame and the number of frames per second (525 lines times 30 frames per second or 15,750 c.p.s.).

A sawtooth signal must also be applied to the vertical deflection coils. Since the spot must return to the top of the screen to begin each field, the vertical sawtooth frequency is equal to the field frequency or 60 c.p.s.

11. Synchronizing Signals.—The scanning action that takes place in the picture tube at the receiver must be in synchronization with that in the camera tube. This cannot be accomplished satisfactorily unless some form of synchronizing information is passed from the transmitter to the receiver. This information takes the form of sync pulses which are combined with the video signal.

Separate sync pulses are necessary for the horizontal and vertical deflection circuits. These signals are generated at the transmitter, mixed, and fed to the camera tube deflection circuits. Here they are separated and used to control the frequencies of the horizontal and vertical scanning signals. In addition the mixed sync signals are combined with the video signal and transmitted to the receiver where they are removed from the video signal, separated into vertical and horizontal sync pulses, and applied to the deflection circuits to keep them in synchronization with the deflection circuits at the transmitter.

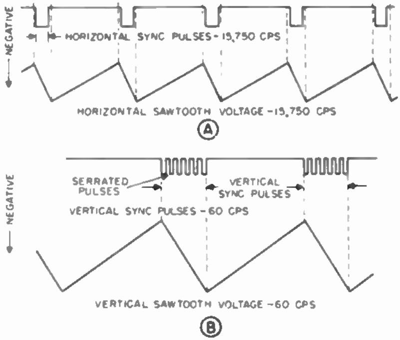


Fig. 6.—A. Horizontal sync pulses. B. Vertical sync pulses.

The horizontal sync pulses have a square wave shape as shown in Fig. 6A. They occur at the horizontal scanning frequency of 15,750 c.p.s. The vertical sync pulses occur at the vertical scanning frequency of 60 c.p.s. Each vertical sync pulse is made up of six smaller pulses as illustrated in Fig. 6 B. This is necessary in order to avoid interference with the horizontal synchronization.

12. Blanking.—When the luminous spot, scanning the screen of the picture tube, reaches the bottom of the screen, it must be returned to the top to begin scanning the next field.

As the spot travels from the bottom to the top of the screen, it creates a number of bright lines in the reproduced image. These lines are eliminated by means of a series of blanking pulses. It is also necessary to eliminate the horizontal retrace lines. This is accomplished in the same way.

Blanking pulses are square in shape, occur at the horizontal and vertical deflection frequencies, and are combined with the video signals as shown in Fig. 7. They serve to cut-off the electron beams in the camera and picture tubes during the retrace periods. Since the vertical retrace period is considerably longer than the horizontal retrace period, the

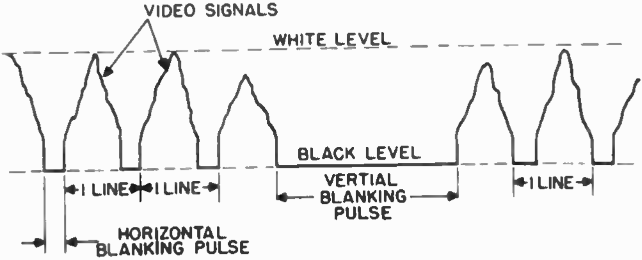


Fig. 7.—Combined vertical and horizontal blanking pulses and video signal.

vertical blanking pulses are longer than the horizontal blanking pulses.

13. Composite Video Signal.—The signal which is transmitted consists of the camera or picture signal, the horizontal and vertical sync signals, and the horizontal and vertical blanking signal. All of these signals are combined to form

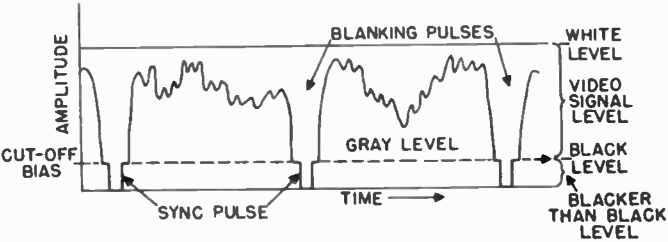


Fig. 8.—The composite video signal.

the composite video signal, as illustrated in Fig. 8. The blanking pulses are mixed with the picture signal. The sync pulses occur during the blanking pulses and are superimposed upon them. The maximum level of the camera signal corresponds to white on the picture tube screen. The picture signal level corresponding to black on the screen, called the "black level", is equal to the maximum amplitude of the negative blanking pulses. The sync pulses are more negative and thus have no effect on the reproduced image.

The black level corresponds to 75 percent modulation of

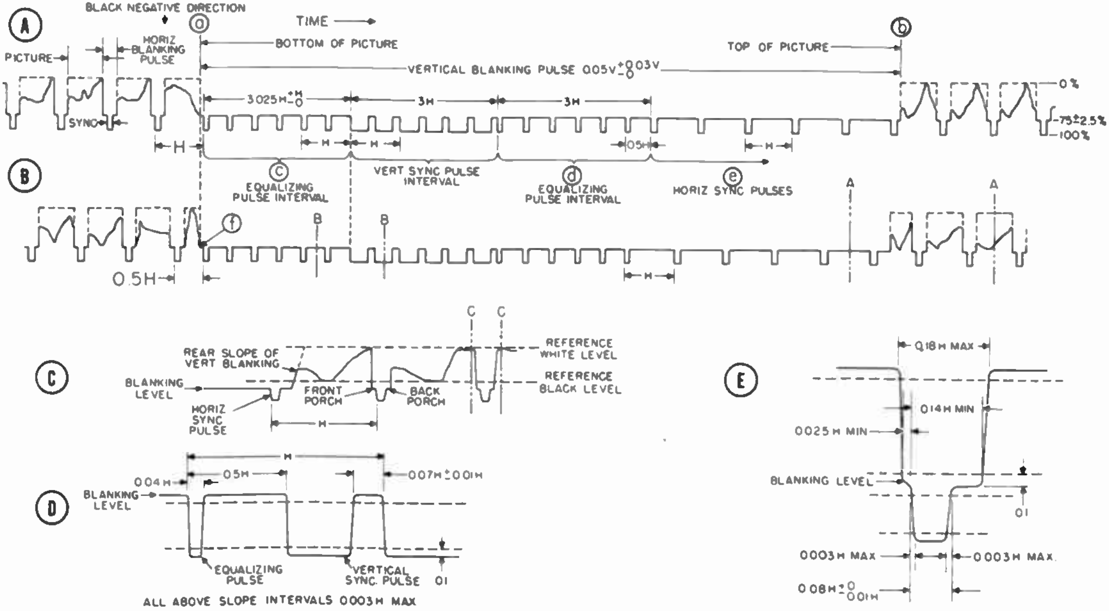


Fig. 9.—The standard television signal.

the r-f carrier while the sync signals account for the remaining 25 percent.

14. Standard Television Signal.—The standard television signal is shown in Fig. 9.

H equals the time from the start of one line to the start of the next or 63.5 microseconds.

V equals the time from the start of one field to the start of the next or 16,667 microseconds.

Section c of waveform A is a series of equalizing pulses which are superimposed on the vertical blanking pulse. A second group of equalizing pulses occurs at d. The equalizing pulses serve to provide a half line difference between scanning fields to permit interlaced scanning.

The vertical sync pulse occurs between the two groups of equalizing pulses. It is broken into a series of pulses to provide continuity of horizontal synchronization.

At B a second waveform is shown. It is identical to A except for the fact that the first horizontal sync pulse after the end of the vertical blanking period occurs one half line before the corresponding horizontal pulse in A. This accounts for the half line displacement between fields. C and D are enlarged sections of B while E is an enlarged section of C.

CAMERA TUBES

15. Among the various types of camera tubes so far developed are the iconoscope, the orthiconoscope or orthicon, the image-orthicon and the image dissector. The iconoscope, the orthicon and the image-orthicon are many times more sensitive than the image dissector and have almost entirely supplanted it in use.

16. The Iconoscope.—The construction of the iconoscope is shown in Fig. 10. Its major parts are the glass envelope,

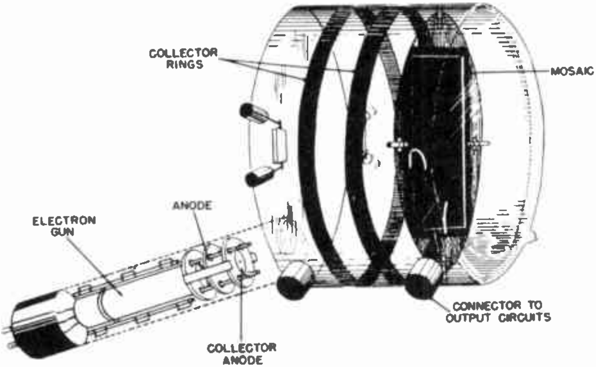


Fig. 10.—Construction of the Iconoscope.

the electron gun assembly, the collector anode, the mosaic, and the collector rings.

The image is focused on the mosaic by a suitable optical system mounted in the camera. The mosaic is a mica plate coated with millions of tiny photosensitized silver globules. Each of these tiny globules is insulated from the others. The back of the mosaic is coated with aluminum or graphite. Light from the image strikes the mosaic causing the silver globules to release electrons and assume a positive charge. This positive charge is distributed over the sensitized area of the mosaic in the same manner as is the light in the image. Because the globules are insulated from their surroundings, they retain the charge which increases in amplitude as long as light is striking the mosaic.

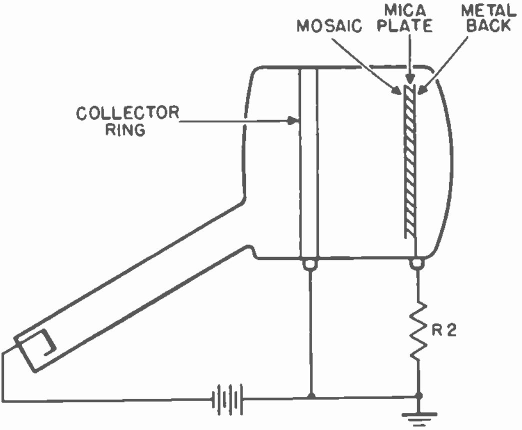


Fig. 11.—Electron path in iconoscope circuit.

The electron gun assembly is mounted in the neck of the tube. It forms an electron beam. Sawtooth currents flowing through deflection coils (not shown) mounted on the neck of the tube cause the beam to scan the mosaic. As the beam strikes the mosaic, it causes the globules to release secondary electrons. These secondary electrons are releasd in numbers proportionate to the positive charge the globules accumulate due to the light from the image, those in lighter areas releasing fewer electrons than those in darker areas. The secondary electrons are collected by the collector rings and the collector anode. From here they pass through a resistor to the signal plate on the back of the mosaic, as shown in Fig. 11. The picture signal appears across resistor R2. It varies as the electron beam strikes light and dark areas of the mosaic.

17. The Orthiconoscope.—This tube is of the storage type like the iconoscope. The image is stored on a mosaic until the scanning beam converts it into an electrical signal. The scanning beam in the orthicon is of much lower velocity than that in the iconoscope and it does not release secondary electrons from the mosaic. Instead electrons from the scanning beam are collected and passed through a resistor to generate the signal. The absence of secondary emission eliminates the distribution of spurious electrons over the mosaic and the spurious shading signal generated in the iconoscope.

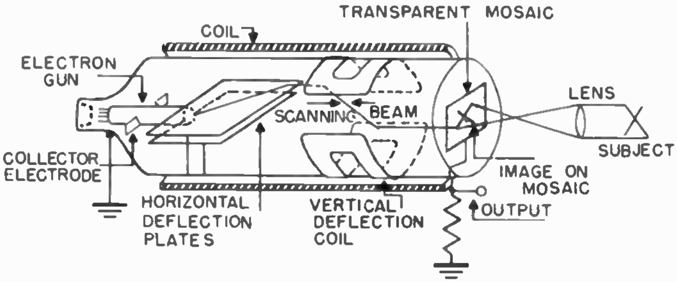


Fig. 12.—Construction of the orthiconoscope.

The construction of the orthiconoscope is shown in Fig. 12. This tube is from 10 to 20 times as sensitive as the iconoscope.

18. The Image Orthicon.—The image orthicon is the most sensitive type of camera tube now in use. It is more than 100 times as sensitive as the orthicon. It has the disadvantages of high noise level and poorer resolution than the iconoscope. The image orthicon consists of three sections; the image section, the scanning section, and the multiplier section, as shown in Fig. 13. The optical image is focused on the front of a translucent photosensitive-plate or photo-

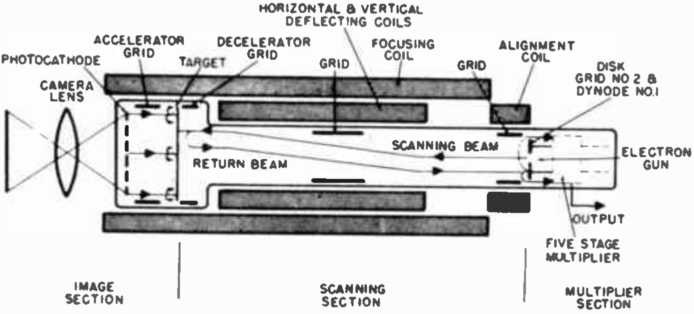


Fig. 13.—Construction of the image orthicon.

cathode. Photo-electrons are emitted from the rear of the photocathode, their distribution and number corresponding to the intensity of the light in the various portions of the image.

The electrons emitted by the photocathode pass to the target. While traveling to the target, the electrons are held on parallel courses by the magnetic field of the focusing coil. In addition they are accelerated by the potential on a grid located between the photocathode and the target. The accelerated electrons strike the target with sufficient impact to release secondary electrons, setting up a positive charge on the target whose distribution corresponds to the light values in the image.

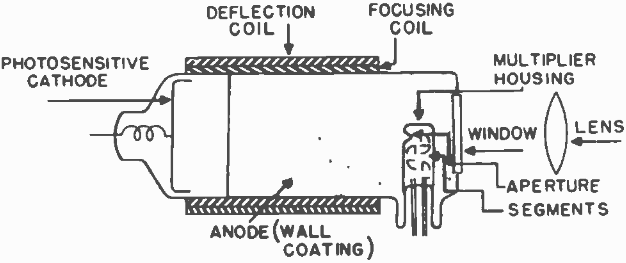


Fig. 14.—Construction of the image dissector.

A low velocity electron beam generated by the electron gun mounted in the tube scans the target. A decelerator grid slows the electrons in the beam so that they stop just short of the target and turn back toward the electron gun. The beam comes close enough to the target to deposit sufficient electrons to neutralize the charge on the target. Thus the returning beam has a varying number of electrons depending upon the charges on the areas of the target which is scanned. The beam then passes through the multiplier section, where the strength of the signal is increased, and finally to the signal anode.

19. Image Dissector.—The image dissector is characterized by low light sensitivity and excellent resolution capabilities. Its construction is illustrated in Fig. 14.

When the image is focused on the photocathode electrons are released. A silver coating on the inner surface of the tube acts as a positive anode to draw the electrons away from the photocathode. These electrons are accelerated down the length of the tube toward the aperture. The focusing coil keeps the electrons travelling in parallel paths. The entire electron image is then moved horizontally and vertically by the forces set up by the deflection coils. In this way the image is moved past the aperture, permitting electrons to enter it in a chain of impulses. Thus instead of moving a single beam of electrons to scan the image on the mosaic as in the iconoscope, the entire electron image is moved back and forth past a small opening at the horizontal and vertical scanning frequencies. The electrons which enter the aperture are passed through a multiplier section which greatly increases the signal amplitude at the output of the tube.

PICTURE TUBES

20. Picture tubes are generally classified by screen size and the type of deflection and focusing used. Two types of focusing and deflection are used, electrostatic and electromagnetic. Screen sizes range from seven inches to thirty inches. Electrostatic deflection and focusing are confined to tubes having screen sizes of less than ten inches.

The important parts of a picture tube are; the glass envelope, the electron gun assembly, and the screen, as illustrated in Fig. 15.

21. The Electron Gun.—The electron gun acts upon the electrons emitted by the cathode, forming them into a narrow beam which is focused to a fine point on the screen. The cathode consists of a small cylinder mounted within the grid cylinder. It is heated by a coil mounted within and insulated from it. Emission takes place only from the coated end of the cathode. The emitted electrons pass through a small hole in the end of the grid cylinder. The grid is operated at a negative potential and controls the number of electrons which pass through it into the pre-accelerator electrode. The pre-accelerator is operated at a high positive potential and increases the velocity of the electrons. From the pre-accelerator the electrons pass into the first or focusing anode (used in electrostatically focused tubes only). The focusing anode serves to further confine the electrons in the beam and to focus them to a fine spot at the screen. The potential on the focusing anode is made variable so that the focusing may be varied for different operating conditions.

After leaving the focusing anode the electrons enter the second anode which is operated at a high positive potential to increase the velocity of the electron beam.

In magnetically focused tubes, the focusing anode is omitted and a coil is placed over the neck of the tube. A current is passed through this coil and the resultant magnetic field performs the focusing function.

22. Electrostatic Deflection.—Electrostatic deflection is used in the smaller picture tubes. In these tubes two sets of metal plates are mounted between the electron gun and the fluorescent screen. They are referred to as the horizontal and vertical deflection plates. The horizontal deflection plates are mounted upright, one on each side of the electron beam as shown in Fig. 15. They deflect the electron beam horizontally when a difference in potential exists between them.

The vertical deflection plates are mounted horizontally one below and one above the electron beam. They deflect the electron beam vertically when a difference in potential exists between them.

23. Electromagnetic Deflection.—Electromagnetic deflection is used with all large picture tubes. When magnetic deflection is used four coils are mounted around the neck of the tube in a cylindrical container called a yoke, and the four deflection plates used with electrostatic deflection are omitted. The coils mounted above and below the electron beam deflect the beam horizontally when a current is passed through them. The coils mounted on the sides of the tube deflect the beam vertically when a current is passed through them.

Magnetic deflection is preferred with large tubes because the large deflection currents required can be generated more economically than can the large deflection voltages which are necessary with electrostatic deflection. In addition it makes possible a shorter tube for a given screen size, as well as smaller spot sizes.

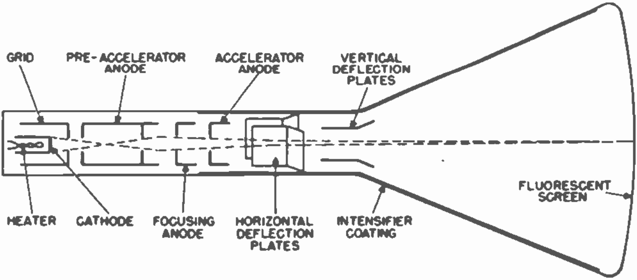


Fig. 15.—Construction of an electrostatic picture tube.

24. Intensifier.—The electron beam must impinge upon the fluorescent screen at high velocity in order to cause it to become luminous. The required velocity is secured by connecting a high voltage source to a conductive coating on the inner wall of the tube. The potentials required for the various tubes range from a few kilovolts to as high as 30 kv. The coating on the inner wall of the tube is called the intensifier band.

25. Fluorescent Screen.—When the fluorescent screen is struck by electrons it glows in accordance with the velocity and number of electrons which impinge upon it. The emission of light by the screen when it is being bombarded by electrons is referred to as fluorescence. The emission of light after the bombardment has ceased is called phosphorescence. Picture tube screens are both fluorescent and phosphorescent. A certain period or persistence of phosphorescence is necessary in order to eliminate flicker.

To be suitable for television a screen material must be stable and have a long life: it must produce a sufficiently bright image; have a suitable persistance characteristic; and emit light of a pleasing color. White is regarded as the most desirable color.

26. Ion Traps.—In addition to useful electrons, the beam from the electron gun in the picture tube contains a number of heavier ions. These ions have the same charge as the electrons and in electrostatically deflected tubes they are dispersed over the entire screen by the deflecting voltages. In magnetically deflected tubes where deflection is dependent upon the mass of each object in the beam, the heavier ions are deflected very little. Thus, they travel an almost straight path to the screen where, in time, they cause a dark discoloration.

This discoloration is avoided by the addition of an ion trap.

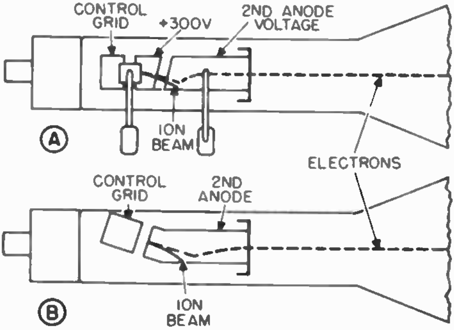


Fig. 16.—A. Anode gap ion trap. B. Bent gun ion trap.

Two types are illustrated in Fig. 16. In A the first and second anodes are constructed with an oblique gap which causes both electrons and ions to be deflected to a path at right angles to the gap. A magnet placed on the neck of the tube, behind the focus coil, applies a field to the electrons and ions which causes the electrons to return to their original path. The heavier ions are not so readily affected by the magnetic field and continue along their path until they are absorbed by the second anode.

In B the electron gun is bent so that the electrons and ions entering the second anode will strike the side of the anode. A bending coil is placed over the neck of the tube. The field from this coil alters the path of the electrons but not the ions, so that the electrons pass on to the screen while the ions are absorbed by the anode.

TELEVISION TRANSMITTERS

27. A block diagram of the major units of a television transmitter is shown in Fig. 17. The transmitter consists of: the camera which includes a preamplifier and sweep and blanking circuits; the sync signal generator which generates and times the sync and blanking signals; the control amplifier which mixes sync, blanking and video signals to form the composite video signal; the video modulator; and the picture signal transmitter.

28. Television Camera.—The television camera is made up of the camera tube, the optical system which focuses the image on the mosaic or photocathode, a preamplifier for the camera signal, and an electronic view finder. In addition, power supply, and sync and sweep circuits may be mounted in the camera, although in most new equipment they are mounted in a separate unit called a camera auxiliary.

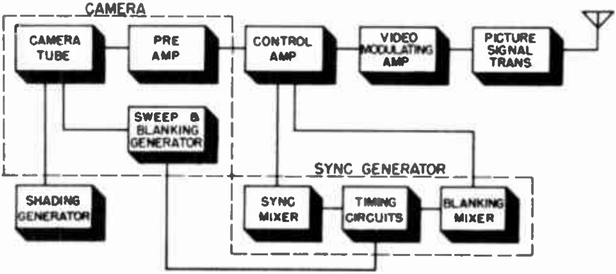


Fig. 17.—Block diagram of a television transmitter.

29. Preamplifier.—Fig. 18 shows the circuit of a typical video preamplifier for use with an image orthicon camera tube. Four stages of amplification are provided. The first two stages are shunt-peaked to produce a frequency response flat to 8 mc. The third stage is coupled to a network which compensates for high frequency losses in the input coupling. The network is followed by an additional shunt-peaked stage which is coupled to a cathode follower. The cathode follower

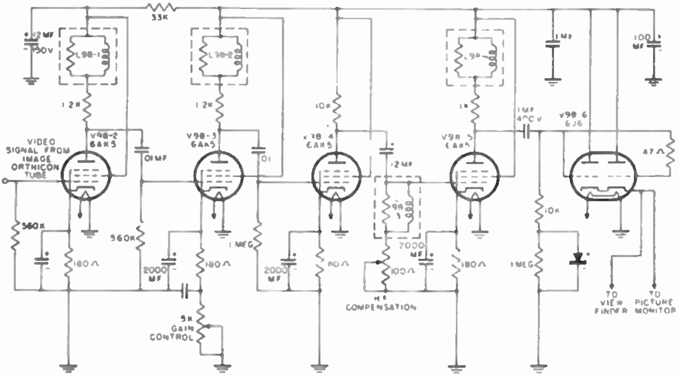


Fig. 18.—Video amplifier for use with image orthicon.

matches the transmission line which carries the camera signal to the control amplifier.

30. Camera Sweep Circuits.—A typical camera tube sweep circuit is shown in Fig. 19. Horizontal and vertical sync pulses are received from the sync generator. The horizontal sync pulses are applied to the grid of a blocking-oscillator, discharge-tube combination whose output is a sawtooth voltage. The sawtooth voltage is applied to the grid of a 6BG6-G

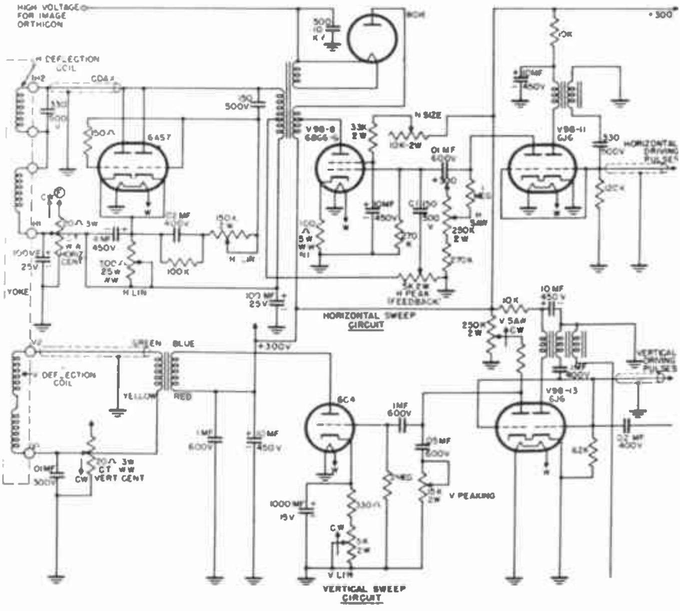


Fig. 19.—Vertical and horizontal sweep circuits for image orthicon.

power amplifier which feeds the camera tube yoke through a coupling transformer. A 6AS7 is used as a damper. High voltage for the camera tube is secured from a kickback circuit operating from the power amplifier output.

The vertical sync pulses are applied to a blocking-oscillator, discharge-tube combination which produces a sawtooth voltage at the vertical sweep frequency. The sawtooth voltage is applied to the grid of a 6C4 power amplifier whose output feeds the vertical deflection coils.

31. Synchronization Signal Generator.—The synchronization signal generator furnishes all of the timing pulses required by the complete system. The waveshapes and timing of these pulses are shown in Fig. 20. The sync generator supplies: vertical and horizontal driving pulses to the camera; the composite sync signal consisting of horizontal sync pulses, serrated vertical sync pulses, and equalizing pulses, to the control amplifier; and the composite blanking signal consisting of 60 c.p.s. vertical blanking pulses and 15750 c.p.s. horizontal blanking pulses, to the control amplifier.

The synchronization signal generator is made up of three sections; the timing circuits, the pulse-shaping circuits, and the synthesizing circuits.

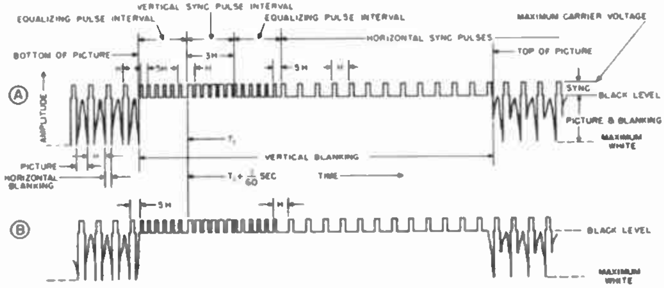


Fig. 20.—Sync and blanking pulse duration and timing.

32. Timing Circuits.—The timing circuits produce two signals, one at 31.5 kc. and the other at 60 c.p.s. The 31.5 kc. signal is generated by a stable oscillator whose frequency is constantly compared to the 60 c.p.s. power line frequency by means of a discriminator, reactance-tube circuit (Fig. 21).

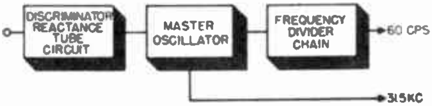


Fig. 21.—Block diagram of the timing circuits.

The 60 c.p.s. signal is produced by a chain of frequency dividers operating from the output of the 31.5 kc. oscillator. The oscillator output is divided in four steps of 3 (10.5 kc.), 5 (2.1 kc.), 5 (420 c.p.s.), and 7 to 60 c.p.s.

33. Pulse-Shaping Circuits.—Operating from the 31.5 kc. and 60 c.p.s. outputs of the timing circuits, the shaping circuits produce properly shaped and timed vertical and horizontal sync and blanking pulses.

Equalizing pulses must occur at a frequency of 31.5 kc. They are generated by a multi-vibrator (Fig. 22) keyed by the 31.5 kc. output of the timing oscillator.

31.5 kc. output from the equalizing pulse shaper is fed to a frequency divider whose output is 15.75 kc. The output of the frequency divider keys a multivibrator which generates the horizontal sync pulses at a frequency of 15.75 kc.

The output of the frequency divider is also fed to a delay circuit which in turn keys a multivibrator which generates the horizontal blanking pulses. The delay circuit is used to obtain the proper time relationship between the horizontal blanking and sync pulses.

31.5 kc. output from the equalizing pulse shaper is fed to an integrating circuit which produces a sawtooth output. The sawtooth signal is then passed through shaping amplifiers which form the serrated vertical sync pulse.

The vertical blanking pulse is generated by a multivibrator keyed by the 60 c.p.s. output of the divider chain.

34. Synthesizing Circuits.—The synthesizing circuits combine the outputs of the shaping circuits. The equalizing pulses are combined with the horizontal sync pulses. The combined horizontal sync and equalizing pulses are then combined with the vertical sync pulses. In addition, the horizontal and vertical blanking pulses are combined in the synthesizing circuits.

35. Control Amplifier.—In the control amplifier the video signal from the camera is combined with the mixed blanking signals and the composite sync signal to form the composite video signal.

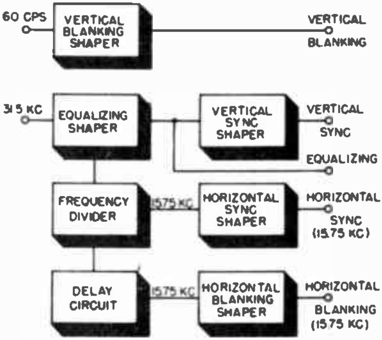


Fig. 22.—Block diagram of the pulse shaping circuits.

A block diagram of a typical control amplifier is shown in Fig. 23. The camera signal is fed to the input of a two stage video amplifier whose output is applied to a mixer stage. The combined blanking signal is applied to the same mixer through an amplifier stage. The output of the mixer contains the combined blanking and video signals. The following stage is a clipper which fixes the blanking or black level in the video signal. The output of the clipper is passed through an amplifier stage.

The composite sync signals from the synthesizing circuits is passed through an amplifier whose output is common with

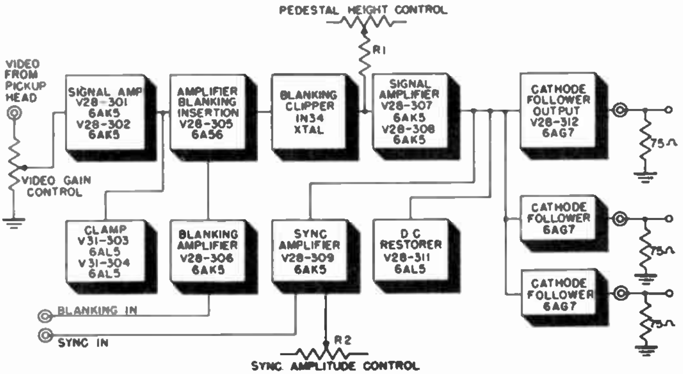


Fig. 23.—Block diagram of control amplifier.

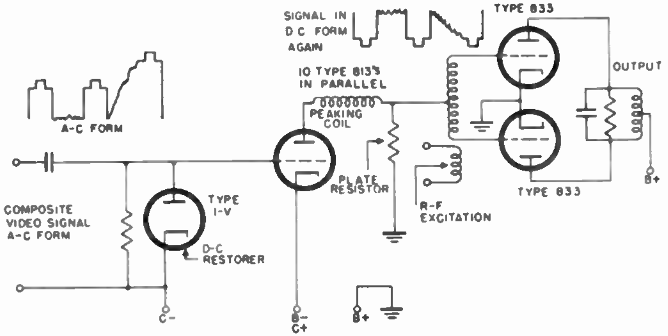


Fig. 24.—Reinserting the d-c component at the video modulator.

the last video signal amplifier. The two signals combine here to form the composite video signal. The composite signal is fed to a number of cathode follower circuits to secure a match to the transmission lines which carry it to the modulator and monitors.

36. Video Modulator.—The video modulator consists of several stages of video amplification, a sync expander, and a d-c reinserting circuit.

Two types of modulation are used; low level and high level. In high level modulation the final power amplifier is modulated. Since it is difficult to generate the large modulating voltage required for plate modulation, the grid of the final amplifier is usually modulated. With low level modulation a low power r-f amplifier is modulated. The modulated r-f carrier is then amplified by a series of wideband stages.

The d-c component of the video signal, which represents the average brightness of the televised scene is lost when the signal is passed through the video amplifier stages to the modulator stage. The d-c level is restored by the circuit arrangement of Fig. 24. The time constant of the resistor-capacitor combination connected to the plate of the d-c restorer is much greater than the time interval of one line of the television image. Consequently, a voltage is built up across the diode which is about equal to the peak value of the composite video signal. This voltage is applied to the grid of the video modulator where it compensates for variations in sync pulse amplitude and maintains a fixed sync and blanking level in the modulated carrier. The average level of the camera-signal component changes, with relation to the sync level, as the background illumination changes, in the scene being televised. To preserve the reference level, the video modulator is conductively coupled to the grid of the modulated r-f amplifier.

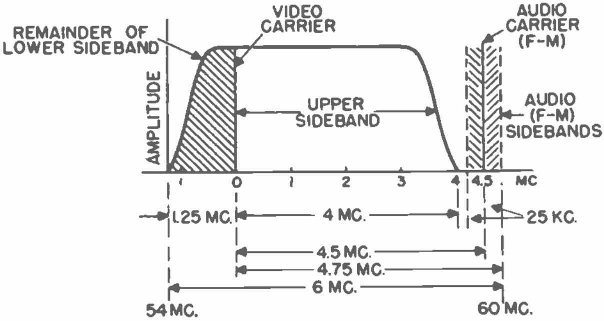


Fig. 25.—Spectrum occupied by a single-sideband television signal.

37. Side-band Suppression.—The sidebands of a modulated r-f signal extend above and below the carrier frequency. Since the video signal contains frequency components extending from approximately 30 c.p.s. to 4.25 mcs., the video modulated r-f signal occupies an 8.5 mc band using normal double sideband transmission. To limit the width of the television signal so that it will fit into an assigned channel, vestigial sideband transmission is employed. With this system most of the lower sideband is suppressed before transmission. The resulting signal occupies a band as illustrated in Fig. 25. The picture signal carrier is located 1.25 mcs. from the lower limit of the assigned channel. The portion of the lower sideband which is not attenuated occupies the 1.25 mcs. between the carrier and the lower limit of the channel. The remainder of the channel is sufficient for the complete 4.25 mc. upper sideband, the sound carrier and its sidebands.

Two different methods are used to attenuate the lower sideband. In high level modulated transmitters a filter is placed between the final r-f power amplifier and the antenna. The filter is tuned to attenuate the lower sideband. In low level modulated transmitters the r-f amplifiers following the low level modulated stage are tuned so that the unwanted portion of the lower sideband is removed.

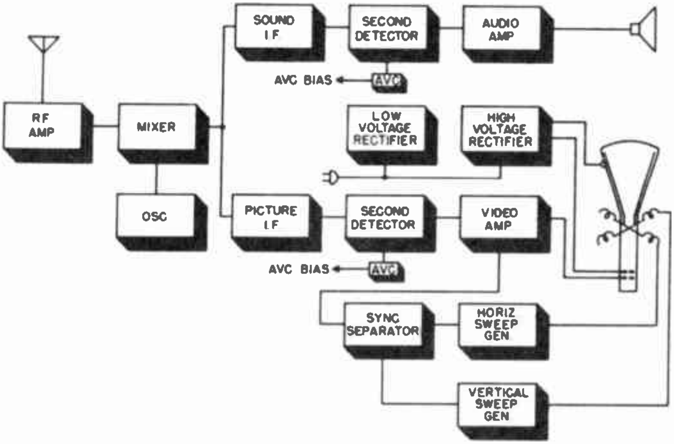


Fig. 26.—Block diagram of a television receiver.

TELEVISION RECEIVERS

38. A block diagram of a television receiver is shown in Fig. 26. The receiver consists of six sections; the r-f section which includes an r-f amplifier, a mixer and an oscillator; the video channel which includes a number of video i-f amplifier stages, a video detector and one or more video frequency amplifier stages; the sweep circuits which include horizontal and vertical sync separating and segregating circuits, sync oscillators, sawtooth generators and amplifiers, and a horizontal damping circuit; the picture tube; the power supplies; the sound channel which is a complete f-m receiver minus its r-f stages.

39. **R-f Section.**—The r-f section selects the desired sound and picture carriers, and amplifies and converts them to separate intermediate frequencies. The r-f circuits must have a bandwidth of 6 mc. and be capable of tuning over a broad frequency range.

A typical r-f section is shown in Fig. 27. The antenna is coupled to the cathode of the r-f amplifier to secure a match to low impedance coax transmission line. The r-f amplifier consists of a dual triode, with elements paralleled, operating as a grounded grid stage to eliminate the need for neutralization. The mixer uses a high gain pentode. Resistors R58 and R59 reduce the Q of the r-f amplifier plate and mixer-grid tuned circuits to secure the required bandwidth. The oscillator is a triode operating in a modification of the Colpitts circuit. The output of the oscillator is capacitively coupled to the grid of the mixer stage.

The r-f section in Fig. 27 is continuously tuned by means of constantly variable inductances. In other circuits, switching arrangements are used to substitute various values of inductance and capacitance. A separate switch position is provided for each channel. In addition, a capacitive trimmer, in the oscillator circuit, is usually available for fine tuning.

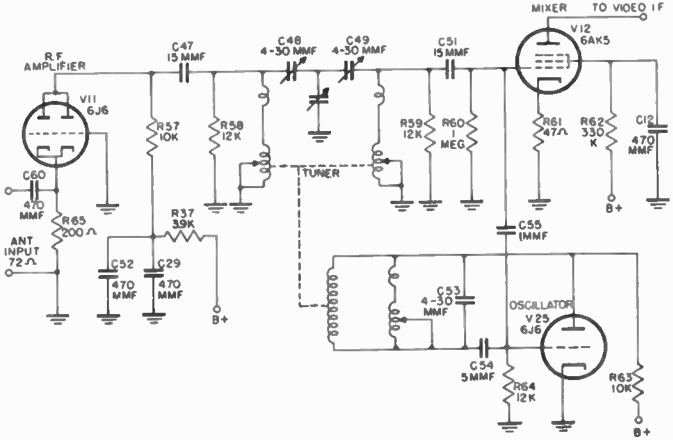


Fig. 27.—Typical r-f section of television receiver.

40. Separating Video and Audio I-F Signals.—Both audio and video i-f signals appear in the output of the mixer stage. Commonly used video intermediate frequencies range from 25 mcs. to 26.5 mcs. while audio intermediate frequencies range from 21 to 22 mcs.

In many receivers the video and sound i-f's are separated at the output of the mixer. Several methods are illustrated in Fig. 28. In A and B tuned coupling circuits are provided for the video i-f signal. The sound i-f signal is obtained by coupling a circuit, sharply tuned to the sound i-f, to the video i-f tuned circuit. Two other methods are shown at C and D. In C separate tuned circuits are provided for the video and sound intermediate frequencies. The circuits are connected in series in the plate circuit of the mixer. At D the video i-f tuned circuit is connected in the plate of the mixer and the sound i-f tuned circuit is connected in the suppressor-screen circuit.

In all of the cases shown the video and sound intermediate frequencies are fed to separate i-f amplifying systems. The sound tuned circuits are sharply tuned and provide sufficient rejection of the video i-f signal. Such is not the case with the video i-f resonant circuits. Consequently the sound i-f signal is fed into the video i-f system where traps are used to attenuate it.

In some receivers the sound i-f signal is not separated from the video i-f signal until both have passed through one or more common i-f amplifiers. This arrangement eliminates the need for one or more of the sound i-f amplifier stages. In another type of circuit, referred to as the inter-carrier system, the sound and video i-f signals are amplified by a common broad-band i-f system. The sound signal is not separated from the video signal until the signals have passed through the video detector and first video amplifier stages.

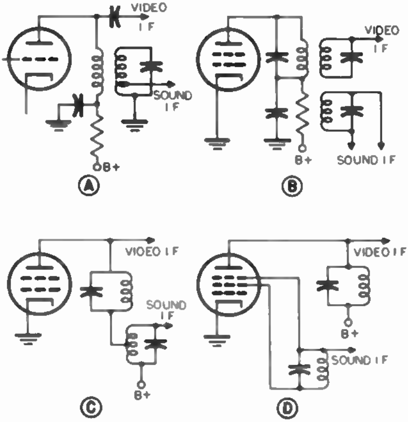


Fig. 28.—Methods used to separate video and audio i-f signals.

41. Video I-F Amplification.—The sensitivity, selectivity, and bandwidth of a television receiver, with respect to video signals, is governed mainly by the characteristics of its video i-f amplifying system. A 4 mc. amplifier bandwidth is necessary for maximum picture detail. In addition, the selectivity of the video i-f amplifying system must be such that it will reject adjacent channel video and sound signals as well as the associated sound i-f signal. Sufficient gain must be available to bring the amplitude of the video i-f signal to a level suitable for operation of the video detector.

Two circuit arrangements are used to achieve the required bandwidth and gain characteristics for video i-f amplification. They are referred to as over-coupling and stagger-tuning.

42. Overcoupling.—A typical broadband, overcoupled video i-f amplifier is shown in Fig. 29. The circuit is the same as that found in ordinary a-m broadcast receivers, except for the degree of coupling used between stages. Fig. 30 illustrates the effects of different degrees of coupling. As the coupling between stages is increased, the gain of the stage continues to rise until critical coupling is reached. Up to this point, the selectivity of the tuned circuits remains substantially constant.

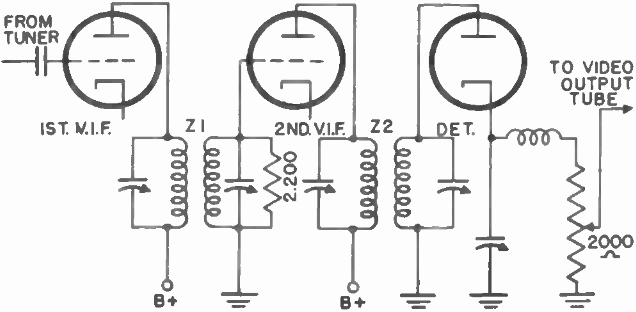


Fig. 29.—Overcoupled video i-f amplifier.

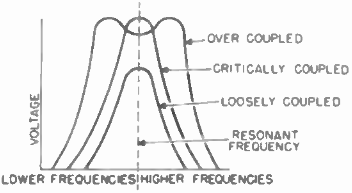


Fig. 30.—Effects of varying the degree of coupling between tuned circuits.

When coupling is increased beyond this point, the double humped response curve shown in Fig. 30 results and the amplifier pass band is considerably broadened. In most circuits of this type, shunting resistors are placed across the coupling transformer secondaries to further broaden the frequency response.

43. Stagger-Tuned Circuits.—A typical stagger-tuned i-f system is shown in Fig. 31. With this circuit, each stage is peaked to a different frequency; the overall response curve of the system being considerably broader than that of each individual stage. The system illustrated consists of four stages with single-tuned couplings, each peaked to a different frequency. Traps are provided to improve the selectivity with respect to associated and adjacent-channel sound-signals.

44. Video Detectors.—Almost all television receivers use diode video detectors. The diode video detector is identical to the diode detector used in a-m superhetrodynes except for the value of load resistance used. If the high value of load resistance used with an a-m detector were used with a video detector, degenerative effects would greatly reduce the output at the higher frequencies. To compensate for these effects, low values of load resistance, from 3,000 to 5,000 ohms, must be used.

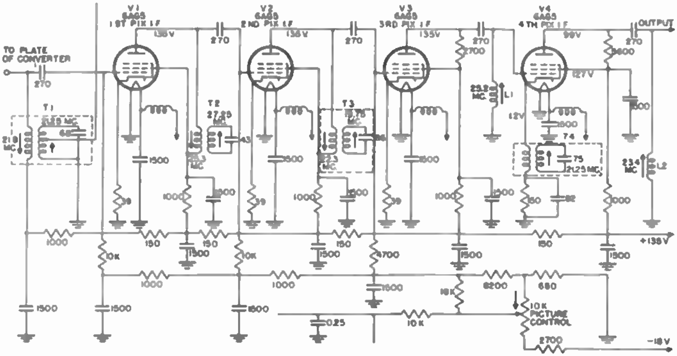


Fig. 31.—Stagger-tuned i-f amplifier.

The signal applied to the grid of the picture tube must be negative in polarity. Since a reversal in polarity takes place as the signal passes through each stage in the receiver, the number of stages determines the actual signal polarity at the picture-tube grid. The proper polarity can be obtained by connecting the detector diode to produce a positive or negative signal at its output. This is accomplished by reversing the connections of the plate and cathode.

In addition to detecting the 4 mc. video signal, the video detector must reject the video i-f component. This is accomplished by placing a filter in the output of the detector.

45. Video Amplification.—From one to three stages of video amplification are provided, after the video detector, to bring the video signal up to a level suitable for operation of the picture tube. A video amplifier is a resistance-coupled amplifier with provisions for extension of its frequency response to below 30 c.p.s. and above 4 mcs. In addition to wideband response, video amplifiers must be relatively free from phase distortion. Extended high frequency response is obtained by: using tubes with low inter-electrode capacities and high Gm; using a low value of plate load resistance; careful placement of parts and leads; the addition of high-frequency compensating circuits. Low frequency response is extended by: using high values of grid resistance; using large coupling and cathode capacitors; careful decoupling of screen and plate supplies; the addition of low-frequency compensating circuits.

46. High-Frequency Compensation.—The factor which reduces the high-frequency response of an amplifier is distributed capacity which shunts the load resistance as shown in Fig. 32. This capacity is the sum of stray wiring and parts capacity, to ground and the input and output capacities of the tube.

The output of an amplifier is equal to the change in plate current times the plate impedance. The plate impedance is made up almost entirely of the plate resistor and the distributed capacitance. An increase in impedance will increase output, while a decrease will decrease output. Since capacitive reactance decreases with increasing frequency, the plate impedance decreases as the frequency increases. As a result, the gain of an amplifier falls off as frequency increases.

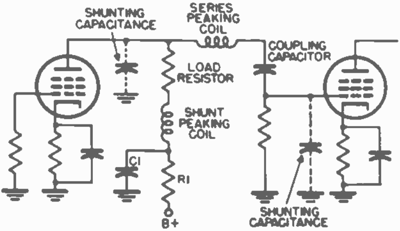


Fig. 32.—Video amplifier with high and low frequency compensation.

To compensate for the effects of the distributed capacitance, a small value of inductance is placed in series with the plate load resistor as shown in Fig. 32. Since the reactance of the inductance increases with increasing frequency, it compensates for the decrease in capacitive reactance and maintains the plate impedance at a relatively constant value between 30 c.p.s. and 4 mc. This type of compensation is referred to as shunt-peaking.

In addition to the inductance in series with the plate resistor, a second inductance may be placed in the coupling circuit as shown in Fig. 32. The addition of this inductance effectively isolates the input impedance of the following stage from the plate circuit of the amplifier. This type of compensation is referred to as series-peaking. A combination of shunt and series-peaking is generally used. Besides correcting the frequency response of an amplifier, shunt and series-peaking permit the use of higher plate resistance with correspondingly greater gain.

47. Low-Frequency Compensation.—At low frequencies the reactance of the coupling and cathode capacitors causes a loss in amplifier gain. This loss is compensated for by the addition of a resistor-capacitor combination (R1-C1 in Fig. 32). At low frequencies the reactance of the capacitor rises to a value which increases the plate impedance and the gain of the amplifier sufficiently to compensate for the loss due to the coupling and cathode capacitors.

48. D-C Restoration.—The d-c component of the video signal represents the average brightness of the televised scene. As the signal passes through the various stages of the receiver, this d-c component is lost. To faithfully reproduce the average brightness of the televised scene, the amplitude of the blanking pedestals of the composite signal must remain constant just above the cut-off bias of the picture tube.

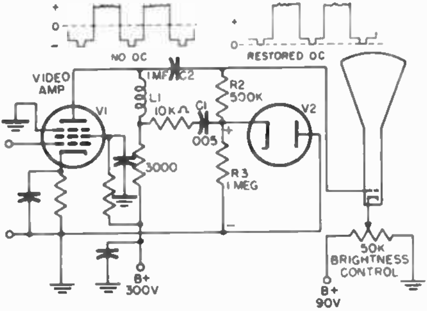


Fig. 33.—Diode d-c restorer circuit.

A simple diode d-c restorer circuit is shown in Fig. 33. It is connected across the output of the video amplifier. A portion of the output of the video amplifier is applied to the cathode of V2 through C1. When the video signal swings negative, current flows through V1 charging C1. The voltage thus developed is applied to the grid of the picture tube through isolating resistor R2. Since the most negative portion of the composite video signal is the sync tips, the voltage applied to the grid of the picture tube is determined by the sync tip amplitude. In the interval between sync pulses C1 discharges through R3. The time constant of C1-R3 is long enough to maintain a substantially constant voltage during this interval. Any variation in the sync level will produce a change in the d-c voltage developed by the restoring circuit. This voltage change will compensate for the variation in sync level and maintain a constant blanking and sync level at the grid of the picture tube. Under these conditions variations in the average amplitude of the video component of the composite signal will produce changes in the average brightness of the reproduced scene.

49. Automatic Gain Control.—The purpose of a.g.c. is to maintain constant picture brightness despite variations in the average strength of the received signal. In addition to changing the picture brightness, a fading signal will effect the stability of the picture. A.g.c. circuits generate a d-c voltage whose amplitude is proportional to the strength of the received signal. The picture i-f and r-f stages utilize variable-mu tubes to whose grids the a.g.c. voltage is applied as bias. Variations in the strength of the received signal cause changes in the bias on the picture i-f and r-f stages which results in a compensating change in receiver gain.

A typical a.g.c. circuit is shown in Fig. 34. The video i-f signal is coupled to full wave detector V1 through coupling capacitor C1. The detected signal appearing across R2 is applied to rectifier V2. When V2 conducts, C2 is charged to a value equal to the amplitude of the sync signals. The time constant of C2-R3-R4 is long enough to maintain the charge across C2 at substantially the same value for a period equal to several horizontal sync pulses. Variations in the amplitude of the sync pulses will change the voltage across C2. Since the sync pulse amplitude is maintained constant at the transmitter, a change in the sync amplitude at the receiver can only result from signal fading. The voltage developed across C2 is the a.g.c. voltage. It is amplified by V3 and applied to the grids of the r-f and i-f amplifiers through suitable decoupling filters.

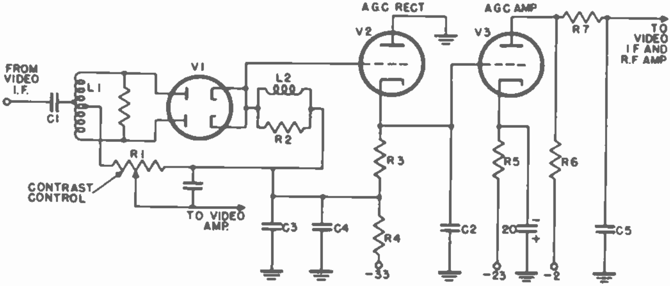


Fig. 34.—Delayed a.g.c. circuit.

The a.g.c. amplifier is operated with —33 volts on its plate and —23 volts on its grid. This places a 10 volt bias on the tube which keeps it from conducting until the a.g.c. signal exceeds this value. As a result, a.g.c. action does not take place on weak signals but is delayed until the signal strength reaches a predetermined value.

50. Separating the Composite Synchronizing Signal.—At the output of the video detector or amplifier, the sync signals are separated from the video and blanking signals. This separation is accomplished by a clipping circuit as illustrated in Fig. 35. The circuit at A is a diode clipper. The composite video signal is applied to the plate of the diode. When the diode conducts, current flows through R developing a bias on the cathode of the tube. The values of R and C are chosen so that the bias developed is in excess of the amplitude of the blanking signals but less than the amplitude of the sync pulses. Consequently, the diode conducts only during the duration of the sync pulses with the result that only the sync pulses appear in the output circuit.

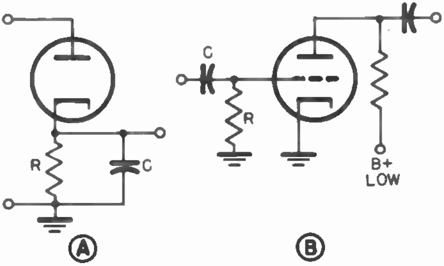


Fig. 35.—Diode and triode clippers.

The circuit at B is a triode sync clipper. The values of R and C are chosen so that the triode remains cut-off except during the sync pulse intervals. The plate voltage on the stage is adjusted so that the blanking level is just equal to cut-off voltage with the result that the blanking signals and the still lower amplitude video signal do not appear in the output of the clipper. The triode sync clipper amplifies the sync signals in addition to separating them from the composite video signal.

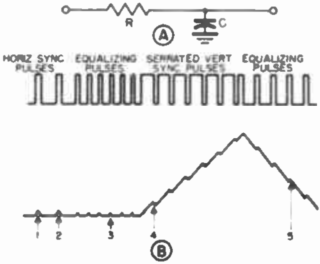


Fig. 36.—Integrating circuit and input and output waveforms.

51. Segregating the Vertical Sync Signal.—The signal at the output of the sync clipper consists of the vertical sync pulses, the horizontal sync pulses and the equalizing pulses as shown in Fig. 36. The horizontal pulses occur at a frequency of 15,750 c.p.s. while the vertical sync pulses occur at a frequency of 60 c.p.s. The equalizing pulses occur in groups before and after the vertical sync pulse. The vertical pulse is slotted or serrated into six parts.

This composite sync signal is applied to a simple filtering or integrating circuit consisting of a resistor and a capacitor as shown in A. The time constant of the filter is very long so that each pulse results in only a slight charge on capacitor C. The effect of the horizontal sync pulses is shown at 1 and 2 of B. The horizontal pulses charge the capacitor slightly but the period between pulses is too long to permit successive pulses to build up a large charge on C. The equalizing pulses which precede the vertical sync pulse also fail to build up a large charge as shown at 3 in B.

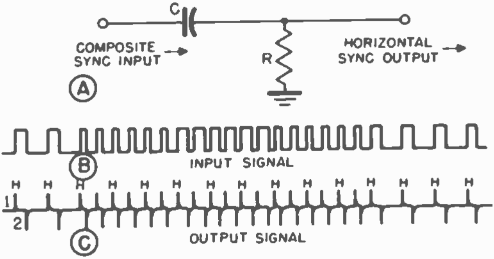


Fig. 37.—Differentiating circuit and input and output waveforms.

The vertical sync pulses occur close enough together so that the charge on C does not leak off between pulses but remains and builds up with each successive pulse as shown in B. When the last vertical pulse has been completed, the voltage across C cannot be maintained by the equalizing pulses and so falls slowly to zero. The pulse formed across C is the segregated vertical sync pulse occurring 60 times per second. In practice two or three integrating circuits are often cascaded to secure improved integrating action.

The integrated vertical sync pulses, appearing across capacitor C, are fed to the vertical sync generating circuits.

52. Segregating the Horizontal Sync Signal.—The composite sync signal is also applied to a high frequency filter or differentiating circuit. The circuit consists of a resistor and capacitor as shown in Fig. 37. The signal is applied across the capacitor and resistor in series while output appears across the resistor.

The time constant of the circuit is very short (1 to 5 microseconds) compared to the duration of the sync pulses. When a pulse occurs, capacitor C charges almost immediately to the peak value of the pulse. During the time the pulse remains at peak value, the charge on C dissipates itself and the voltage falls to zero. The voltage developed across C is in the form of a sharp spike as shown at 1 in C. When the trailing edge of the pulse occurs, a second spike is formed. This one is in the negative direction as shown at 2 in C. Two spikes are thus generated for each pulse and the output of the differentiating circuit appears as shown in Fig. 37C. This signal is applied to the horizontal sweep oscillator. Those pulses marked H in Fig. 37C occur at the horizontal sweep frequency and control the frequency of the sweep oscillator. The oscillator is so designed that the other pulses do not effect it.

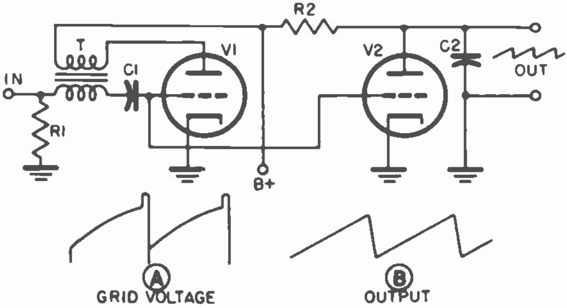


Fig. 38.—Blocking-oscillator, discharge-tube sawtooth generator.

53. Saw-tooth Generators.—Saw-tooth waves are required to produce linear scanning of the electron beam in the picture tube. These waves are usually generated by a blocking oscillator circuit as shown in Fig. 38. In a blocking oscillator, high values of plate current flow for short periods. During the remainder of the time, the tube is cut off by the grid leak bias developed by the RC combination in the grid circuit. The plate current cycle is triggered by sync pulses applied to the grid through capacitor C1. This maintains oscillation at the desired scanning frequency. The grid signal of V1, shown at A, is applied to the grid of a discharge tube, V2. Between pulses the discharge tube remains cut off and capacitor C2 connected to its plate charges slowly to form the rising or trace portion of the saw-tooth waveform. When a pulse occurs, current flows through V2, and C2 discharges to form the retrace portion of the saw-tooth.

Saw-tooth voltages may also be generated by a multivibrator. A typical circuit is shown in Fig. 39. The saw-tooth voltage is developed across capacitor C3. Capacitor C3 charges through resistor R2 during the time that V2 is not conducting. When V2 conducts, C3 discharges. The multivibrator is triggered by sync pulses applied to the grid of V1.

Separate saw-tooth generators are provided for the 15,750 c.p.s. horizontal sweep and the 60 c.p.s. vertical sweep.

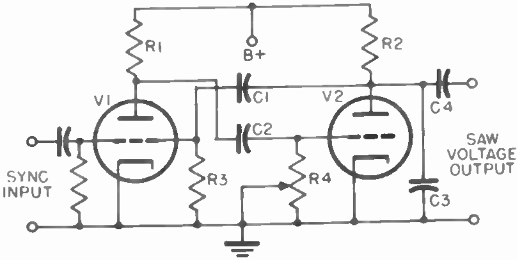


Fig. 39.—Multivibrator sawtooth generator.

54. Deflection Amplifiers.—Electrostatically deflected picture tubes require large saw-tooth voltages for proper deflection of the electron beam. These voltages are generated by passing the saw-tooth voltages, produced by the horizontal and vertical saw-tooth generators, through suitable amplifiers. Push-pull amplifiers are generally used in preference to the single-ended stages, because with single-ended amplification it is impossible to secure uniform focussing of the image.

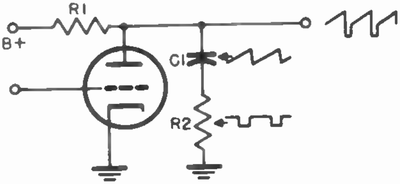


Fig. 40.—Addition of resistor R2 produces peaked sawtooth waveform.

Magnetically deflected tubes require saw-tooth current to produce proper deflection of the electron beam. A peaked saw-tooth voltage must be impressed on the deflection coils to produce a saw-tooth current in them. This peaked saw-tooth is generated by adding a peaking resistor in series with the charging capacitor in the discharge tube circuit as shown in Fig. 40.

The deflection amplifiers are transformer coupled to the respective deflection coils. A damping circuit is connected across the horizontal deflection coil to eliminate the spurious oscillations which occur when the saw-tooth current suddenly drops to zero during the retrace period. The damping circuit loads the tuned circuit and damps out the oscillations.

Section 11

SOUND SYSTEMS

The assembly of a number of components to create a complete sound system is not difficult if the principles of system design are thoroughly understood. The major units which make up a sound system are microphones, amplifiers, loud-speakers, and record players. Other materials, such as microphone and loud-speaker stands, cabling, etc. are also used. In order to assemble a sound system which will perform properly, it is necessary to be familiar with all the components used, and what is required of each of them.

1. Requirements.—The most important physical and electrical characteristics of a sound system are power, fidelity, gain, number and type of controls, number and type of input sources, and number and type of loud-speakers. The elements which determine these characteristics must be carefully considered before the components of a sound system can be specified. All of the components which make up a complete system must be carefully coordinated if the system is to operate properly. No component can be chosen without regard to the other parts of the system with which it is to be used.

2. Power.—Before the components of a system can be selected, the power necessary to supply the required sound volume must be determined. The absolute unit of power measurement, as applied to sound, is the acoustic watt. It is not convenient to think in terms of the acoustic watt when designing a sound system. The audio watt is more convenient to work with. The power requirement of a specific installation can be expressed in terms of the number of watts of audio power required from the amplifier to be used if the efficiency of the loud-speaker system is taken into consideration.

The efficiency of good loud-speakers used with sound systems is approximately 25%. Assuming that the loud-speakers used have an efficiency of 25%, it is possible to give the power requirements of a particular installation in terms of watts of audio power.

Fig. 1 is a chart showing the approximate power required for adequate coverage of auditoriums of various sizes. The size of the auditorium is based on its volume in cubic feet.

The shaded area indicates the approximate limits within which the power requirements fall. The exact power requirements vary depending upon the type of material to be reproduced, the quality of reproduction desired, and the noise level. The upper limit of the shaded area of the curve applies when music is to be reproduced and high quality is desired. The same is true for an installation where the noise level is high.

If a system is to be used primarily for speech reinforcement, and a bulk of the power is concentrated in the frequency range of 200 to–3,000 cps, the lower part of the shaded area should be selected.

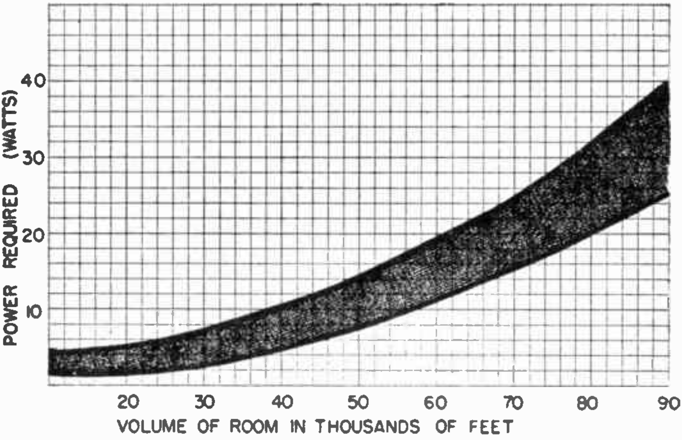


Fig. 1 Audio power required for rooms of various sizes.

In multiple installations, that is, installations where several areas are to be served, it is necessary to determine the total power requirements of all the locations which are to be equipped with loud-speakers, and then arrange the distribution of power to the various loud-speakers in accordance with the requirements of its individual location.

3. Fidelity.—The term, fidelity, includes a number of considerations. By definition, fidelity is the degree with which a system accurately reproduces at its output the essential characteristics of the signal that is impressed on its input. The fidelity requirements of a system depend largely upon the type of material which is to be reproduced.

Frequency response is an important characteristic which helps to determine the fidelity of a system. Frequency response is a rating which indicates the range over which a system reproduces all frequencies uniformly; thus, a system may be said to have flat response between 100 and 6,000 cps, meaning that a curve of its output plotted against frequency is flat from 100 to 6,000 cps. The term "flat" is usually understood to mean within one or two decibels.

4. Distortion.—Fidelity also includes the distortion characteristics of a system. For systems of the highest quality, harmonic distortion must be kept below 1% at normal operating level.

Harmonic distortion refers to the presence of frequencies in the output which were not in the input, but were generated in the system itself, and which are harmonically related to the input frequencies. If the equipment is to be used for speech reinforcement only, distortion content up to 5% is not objectionable, providing the highest frequency reproduced is limited to approximately 5,000 cps. Harmonic distortion becomes increasingly unpleasant to the ear as the upper frequency limit is raised.

5. Gain.—The overall gain of a system is important and must be carefully considered. Gain is measured in decibels, or db. A decibel is an expression of a ratio of power or a ratio of voltage; thus, if we know the input voltage, Ei, of a system and the output voltage, Eo, of the same system, the overall gain of the system may be determined by using the expression·

$$Gain\ in\ (db) = 20\ log\ \frac{Eo}{Ei} + 10\ log\ \frac{Zin}{Zout}$$

Where Zin and Zout are Input and Output Impedances.

If the input power, Pi, and the output power, Po, are known, the gain may be determined by the following formula:

$$Gain\ in\ (db) = 10\ log\ \frac{Po}{Pi}$$

Decibels may be added or subtracted; an amplifier always adds a certain number of db, and an attenuator subtracts a certain number of db. Thus, if a pre-amplifier with a gain of 20 db is used with a power amplifier with a gain of 60 db, the total gain will be 20 + 60, or 80 db.

"Dbm" is the term used to indicate the volume level of constant tones. It means that the level, or sound volume, of a constant tone is the specified number of db above 1 milliwatt.

6. Volume Unit.—The volume unit is another term commonly encountered. The volume unit is similar to the dbm in that it is used to indicate the level of a signal in db above or below 1 milliwatt. The volume unit indicates that the measurement was made on average program material rather than on a constant tone as does the dbm. The volume unit is abbreviated "vu."

In order to determine the gain necessary for a given sound system, it is necessary to know the output level of the system and the level which will be available at the input source. Assume that for an installation, 60 watts is required, and the microphone input level is —75 vu. Sixty watts is equivalent to +48 vu. The required gain of the amplifier will, therefore, be 48 + 75, or 123 db. Notice that the level of the microphone was specified as —75 vu. This means that the level of the microphone is well below 1 milliwatt, which is usually the case.

7. Volume Range.—The term, volume range, is used to indicate the range in db between the maximum output power of an amplifier and the noise level of the entire system. Volume range is an expression of the useful range over which a system will work. The output level cannot exceed the maximum rated power of the equipment, nor can the output be lower than the noise level.

For satisfactory reproduction of music, a volume range of 65 to 70 db is considered adequate. Wide volume ranges are not required in outdoor systems. Indoor reproduction always requires a wider range. Good indoor reproduction of speech requires a range of 50 to 60 db, whereas outdoors, a range of 30 to 50 db is sufficient.

Hum is usually the factor which determines the noise level. For satisfactory results, the hum and any other noise should be 10 db below the minimum sound level to be reproduced. In large systems, this requirement should be strictly adhered to.

The other elements which must be determined before the equipment for a given installation is chosen are the number and type of controls, the number and type of input sources, and the number and type of loud-speakers. All of these must be arbitrarily chosen depending upon the desires of the user. They must, however, be chosen so that they can be properly coordinated with the rest of the system. Familiarity with the various types of microphones, amplifiers, and speakers, and a knowledge of their operation make this problem a simple one.

INPUT SOURCES

The input sources for public address systems are generally limited to microphones, turntables, remote lines and radio tuners. The number and type of source depends entirely upon the use for which the system is designed.

8. Microphones.—There are many types of microphones available. Each has certain advantages and disadvantages. The type of material, the placement of the microphone, whether it is to be used indoors or outdoors, the frequency response desired, and a number of other factors, affect the choice of a microphone.

The basic types of microphones, grouped according to their principle of operation, are:

1. Carbon
2. Crystal
3. Dynamic
4. Ribbon
5. Condenser

Each of these microphones has its own set of characteristics in respect to (1) output level, (2) frequency response, (3) output impedance, (4) directivity. These characteristics determine whether or not a microphone is suitable for a given application.

9. Output Level.—The output level of a microphone is important because it governs the amount of amplification that must be available for use with the microphone.

The output level of microphones is usually given in volume units preceded by a minus sign. The minus sign means that the output level is so many vu below the reference level of 1 milliwatt for a specified sound pressure.

The unit of sound pressure used in rating microphones is referred to as a "bar." A bar is equal to a sound pressure of 1 dyne per square centimeter. Speech provides sound pressures between 0.4 and 15 bars. For music, the pressure ranges from 0.5 bars to 1250 bars.

Microphones are rated in a number of different ways. This often causes confusion. It is a good idea to convert their output level rating to db below 1 milliwatt for a sound pressure of one bar.

The table in Fig. 2 gives correction factors which, when applied to the corresponding method of microphone rating, will convert it to output level in db below 1 milliwatt for a sound pressure of 1 bar. When a rating has been converted to these terms, it is much simpler to use when calculating amplifier gain requirements, etc. In the chart of Fig. 3, which gives the characteristics of typical microphones, all the output levels are given in terms of db below 1 milliwatt for a pressure of 1 bar.

COMPARISON OF MICROPHONE RATINGS

Rating Given	Correction Factor
db below 1 mw/1 bar	0 db
db below 1 mw/10 bars	—20 db
db below 1 volt/bar	2 db
db below 1 volt/10 bars	—18 db

Fig. 2 Chart for the conversion of microphone ratings to db below one milliwatt per bar.

A microphone with a low output level necessitates the use of an amplifier with greater gain, which, in turn, increases the possibility of noise and hum. The absolute minimum noise level which can be practically attained at the grid of the input tube of an amplifier is about —125 vu. From this, it has been determined that to have a reasonably quiet installation, the microphone level must not be below —85 vu.

When very low level microphones are used, it is very often necessary to provide a direct current heater supply for the input tube, in order to eliminate hum which results when an AC heater supply is used.

10. Frequency Response.—The frequency response of a microphone is a rating of the relative output voltage which results from sound waves of different frequencies. The simplest way to present a complete picture of the frequency response characteristics of a microphone is to plot a curve of its output voltage versus input frequency. Since modern microphones are relatively flat over their range, it is often considered sufficient

Manufacturer	Model	Impedance	Output * Level	Freq. Range	db variations	Type of Unit	Directivity	Special Features	Comments
Radio Corporation of America	44 B$_x$	50 or 250	—75	80-15,000	± 5 db	Velocity	Bi-directional		High quality broadcast type
	74 B	50-250 15,000	—76	50-9,000	± 5 db	Velocity	Bi-directional		Low Priced model
	88 A	50 or 250	—76	60-10,000	± 5 db	Pressure Actuated	Non-directional		General remote use
Western Electric Co.	639 A	30	—82	40-10,000	± 4 db	Combination Dynamic & Velocity	Non-Uni Bi-directional		
	633 A	30	—78	40-10,000	± 2 db	Dynamic	Semi-or non-directional	Detachable baffle makes semi-directional	
	630 A	30	—78	40-10,000	± 5 db	Dynamic	Non-directional		
Amperite Company	PGH PGL	High 50	—75	40-10,000	± 3 db	Dynamic	Uni-directional		Baffle increases output by 4 db
	RBBH$_n$ RBB$_n$	High 800	—85	40-11,000	± 3 db	Velocity	Bi-directional		Acoustic compensator used as tone control
American Microphone Co.	D 4T	38000	—86	60-7500	± 2 db	Dynamic	Non-directional		
	D 4	30-50	—86	60-7500	± 2 db	Dynamic	Non-directional		
Astatic Corporation	D-104	High	—48	150-4000	± 5 db	Crystal	Semi-directional	High output level	Especially suitable for speech
	K-2	High	—58	30-10000	± 5 db	Crystal	Non-directional		Rising characteristic above 6000 cps.
Brush Development Co.	BR 25	High	—64	30-7000	± 2 db	Crystal	Non-directional		Sound-cell type
	AP	High or Low	—50	100-5000	± 5 db	Crystal	Semi-directional	Variable tone control	Diaphragm type
Shure Brothers	730A	High	—61	30-10,000	± 5 db	Crystal	Cardioid		
	55A	35-50	—74	40-10,000	± 5 db	Dynamic	Cardioid		Also available in 200-500 and High impedance
The Turner Company	33X	High	—52	30-10,000	± 5 db	Crystal	Semi-directional		
	99	30-50 200-500 High	—72	40-9000	± 5 db	Dynamic	Semi-directional		Rugged construction

Fig. 3 Characteristics of typical microphones.

* Refers to db below 1 mw. for sound pressure of 1 dyne / sq. cm. — 1 bar

to specify the range over which their output does not vary more than plus or minus 2 vu.

For ordinary public address use, a microphone's frequency response curve should be reasonably flat between 50 and 9,000 cps. With systems designed specifically for speech reinforcement, a lower limit of 150 cps and an upper limit of 5,000 cps is entirely satisfactory. Where it is desired to reproduce music with the highest possible fidelity, the frequency response should be flat (with 2 vu.) from about 30 to 15,000 cps. Fig. 4 shows the response of several types of microphones.

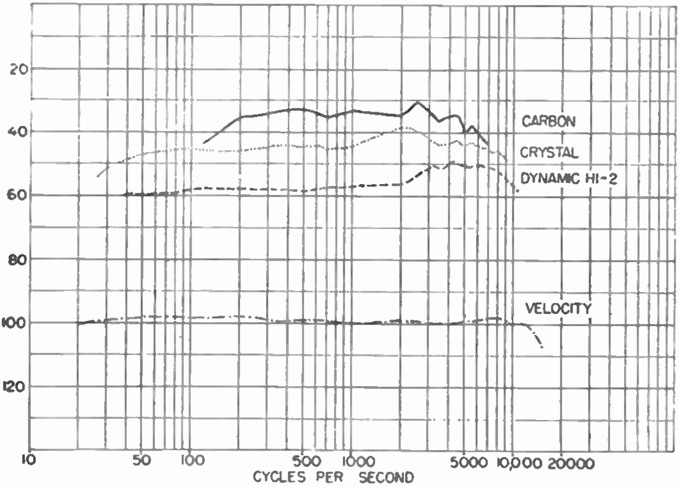


Fig. 4 Frequency response curves for typical carbon, crystal, dynamic and velocity microphones.

11. Output Impedance.—The output impedance of a microphone must match the input impedance of the amplifier. Microphones generally employed in public address have impedances of from 20 to 500,000 ohms.

12. Directivity.—Microphones do not respond equally to sounds reaching them from all angles. Their frequency response characteristics also vary depending upon the angle at which the sound reaches them. A microphone may respond equally to all frequencies between 40 and 10,000 cycles per second when the sound is originating directly in front of it, while the high frequency response falls off rapidly as the sound originates farther to either side. Where it is necessary to pick up sound from all directions, the directional characteristics of some microphones are not suitable.

Fig. 5 shows examples of the four important directivity characteristics which can be obtained with the various types of microphones.

The directional characteristics of a microphone can be used to accomplish a number of things. Noise pickup can be reduced by choosing and placing the microphone so that it will not respond to sound originating at the point where the noise is produced. Feedback, which can be very troublesome, can often be completely eliminated by the careful choice and placement of a microphone.

When a very highly directional microphone characteristic is required, it is secured by using a unidirectional microphone mounted in a wooden parabolic reflector. The microphone is mounted at the focal point of the reflector with its diaphragm facing the reflector. (See Fig. 6). This arrangement is capable of picking up sounds originating 50 to 100 feet from the microphone in an area limited to 10 feet in diameter.

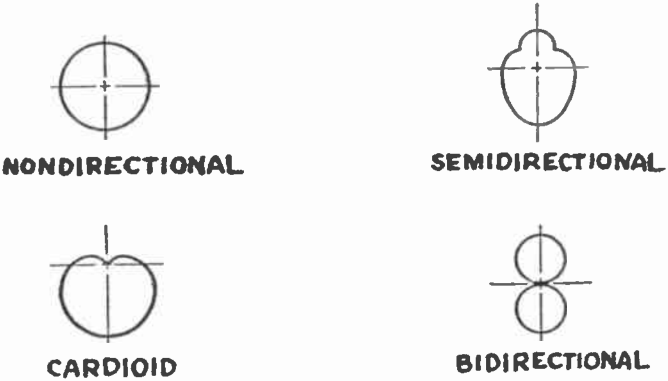


Fig. 5 The four principal microphone polar response patterns.

13. Carbon Microphones.—When the maximum output level is required from a microphone, the carbon microphone is often used. While it does have the advantage of high output, the frequency response characteristics of the carbon microphone are poor.

The carbon microphone consists essentially of a small cup filled with carbon granules and a diaphragm. Fig. 7 shows the construction of a typical carbon microphone.

When sound waves strike the diaphragm, it moves, changing the pressure upon the carbon pile. As the pressure on the carbon pile changes, the resistance of the pile varies. Since the pressure on the carbon pile is directly related to the sound striking the diaphragm, the resistance of the microphone varies in accordance with the sound waves.

Two carbon piles, or buttons, are employed in the better carbon microphones. A double button microphone is connected to the input of an amplifier through a transformer, as shown in Fig. 8. A battery is connected in the circuit as shown. The current through the primary of the transformer varies in accordance with the sound waves striking the diaphragm of the microphone.

A carbon microphone generates a continuous hiss. This hiss is due to small variations in contact resistance which take place between the carbon granules.

The average output level of carbon microphones is of the order of —30 vu. The best carbon microphones have a frequency response of approximately 60 to 7,000 cps. They are substantially nondirectional, although their high frequency response above 3,000 cps usually falls off at angles exceeding 40° from the front of the microphone.

Carbon microphones are no longer widely used in public address work. Their ruggedness and low cost does make them useful in a few cases.

14. Crystal Microphones.—The crystal microphone is the type most widely used in public address installations. The crystal microphone has a relatively high output level and a high impedance. The impedance of the crystal microphone is high enough so that it can be connected directly into the grid circuit of an amplifier, eliminating the need for an input transformer. A long cable will reduce the output voltage available from a crystal microphone, but will not affect its high frequency response.

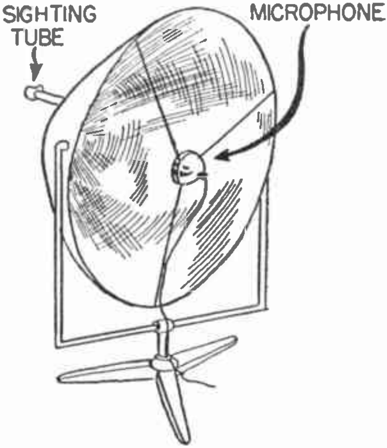


Fig. 6 A microphone mounted in a parabolic reflector to obtain sharply directional response.

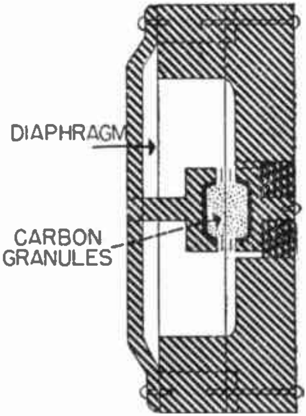


Fig. 7 Construction of a carbon microphone.

The most commonly encountered type of crystal microphone employs a diaphragm which moves in accordance with sound waves striking it and exerts pressure on a Rochelle salt crystal (see Fig. 9). This type of construction permits complete enclosure of the crystal and reduces the effects of humidity.

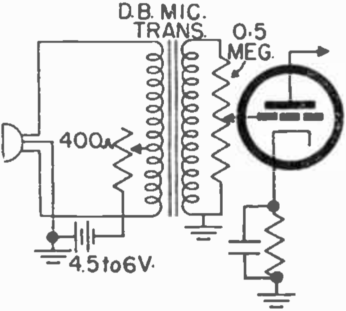


Fig. 8 Circuit diagram showing method used to connect a carbon microphone to the grid of an input tube.

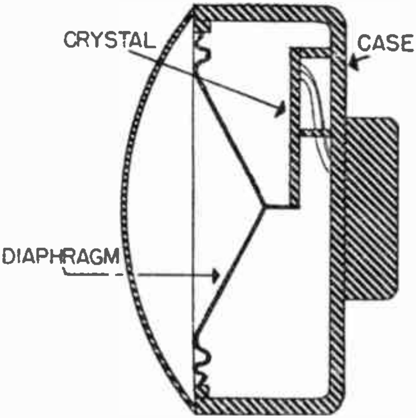


Fig. 9 Cross sectional view of the construction of a crystal microphone.

The output level of this type of microphone is usually between —48 and —60 vu. Their output impedance is almost always more than 100,000 ohms.

The crystal microphone is normally nondirectional, although a special pressure gradient crystal microphone which gives a unidirectional response pattern is now being marketed. These microphones give excellent results.

Good units usually have a frequency response substantially flat between 50 and 10,000 cps. Units are available with slightly wider frequency response ranges.

Fig. 10 shows a typical input circuit used with a crystal microphone. The grid resistor usually has a value of between 3 and 5 megohms.

A crystal microphone should not be used in locations where the humidity is extremely high. They should never be subjected to high temperatures. If a crystal microphone is subjected to a temperature of 130°, it will be rendered completely useless. Care must always be taken to avoid exposing a crystal microphone to direct sunlight for any length of time.

15. Dynamic Microphones.—The dynamic microphone consists of a metal diaphragm, a coil which is connected to it, and a magnet. Its construction and operation are similar to that of a dynamic loud-speaker. When sound waves strike the diaphragm, the coil moves. Since the coil is in the field of the permanent magnet, a current is induced in the coil which is directly proportional to the sound waves striking the diaphragm (see Fig. 11). This current constitutes the output of the microphone. Dynamic microphones are available with limited or wide range frequency response characteristics.

The natural output impedance of a dynamic microphone is between 30 and 50 ohms. Very often, a transformer is incorporated in the microphone, raising its output impedance to a value between 200 and 25,000 ohms. The average dynamic microphone is simple and sturdy. It is not affected by atmospheric changes, has a long life, and is, therefore, well adapted to all-around public address work.

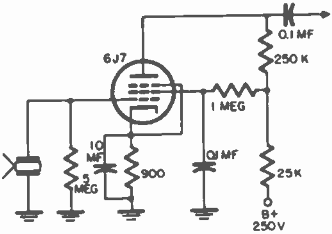


Fig. 10 Circuit diagram of method used to connect a crystal microphone to the grid of an input tube.

The output level of most dynamic microphones is about 55 db below 1 milliwatt per bar. The ordinary dynamic microphone is essentially nondirectional, although its high frequency response falls off rapidly on either side, as shown in Fig. 12. To make full use of a dynamic microphone's frequency range, the microphone should face directly toward the source of sound. A special type of dynamic microphone is available for use when high background noise levels are encountered. The response of these units falls off rapidly as the distance between the microphone and the source of the sound increases.

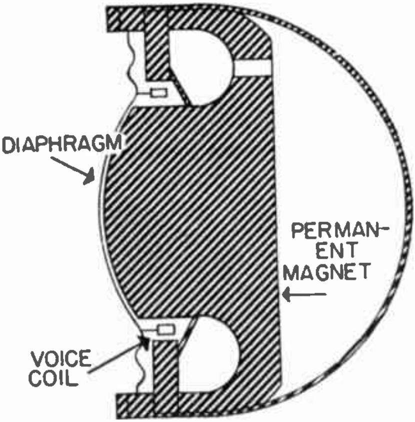


Fig. 11 Cross sectional view showing the construction of a dynamic microphone.

16. Velocity Microphones.—The velocity, or ribbon, microphone consists of a very thin ribbon of aluminum foil suspended in the field of a powerful permanent magnet, as shown in Fig. 13. The ribbon is corrugated and can move quite freely. The ribbon moves in accordance with the velocity of the sound wave.

Response is proportional to the difference in sound pressure between the two sides of the ribbon.

The natural impedance of the ribbon element is about ¼ of an ohm. A transformer is usually mounted within the microphone case, stepping up the impedance at the microphone terminals to a value between 25 and 35,000 ohms. For public address use, the high impedance units are convenient, since they can be connected directly to the grid of an input tube.

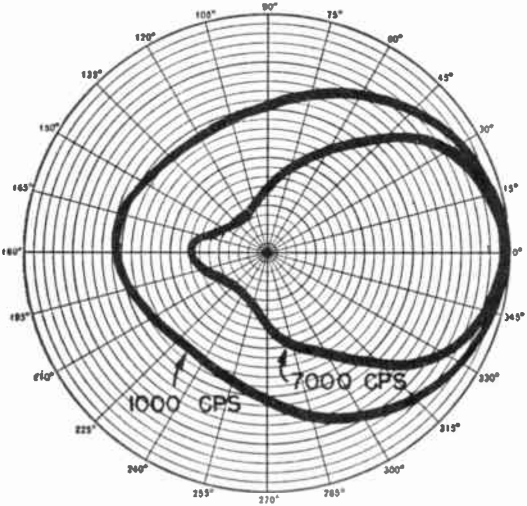


Fig. 12 Polar pattern of the directivity of a dynamic microphone.

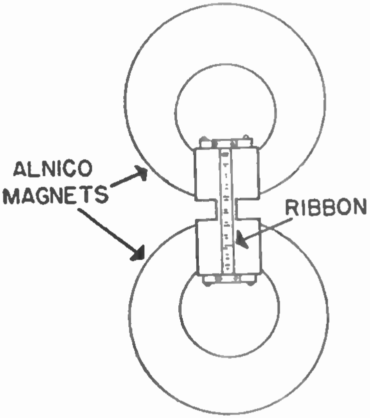


Fig. 13 Construction of a velocity microphone unit.

The output level of velocity microphones is usually about 60 db below 1 milliwatt per bar. Generally, velocity microphones have excellent response characteristics.

The velocity microphone is bidirectional. Maximum response is to sound reaching the front or back of the microphone at a 90°

angle to the plane of the ribbon faces. Unlike the crystal and dynamic microphones, the overall response of the velocity microphone falls off as the angle of the sound reaching it varies from 90° to the faces of the ribbon (see Fig. 14).

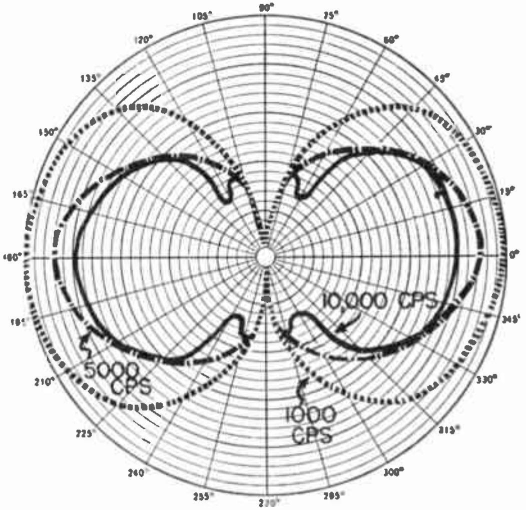


Fig. 14 Polar pattern of the directivity of a velocity microphone.

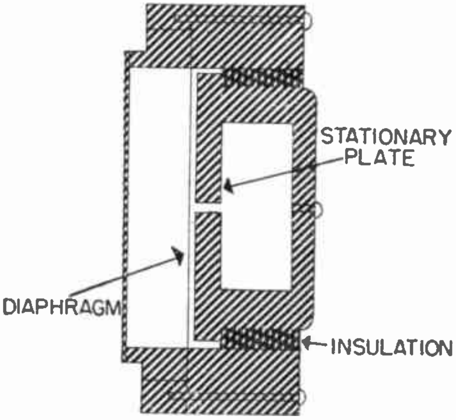


Fig. 15 Cross sectional view of the construction of a condenser microphone.

The velocity microphone is quite sensitive to movement of the air surrounding it, and it must be carefully protected from puffs of wind when used out-of-doors. A ribbon microphone should be at least 18 inches from the source of the sound.

17. Condenser Microphones. — The condenser microphone consists of a fixed plate and a diaphragm, as shown in Fig. 15. The diaphragm is actuated by the changing pressure of the sound waves striking it, causing the diaphragm to change its position in relation to the fixed plate. This results in a change in the capacitance between the diaphragm and the plate, which is utilized to produce a corresponding voltage drop across a resistor connected in series with the microphone and a charging source.

The output level of the condenser microphone is extremely low, and an amplifier must be used with it. The amplifier must be mounted directly at the microphone, usually right in the microphone case. The condenser microphone has very excellent frequency response and low distortion. Because of the necessity of mounting an amplifier at or in the microphone case, the condenser microphone is not recommended for public address use.

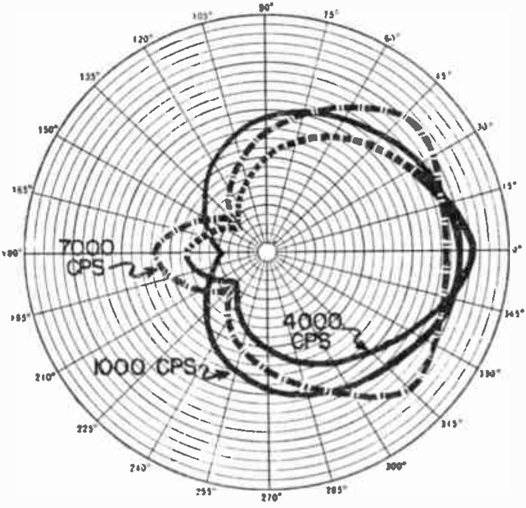


Fig. 16 Polar pattern of the directivity of a dual unit or cardioid microphone.

18. Combination Microphones.—Microphones are available which make use of two units to secure a particular directional pattern. A dynamic unit is often combined with a velocity, or ribbon, unit. Fig. 16 shows the directional pattern which results when a bidirectional velocity unit and a nondirectional dynamic unit are combined. The resultant directivity pattern is known as a cardioid, since it is heart-shaped. Other units are also combined to secure similar directivity patterns.

19. Record Players.—Many public address systems require the use of a phonograph unit for the reproduction of recorded material. In some applications, an automatic record changer can be used. When the highest quality of reproduction is necessary, and it is desired to keep record wear to a minimum, a good turntable and a properly designed pickup and arm should be used.

20. Turntables.—A wide variety of excellent turntables is available on the market. The choice of a turntable is usually governed by its quality of construction and the type of drive used.

Rim-driven turntables are usually considered to be superior. In this type, the motor is coupled to the turntable by a rubber disc which is connected to the motor shaft and contacts the rim of the turntable. For good reproduction, a turntable should be free of "wabble" and speed variations.

21. Pickups.—Phonograph pickups may be classified into three types depending upon their principle of operation. These are: crystal, dynamic, and magnetic. The operation of these pickups is essentially identical to the type of microphone to which it corresponds.

Crystal pickups are the type most commonly used in public address work. The crystal pickup has the advantages of high output level and high impedance. Because of their high impedance, crystal units may be connected directly to the grid of the input stage, as shown in Fig. 17.

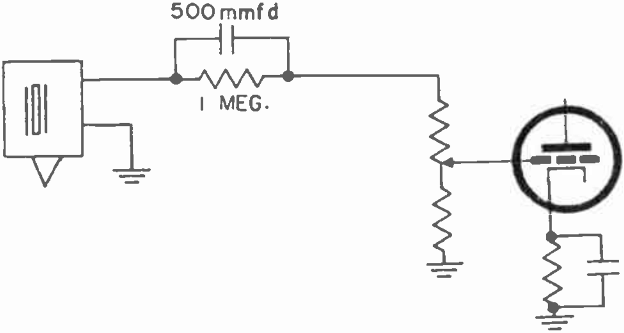


Fig. 17 Crystal pickup input circuit which gives some low frequency equalization.

The crystal pickup is subject to damage when exposed to temperatures higher than 130° F. The output of crystal pickups is usually between 0.3 and 3 volts.

22. Radio Tuners.—In order to make it possible to feed broadcast programs into a sound system, a radio tuner is often provided. The radio tuner is essentially a tuned radio frequency or a superheterodyne receiver. Fig. 18 shows the circuit diagram of a typical tuner suitable for public address work.

AMPLIFIERS

The suitability of an amplifier for an installation depends upon a number of factors, the most important being its power output, frequency response, gain, number of inputs, input impedances, output impedance, distortion, its controls, and the type of power supply from which it operates. The requirements of the instal-

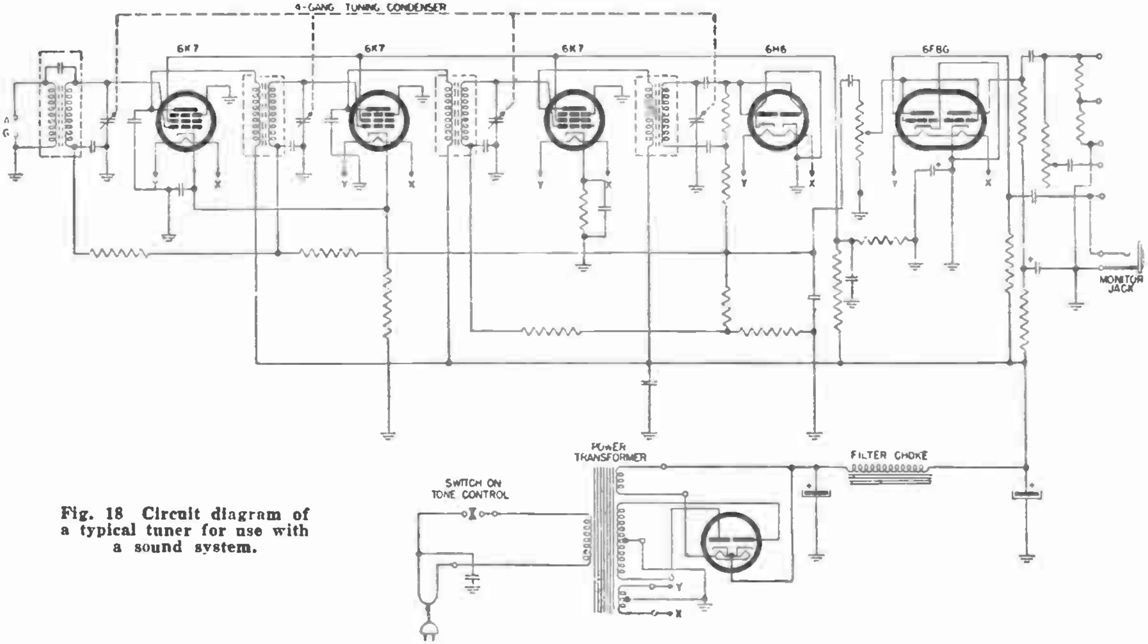


Fig. 18 Circuit diagram of a typical tuner for use with a sound system.

lation must be determined before the amplifier can be chosen. A thorough knowledge of the advantages and limitations of the various circuits used in public address amplifiers is necessary in order to facilitate the choice.

23. Input Circuit.—Two or more input channels are required for the average public address installation. The exact number of channels necessary depends entirely upon the installation.

The use of triode tubes in the input stage, especially the high-mu types, such as the 6F5, tends to discriminate against the high frequency components of the input signal. This is due to the "Miller effect," which may be stated simply in this manner: The effective input capacity of a vacuum tube which appears as a shunt capacity across the input circuit is equal to the grid plate capacity of the tube multiplied by the amplification factor of the tube.

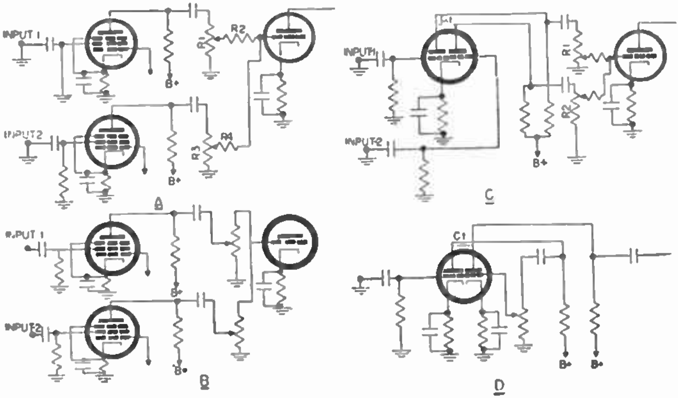


Fig. 19 Mixer circuits. A and B are good. C and D are poor.

The grid plate capacity of triodes is appreciably higher than that of pentodes, and when a high ratio step-up transformer is connected to the grid of such a tube, the shunting capacity across the secondary of the transformer is usually appreciable. The result is a decrease in the high frequency response of the system. This is not true when a crystal microphone or pickup is used, since the only effect of increased capacity across both units is a decrease in their output.

Most multi-channel public address amplifiers utilize a single stage of amplification in each channel, the output of these amplifiers being mixed and fed into the next stage. For optimum performance, each channel should have a separate gain control. Mixing should never take place in the input tube. Volume controls should never be placed directly in a microphone circuit because of the low signal level. When a control is connected in a low level circuit, the noise due to the rotation of the control receives a great deal of amplification and is often noticeable in the output.

The mixing circuit, used in an amplifier, should be carefully examined since some of them do not entirely eliminate interaction between the various channels. Fig. (a) and (b) of Fig. 19 are suitable. They give separate gain control of each stage, and no interaction results from their use. The circuits shown in (b) and (c) of Fig. 19 are not suitable, since cross-talk usually results when they are used. This cross-talk results from the capacity, CT, between the elements of the dual tube.

The input circuits, as shown in Fig. 19, are intended for use with high impedance microphones or phono pickups. If low impedance input circuits are required, transformers must be used. These transformers must be very well shielded, especially if they are operating at levels below —60 vu. Insufficient shielding usually results in hum pickup.

When a transformer is added to a circuit, a certain amount of voltage gain results. This voltage gain due to an input transformer is equal to the square root of the impedance ratio of the primary and the secondary. The gain in db may be found by the following formula:

$$\text{Gain (in db)} = 20 \log \sqrt{\frac{Z2}{Z1}}$$

Z1 is the primary impedance and Z2 is the secondary impedance of the transformer.

24. Output Impedance.—While the output impedance of an amplifier necessary to fill the requirements of any installation depends upon the installation itself, it is well to choose an amplifier whose output transformer makes available a selection of impedances. This adds flexibility to the system which may be useful at a later time.

Amplifiers are available with tapped transformers, permitting the selection of impedances between 2 and 6,000 ohms. The low impedances are useful only if the speakers are to be mounted at the amplifier. When long speaker lines are used, considerable power loss will occur unless an impedance of 250 ohms or higher is used. The usual practice is to use a 500 ohm output impedance and install line transformers at each speaker.

Fig. 20 shows the circuit used in a multispeaker installation to connect the speakers to the amplifier. Regardless of the number of speakers and the way in which they are connected, all impedances must be so selected that efficient power transfer takes place. The problem of impedance selection to solve problems of power distribution is covered later in this section.

25. Gain.—The overall gain required of an amplifier must be carefully determined before an installation is made. In order to determine the gain required from an amplifier, the output level of the input sources (microphones, etc.) and the required maximum output power must be known. It is necessary to find the db level to which the maximum output of the amplifier corresponds. The difference between this level and the level of the input source is the gain required from the amplifier.

Commercial amplifier gain ratings are often confusing. This is due to the fact that microphones and amplifiers are not always rated in the same terms. Assume that a commercial amplifier is rated as having a gain of 130 db. The input impedance of the amplifier is 500,000 ohms. The manufacturer rates the amplifier at 35 watts output. Thirty-five watts is equal to +45 vu. In order to find the input signal which will give maximum output, the gain of the amplifier is subtracted from the maximum output level. The output level is +45 vu, the gain is 130 db. Subtracting, we find that the input level is —85 vu. A level of —85 vu corresponds to a voltage of .000106 across 600 ohms. In order to find the voltage which must be developed across the input of this amplifier, we must convert to find what voltage will be developed across 500,000 ohms. The required input voltage is .0031 volts, which corresponds to 52 db below 1 volt. To obtain sufficient gain, the microphone used should have a gain of 52 db below 1 volt per bar or more. As a rule, amplifiers rated over 110 db have sufficient gain for public address work.

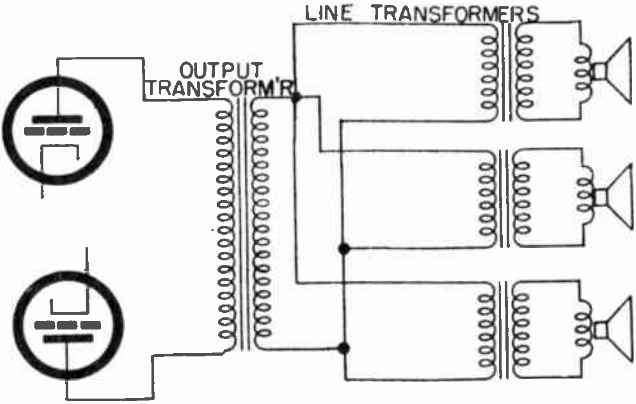


Fig. 20 Method used to connect three speakers to an amplifier.

26. Power Amplifiers.—The power amplifier circuit and the components used is usually the most important factor governing the percentage of distortion present in a system. Since it is usually desired to keep distortion to the lowest value consistent with economy, the power amplifier should be carefully designed. Some form of degenerative feedback should always be used. Feedback reduces harmonic distortion, stabilizes the output impedance, and reduces the effects which resonance in the loudspeakers has on the output.

Push-pull triodes gives the lowest percentage of distortion, while the use of beam tubes results in distortions higher than is permissible unless sufficient degenerative feedback is used. From 15 to 20 db of feedback should be used in beam power amplifiers.

Beam power tubes used in push-pull parallel also give an increase in distortion and are not recommended when highest quality reproduction of music is desired. Since the allowable distortion for systems designed specifically for speech reinforcement is greater than for the reproduction of music, the use of push-pull parallel tubes is permissible.

27. Power Output.—The power required from the amplifier depends upon the particular installation. When an amplifier is selected, the method that was used to rate its output is important. The amount of distortion present when the amplifier is operating at its rated output level must be known.

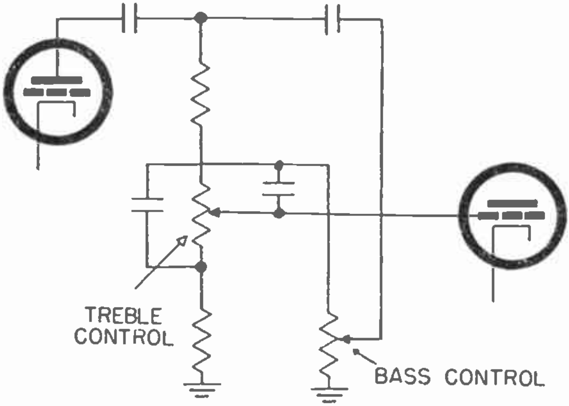


Fig. 21 Circuit used to obtain separate high and low frequency tone control.

Amplifiers are usually rated at a specified wattage with a given distortion content. As the output from an amplifier is decreased, the percentage of distortion present in the output decreases. Therefore, an amplifier suitable for a speech reinforcement installation requiring 30 watts at 5% distortion might be used in an installation where less than 2% distortion was desirable if it could be operated at a considerably lower output level.

28. Controls.—The number and type of controls with which a sound system is equipped are important factors influencing the flexibility of the system. A system should be equipped with an individual gain control for each input channel and a gain control which affects the gain of the entire system.

Almost all amplifiers used in public address systems have built-in tone controls. Both high-frequency (treble) and low-frequency (bass) controls are usually available. Fig. 21 shows a circuit for separate high and low frequency controls.

The high-frequency control is particularly useful when equipment is used in a room with hard walls. Under these conditions, feedback usually occurs due to reflected sound, and since the high frequencies reflect more efficiently than do the low frequencies, attenuation of the high frequencies usually reduces feedback effects. The high-frequency tone control is usually useful when background music is being reproduced as in restaurants, etc. Under these conditions, the high frequencies should be attenuated since they tend to make conversation difficult.

The low-frequency tone control is particularly useful when speech is being reproduced. Under these conditions, attenuation of the lower frequencies helps remove the "tubbiness" which occurs at times in certain types of installations.

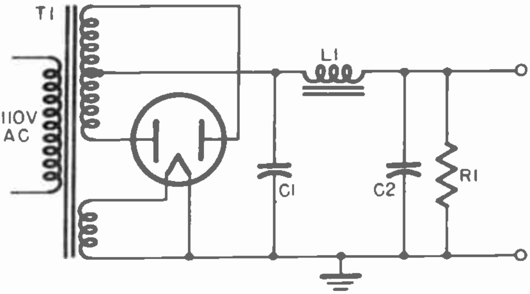


Fig. 22 A rectifier type power supply circuit.

Compression and expansion controls are sometimes provided in large installations. Compression is often advantageous when a system is used for speech reinforcement. When compression is used, the speaker may move close to and away from the microphone and may raise and lower his voice considerably without creating the necessity of constantly resetting the gain controls of the system. A good compressor will smooth out a wide volume range and automatically adjust the gain of the amplifier so that the sound from the loud-speakers will remain constant.

Volume expansion is useful only in high quality music-reproducing systems and is not used very often in public address work.

In many installations, it is advantageous to provide a means of remote control. The remote control usually takes the form of a small box connected to the amplifier through a long cable. Remote control is ordinarily desirable for gain only.

29. Power Supply.—Amplifiers are usually equipped with rectified type power supplies suitable for use with 115 volts alternating current. Fig. 22 shows a typical power supply circuit used in audio amplifiers.

A system may be operated from 6 to 12 volts DC by using a vibrator supply or motor generator as a source of high voltage. Fig. 23 shows a typical vibrator type power supply. Small mobile sound systems often make use of this type of power supply.

When large systems must be operated in locations where regular AC power lines are not available, gasoline engine driven generators are usually used.

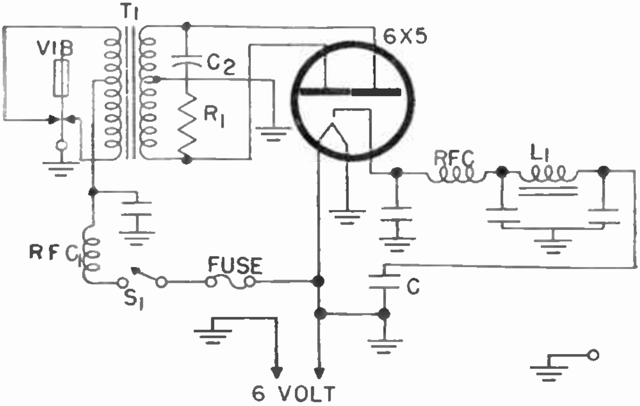


Fig. 23 A vibrator type power supply.

LOUD-SPEAKERS

Two basic types of speakers are used in public address systems. These are the cone speaker and the horn type speaker. Occasionally, where a system is used to reproduce music and the highest quality is desired, a dual speaker system is used.

Dual speaker systems consist of a cone speaker mounted in a low-frequency horn or reflex enclosure and a high-frequency multi-cellular horn. Recently, a number of excellent co-axial speakers—that is, units which combine a low-frequency cone speaker and a high-frequency horn in one unit—have been placed on the market. Their greatest advantage is compactness.

There are a number of specific requirements which must be considered when choosing a speaker. The characteristics which determine the suitability of a speaker are: (1) efficiency, (2) power-handling capacity, (3) frequency response, (4) directivity, (5) impedance, (6) source of field supply.

30. Efficiency.—The average cone type speaker used in radio receivers has a very low efficiency, usually between 5 and 10%. In this application, speaker efficiency is not important, since the amounts of power concerned are relatively small. A receiver is required to furnish entertainment to a relatively small group, and it is a simple matter to obtain sufficient acoustic power even with speakers of low efficiency.

When it is necessary to cover a large area or a large group of people, speaker efficiency becomes a major factor. Audio power in large quantities is expensive and must be utilized efficiently. The following will serve to point out the importance of using speakers of good efficiency:

Assume that a particular installation requires 40 watts of acoustic power. If speakers whose efficiency is 25% are used, 160 watts of audio power will be required. If speakers whose efficiency is only 10% are used, 400 watts of audio power will be required. The difference in cost between an amplifier capable of producing 400 watts and an amplifier capable of producing 160 watts is much greater than the difference in cost between speakers of low efficiency and speakers of good efficiency.

In all installations where considerable power is required, it is always economical to use speakers of good efficiency. Good efficiency may be considered as 25%. Higher efficiencies are available when dual speaker systems are used.

31. Power Handling Capacity.—The speakers used in a system should be able to handle the entire output of the amplifier. Where fidelity is an important factor, the speakers should be able to handle considerably more power than will be required of them when operating at normal level.

Cone type speakers are available which are able to handle powers up to 25 watts. Horn type units are available which are capable of handling up to 50 watts in a single unit. When greater power handling capacity is required, groups of speakers are usually used.

32. Frequency Range.—In wide range, high fidelity sound systems, the loud-speaker unit is usually the determining factor in the overall frequency response of the system| It is easier to obtain wide range frequency response in microphones and amplifying equipment than it is to convert wide range audio power to acoustic power.

The frequency response of a speaker is not dependent upon the speaker alone, but also depends upon the way in which the speaker is baffled, and upon the acoustics of the room.

Good cone speakers have excellent response characteristics at the lower frequencies when properly baffled, but their high frequency response is not sufficient when the highest fidelity is desired. Since properly designed horn units have excellent high frequency response characteristics, they are usually combined with cone type speakers in order to obtain a wide range frequency response characteristic.

In speech reinforcement systems, wide range frequency response is not altogether desirable. This is due to the fact that the low frequencies which require a large portion of the overall power do not contain a great deal of the intelligence to be transmitted. Since this is true, when fidelity is not important and economy and coverage are the primary factors, the low frequencies may be eliminated, resulting in a considerable reduction in audio power requirements. The higher frequencies add little to the intelligibility of speech, and they may be similarly dispensed with.

33. Directivity.—Speaker directivity is an important factor in the establishment of adequate coverage. In indoor installations, the problem is usually one of evenly distributing sound volume over an entire room area.

Cone speakers give very little directional effect. In wide range systems utilizing dual speaker arrangements, distribution of the higher frequencies becomes a problem, since horns are highly directional. To eliminate this directivity, carefully designed multicellular horns are used.

In outdoor installations, the directive qualities of the horn are utilized to make possible a considerable saving in power. Horns are mounted and directed so that sound energy is distributed only to those areas where it is desired, eliminating distribution of sound to areas where it is not necessary. Horns consist of projector and driver units or cone speakers mounted in horn type parabolic baffles.

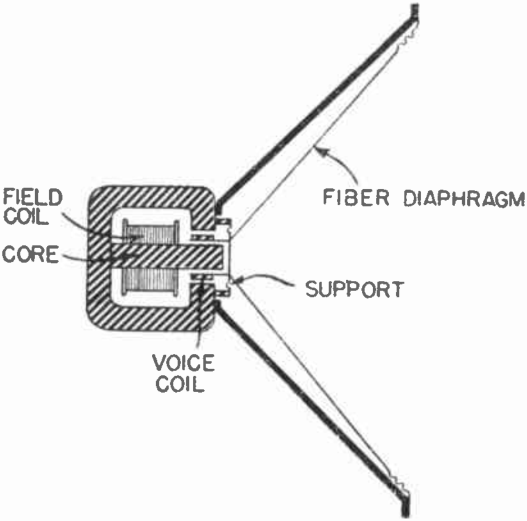


Fig. 24 Cross sectional view of the construction of a dynamic speaker.

34. Impedance.—The voice coil impedance of a speaker must always be properly matched to the amplifier. Since the voice coil impedance of speakers used in public address systems ranges between 8 and 16 ohms, prohibitive losses result when lines are run any great distance between the amplifier and the speaker. In order to eliminate these losses, transformers are mounted at the speakers which step up their effective impedance to 500 ohms or more. Lines of this impedance may be run for considerable distance without prohibitive losses.

By using tapped transformers at the amplifier and at the speakers, impedance taps may be so selected that the audio power absorbed by each speaker is equal to a predetermined amount.

35. Field Excitation.—While permanent magnet speakers are usually preferable, DC excited, field type speakers are sometimes used. These speakers require a source of DC excitation. Excitation is usually supplied from the amplifier or by a DC rectifier type power supply mounted at the speaker.

36. Cone Speakers.—The cone speakers used in public address systems are of the dynamic type. Fig. 24 is a cross-sectional view of the construction of a typical dynamic loudspeaker. The voice coil is connected to the diaphragm or cone and is free to move along the axis of the center pole of the magnet. The signal is applied to the voice coil. When current flows through the coil, it sets up a field around the coil which reacts with the field of the magnet, causing the coil to move. The direction of movement is determined by the polarity of the current, and when an alternating voltage is applied to the coil, the coil moves back and forth.

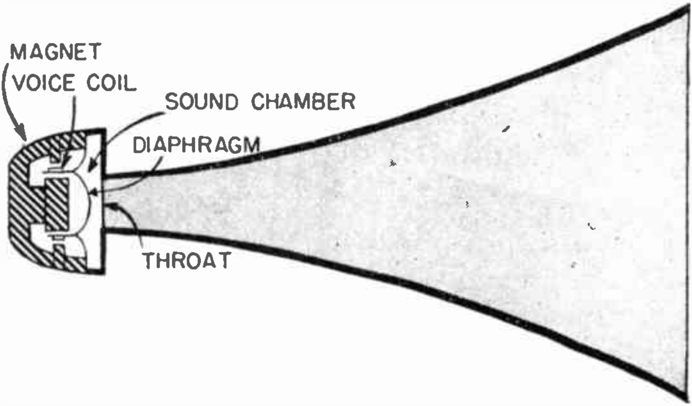


Fig. 25 Cross sectional view of the construction of a horn type reproducer.

Since the field coil is connected to the cone of the speaker, the cone moves with it, setting up sound waves in the air surrounding the cone. The speaker shown in Fig. 24 obtains its magnetic field through the use of a field coil through which direct current is passed.

In recent years, improvements in magnetic materials have made it possible to eliminate the field coil and replace it with a permanent magnet. In general, permanent magnet fields are recommended for all public address applications. Their use eliminates the need for a source of field excitation and reduces the amount of cabling necessary in the loud-speaker system. It will be found that the PM speaker, while initially higher in cost, will in the long run, be the most economical.

37. Horns.—The horn type loud-speaker operates in a manner similar to that of the cone speaker. The major difference between them is that in the cone speaker, the diaphragm is coupled directly to the air, while in horn type speakers, the diaphragm is connected to the air through the horn. The horn acts as an impedance coupling device. Fig. 25 shows the construction of a typical horn type loud-speaker.

The speaker consists of two major parts; the driver unit and the horn. The driver unit operates on the dynamic principle. Units are available with permanent magnet or field coil excitation.

To secure satisfactory response, a horn must be quite long, and in order to shorten it, a folded horn has been devised. Fig. 26 shows a cross-section of the construction of a typical folded or re-entrant horn.

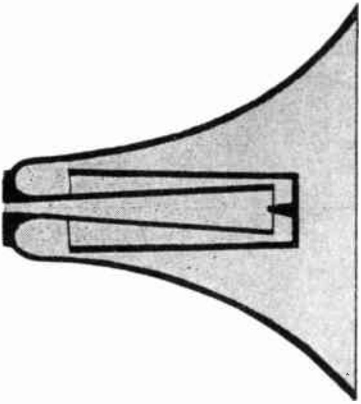


Fig. 26 Cross sectional view of the construction of a folded horn.

One of the advantages of the horn type loudspeaker is its directivity characteristics. In many large outdoor installations, a directional loud-speaker system is advantageous. Fig. 27 shows the directivity pattern of a typical horn type speaker.

The principle of the horn is particularly adaptable for use at high frequencies. Horn type loudspeakers are available whose frequency response cuts off below 800 cycles but extends to beyond 15,000 cps. These horns are combined with cone speakers to secure a loud-speaker system with a wide band frequency response characteristic.

Since horns are quite directional, especially at the higher frequencies, an ordinary horn, when used in the high frequency channel of a multichannel wide range reproducing system, produces an undesirable directional effect. In order to eliminate this directional effect, multi-cellular horns are used. Fig. 28 shows the construction of a multi-cellular horn. A multi-cellular horn is, in reality, a group of horns operating from a single driver unit. Each horn is pointed in a slightly different direction, and, therefore, increases the angle of radiation. A multi-cellular horn usually gives a radiation angle of about 100°.

High frequency horn units have been combined with low frequency cone type units to form wide range coaxial loud-speakers. The high frequency driver unit is mounted on the back of a cone speaker, and the throat of the horn passes through the pole piece of the cone unit.

38. Baffling.—The frequency response characteristics of a speaker system are to some extent dependent upon the type of baffling used. Proper baffling is required whenever cone type speakers are used. A baffle may consist of an open-backed box, a large flat piece of composition wallboard, a reflex cabinet, or a low frequency horn.

Where quality of reproduction is not important, the small wall type speaker cabinets are suitable. In a wide range system, either the low frequency horn or a reflex cabinet should be used.

While the reflex cabinet is inferior to the low frequency horn in response characteristics, it is widely used in preference to the horn because of its compactness. Reflex inclosures must be carefully designed. The volume of a reflex cabinet in cubic feet should be about equal to the radius of the cone of the speaker used with it, measured in inches. Several manufacturers make available properly designed cabinets for use with speakers of

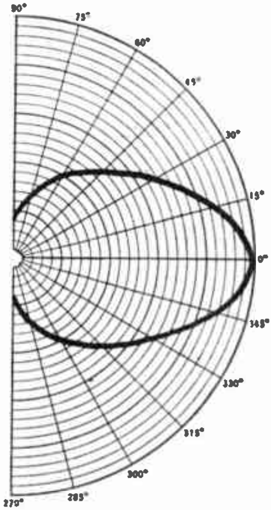


Fig. 27 Polar pattern of the directivity of a typical horn type reproducer.

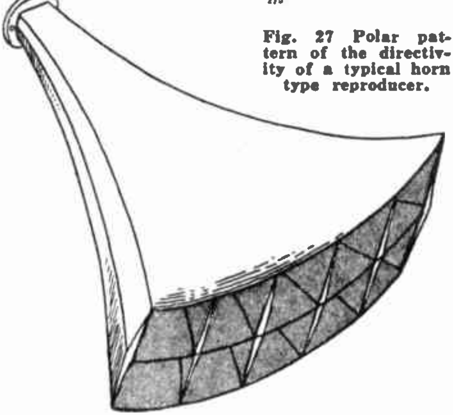


Fig. 28 Construction of a typical multicellular horn.

standard sizes. Fig. 29 shows the construction of a typical reflex speaker inclosure.

The use of low frequency horn units is usually prohibited by their size. In large auditoriums where enough room is available, their use is advisable when a wide range system is used. Fig. 30 shows the construction of a low frequency horn. These horns are usually constructed of braced plywood.

Small horn units are available for use with cone speakers. They are usually used in outdoor installations. They protect the speaker and give a directional effect which is often desirable. The low frequency response of these horns is poor. Fig. 31 shows the construction of a horn designed for use with a cone type speaker unit.

When 360° distribution from a single speaker is desired, a radial baffle may be used. These units are usually mounted in the center of the ceilings of large rooms. They are the most satisfactory means of obtaining 360° distribution from a single unit. Fig. 32 shows the construction of a radial speaker inclosure.

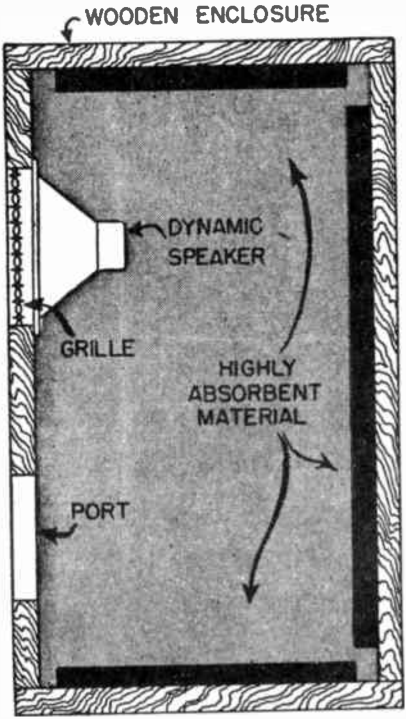


Fig. 29 Cross sectional view of the construction of a reflex inclosure.

ACCESSORIES

The accessories; that is, the microphone stands, cables, etc., used with a public address system, should be carefully chosen. The use of improperly designed stands, poor quality cable, etc., usually result in a great deal of trouble when the system is put into use.

39. **Microphone Stands.**—For general use in permanent installations, heavy-based microphone stands should be used. The mechanism used to adjust the height of the microphone is important. It should work easily and permit adjustments to be made quickly. The design should be such that adjustment of

the height does not create undue noise transmission to the microphone.

Lightweight collapsible stands similar to music racks are convenient for use with portable systems. Since these stands may be upset quite easily, they must be used with care. A number of stands have been designed for special applications. Short stands are available for use on tables. Goose-necked type stands which permit adjustment of the position of the microphone, and a boom type stand particularly useful when the microphone must be held at a point where it is inconvenient to place a stand, are also available. Fig. 33 shows several types of microphone stands suitable for use in public address work.

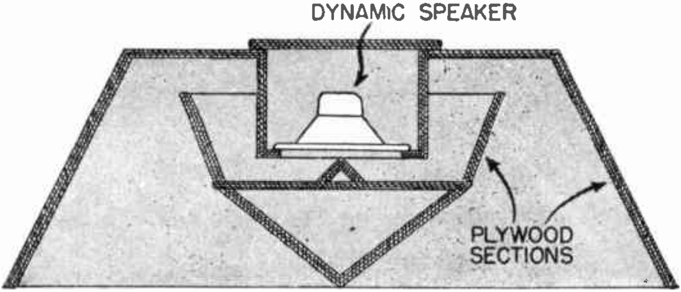


Fig. 30 Cross sectional view of the construction of a low frequency horn.

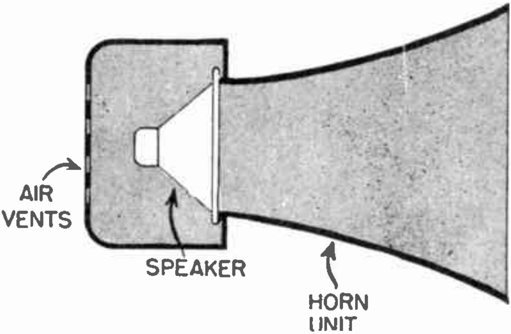


Fig. 31 Horn unit for use with cone speakers.

40. Cabling.—The quality of the cabling used with public address equipment is important. Some of the cabling is subject to considerable abuse. This is particularly true of microphone cables. Microphone cables should be of the highest quality. Portable microphone cables should use No. 14 wire or larger, and they should be heavy-duty rubber covered.

When microphone cables are installed permanently and are operated at low impedance, lead covered cabling is often used. The use of this type of cable greatly reduces the possibility of hum pickup.

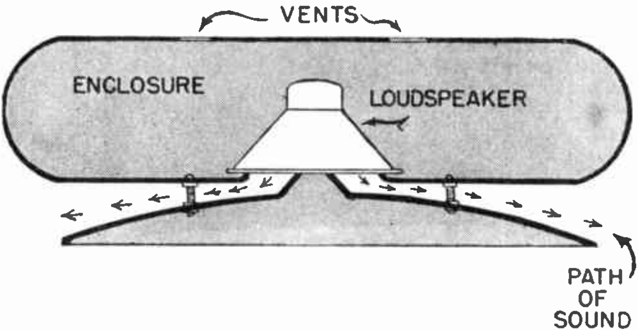


Fig. 32 Radial inclosure for use with cone speakers to obtain 360° distribution of sound.

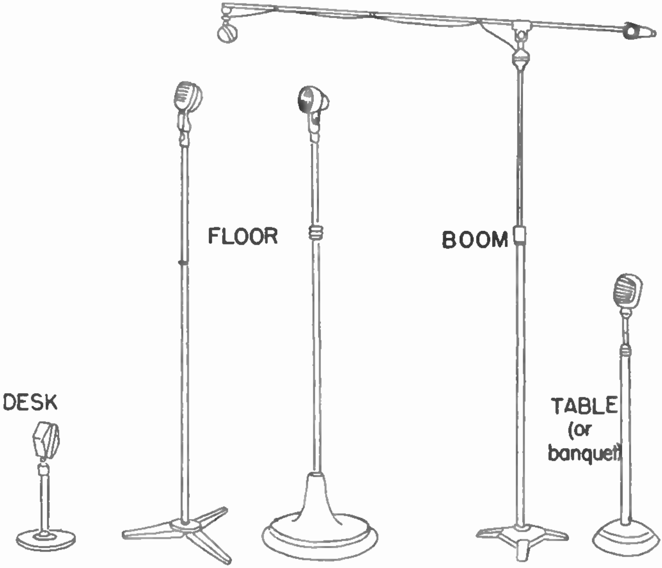


Fig. 33 Microphone stands.

LAYOUT

Before the installation of a sound system is made, the requirements of the location must be determined. As has been previously described, the important requirements which must be determined are the power, fidelity, gain, the number and type of controls, the input sources, the number and type of loud-speakers, and the accessories. The placement of the components should be selected at the same time.

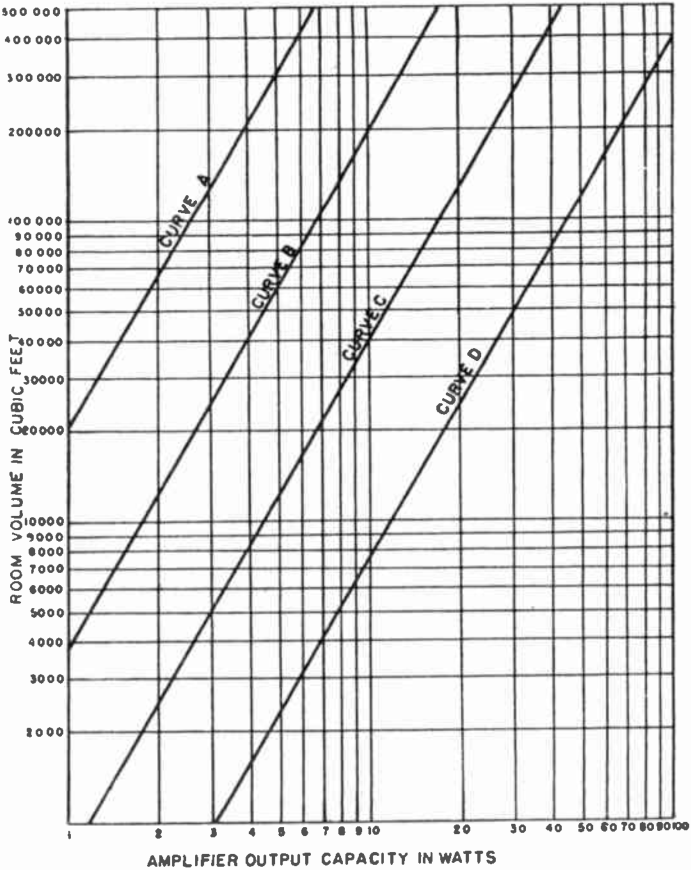


Fig. 34 Curves giving amplifier output capacity in watts for rooms of various volumes in cubic feet. See text for use of each curve.

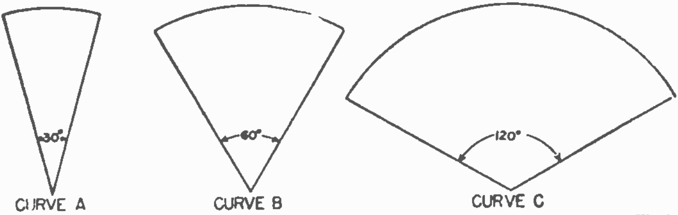
41. Determining Power Required.—The audio power required from the amplifier used with an indoor installation is governed by several factors. The most important of these are: the cubic volume of the room or rooms to be served; the acoustic characteristics of the walls, ceiling, and floor; the average noise level prevailing; the frequency range of the system and of the material to be reproduced; and the efficiency of the speaker system.

The chart of Fig. 34 gives the amplifier power capacity required for rooms of various volumes. Curve A is for speech reinforcement systems using high efficiency horn type speakers when the prevailing noise level is low. If the noise level is high, curve B applies, providing horn type speakers are used. Curve B also applies when cone speakers are used and the noise level is low. When the noise level is high and cone speakers are used, curve C applies. Curve C should also be used for the average music reproducing system when the noise level is low. For very high quality, wide range, reproduction curve D should be used.

The curve of Fig. 35 gives the amplifier power capacity for outdoor voice reinforcement. The power required for outdoor installation depends upon the distance between the loud-speakers and the farthest point to be covered. Curve A is for a system using a single horn type speaker covering an angle of 30°. Curve B is for a system covering an angle of 60°. Curve C is for a system covering an angle of 120°.

42. Frequency Response.—The frequency response of a public address system is an important consideration. For systems used predominantly for music, the range of equipment should extend from at least 60 to 10,000 cps. When a system is used for a direct pickup, and optimum fidelity is desired, a frequency response of from 35 to 15,000 cps is required. This means that if the sound to be reinforced is being picked up directly from an orchestra or a singer, a wide range should be used. If, however, the source of sound is from recordings or electrical transcriptions, there is no necessity for an extremely wide range. A frequency response of from 80 to 8,000 cps is adequate for such a system.

Both the upper and lower limits of the frequency response of a system are important. It has been conclusively determined through subjective tests that the upper and lower limits are related, and that when the upper limit is raised, the lower limit



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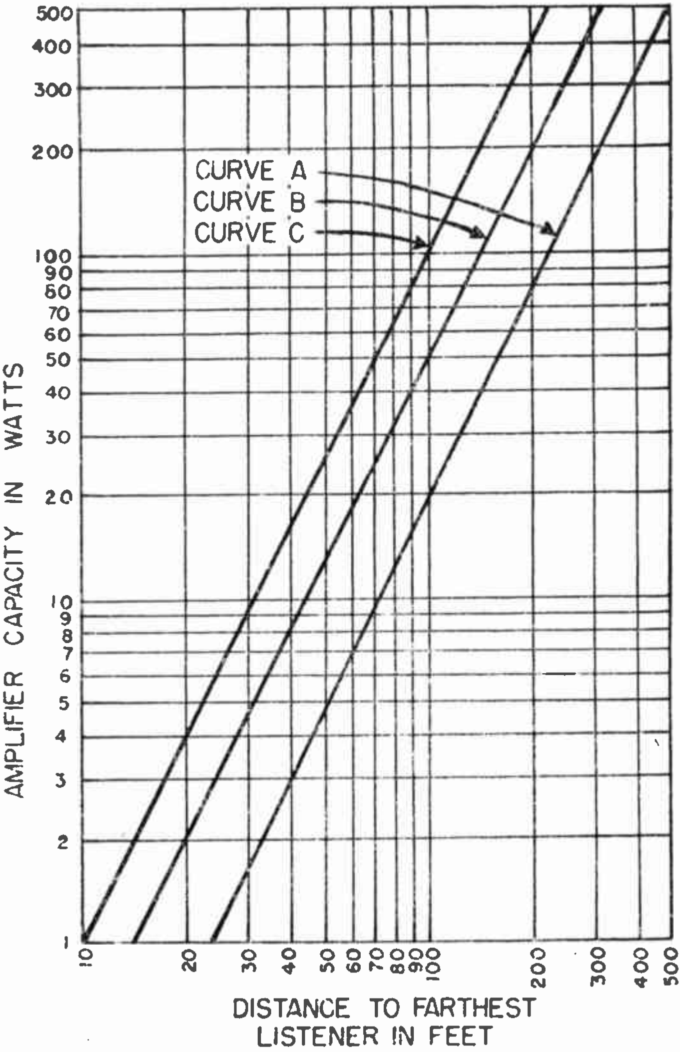

Fig. 35 Curves giving amplifier output power capacity in watts for outdoor sound reinforcement. The amplifier power output depends upon the distance between the loud-speakers and the farthest listener, and the angle of coverage of the loud-speaker system. The curves given are for use with high efficiency horn type reproducers.

should be lowered. It is a fairly well established fact that the product of the upper and lower frequency limits should be 640,000.

This means that if the upper limit is 10,000 cps, the lower limit should be 640,000 ÷ 10,000, or 64 cps. When the upper limit is 5,000 cps, the lower limit should be 128 cps. The center point of the audible sound range is usually regarded as 800 cps.

For best results, the response of a system should be the same number of octaves above 800 cps as it is below. An octave is the difference between two tones whose frequencies are related by a factor of 2. For example, one octave below 800 cps is 800 ÷ 2, or 400 cps. One octave above 800 cps is 1600 cps.

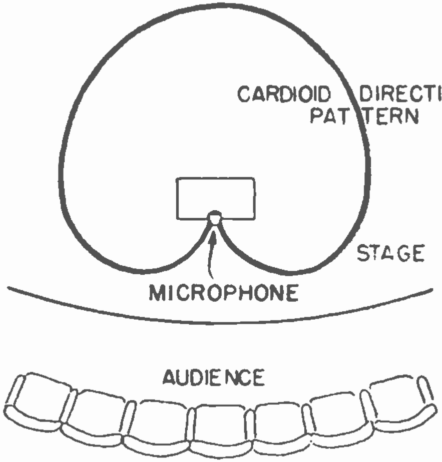

Fig. 36 The use of a cardioid microphone in a lecture room or auditorium.

The wider the frequency response of a sound reinforcement system, the more important it is to keep distortion content to the lowest possible percentage. Distortion can completely negate the advantage of a wide frequency response characteristic.

Very often a sound reinforcement installation is to be used for speech only. Examples of this are systems for use in baseball fields, race tracks, etc. As has been previously mentioned in Par. 32, the intelligence transmitted by speech is almost entirely confined to the frequencies between 300 and 6,000 cps. By designing a system whose upper limit is 6,000 and whose lower limit is 300 cps, a considerable amount of power can be saved without reducing the efficiency of the system. When it has been determined that a system is to be used for speech reproduction only and fidelity is not considered an important factor, the system can be designed so as to have a narrow frequency response range. This will appreciably decrease the overall cost of the system.

43. Microphone Selection.—Microphones should be carefully selected in order to utilize the electrical and physical characteristics of the various types, as described in Par. 8. There are no particular rules which can be strictly adhered to in the selection of a microphone. There are, however, a few points which should be kept in mind.

A microphone should be selected with frequency response characteristics equivalent to those of the other components in the system. A crystal microphone should never be used where it is liable to be subjected to a temperature of more than 120°.

Cardioid microphones should be used when "behind the mike pickup" must be eliminated. Fig. 36 shows the application of a cardioid microphone on a speaker's platform. The back of the microphone faces the audience. Since the microphone is not sensitive to sounds reaching it from this direction, no audience sounds will be picked up and amplified through the system.

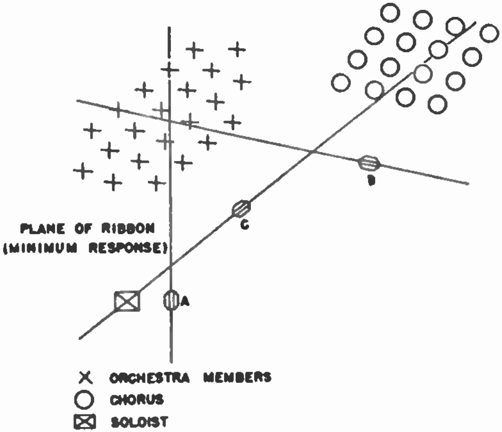

Fig. 37 Typical placement of velocity microphones allowing separate control of the degree of reinforcement of the sound source.

The cardioid microphone may be utilized in the same way to eliminate the sounds of people dancing or moving about in dance hall or night club installations. In installations where large sound reflecting surfaces exist, the cardioid microphone is helpful in eliminating feedback.

The velocity microphone is usually preferred for vocalists. Since it does not pick up sound from either side, it is also helpful in eliminating the effects of feedback.

In systems where a speaker must move about a great deal, the lapel microphone is very useful. A number of contact microphones are available for use with string instruments.

Many installations require the use of more than one microphone. An example of this is illustrated in Fig. 37. Three microphones are used to pick up sound originating at three different points. Microphone A picks up sound from a soloist, microphone B picks up sound from a chorus, and microphone C picks up sound from an orchestra.

The microphones used have been chosen and placed so that they will pick up the designated sound only. In other words, the microphone in front of the orchestra will pick up sound from the orchestra, but not from the chorus or the soloist. This makes it possible to control the pickup from the three elements; that is, the orchestra, the chorus and the soloist individually, so that each may be given the proper degree of reinforcement. A microphone set-up such as this is particularly useful in adjusting the level necessary for a vocalist, since a vocalist requires a greater degree of sound reinforcement than does an orchestra.

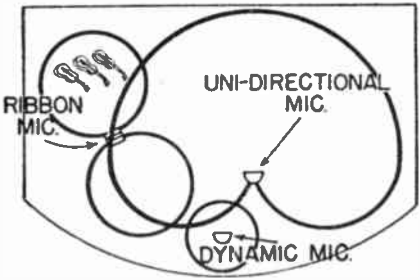

Fig. 38 Arrangement of a velocity, a cardioid, and a dynamic microphone.

Fig. 38 shows another multiple microphone installation. Here, a unidirectional cardioid microphone is used for overall pickup. It faces the orchestra so that the audience is in the dead area of the microphone. A dynamic microphone is used for pickup from a master of ceremonies or vocalist. A third microphone, this one a velocity microphone, is used to pick up sound from the violin section of the orchestra.

44. Gain.—After the power output which will be required from the amplifier has been determined, and the microphones and other input sources have been selected, the gain which will be required from the amplifier can be determined. The first step in determining the gain is to find the volume level in vu to which the power output of the amplifier corresponds. The curve in Fig. 39 gives a number of typical values of output power and the volume level in vu to which they correspond.

It is then necessary to determine the output level of the microphone to be used. Since microphones are rated in a number of different ways, their ratings should be converted to db below 1 mw/1 bar, as described in Par 9. The output level of microphones is usually a number of db below 1 mw, and, therefore, the output level must be added to the power output of the amplifier (in vu) to obtain the gain in db required from the amplifier.

The following is an example of the procedure followed: Assume that the power required from the amplifier is 15 watts. 15 watts is equivalent to +42 vu. If the microphone to be used with the amplifier has an output level of 53 db below 1 mw, the gain required from the amplifier in this installation would be 42 + 53, or 95 db.

In practice, it is usually wise to add a safety factor of about 10%. In this case it would bring the gain required to 105 db. If an amplifier is to be used with a number of microphones, the gain required for use with each microphone should be determined.

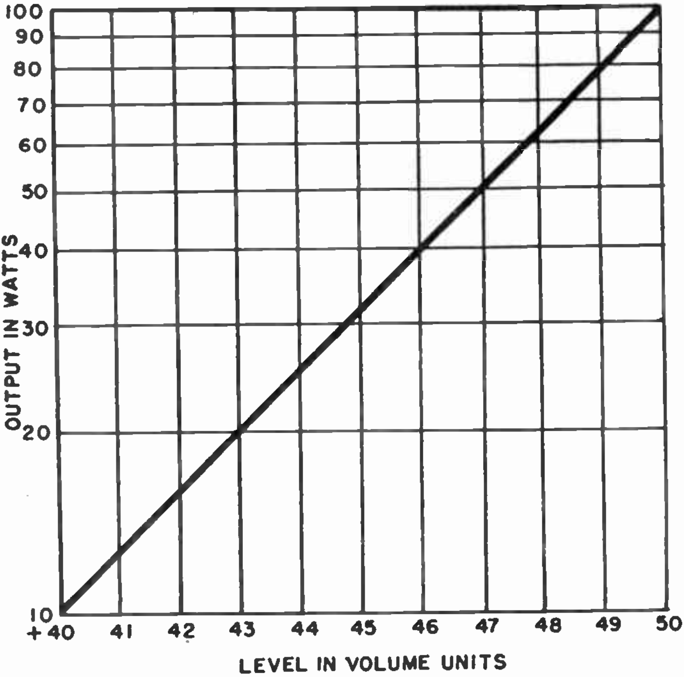

Fig. 39 Power versus volume units.

45. Loud-Speaker Selection and Placement.—The type and number of loud-speakers used in an installation depends upon the audio power which they must convert into sound, the frequency response characteristics which are desired, and the conditions under which they will be used.

In indoor installations, it is common practice to use cone speakers unless special requirements must be met. As a rule, permanent magnet dynamic speakers are the most economical type for indoor use.

In wide range systems where the frequency response of a cone speaker is not sufficiently broad, a multi-channel system utilizing a cone speaker and a high frequency horn and driver unit may be used. Where wide range is desired and space is limited, coaxial speakers combining a horn and a cone in one unit may be used.

In indoor installations designed specifically for voice reinforcement, horn type reproducers give excellent results. There are a number of compact reflex horn units especially designed for this purpose.

In outdoor installations, it is common practice to use horn units. The horns may either be of the straight or folded type. The folded ones are usually preferred because they are more compact. Cone speakers mounted in suitable horn inclosures may also be used in outdoor installations although in most cases, they are not as dependable as are driver type horns especially designed for outdoor use.

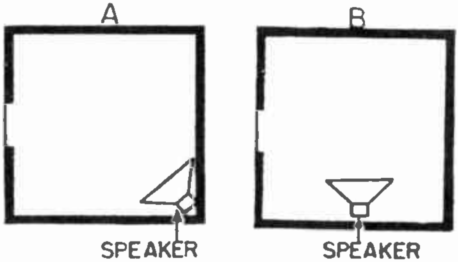

Fig. 40 Two methods of mounting a loud-speaker in a square room.

Cone speakers are available which will convert 25 watts of audio power into sound. When greater quantities of power must be handled, a number of cone speakers may be used with their voice coils connected in series or in parallel. Horn type reproducers are available which will handle as high as 100 watts. These horns utilize multiple driver units.

The placement of the speakers is a very important problem, because proper speaker positioning is necessary in order to avoid feedback and to obtain adequate coverage. Added to this is the problem of minimizing interference between speakers.

There are no rules which can be applied to all installations, but there are a number of points which should be kept in mind when selecting speaker locations.

Whenever possible, all sound should originate at one point. In other words, if more than one speaker is used, when possible, they should be mounted close together. When direct sound pickup is used, the loud-speakers should be kept close to the original source of sound, that is, the orchestra, speaker, etc.

Whenever a sound is heard coming from two or more sources at different distances from the listener, the difference in time it takes for the sound to reach the listener's ears causes it to have the characteristics of an echo, and a great deal of intelligibility is lost. Speakers should never be placed at two ends of a room. As a rule, they can be mounted on one wall or in one corner of a room. Most of the sound heard by a listener must come from one point or from speakers which are equidistant from the listener.

A number of typical examples will serve to point out the procedure used in locating speakers. Fig. 40 shows two methods of mounting a speaker in a square room. In (a), the speaker is mounted in one corner of the room. This gives the best distribution of sound when a single speaker is used. In (b), the speaker is mounted on one wall.

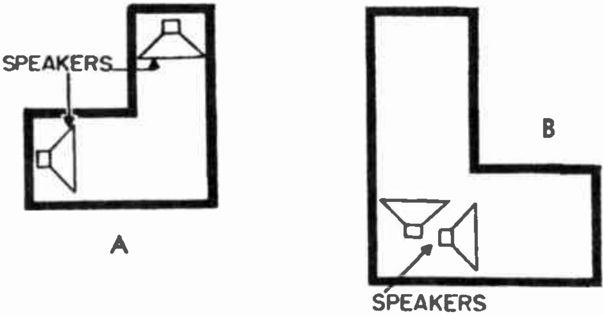

Fig. 41 Wrong and right way to mount two speakers in an L shaped room. A is wrong, B is right.

Fig. 41 shows the right and wrong way to position speakers in an L-shaped room. (a) shows the wrong way in which a speaker is mounted at the end of each leg of the L. (b) shows the correct position. Both speakers are mounted at the junction of the legs of the L, directed so as to obtain even distribution of sound.

In an oblong-shaped room, a radial speaker or a group of speakers may be mounted in the center of the room. Fig. 42 shows an installation of this type, using two loud-speakers. One loud-speaker is pointed toward each end of the room.

Fig. 43 shows a three-room installation. A single speaker is mounted in each room. Located in this way, the speaker lines are kept quite short, and if a listener is able to hear sound originating from two speakers, both speakers will be almost equidistant from him. This condition will exist near the openings between the rooms.

In auditoriums, two speakers may be used with one speaker mounted on each side of the stage, provided the stage is not too wide. Fig. 44 shows an installation of this type.

In an auditorium with a high balcony, the speakers should be mounted as shown in Fig 45. If two speakers are used, one should be pointed at the audience in the orchestra, and the other pointed at the audience in the balcony. If four speakers are used, two of them may be pointed at the balcony and two at the orchestra. This is especially important when multicellular horns are used which are comparatively broad in the horizontal plane and quite directive in the vertical plane.

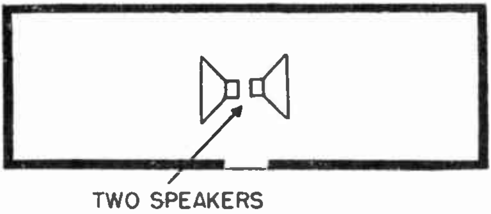

Fig. 42 Placement of two loud-speakers in an oblong shaped room.

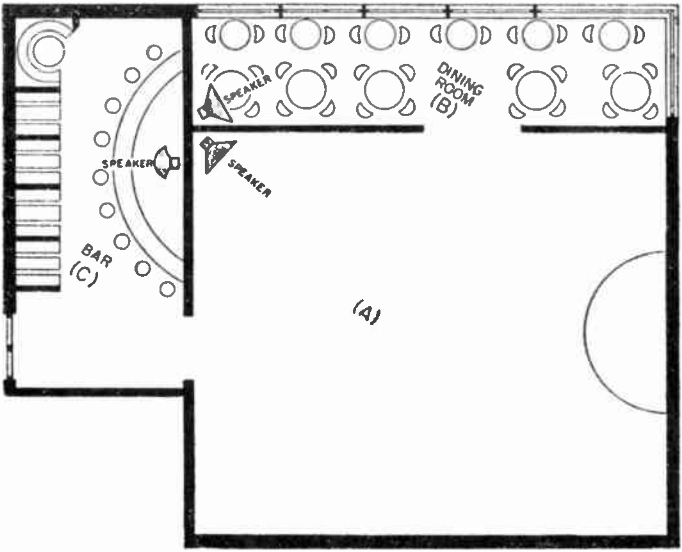

Fig. 43 Placement of speakers in a typical three-room installation.

In the installations of Figs. 41, 42, and 43, no allowances have been made for conditions of direct pickup. In Fig. 43, if an orchestra were located in Room A, the speaker in Room A would have to be located close to the orchestra. Fig. 46 shows an example of how this might be done. It has been necessary to change the more ideal speaker setup of Fig. 43. The change is absolutely necessary in order to eliminate the serious interference which would occur between the loud-speaker and the orchestra, if the speaker was left in its original position.

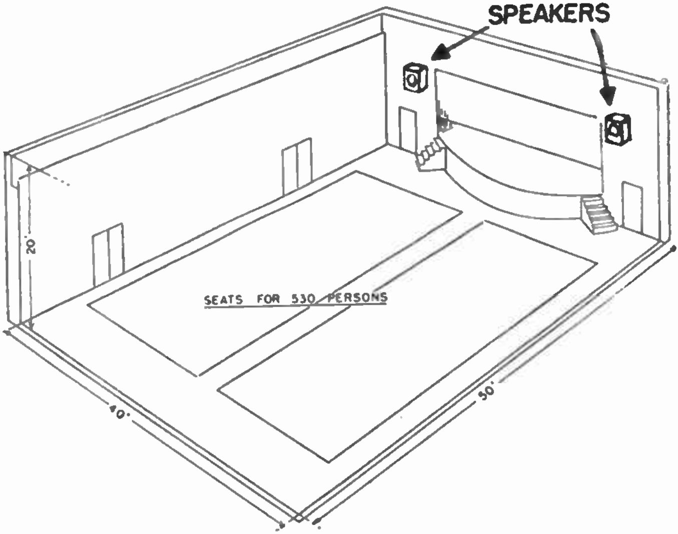

Fig. 44 Placement of speakers in a small auditorium.

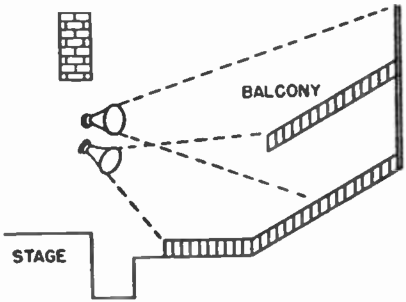

Fig. 45 Placement of speakers to obtain proper coverage of a balcony and orchestra.

In almost all indoor installations, the speakers are mounted near or on the ceiling. This keeps them out of the way and allows a clear path for the sound to any part of the room.

In outdoor installations, the speakers should be mounted 10 or more feet above the ground. All speakers should be located at the same point. This point does not necessarily have to be at the point of direct pickup since in many outdoor installations sound from the point of pickup is a negligible factor. Fig. 47 shows two alternate locations for speakers at a ball park having U-shaped stands.

INSTALLATION

After the components of a sound system have been selected, and the position of the microphones and speakers have been determined, the actual job of making the installation begins. The work of installation consists mainly of mounting the equipment, connecting the amplifier to the source of power, and connecting

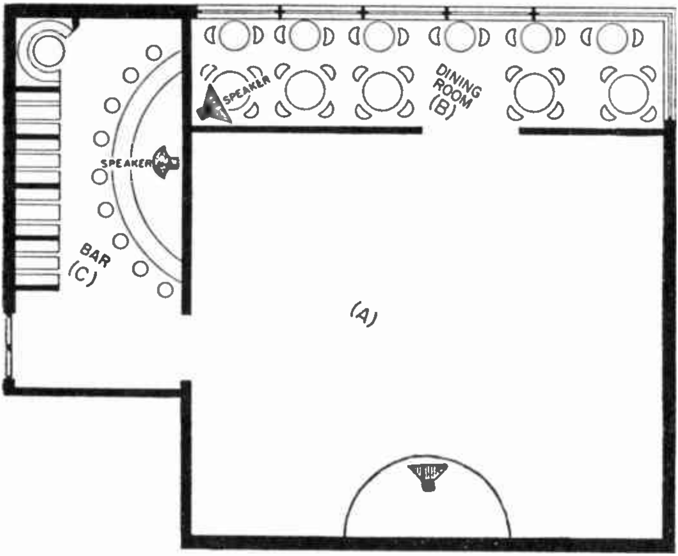

Fig. 46 Rearrangement of installation of loud-speakers shown in Fig. 43 to satisfy requirements of direct pickup in Room A.

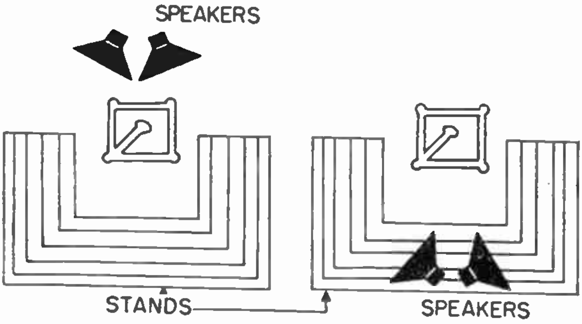

Fig. 47 Two locations for loud-speakers at a ball park having U-shaped stands.

the speakers and microphones to the amplifying equipment through suitable lines and cables. There are a few problems peculiar to sound installation which must be solved at the time the installation is being made.

46. Installing Microphones.—When microphones and microphone cables are installed, care must be taken to avoid hum pickup, cross-talk, and losses in frequency response and level. High impedance circuits are very susceptible to hum pickup, and when long lines are used with high impedance microphones, with the exception of the crystal type, loss of high frequency response results. When low impedance microphone circuits are used, there is very little frequency discrimination or loss of level in cabling. These facts should be kept in mind when designing any system in which the microphone circuits must be run a considerable distance.

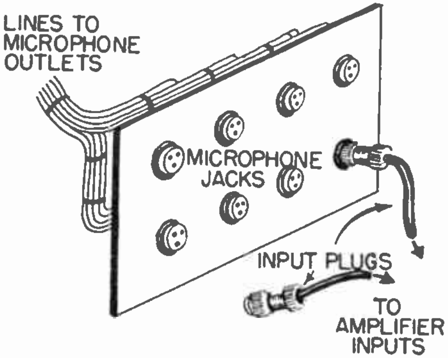

Fig. 48 A patch board to permit the selection of permanently installed microphone lines.

The cables used with high impedance microphones usually consist of a single conductor with an overall shield and rubber covering. The shield acts as one of the conductors in the microphone circuit. The shield is grounded and is connected to the microphone case and microphone stand.

Two or three-wire shielded cable is often used with microphones.

When two-wire shielded cable is used, the shield is connected to ground at the amplifier, and to the microphone case and stand at its other end. The shield does not act as one of the microphone circuit conductors, and, therefore, the likelihood of hum pickup with two-wire cable is less than with single wire shield cable.

Where microphone or other low level circuits are carried for long distances in flexible cables, three-wire shielded cable is most effective. Two of the wires serve in the microphone circuit; the third is used as a ground lead. The shield is connected to ground at the amplifier end of the cable only. The microphone case is grounded through the third conductor.

When microphone cables are installed permanently in floors or walls, lead covered twisted or parallel pair may be used. The capacitance of lead covered cable is quite high, and, therefore, it can only be installed in short lengths when high impedance ribbon or dynamic microphones are used. The capacitance of the cable impairs the high frequency of these microphones. Since crystal microphones are not affected by capacity, longer lengths of lead covered cable may be used with them.

Permanently installed microphone cables can be connected to a patch board at the amplifier so that only those cables in use need be connected to the amplifier. (See Fig. 48.)

47. Microphone Break-In.—Some installations require facilities for a microphone break-in. A typical example of such an installation is one used to reproduce recorded music, but which is occasionally used for paging purposes. A suitable switch connected as shown in Fig. 49 enables convenient microphone break-in. When the switch is pushed, the volume from the phonograph is reduced and the microphone channel is opened. With this circuit, a resistance equal to the impedance of the microphone is connected across the microphone input when it is not in use.

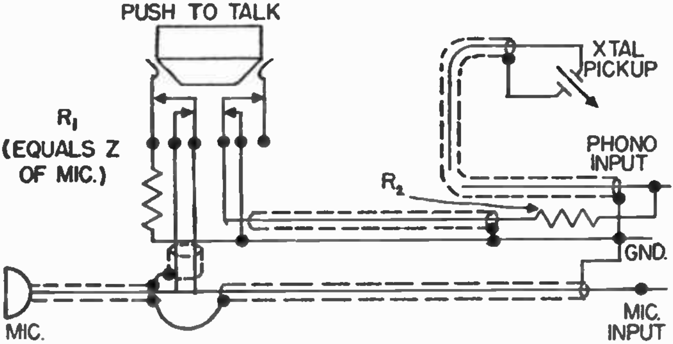

Fig. 49 Circuit diagram of a switching system to provide microphone break-in for a system used to play records.

48. Amplifier Installation.—When installing an amplifier, care should be taken to be sure that it will receive proper ventilation, otherwise, components may be damaged by excessive heat.

When an amplifier must be located where vibration may cause microphonic noises, it should be mounted on shock absorbing mountings. Lord mountings are most suitable. The mountings are available in various sizes based on the number of pounds the mounting will support while operating normally. To determine the size of the mountings required for an amplifier, the corners of the amplifier should be weighed separately. This is necessary because a number of the heavy components are usually located near one end of the amplifier chassis with the result that the weights at the different corners vary. When the exact weights have been determined, mountings of the proper sizes can be chosen. When an amplifier is mounted in this fashion, it should be grounded through a length of heavy braid.

The amplifier should be suitably fused. If the amplifier is not equipped with fuses, a fused power receptacle should be provided. To protect the amplifier components, a 500 ma. fuse can be connected between the center tap of the high voltage winding of the power transformer and ground, as shown in Fig. 50.

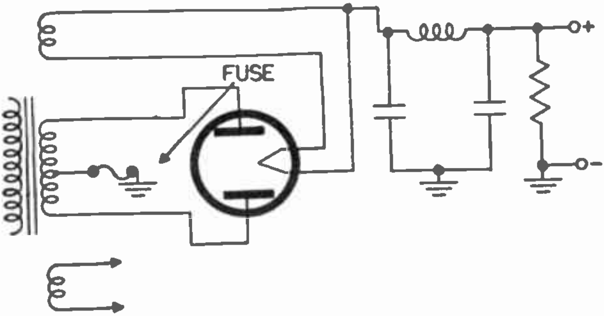

Fig. 50 Location of fuse in power supply.

49. **Speaker Installation.**—When the loud-speakers for a system are installed, the problems of impedance matching and power distribution must be solved. If the speakers are not properly matched, considerable loss in output will result. When a system uses more than one speaker, it is often necessary to have each speaker in the system dissipate a different amount of power.

Amplifier output transformers are equipped with a number of taps. By using a line transformer located at each speaker, and by selecting suitable impedance taps on the line transformer primaries and the output transformer secondary, the power can be distributed as desired. The distribution of power will not be exactly as required, but it will be close enough for all practical purposes.

It is first necessary to determine the power which is to be fed to the various speakers. In order to facilitate the selection of the taps, a chart should be made up showing the various outputs from the amplifier to be used for all of the possible combinations of taps.

The charts of Fig. 51 are for 15, 25, and 50 watt amplifiers.

A chart for a specific amplifier and pair of transformers may be made by using the following simple formula:

$$\frac{ZO}{ZL} \times \text{Rated Amplifier Power} = \text{Power at Speaker}$$

ZO = Impedance Rating of Amplifier Transformer Tap
ZL = Impedance Rating of Line Transformer Tap

The following is an illustration of the procedure which is followed to fill in the chart. Assume that we have an amplifier whose rated output is 100 watts. The taps on the secondary of the output transformers are 4, 8, 15, 30, 250, and 300 ohms. The taps on the line transformer are 500, 750, 1000, 1,500, and 2,000 (see Fig. 52). Actual transformers usually have more taps; however these will serve to illustrate. Applying the formula:

$$\frac{ZO}{ZL} \times \text{Rated Amplifier Power} = \text{Power at Speaker}$$

we have:

$$\frac{4}{500} \times 100 = P$$
$$100 \div 125 = P$$
$$0.8 = P$$

Proceeding to the next set of taps: that is, 8 ohms on the power transformer and 500 ohms on the line transformer, and applying the formula, we find that the power transferred to the speaker will be 1.6 watts. This procedure is continued until the chart is completed.

An example will serve to illustrate the procedure which should be followed from this point. Assume that an installation is to use three speakers. These speakers are to absorb 12, 4, and 3 watts respectively. The amplifier used with the system has a rated output of 25 watts, therefore, the chart for a 25 watt amplifier (see Fig. 51) should be used. The next step is to locate, under the various amplifier transformer taps, a tap which can be combined with three different line transformer taps and give the desired power distribution. Under the 250-ohm amplifier tap, we find 12.5, 4.16 and 3.16 watts. The line transformer taps which are to be used are 500, 1500 and 2000 ohms, as shown in the chart.

It is next necessary to determine the reciprocals of the line transformer impedances selected. The table in Fig. 53 shows reciprocals for typical line transformer primary impedances. The reciprocals of the three line transformer impedances are added, and the total is divided into one. The result is the effective impedance at the amplifier of the three lines running to the line transformers. The result in the example is 310 ohms. Since the amplifier does not have a 300-ohm tap on its output transformer, the next lowest tap is used. This is the 250-ohm tap.

15 WATT AMPLIFIER

Line Trans. Taps	Amplifier Taps 4	8	15	350	385	415	500
375	.16	.23	.60	14.0	x	x	x
500	.12	.24	.45	10.5	11.55	12.5	15.0
750	.08	.16	.30	7.0	7.7	8.25	10.0
1000	.06	.12	.225	5.25	5.77	6.25	7.5
1500	.04	.08	.15	3.5	3.85	4.12	5.0
2000	.03	.06	.112	2.62	2.88	3.12	3.75
3000	.02	.04	.075	1.75	1.92	2.06	2.5
4000	.015	.03	.056	1.31	1.44	1.56	1.87
6000	.01	.02	.037	.875	.96	1.03	1.25

25 WATT AMPLIFIER

Line Trans. Taps	Amplifier Taps 4	8	15	170	190	250	350	385	415	500
375	.266	.533	1.00	11.33	12.66	16.6	23.33	x	x	x
500	.200	.400	.75	8.5	9.5	12.5	17.50	19.25	20.75	25.0
750	.133	.266	.50	5.66	6.33	8.33	11.66	12.83	13.83	16.6
1000	.100	.200	.375	4.25	4.75	6.25	8.75	9.62	10.37	12.5
1500	.066	.133	.25	2.83	3.16	4.16	5.83	6.41	6.91	8.3
2000	.050	.100	.185	2.12	2.37	3.12	4.37	4.81	5.18	6.25
3000	.033	.066	.125	1.41	1.58	2.08	2.91	3.20	3.45	4.16
4000	.025	.050	.093	1.06	1.18	1.56	2.18	2.40	2.69	3.12
6000	.016	.032	.062	.70	.79	1.04	1.45	1.60	1.72	2.08

50 WATT AMPLIFIER

Line Trans. Taps	Amplifier Taps 4	8	15	170	190	250	350	385	415	500
375	.533	1.06	2.0	22.66	25.3	33.3	46.66	x	x	x
500	.40	.80	1.5	17.0	19.0	25.0	35.0	38.5	41.5	50.0
750	.266	.53	1.0	11.33	12.65	16.6	23.33	25.66	27.66	33.3
1000	.20	.40	.75	8.5	9.5	12.5	17.5	19.25	20.75	25.0
1500	.133	.266	.50	5.66	6.32	8.3	11.66	12.83	13.83	16.65
2000	.10	.20	.375	4.25	4.75	6.25	8.75	9.62	10.37	12.5
3000	.066	.133	.25	2.83	3.16	4.16	5.83	6.41	6.91	8.32
4000	.05	.10	.187	2.12	2.37	3.12	4.37	4.81	5.18	6.25
6000	.033	.066	.125	1.41	1.58	2.08	2.91	3.20	3.45	4.16

Fig. 51 Charts giving power transfer obtained with different output and line transformer taps.

A number of other impedances are available on an output transformer by using two intermediate taps rather than the common lead and one tap. Fig. 54 shows the impedances which can be obtained by using two taps.

The impedances of the taps shown in the chart are those which are commonly encountered on output transformers. Referring to this chart, notice that by using the 30-ohm and the 500-ohm tap on the output transformer, we can secure an impedance of 285 ohms, which is quite a bit closer to the 310 ohms necessary to secure an exact match in the example just described.

Fig. 55 shows the circuit which results when the three speakers and the amplifier used in the example are wired together. A check should always be made to make sure that the output transformer will handle the required power when the selected taps are used.

Speaker Power in Watts using 100 Watt Amplifier

Line Taps	4	8	15	30	250	300
500	0.80	1.60	3.00			
750	0.53	1.07				
1000						
1500						
2000						

Fig. 52 Calculating a chart for use with a 100-watt amplifier (See Text).

When a group of speakers are used, and the power must be distributed equally between each of them, the following procedures may be used. Assume that we have a 50-watt amplifier and wish to distribute its output equally to three speakers. Referring to the chart for a 50-watt amplifier in Fig. 51, we find that by using the 250-ohm tap on the amplifier with the 750-ohm tap on a line transformer, 16.66 watts, or 1/3 of the output of a 50-watt amplifier will be transferred to the speaker. The speakers may then be connected, using the 750-ohm tap at each line transformer and connecting all the speaker lines to the 250-ohm tap on the amplifier, as shown in Fig. 56.

If speakers are located close together, and the voice coils are of equal impedance and power handling capacity, they may be connected in series or parallel, as shown in Fig. 57. Under these conditions, each speaker will absorb the same amount of power. In order to determine the resultant impedance when two or more speakers are connected in parallel, the following formula is used:

Line Trans. Tap	Reciprocal	Line Trans. Tap	Reciprocal
375	.002666	3000	.000333
500	.002000	4000	.000250
750	.001333	5000	.000200
1000	.001000	6000	.000166
1500	.000666	7500	.000133
2000	.000500	8000	.000125
2500	.000400	10000	.000100

Fig. 53 Reciprocals of impedances of typical output transformer taps.

Resultant Impedance	Tap 1	Tap 2	Resultant Impedance	Tap 1	Tap 2
0.64	8	4	85.0	125	4
1.00	15	8	106.0	200	30
3.00	15	4	150.0	250	15
4.80	60	30	170.0	250	8
12.10	125	60	190.0	250	4
21.00	250	125	215.0	500	60
24.00	60	8	285.0	500	30
32.50	60	4	350.0	500	15
43.66	500	250	385.0	500	8
71.00	125	8	415.0	500	4

Fig. 54 Output impedances available if two taps are used instead of common and one tap.

$$ZT = \frac{1}{\frac{1}{Z1} + \frac{1}{Z2} + \frac{1}{Z3}}$$

ZT = The total impedance
Z1, Z2, and Z3 = The impedance of the speaker voice coils.

This formula can be used with any number of speakers.

If speakers are connected in series, it is only necessary to add their individual impedances to find the total impedance. When the total impedance is found, it may be matched to the amplifier by selecting the proper tap on the output transformer or by using a line transformer if a long line is used.

50. Speaker Lines.—The wire used in speaker lines must be of sufficient size to keep line losses within tolerable limits.

When speaker line impedance is under 60 ohms, short lines only should be used. When a line impedance of 60 ohms or more is used, lines may be run for considerable distance, providing wire of sufficient size is used. The curves of Fig. 58 give recommended wire sizes for lines of various impedances and lengths.

51. Speaker Switching.—In many installations, it is necessary to have facilities for switching speakers in and out of the system. When a large number of speakers are used, and one or more speakers must be turned off, a resistance should be substituted in the circuit in place of the speaker or speakers turned off in order to maintain constant load impedance. Fig. 59 shows a circuit which can be used to accomplish this. The substitute resistor should have a resistance equal to the impedance of the speaker or the group of speakers being disconnected from the circuit.

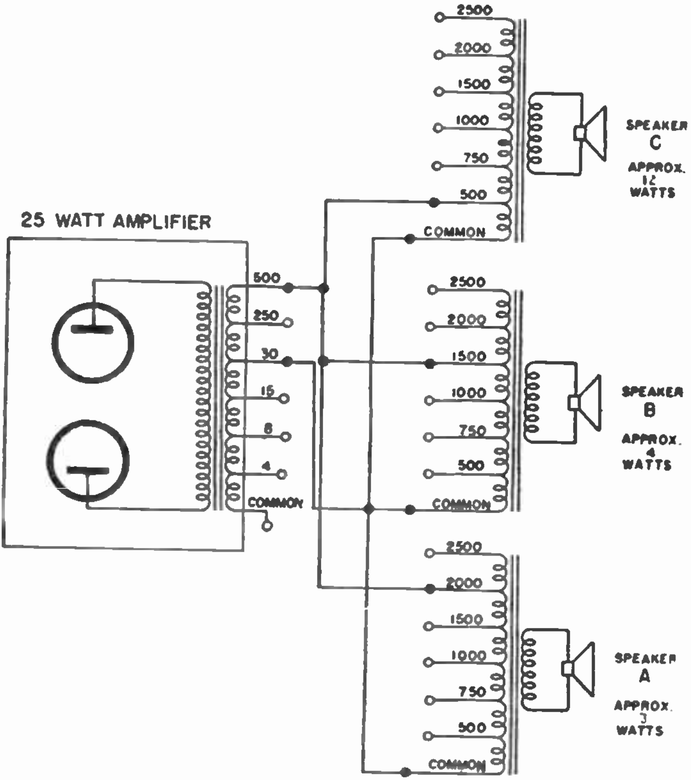

Fig. 55 Circuit diagram of output and line transformer connections to obtain power distribution as described in text.

52. Speaker Phasing.—When a group of speakers are mounted at one point or near together so that they cover the same area, it is necessary that they be correctly phased. If the speakers are not phased properly, the sound waves from the improperly phased speakers will tend to cancel out, reducing the effective output of the system.

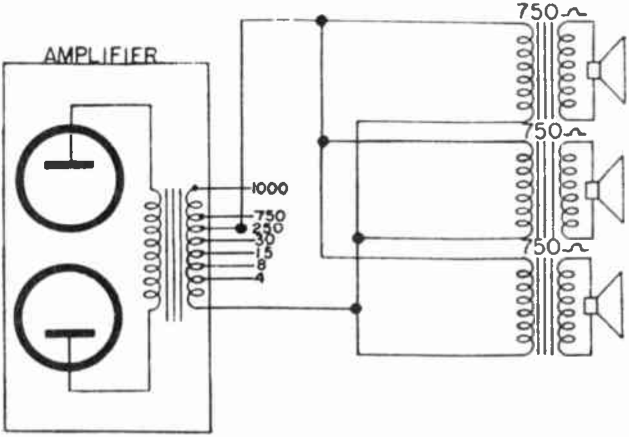

Fig. 56 Connection of three speakers to obtain equal power distribution using line transformers.

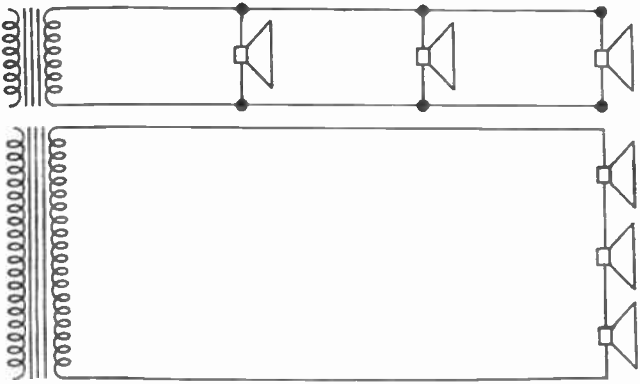

Fig. 57 Connection of speaker voice coils to obtain equal power distribution.

There are a number of ways to check the phasing of speakers. Two speakers may be connected to an amplifier in the same manner. They will be connected when installed and placed close together facing each other. A low frequency signal from an audio geenrator or a record should be fed through the amplifier. By listening to the speakers, it is possible to determine whether or not the low frequencies are being canceled. If the low frequencies are absent when the speakers are facing each other, then the phasing is correct if the speakers are to be mounted so that they face in the same direction. When the test is made, if the low frequencies can be heard, then the low frequencies are not being canceled, and the phasing is correct if the speakers are to be mounted facing away from each other. If the phasing is incorrect in either of the two cases just described, all that is necessary is that the connections to one of the voice coils be reversed.

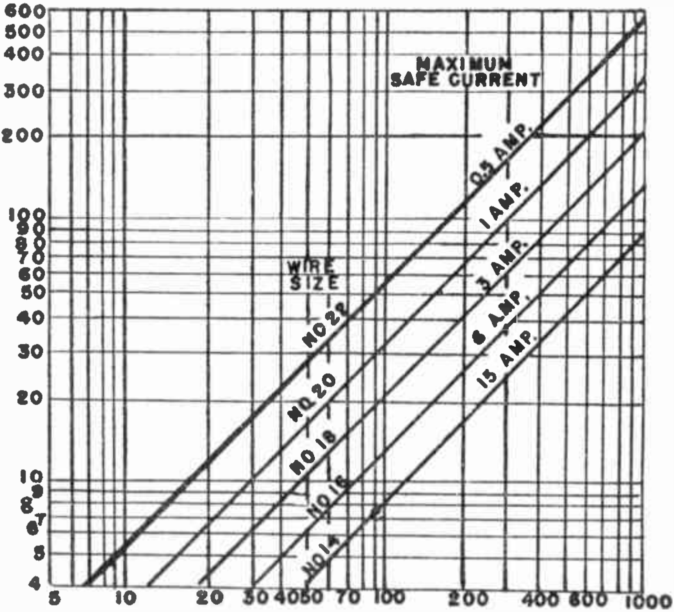

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Fig. 58 Curves giving wire size for speaker lines. Loss will not exceed 0.5 db if curves are used.

The phasing of speakers may also be checked by using the circuit shown in Fig. 60. The apparatus consists of a pair of headphones connected to the input of an amplifier through two long cords and a double-pole, double-throw switch. The amplifier is equipped with an output indicator. The sound system whose speakers are to be checked for correct phasing should be turned on and a constant tone fed into its input. The double-pole, double-throw switch must be marked to show "in-phase" and "out-of-phase." This may be done by holding both phones in front of one speaker and noting the position of the switch which gives the greatest indication on the output meter. This position should be marked, "in-phase," and the other position

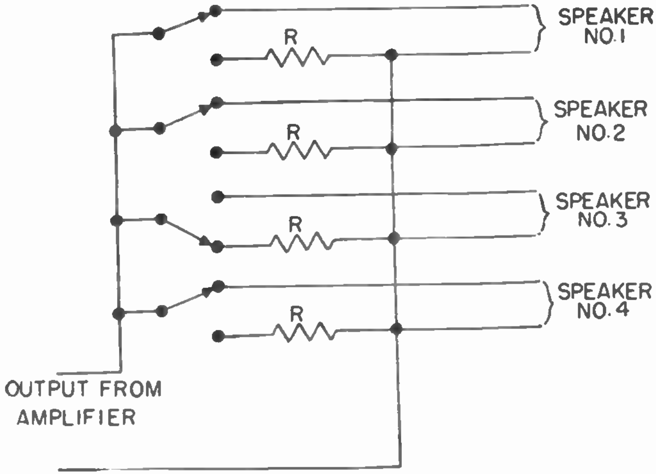


Fig. 59 Circuit used to permit the disconnection of speakers without changing amplifier load conditions. R should be equal to the impedance of the speaker or group of speakers being disconnected.

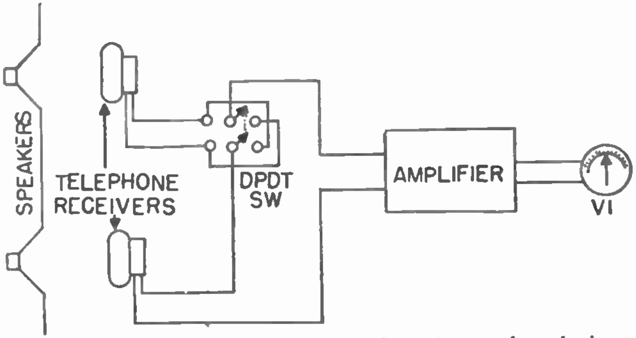


Fig. 60 Setup of equipment used to determine speaker phasing.

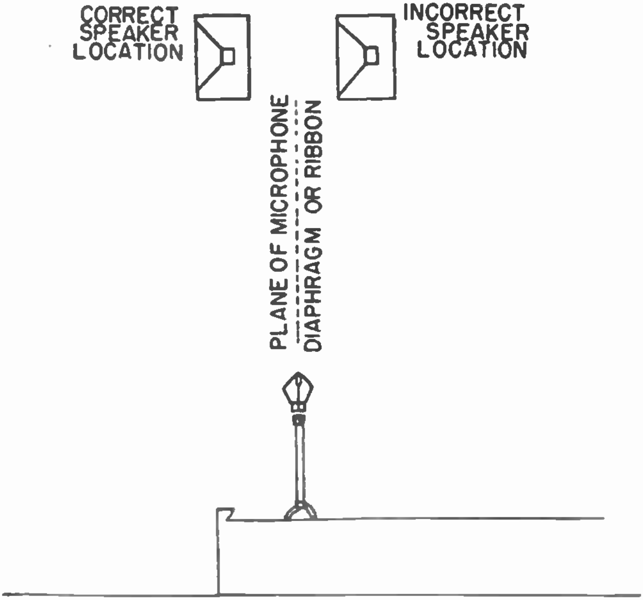


Fig. 61 Right and wrong location of a loud-speaker with respect to a microphone.

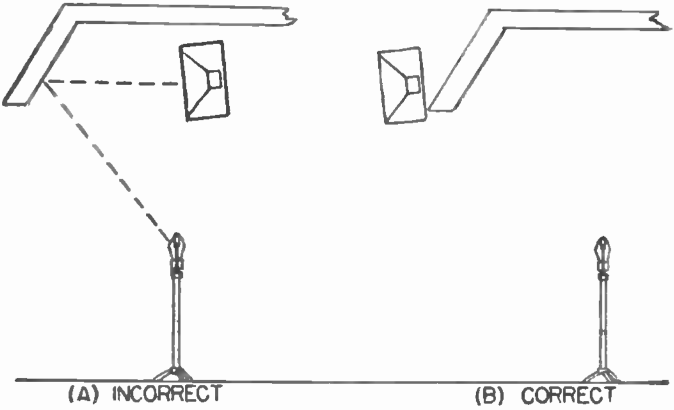


Fig. 62 Correct and incorrect placement of loud-speaker in relation to microphone and reflecting surface.

should be marked, "out-of-phase." The equipment may now be used to check the phasing of two speakers. One phone is held in front of each speaker. If the greatest output is indicated when the switch is in the "in-phase" position, then the speakers are phased properly.

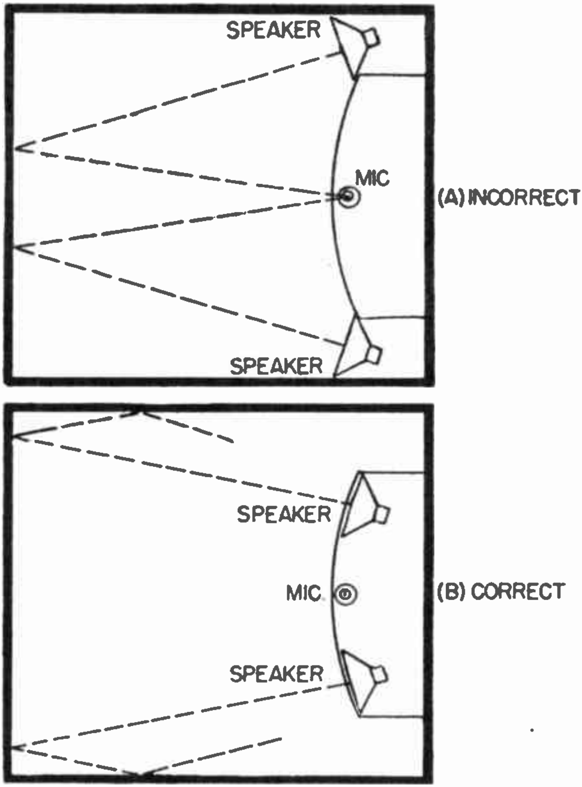
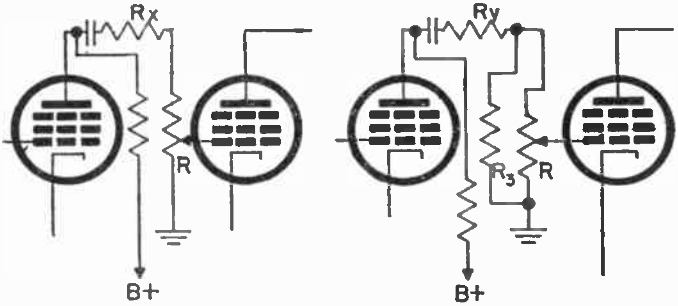


Fig. 63 Correct and incorrect loudspeaker placement to eliminate feedback.

53. Feed-Back.—Careful attention must be given to the factors which create feedback, otherwise considerable trouble will be experienced. There are two forms of feedback. They are acoustic feedback, which is caused by coupling between the speakers and the microphones, and electrical feedback, due to capacitive couplings between the output circuits and the input circuits.

Electrical feedback can be avoided by keeping the input and output wiring well separated.



Gain Reduction	Value of R_x	Gain Reduction	Values	
			R_y	R_3
3 db	41 % of R	15 db	150 % of R	50 % of R
6 db	100 % of R	20 db	150 % of R	20 % of R
10 db	216 % of R			
15 db	462 % of R	30 db	280 % of R	10 % of R

Fig. 64 Circuit and resistor factors to limit the gain of an amplifier as described in text.

Acoustic feedback is often difficult to eliminate, and in severe cases, may limit the usable output of a system. Acoustic feedback manifests itself as a continuous tone radiated by the speakers of a sound system. Acoustic feedback can be avoided by careful attention to the location of speakers and microphones. There are a few general principles of microphone and speaker location which, if followed, give reasonable assurance that little or no trouble will be experienced with feedback other than feedback due to direct reflection from the back and sides of a room.

A microphone should never be located in front of a speaker. If the speaker or speakers used in a system are located in front of the microphone, as shown in Fig. 61, the possibilities of feedback will be greatly reduced.

Speakers should not be mounted close to reflecting surfaces. When there is a flat surface close to and in front of the speakers, sound will usually be reflected by the surface to the microphones. Fig. 62 (a) shows an example of how an overhang from a ceiling can cause feedback. In Fig. 62 (b), the speaker has been relocated, and the feedback is eliminated.

Fig. 63 (a) shows how the arrangement of two speakers in a room can cause feedback, and Fig. 63 (b) shows how the feedback may be corrected by changing the direction in which the speakers are pointing, so that the sound strikes the walls at an angle.

After an installation has been made and trouble is experienced with feedback, the positions of the speakers should be changed experimentally until the position which gives the greatest reduction in feedback is found.

The following procedure is often helpful when attempting to locate a surface which is reflecting sound back to the microphone. Stand at the microphone location. The direction from which the reflection is coming may be observed by cupping the hands around the ears and moving the head until the direction of the loudest reflected sound is found. The hands cupped over the ears make the ears considerably more directional. When the source of the reflection has been located, speaker and microphone positions may be changed in order to eliminate feedback.

Sound reflections may also be eliminated by covering the reflecting surfaces with a sound-absorbing material. There are a number of materials on the market especially designed for this purpose. Draperies and floor carpeting tend to improve the acoustic conditions in a room, and will usually help to eliminate feedback when it occurs.

If a system is installed in a location and is intended for use in a room filled with people, feedback may occur when the room is empty, but may not occur when the room is full of people.

Cardioid and other directional microphones are often very effective in eliminating feedback. The side of the microphone which is not sensitive to sound should be pointed in the direction from which reflected sound is coming.

54. Gain Control Adjustment.—It is often desirable to modify the gain control of an amplifier so that the gain cannot be increased beyond the point which gives maximum output within the limits of permissible distortion. There are also instances when it is advisable to limit the output of an amplifier to the maximum value that will ever be needed for normal operation of the system.

In order to accomplish this, the gain control of an amplifier may be modified as shown in Fig. 64. In (a), a resistor, RX, is added in series with the gain control, R. The chart gives values of RX in terms of a percentage of R and the resultant reduction in maximum gain for each value of RX. Circuit A and Chart A are used for gain reductions up to 15 db. Circuit B and Chart B are used for gain reductions greater than 15 db.

The following is an example of how circuit A is used. Assume that a 3 db reduction in the gain of an amplifier is required. The volume control, R, has a total resistance of 100,000 ohms. Referring to the chart, a 3 db reduction will result if a resistance 41% of the value of R is connected in series with R. 41% of 100,000 ohms is 41,000 ohms. RX should, therefore, be 41,000 ohms. The same procedure is followed with circuit B, except that two resistors, RS and RX, are used.

Section 12

SOUND RECORDING

1. Sound recording techniques make possible the creation of a permanent record of sounds such as music or the human voice for later reproduction.

To date, a number of ways have been devised to make sound recordings. Recording has found a wide variety of uses in our everyday life. The best known application of recording is the popular disc record. Disc recording plays an important part in modern broadcasting, enabling the broadcaster to record and reproduce programs across the country at the most favorable times of the day. Recordings are also made by broadcasters for reference purposes.

Another form of recording, commonly referred to as "sound-on-film" recording, is used with motion pictures. It provides a method whereby visual impressions and their accompanying sound can be recorded together on a single sensitized film strip.

Other forms of recording which are finding broad use are film embossing, wire, and magnetized tape methods.

2. **Disc Records.**—Disc records can be classified into two types. These are pressed records: this category includes popular entertainment records and electrical transcriptions as used by the broadcasting companies; and instantaneous recordings or "acetates," as they are sometimes called.

3. **Instantaneous Recordings.**—These recordings are made and used by radio broadcasting stations for delayed broadcasts, reference, program study, etc. Instantaneous recordings can be made at home or in studios which specialize in their production. They are helpful in voice training, auditioning, the creation of sound effects, and in many other ways. As previously mentioned, instantaneous recordings are often referred to as "acetates." This name, which refers to the surface of the disc on which the recording is made, is not entirely accurate, since a number of other materials are used.

Instantaneous recordings are made on specially prepared discs. These discs consist of a ridged base coated with a lacquer-like varnish. The base materials used are paper, glass, fiber, and aluminum. Both the base and the coating must have carefully controlled characteristics if they are to perform properly.

When a recording is made, a thin strip or thread is cut from the coating of the disc leaving a long spiral groove on the face of the disc. The groove is cut by a stylus which is attached to a recording head or cutter. The output of an audio amplifier is connected to the head, and as the output of the amplifier varies in accordance with the sound to be recorded, the stylus is moved from side to side. The long groove cut on the face of the disc undulates from side to side. These undulations constitute the recorded sound.

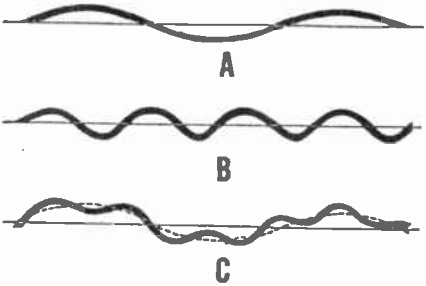


Fig. 1. The appearance of the waves in the surface of the recording blank.

When a continuous tone of one frequency is impressed on the cutting head, the groove cut on the disc is similar to that shown in Fig. 1 (a). In Fig. 1 (b), a note one pitch higher than that of Fig. 1 (a) is shown. When the notes of (a) and (b) are recorded simultaneously, the undulations of the groove appear as shown in Fig. 1 (c).

4. **Equipment.**—Recordings are made with equipment designed specifically for the purpose. A single recording unit consists of a microphone, an amplifier, a cutting head and arm, a feed mechanism, a turntable, and a drive motor.

RECORDING AMPLIFIERS

5. The creation of a record from which a faithful reproduction of the original sound can be obtained requires the use of a carefully designed amplifier. The design and construction of a recording amplifier is more difficult than that for one to be used in public address work or for the reproduction of radio broadcasts. To secure optimum results, the frequency response of the recording amplifier should be flat within 1.5 to 2 db over the entire audible range. The power handling capacity of the amplifier should be in the neighborhood of 15 to 20 watts. In most applications, a recording amplifier is operated at an average level of 1/10 to 1 watt. Even at power levels as low as this, instantaneous peak amplitudes of 10 to

15 watts are encountered, and if the amplifier cannot handle them, noticeable distortion will result.

6. **Requirements.**—The specific use to which a recording amplifier is to be put governs its requirements. Where it is intended to record for reference purposes only, a frequency range of 150 to 2,000 cycles per second is adequate. Fig. 2 is a graph illustrating the response characteristics of a typical amplifier for use in reference recording.

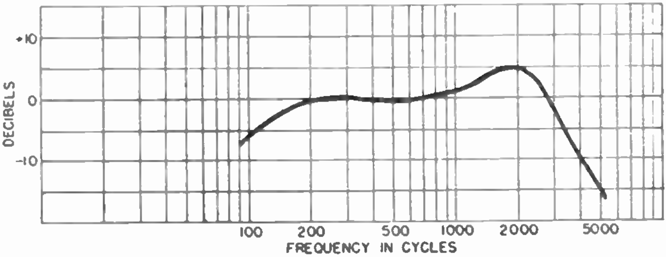


Fig. 2 Response curve of an amplifier system for use in reference recording.

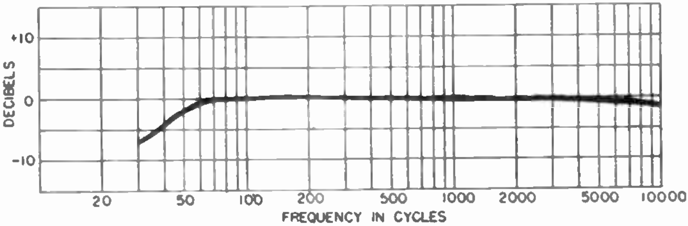


Fig. 3 Response curve of an amplifier suitable for the reproduction of recordings when good fidelity is desired.

The frequency response requirements of an amplifier designed for the purpose of recording music are subject to a number of factors. The most important of these is the quality of the equipment which is to be used to reproduce the recorded sound. A response range of 60 to 10,000 cycles per second exceeds the requirements for many applications and is acceptable where critical reproduction is desired. Fig. 3 is a graph illustrating the frequency response of an amplifier designed for critical reproduction.

Response variations up to 3 db (±1.5 db) are acceptable at any point in the frequency range. Deviations greater than this cannot be tolerated by critical listeners.

The total distortion contained in the output of the recording amplifier must be kept as low as possible. Total distortion in the order of two to three per cent is acceptable.

7. **Pre-Amplifiers.**—In almost all applications, the preliminary amplifier required to raise the level of the microphone

output to a point high enough for application to the power amplifier may be incorporated on the chassis with the power amplifier. The pre-amplifier consists of one, two or more voltage amplifiers. Gain of the pre-amplifier varies with the desire of the user. Fig. 4 shows a typical pre-amplifier circuit for use with a microphone or other sound source. This is a single channel pre-amplifier.

In a few applications where elaborate set-ups are used, it is often desirable to locate the microphones or other pickups and the gain controls away from the rest of the recording apparatus. In installations of this type, the pre-amplifiers are located near the microphones, and a 500-ohm line is run to the power amplifier. Fig. 5 shows a complete pre-amplifier and power amplifier for use in this type of installation.

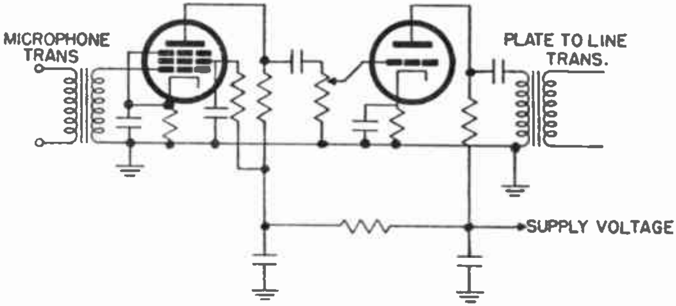


Fig. 4 Circuit diagram of a typical pre-amplifier suitable for use with a low impedance microphone.

8. **Multi-Channel Input.**—Where more than one microphone or other input source is used, a suitable mixing circuit is necessary. Fig. 6 shows the circuit of a typical four-channel mixing pre-amplifier. Individual gain controls are provided for each sound source. The input impedance of the channels depend upon the impedances of the input sources used.

9. **Gain Control.**—A properly designed amplifier must be so equipped that its gain can be adjusted over a wide range. As previously mentioned, this control of the amplifier's gain can be accomplished in the pre-amplifier through the use of a high resistance potentiometer. This type of control is simple and economical. Fig. 4 shows the schematic diagram of a typical pre-amplifier with variable potentiometer gain control.

The gain of an amplifier can be controlled by inserting a variable "T" pad network in the 500-ohm line running between a remote pre-amplifier and a power amplifier. The "T" pads are usually calibrated in db and enable the operator to make accurate settings of the operating level. Fig. 7 shows the circuit diagram of a "T" pad suitable for use in the 500-ohm line between pre-amplifier and the power amplifier.

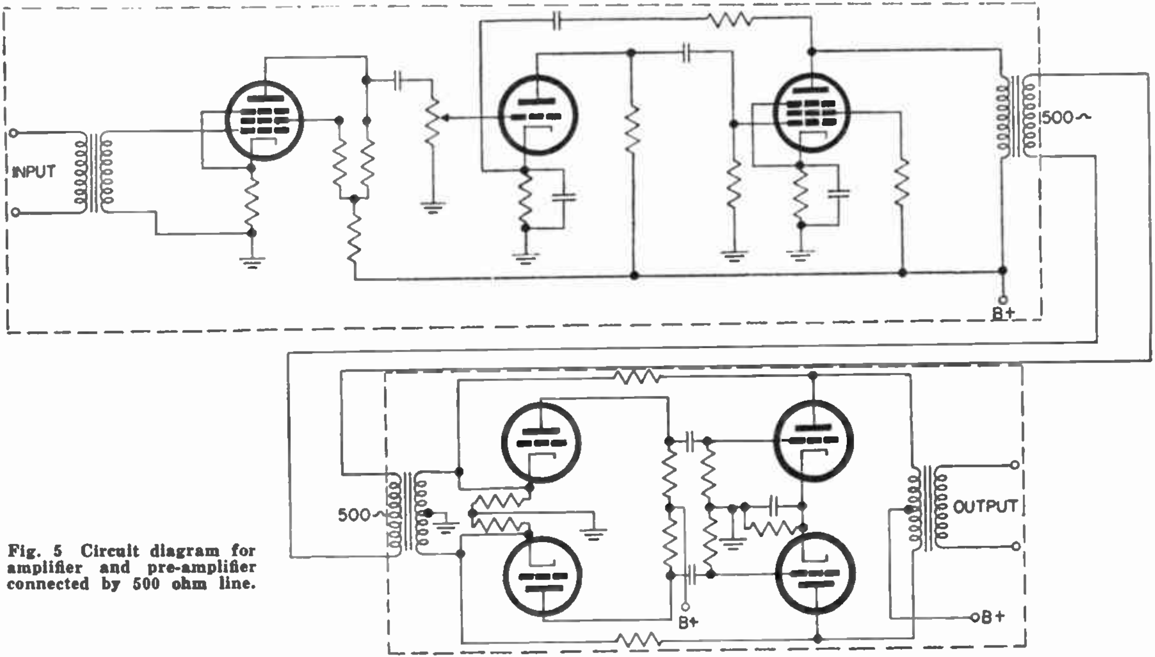


Fig. 5 Circuit diagram for amplifier and pre-amplifier connected by 500 ohm line.

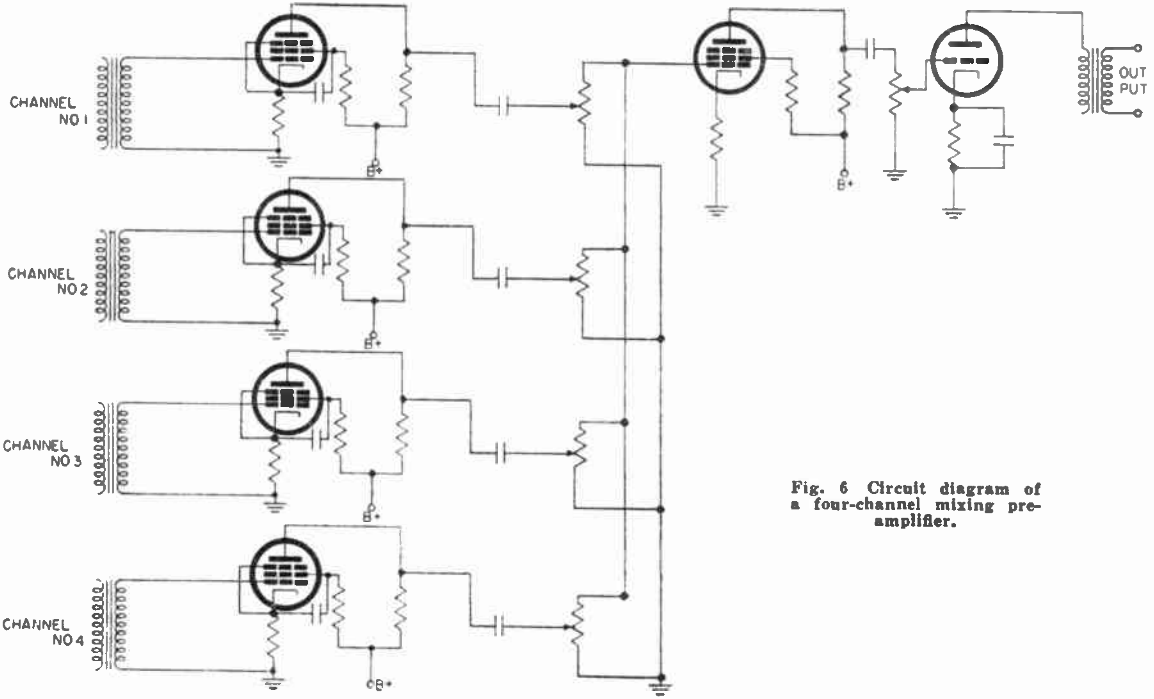


Fig. 6 Circuit diagram of a four-channel mixing pre-amplifier.

10. Tone Control.—As a rule, recording amplifiers are not equipped with continuously variable tone controls since it is desired to reproduce the full range which the amplifier will pass. Should the sound pickup unit or the reproducing equipment require a particular amplifier response characteristic. the proper facilities are usually built in the amplifier. Recording equipment is usually designed to give characteristics which meet standard specifications. These standard specifications are discussed in detail later in this chapter. To secure consistent results, the amplifier should have a fixed predetermined frequency response.

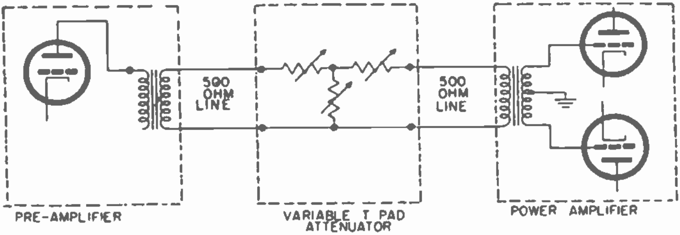


Fig. 7 Variable "T" pad used between pre-amplifier and power amplifier.

11. Power Amplifiers.—As previously stated, the response characteristics and distortion content of the recording amplifier output is critical. To achieve optimum results, the power amplifier must be designed for a broad flat response curve and low distortion content. Because of their low harmonic distortion content and power handling capacity, push-pull circuits give the most satisfactory results and are used almost universally. For many uses, the power handling capacity of the power amplifier does not have to exceed 15 watts, although in some applications, an amplifier capable of handling as much as 50 watts is necessary. Because of their low distortion and constant output impedance independent of the load, triode tubes operated in Class A are particularly suitable. The 2A3 is a typical power triode. Two of these tubes operated in a push-pull circuit as shown in Fig. 8 will deliver 15 watts of audio power with approximately 2% total harmonic distortion. The frequency response of this amplifier is limited by the quality of the components used. The most important components are the input and output transformers. They should be of the highest quality obtainable if optimum results are desired. Beam power tubes such as the 6V6, 6L6, and 807 are suitable for use in recording amplifiers, provided that some form of stabilizing feedback is used. The output impedance of beam power tubes changes with frequency and load. The feedback counteracts this effect.

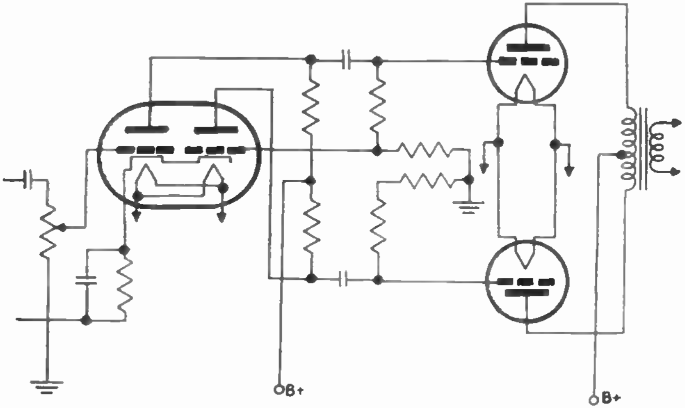


Fig. 8 Circuit diagram of a typical circuit using triode power amplifier tubes in push-pull.

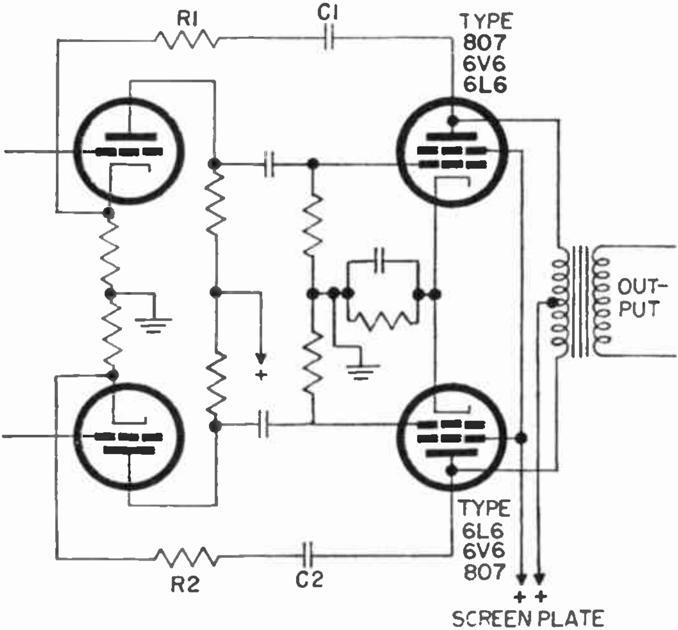


Fig. 9 Circuit diagram of power amplifier using beam tubes and utilizing degenerative feedback.

12. Feedback.—Degenerative feedback gives an appreciable improvement in the stability and distortion content of an amplifier. This is particularly important when beam power tubes are used. Variations in output impedance with changes in load are greatly decreased when degeneration is used in a power amplifier using beam power tubes. Fig. 9 shows a beam power amplifier utilizing degenerative feedback. Feedback may also be used in pre-amplifier stages to flatten their response and reduce distortion.

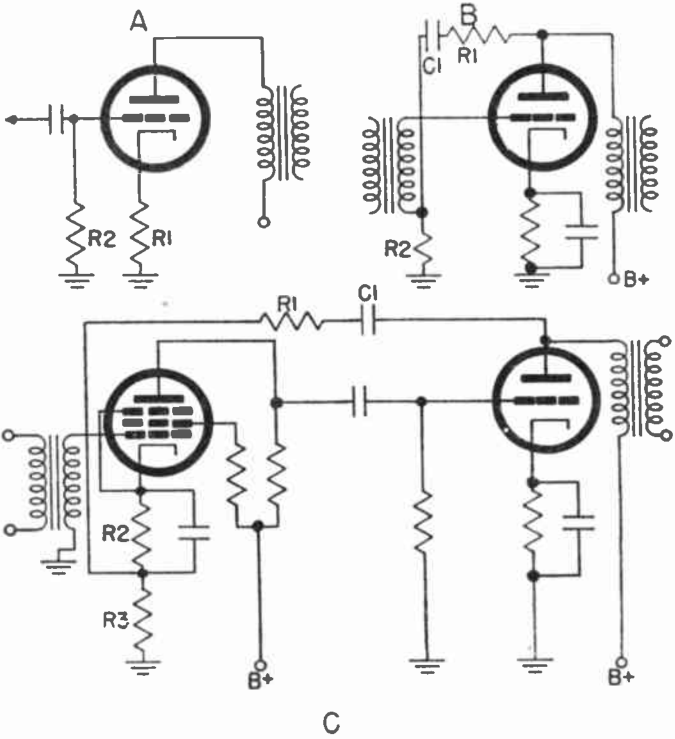


Fig. 10 Three methods of obtaining negative feedback.

Several methods are available which can be used to obtain degenerative feedback. In Fig. 10 (a), the cathode resistor R1 is not by-passed. As the grid voltage increases, the plate current increases, and the voltage drop across R1 increases, since it is in the plate circuit. The increased voltage across

R1 is applied to the grid through R2 in polarity opposite that of the signal on the grid. This constitutes degenerative feedback.

In Fig. 10 (b), voltage is fed from the output back to the ground side of the secondary of the input transformer through the resistance capacitance combination R1-C1. As the potential on the grid becomes less negative, the plate current through the tube increases, producing a reduced potential at the top of the output transformer primary. Negative voltage is fed from this point to the ground end of the input transformer secondary where it increases the negative potential on the grid.

Fig. 10 (c) shows a two-stage amplifier using degenerative feedback. This amplifier utilizes the change in phase which takes place when a signal passes through a vacuum tube amplifier. The signal passing from the grid through V1 and then through V2 goes through a phase change of 360° (180° per tube). Signal voltage is fed back from the plate of V2 through the resistance-capacitance combination R1-C1 and is applied to the junction of the cathode resistor R2 and resistor R3 in such a manner that it constitutes negative feedback.

13. **Bass Boost.**—Through the proper choice of components, feedback circuits can be utilized so as to increase an amplifier's gain over a predetermined band of frequencies. Very often the components are chosen so as to give increased amplification of low frequencies in order to correct for losses which take place in components within the circuit.

In Fig. 10 (c) the value of C1 can be reduced below the value required to give equal feedback for all frequencies, blocking the low frequencies. In this way, the amplifier is made to have a higher gain at low frequencies than it has at high frequencies.

14. **Monitoring.**—When recording, it is necessary to monitor the source of sound in order to determine the characteristics of the material as to balance and content. This is usually accomplished by connecting a separate monitoring amplifier across the 500-ohm line running between the pre-amplifier and the power amplifier. This amplifier has its own gain controls and loud-speaker or head phones and is controlled independently of the other recording circuits.

In cases where a 500-ohm line is not available between the pre-amplifier and the power amplifier, separate windings are often provided on the output transformer to which the input of the monitor is connected.

15. **Volume Level Indicators.**—In order to keep a constant check on the volume level of a program of speech or music being recorded, a volume level indicator is included in recording equipment. The volume level indicator usually consists of a high impedance audio voltmeter. Many of these instruments include an adjustable attenuator to permit indication over a wide range of volume levels.

Volume level indicators now in use vary in reference level, impedance across which they are to be used, and in other characteristics. It is thus possible to obtain two different readings across the same line using two types of indicators.

In an effort to overcome this condition, the volume level indicator has been standardized for monitoring circuits. The basis of this standard is the "vu" or volume unit. The reference level for the volume unit has been established as .001 watt at 1,000 cycles in a 600-ohm load.

The volume level indicator can be located in the circuit at any suitable point in the amplifier between the last gain control and the cutting head. The most convenient place is in one of the 500 or 600-ohm lines running between the various components of the recording system. Fig. 11 shows a typical method of installing a volume level indicator.

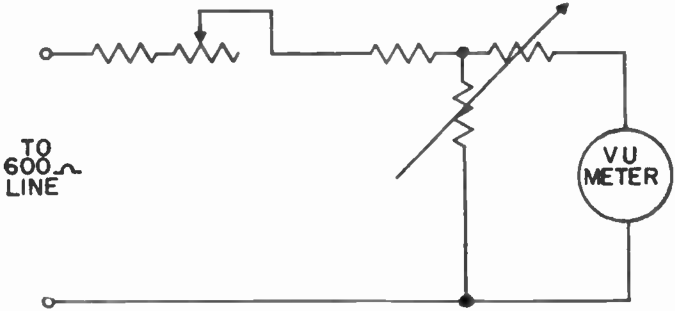


Fig. 11 Method used to connect vu meter to 600 ohm line.

CUTTING HEADS

16. The construction and the electrical characteristics of the various cutting heads available vary greatly. They can be classified into three distinct groups. These are: crystal, magnetic, and dynamic.

Units of varying quality can be obtained in each group. The desires of the user and the use to which the cutter is to be put govern its choice. With systems designed to record the voice for reference purposes only, an inexpensive cutting head with a comparatively narrow frequency range is suitable. Where the highest quality of reproduction is required, a special highly-damped cutting head having a frequency characteristic flat to well beyond 10,000 cycles per second is necessary.

17. **Crystal Cutting Heads.**—The crystal cutter is the most widely used of the three types mentioned above. It is simple in design and construction, has good frequency response characteristics, and low distortion content.

18. **The Piezoelectric Crystal.**—Some crystalline substances possess the ability to produce a charge under certain conditions. When they are stressed mechanically, a charge is produced on their surfaces. If a voltage is applied to the sur-

faces of a crystal with piezoelectric properties, a mechanical deformation of the crystal will take place.

The piezoelectric crystal acts like a generator and converts mechanical motion into an electrical charge. Crystal microphones and phonograph pickups can be thought of as piezoelectric generators. A crystal is also similar to a motor. When a potential is applied to a crystal, it moves. It converts electrical energy into mechanical motion. Crystal headphones and cutting heads are piezoelectric motors.

A piezoelectric crystal as used in microphones and cutting heads is a formation of crystalline Rochelle salt. The Rochelle salt crystal possesses the greatest known piezoelectric property. It is approximately 1000 times as active as a regular quartz crystal.

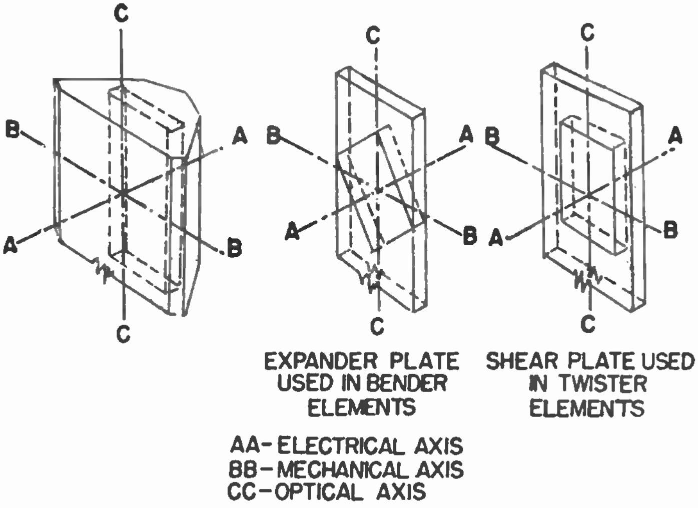


Fig. 12 The two types of crystal plates used to form crystal cutter elements.

19. Crystal Plates.—Rochelle salt crystals are formed in large bars. These bars are cut into slabs or plates for use in the manufacture of crystal elements.

The two commonly used crystal plates are usually referred to as "expander" and "shear" plates as shown in Fig. 12. The crystal is either a shear or expander plate depending upon the way it is cut from the bar.

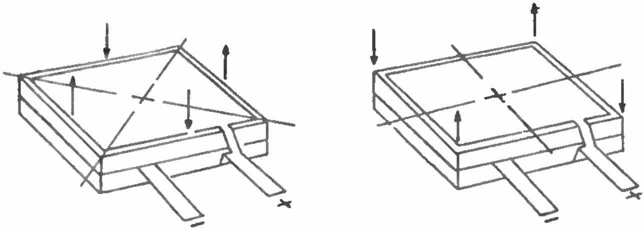
A crystal plate is said to have three axes. They are the electrical (aa), the mechanical (bb) and the optical (cc) axes. An expander plate is cut at a 45° angle to the optical and mechanical axes of a crystal bar. A shear plate is cut with its edges parallel to the mechanical and optical axes of the crystal bar.

When a potential is applied to the two large faces of each plate, mechanical motion is developed at an angle 45° from that of the mechanical and optical axes. Therefore, the expander plate will increase its length and at the same time, decrease its width. If the polarity on the faces of the crystal is changed, the crystal will decrease its length and increase its width.

The same action takes place when a potential is applied to a shear plate, except that expansions and contractions occur along the diagonals of the plate instead of parallel to the edges as in the case of the expander plate.

20. Crystal Elements.—In order to form a crystal element for use in a crystal cutter or other device, a number of crystal plates are cemented together. This makes possible more effective utilization of the properties of the crystal.

An element which consists of a number of expander plates cemented together is referred to as a "bender" element, while an element formed from a number of shear plates is known as a "twister" element. The names, bender and twister, refer to the action which takes place when an electrical potential is applied to the element.



BENDER TWISTER

Fig. 13 Construction of bender and twister crystal elements.

Bender and twister elements are manufactured and sold by the Brush Development Company under the Trade Name, "Bimorph." The multi-plate crystal has a number of important advantages over a crystal employing a single plate. It greatly decreases the undesirable effects of saturation and hysteresis and reduces the effects of temperature on the impedance and sensitivity of the unit. Fig. 13 shows the construction of a bender and a twister crystal element.

21. Crystal Cutter.—The faces of each crystal plate are milled smooth, and foil or graphite electrodes are applied. Leads are connected to the electrodes, and after they have been properly oriented, the plates are bonded together with cement.

The completed crystal element is coated with a special moistureproof material to protect it against deterioration if used under very dry or damp conditions. The crystal element is mounted in a plastic case and held at one end by a metal clamp, as shown in Fig. 14. The other end of the crystal is free, permitting it to move torsionally. A bearing and chuck are mounted on the free end of the crystal. The bearing usually consists of rubber or a similar synthetic material. The chuck usually consists of a light metal such as aluminum. To restrain the crystal from vibrating at more than one mode, it is customary to restrain it slightly along its axes of motion. This is accomplished by cementing a strip of damping material along the length of the element. This strip also gives some damping effect in the other modes and helps to reduce the amplitude of the resonant peak of the crystal. Because the crystal is very stiff, its resonant frequency is normally not in the frequency range to be recorded.

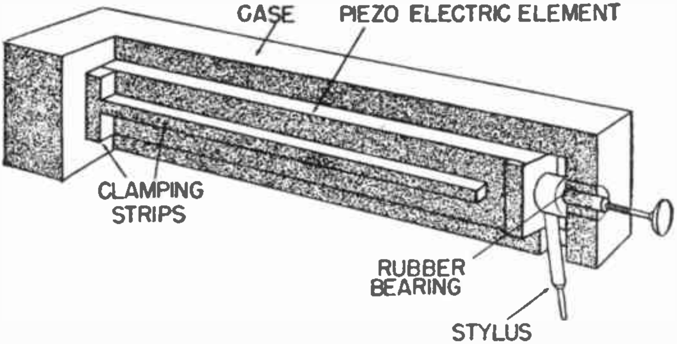


Fig. 14 Cross-sectional view showing the construction of a typical crystal cutting head.

22. Electrical Characteristics.—As a circuit component, a crystal cutting head acts in the same way as does a capacitor and can be considered as such.

Extremes of temperature drastically affect the operation of a crystal cutter. The maximum sensitivity of a crystal is usually at about 75°. As the temperature rises above or falls below 75°, the sensitivity of the crystal falls off slowly. This loss in sensitivity with change in temperature can be minimized by placing a capacitor in series with the cutter. The maximum sensitivity of the cutter is reduced when this is done, but the reduction is not great enough to be prohibitive.

At temperatures in the neighborhood of 130°, Rochelle salt crystals permanently lose their piezoelectric properties. As a rule, temperatures slightly below this, that is, from 110° to 120°, will not injure a crystal cutter.

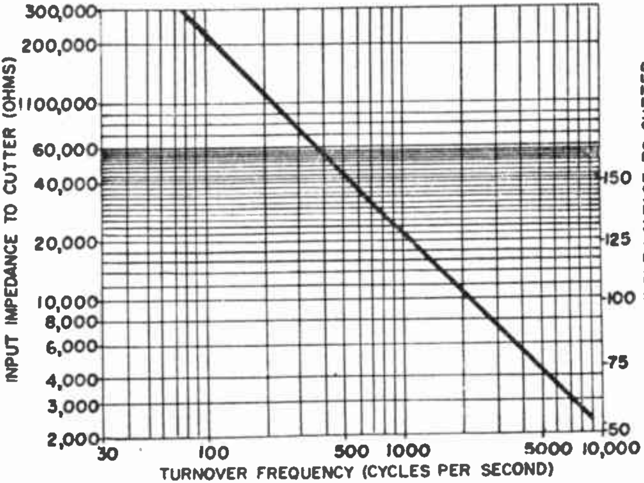


Fig. 15 **The effects of input impedance on the turnover frequency of a crystal cutter.**

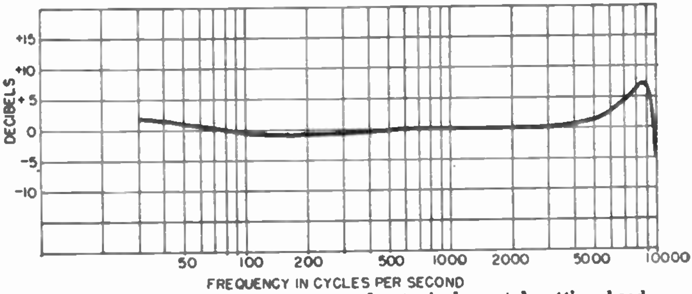


Fig. 16 **Frequency response curve of a typical crystal cutting head.**

A crystal cutter has the advantage that it is quite stiff, and because of this, variations in mechanical load do not greatly affect the cutter's performance. Changes in the mechanical load are due to such things as variations in the hardness of the surface of the recording disc and variations in the depth of the cut.

Since the crystal cutter is effectively identical to a capacitor, its impedance decreases as the frequency increases. It is possible to cut either "constant amplitude" or "constant velocity" recordings (see Par. 46) by varying the impedance of the circuit which couples the cutter to the amplifier.

A typical crystal cutter will cut a constant amplitude recording when the coupling impedance is between 2,000 and 5,000 ohms. When the coupling impedance is raised to 40,000 ohms, the same crystal cutter will cut a constant velocity recording. The turnover frequency (see Par. 48) between constant velocity and constant ampliture can be chosen by varying the coupling impedance as shown in the curve of Fig. 15.

Crystal cutters have excellent frequency response characteristics as shown in the typical curve of Fig. 16.

23. Magnetic Cutters.—The magnetic cutter is a current-operated device. The construction of magnetic cutters varies greatly. Essentially, they consist of a coil and magnet and another magnet to which the cutting needle is attached, as shown in Fig. 17. The movable magnet to which the cutting needle is affixed is damped. This is accomplished in a number of ways depending upon the construction of the particular cutter. The majority of low cost cutters use rubber cushions. Some of the more expensive types are mounted in oil, which gives effective damping.

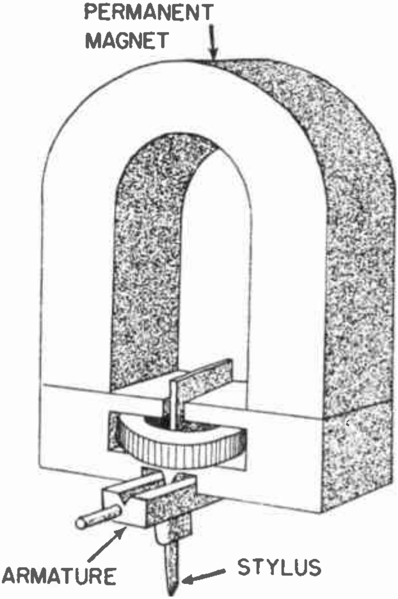


Fig. 17 Construction of a magnetic cutting head.

The coil is connected to the output of the recording amplifier. Current passing through it varies the density of the flux about the fixed magnet. This variation in flux produces a variation in the force exerted on the movable magnet, causing it to change its position. Since the cutting stylus is connected to this magnet, it moves in proportion to the recording amplifier's output.

As a rule, the frequency range of a magnetic cutter is not as great as that of the crystal type. The finest magnetic cutters have a frequency range of from 50 to 8,000 or 9,000 cycles. (See Fig. 18). The distortion content of fine magnetic cutters is as low as 1/10th of 1% at 400 cycles ranging to 2 or 3% at high frequencies.

24. Characteristics.—If a constant voltage input to a magnetic cutter is maintained over the frequency range being recorded, the amplitude of the mechanical motion of the armature will decrease as the frequency increases. This decrease in the amplitude of motion is such that the stylus will move at a constant velocity. Recordings made with the cutter are of the constant velocity type. The impedance of magnetic cutters varies from a few ohms to a few hundred ohms. In most cases, very little power is needed to produce a fully modulated groove.

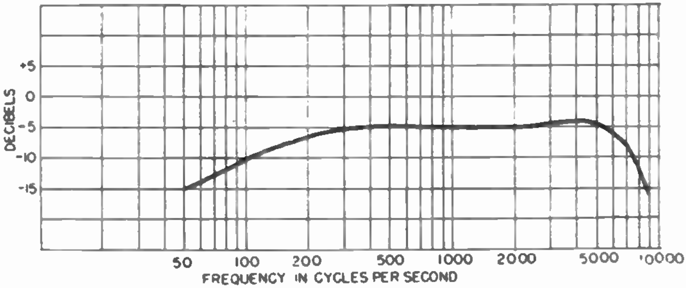


Fig. 18 Frequency response curve of a typical magnetic cutter.

25. Dynamic Cutters.—The dynamic cutter, as the name implies, is of the moving coil type. The cutter consists of a movable coil, to which the cutting stylus is fixed, and a permanent magnet. The coil is connected to the output of the recording amplifier. When current passes through the coil causing a magnetic field to be set up around it, this field acts with the field of the permanent magnet, and as a result, the coil and stylus move. The results obtainable with dynamic cutters are approximately the same as are obtainable with magnetic cutters.

TURNTABLES AND FEED MECHANISMS

26. The construction of the turntable used has a great deal to do with the quality of the recordings produced. "Wabble," changes in speed, and other turntable defects show up unfavorably when a record is played back.

Two standard turntable speeds are used. They are 78.26 and 33⅓ revolutions per minute.

Speed is a very important factor in recording, since variations of as little as 1% are detectable during playback. Speed variations are caused by changes in load on the turntable as the side to side excursions of the stylus increase or decrease in frequency and amplitude.

Wabble results when the turntable, spindle and bearing assembly are not carefully aligned. When wabble occurs, the surface of the recording blank moves closer to and farther from

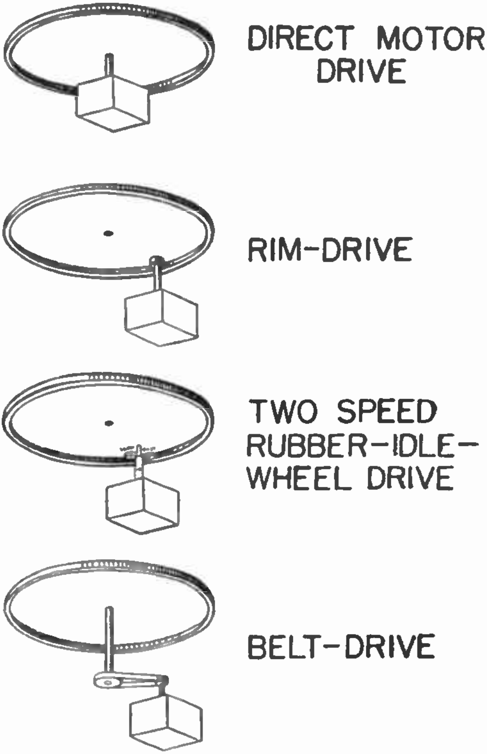


Fig. 19 Four methods used to couple the drive motor to the turntable.

the cutting head as the turntable revolves. This results in changes in the depth of cut. In extreme cases, the stylus may completely leave the surface of the blank at one or more points.

The motors used to drive recording turntables are usually powered by alternating current, and, as is universally the case, vibration at the power frequency is set up within the motor. If this vibration is transmitted to the turntable or cutting head, it will result in hum modulation of the record groove. In good turntable assemblies, the motor is insulated from the turntable sufficiently to eliminate hum transmission.

To avoid the defects described above, a carefully designed and constructed motor and drive system is necessary. Fig. 19 shows a number of driving methods commonly employed in recording equipment.

The gear chain or direct motor drive shown at A requires a very powerful motor free from vibration. If properly designed, this type of drive is very satisfactory. Because good units are very expensive, this drive system is rarely encountered in recording equipment.

Fig. 19B shows the direct rim drive method. This method provides a single speed. The turntable is driven by a rubber wheel attached to the motor shaft. The rubber wheel also serves to isolate the motor from the turntable, reducing the transmission of motor vibrations.

One of the defects of this system arises from the deformation of the rubber wheel which results if the wheel is left in contact with the turntable rim when the equipment is not in use. The point in contact with the turntable rim is flattened. In good units, provisions are available for removing the pulley from contact with the turntable when the equipment is not in use.

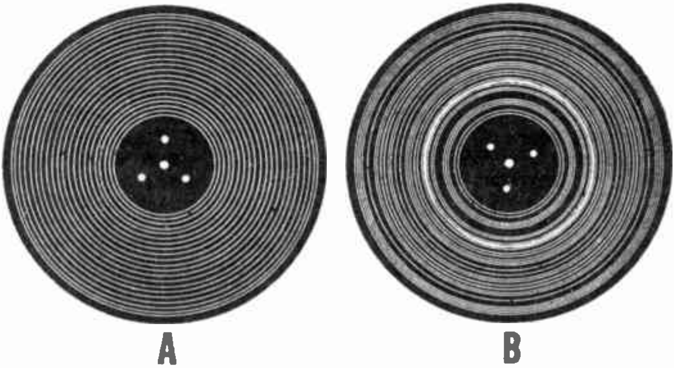


Fig. 20 Appearance of records cut with good and bad feed mechanisms. A is good. B is bad.

In Fig. 19C, a two speed rubber wheel drive system is shown. Two rubber wheels are provided, one giving a 78 R.P.M. turntable speed, and the other a 33⅓ R.P.M. turntable speed. The desired speed can usually be chosen by changing the position of a lever connected to the drive mechanism.

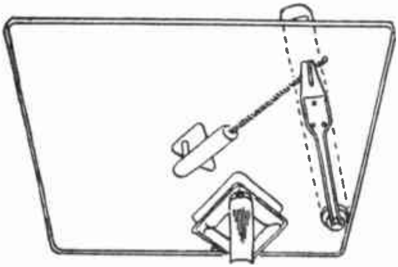
The single and dual speed rubber wheel drives are often constructed so that the rubber wheel mounted on the motor shaft drives an idler, which in turn, drives the turntable. This greatly simplifies the design of facilities for removing the wheel from contact with the turntable and permits better control of the pressures between the rubber wheel and the turntable rim. The possibility of slippage, which is a common fault of direct rubber wheel drive, is also reduced greatly.

Fig. 19D shows a belt drive arrangement often encountered in recording equipment. A rubberized composition belt is connected between pulleys on the motor shaft and turntable spindle. This system is very good with respect to transmission of vibration.

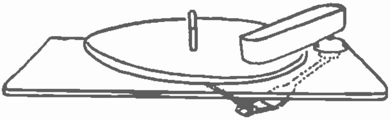
27. Feed Mechanisms.—As the turntable revolves and the stylus cuts the groove, the cutting head must be moved across the record at a constant and carefully controlled rate. When the rate of movement is not constant, the distance between the grooves will vary, and the record will appear as shown in Fig. 20B. This effect is referred to as banding. The cutting stylus must always be held so that it may perform its function properly.

Three types of feed mechanisms are in use.

28. Fan Type Feed.—Low cost equipment usually utilizes this type of feed mechanism. In the fan type feed mechanisms, the turntable motor drives — either a lead screw or a gear chain. The gear chain or lead screw is coupled to an arm similar to an ordinary phonograph pick-up arm. The arm holds the cutting head and guides it across the recording blank. Fig. 21 shows the construction of a typical fan type feed mechanism.



BOTTOM VIEW



TOP VIEW

Fig. 21 Construction of a fan-type feed mechanism.

While the fan type feed is quite suitable for use in low cost recording equipment, the tracking error which is inherent in its design prohibits its use in high quality recording systems. Fig. 22 shows how this tracking error takes place. The arm swings the cutter across the disc in an arc (DC). As the cutter moves across the disc, the angle of the cutting stylus changes slightly so that its cutting face is not held in proper position at all times.

29. Overhead Feed.—The overhead lead screw feed mechanism is found in the best console type recorders. It consists of a carriage mounted on a pivot just off the turntable as shown in Fig. 23. The other end of the carriage is connected to the turntable spindle. The cutter is mounted on a number of guide rails and is driven by a lead screw. The lead screw is coupled to the turntable spindle and is thus kept in synchronization with the turntable. The cutting head is equipped with a half nut which engages the lead screw when the cutter is lowered into cutting position. The carriage usually has provisions for making small changes of the cutter height to permit adjustment of the depth of the cut.

A variation of the overhead lead screw feed mechanism often used in portable equipment consists of a carriage mounted on a pivot which holds it over the turntable. The end of the carriage nearest the spindle does not rest on the spindle. Coupling to the spindle is by means of a bolt and pulley arrangement mounted under the turntable.

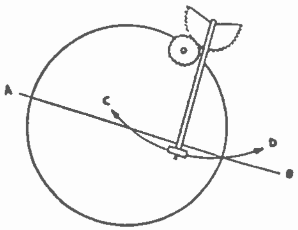


Fig. 22 Tracking error inherent in fan-type feed.

The overhead lead screw feed mechanism has an important advantage over the fan type in that the cutter is moved straight across the recording blank as shown in Fig. 23. In this way, the cutting angle of the stylus is kept constant.

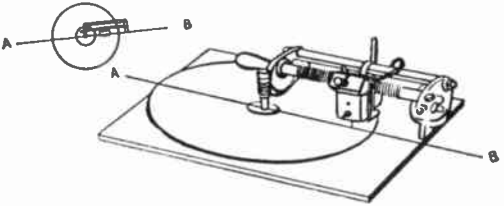


Fig. 23 Construction of the overhead lead-screw feed mechanism.

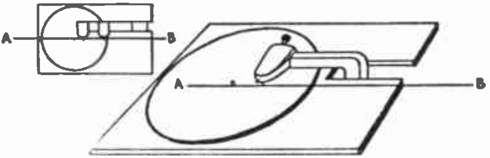


Fig. 24 Underbed lead-screw feed-type mechanism.

30. **Underbed Feed.**—Underbed lead screw feed mechanisms

are often found in portable or semi-portable equipment. The operation of these units is similar to that of the overhead feed in that a lead screw driven by the turntable spindle is engaged by a half nut which guides an arm holding the cutter. The arm rides on guide rails. It has the advantage of straight line travel across the recording disc (see Fig. 24). It has an additional advantage in that it keeps many of the delicate parts below the turntable where they are better protected.

31. Grooves Per Inch.—An important consideration in the design of feed mechanisms is the number of grooves which must be cut per inch. The number of grooves per inch is based upon the number of threads on the lead screw (for lead screw type feed mechanisms). In practice, the number of grooves cut per inch of record surface varies between 90 and 160.

Some feed mechanisms are designed to enable changes in the number of grooves per inch to be made. This is accomplished by changing the lead screw used.

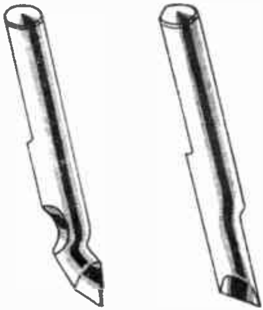


Fig. 25 Enlarged sketch of typical cutting styli.

32. Direction of Feed—Records may be cut with the cutter traveling from the outside to the inside of the blank or vice versa. *Outside-in* feed is preferred for most applications.

On occasion, when the recording equipment cannot be watched closely during use, *inside-out* feed is desirable. It has the advantage that the thread cut from the blank can be guided into the center of the blank where it will not interfere with the recording process. Some feed mechanisms are so equipped that they may be used for either type of feed.

CUTTING STYLI

33. The stylus is mounted in the cutting head. It cuts the coating of the disc in accordance with the sound being recorded. It operates somewhat in the manner of a lathe tool, and its cutting end is shaped somewhat like such a tool. A stylus is a precision instrument and requires a high degree of skill in manufacture.

34. Operation.—The stylus cuts a groove approximately .002 inches deep, and obviously only the tip is subject to wear. The rest of the stylus, called the shank, serves as a connecting link between the cutter armature and the portion of the stylus which cuts the groove. Fig. 25 shows the construction of a typical stylus. All styli are carefully ground to a predetermined pattern which has proved to be most satisfactory.

A properly shaped stylus has a carefully rounded trip which is formed as shown in Fig. 26. Part of the tip away from the cutting face is cut away to help form the cutting edge of the stylus.

The stylus performs two operations. It cuts the groove and it polishes, or more accurately, burnishes, the walls of the groove. In order to perform these two functions properly, it must be carefully ground and polished. To facilitate the burnishing of the groove walls, a small facet is cut on each side of the cutting face.2 The various surfaces which actually perform the cutting action are so small (see Fig. 27) that the grinding and polishing of ‘he stylus tip requires a high degree of skill.

The ability of the stylus to cut a clean well-polished groove determines to a great extent the quality of the record produced. The most common defect which results from a poorly formed stylus is excessive surface noise in playback.

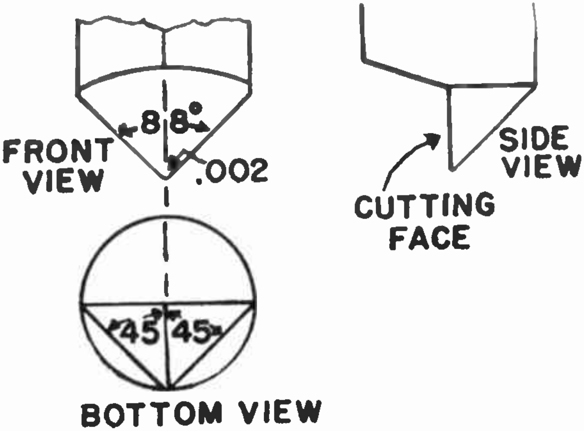


Fig. 26 The formation of the cutting tip of the stylus.

Cutting styli are very delicate and must be handled with extreme care. The life of a cutting stylus depends upon the properties of the material used for its cutting tip, and the surface of the recording blanks with which it is used. Styli are made with steel, alloy and sapphire cutting tips.

35. Cutting Angle.—While the formation of the stylus tip is very important, the position in which the stylus is held in relation to the recording blank is also important, since even a perfectly formed stylus cannot do its job properly unless it is held correctly. The stylus must bhe held so that its cutting face will form a 90° angle with the surface of the recording disc. Since the construction of the various types of styli vary, this cutting angle must be adjusted by changing the position of the cutting head. (See Fig. 28).

If the cutting angle is not correct, the stylus will not cut properly and surface noise will result. In practice, the cutting face should be adjusted to within a few degrees of the prescribed angle (90°).

As the stylus cuts the groove, a long continuous "chip" or "thread" of material is removed from the blank. This thread must be carefully removed from the vicinity of the recording head so that it will not interfere with the stylus. To accomplish this, the cutting stylus is twisted slightly to one side so that the chip is guided toward the inside of the blank. (See Fig. 29). From this point, the chip is often removed with compressed air. The "twist" is normally about two degrees. In practice, the stylus is ground so that when it is placed in the cutting head, it will assume the proper position. This is accomplished by cutting a flat side on the stylus shank. The flat side is engaged and held by the cutting head set screw, as shown in Fig. 30.

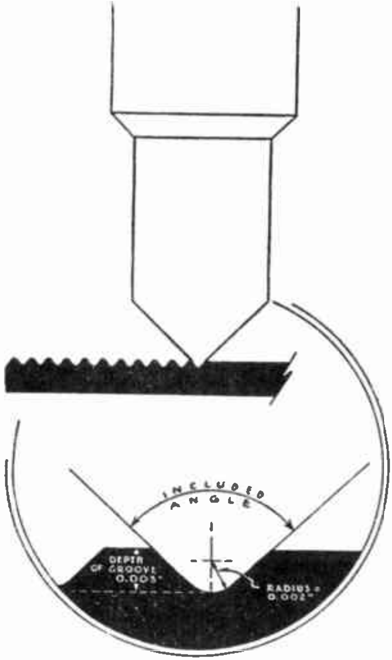


Fig. 27 Illustration of the minute dimensions of the area which actually performs the cutting action.

36. Depth of Cut.—The cutting head must be adjusted so that the stylus will cut a groove of the proper depth. If the groove is too shallow, the playbacking pickup will fail to track. If the groove is too deep, *overcutting* may result. that is, one groove will run into another.

As the groove is cut deeper, the distance across the groove at the surface of the blank becomes greater. The greater is this distance, the narrower will be the walls between adjacent grooves.

(See Fig. 31). A point is finally reached at which no wall remains between adjacent grooves. This defect is referred to as over-cutting. It is especially troublesome at high volumes and low frequencies when the *side excursions* of the stylus are greatest. When overcutting occurs, the playback pickup will move from groove to groove through the openings in the walls of the groove as shown in Fig. 32.

The deepest cut which can be made depends upon the shape of the stylus and the distance between adjacent grooves. Since stylus shape is standardized, the distance between grooves becomes the determining factor. The distance between grooves is directly related to the number of lines cut per inch of recorded surface. As the number of lines increases, the allowable depth of cut decreases.

The relationship between the width of the grooves and the width of the *lands* which remain between grooves is a guide to the proper depth of cut. Fig. 33 shows the land and groove relationships which occur with grooves of three different depths when the number of grooves per inch remains constant.

In A, the groove has been cut too shallow. The land is wider than the groove. Poor tracking will result in playback. In B, the groove to land relationship is 60 to 40. This permits recording at normal volume levels without danger of overcutting. In C. the cut has been made too deep, and overcutting has resulted. The lands are either very narrow or they have been cut away entirely.

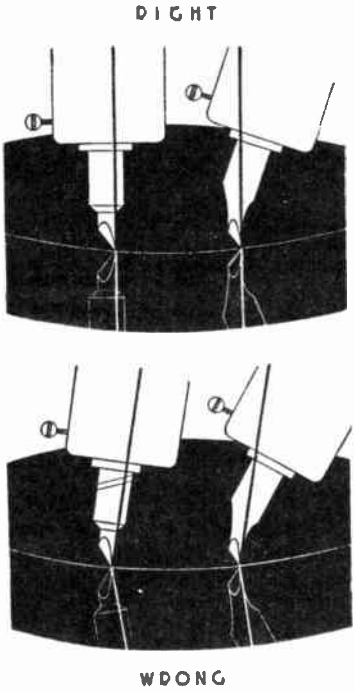


Fig. 28 Wrong and right position of two types of cutting stylus.

If the cut is too deep, but not deep enough to cause overcutting, two other faults may arise. They are surface noise and "echo." Echo results when the stylus cuts so close to an adjacent groove that it causes deformation of the wall of the adjacent groove. This occurs because the action of the stylus is not completely one of cutting. The material which forms the coating on the disc is not only cut by the stylus, but a small portion of it is pushed away from the stylus during cutting. It is this material which causes echo when it is pushed into an adjacent groove.

37. Steel Styli.—Steel styli have a much shorter life than both the alloy and sapphire type. During its first few minutes of use, a steel stylus will cut a recording with very little surface noise. Because they wear rapidly, they produce increasingly greater surface noise, and after about thirty minutes of use, they must be discarded.

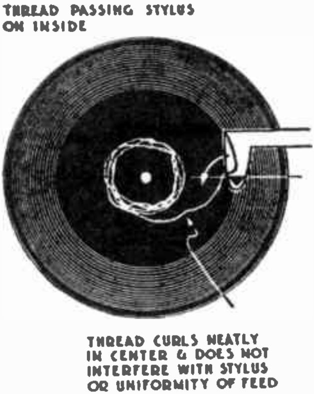


Fig. 29 Disposition of the thread during recording.

Even hard steels are somewhat flexible, and because of this, steel styli do not respond well to high frequencies.

Because of their longer life and superior qualities, allow and sapphire have replaced steel styli.

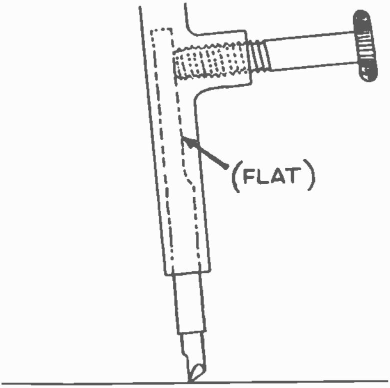


Fig. 30 How set screw engages flat side of stylus shank.

38. Alloy Styli.—Cutting styli are made from a number of alloys. Since the alloys are expensive and their properties are only desirable for the cutting tip, these styli are made with brass or dural shanks. (See **Fig. 34**). Alloy styli are superior to steel in wearing quality and are quite popular. The alloys used in their manufacture vary in hardness. Some of the styli using the hardest alloys will last as long as a sapphire stylus. The use of a very hard alloy results in the creation of considerably more surface noise than is experienced when the better sapphire styli are used. As a result, most alloy-tipped styli use a metal considerably softer than sapphire in order to faciiltate proper polishing of the tip and to obtain a lower coefficient of friction.

One of the most widely used alloys is known as Stellite. Styli tipped with it produce recordings almost as quiet as those made with good sapphire styli. The tip will last for about two hours of actual cutting after which the styli may be returned to the manufacturer for resharpening.

39. Sapphire Styli.—The most widely used cutting styli are those which utilize sapphire as a tip material. Sapphire will take a high polish, it has a low coefficient of friction, and is very hard.

Synthetic and natural gems are used in the manufacture of sapphire styli. The natural gems are slightly more expensive and last a little longer in use. A synthetic will retain its shape for about six hours, while a natural gem will last for about eight hours of cutting time.

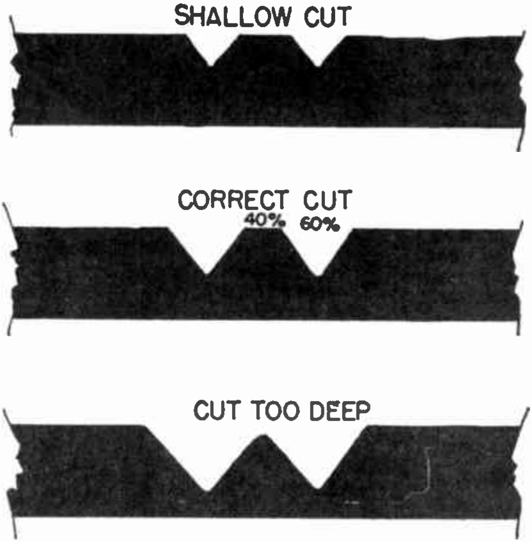


Fig. 31 Cross-sectional view of three recording grooves.

Sapphire styli are made with very rigid shanks. The rigid shank, combined with the hard sapphire, results in an abiilty to transmit the high frequencies to the cutter with little attenuation. The sapphire stylus is thus excellent for recording wide range material.

The grinding and polishing of a sapphire stylus requires a great deal more skill than does that of steel or alloy styli. One of the main disadvantages of sapphire is that it fractures quite easily, and therefore, it must be handled with extreme care.

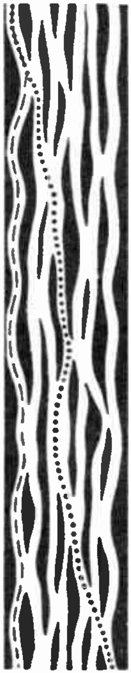


Fig. 32 Path of the playback stylus through the openings in the walls of a record which has been overcut.

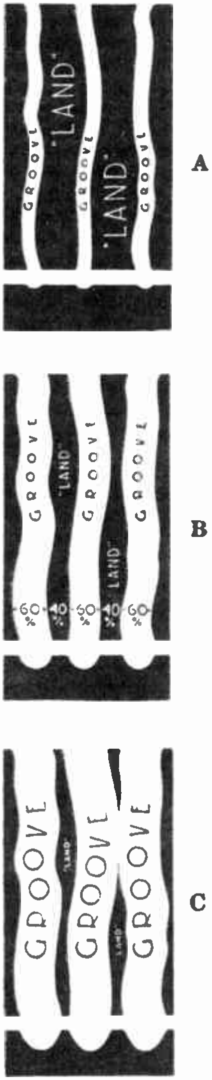


Fig. 33 Examples of improperly and properly cut recording grooves.

RECORDING DISCS

40. The disc on which the recording is made is one of the most critical elements in the recording system. The disc must have a number of specific qualities which are extremely difficult to obtain. Any deviation from these qualities results in an inferior recording. If the recording blank does not fulfill its requirements, there is no way to overcome the blank defects in other parts of the system.

41. Requirements. — The recording blank must be very rigid. If the blank is not rigid, an effect referred to as "rumble" will result. Rumble occurs when the blank flexes as a result of vertical vibration of the stylus and cutting head. The flexing of the blank amplifies these vibrations and they are heard as a rumbling sound during playback. This flexing is a serious defect since vertical vibration of the stylus occurs in even the finestt recording equipment.

The surface of the disc must cut cleanly. Some materials can be cut by a stylus and leave a very smooth lustrous groove. Other materials cannot be cut cleanly. These materials tear and leave a groove whose walls have tiny irregularities which manifest themselves as surface or "background" noise during playback.

If a recording blank does not permit proper cutting, *chatter* may occur. The term, chatter, refers to slight continuous vibrations of the stylus which take place during cutting and cause small wave shaped undulations in the bottom or walls of the groove. When the recording is played back, high frequency noise results.

The material which forms the surface of the disc must be free from abrasive and granular material. A disc not completely free from such materials will cause high frequency background noise or "hiss" when played back.

The surface of the disc must be perfectly flat and completely free from irregularities. When the cutting stylus meets an irregularity during cutting, it is deflected. Since this deflection is not the result of the sound being recorded, it represents a distortion. If the surface of the blank is not perfectly flat, the depth of the cut will vary. In extreme cases, the stylus may completely leave the surface of the blank. This defect is referred to as "skip." (See Fig. 35). Severe cases of skip often cause the

Fig. 34 Construction of an alloy cutting stylus.

Fig. 35 A recording made on a defective blank illustrating the effect called "skip".

stylus to cut through the surface of the disc to the hard base material. A recording on such a disc is useless. Cutting through will usually destroy the stylus.

Irregularities in both the surface of the blank and the hardness of the material which forms the surface will cause changes in turntable load during recording. These changes in load often cause slight turntable speed changes. During playback, this condition will result in "wow" or "tone flutter."

The surface of the disc must cut readily, otherwise, the high frequencies will be attenuated. The ability to permit cutting without the necessity of great pressure is not associated with the hardness of the disc surface material, for the material must also be quite hard.

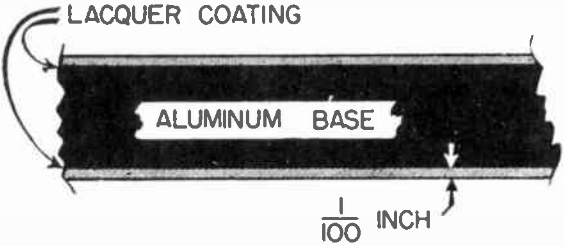


Fig. 36 Cross-section of a recording disc.

The surface material of the disc must be tough enough to withstand playback without undue wear. With a properly designed pickup and turntable, an instantaneous recording should have a useful life of from 100 to 200 playings.

Aside from all of these qualities, the surface material should be such that it does not cause excessive stylus wear. The material should not turn to powder when cut, but should form a continuous thread or chip. It must also, of course, retain its shape and other properties for as long a time as possible. Good discs will last for many years before or after they have been recorded upon.

42. Construction.—In order to fulfill the requirements described above, it has been necessary to form recording discs by using a rigid base material and coating this base with another material. A material has not yet been found which is rigid enough and at the same time possesses the qualities required of the disc surface.

Discs are manufactured with a glass or aluminum base coated with a semi-plastic lacquer-like varnish as shown in Fig. 36. Fibre and paper are also used as base materials, but are inferior to glass and aluminum except in cases where comparatively poor quality can be tolerated.

A number of ways have been devised to place the coating on the disc, one of the most satisfactory being by applying it to the base in the form of an homogeneous sheet. After it has been applied, the coating is cured to remove volatile constituents. The curing process helps in controlling the hardness of the coating.

RECORDING CHARACTERISTICS

43. The physical and electrical characteristics of records vary greatly. These variations manifest themselves in the size and specifications of the blanks used, the number of lines cut per inch, the plane in which the cutting action takes place and others. A group of suggested standards has been created and suggested for use by the N.A.B. They are discussed later in this section.

44. Lateral Engraving.—Lateral engraving refers to the way in which the disc is cut. With this system, the depth of the cut made on the surface of the disc is kept constant while the recording stylus moves from side to side cutting an undulating groove. Most recordings are made using the lateral system since it is simpler to accomplish.

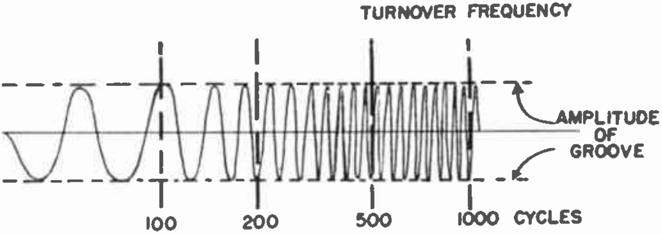


Fig. 37 Waves produced in groove of a constant amplitude recording.

45. Vertical Engraving.—With this system, the cutting stylus does not move from side to side. It travels along a straight line in the horizontal plane and moves up and down in the vertical plane. Vertical engraving is not used as widely as is lateral engraving, but it does permit the production of recordings of very high quality when properly applied.

46. Constant Amplitude.—When the undulations cut in a record are of the same amplitude regardless of the frequency recorded, the recording is said to be a constant amplitude recording. Fig. 37 illustrates the waves produced in a groove of a constant amplitude recording with a varying frequency of constant amplitude being impressed on the cutting head. If the sound pressure at the microphone of a constant amplitude recording system remains the same while the frequency of the sound is varied, the amplitude of the undulations cut in the record will remain the same.

47. Constant Velocity.—With constant velocity recording, the velocity of the cutting stylus remains the same when the frequency of the recorded sound is varied, provided the amplitude of the sound remains constant. Fig. 38 illustrates the undulations cut in a record under the conditions described above.

As indicated in the figure, the amplitude of the modulation of the recording groove increases as the frequency decreases. There is an inverse relationship between the amplitude of the modulations and the frequency of the recorded sound. The amplitude of the wave is twice as great at 100 cycles as it is at 200 cycles.

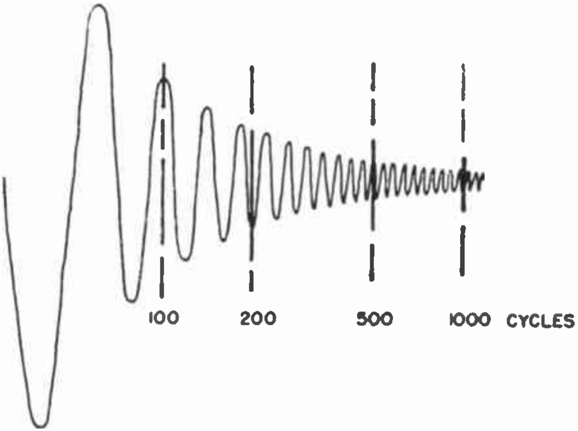


Fig. 38 Waves in groove of constant velocity recording.

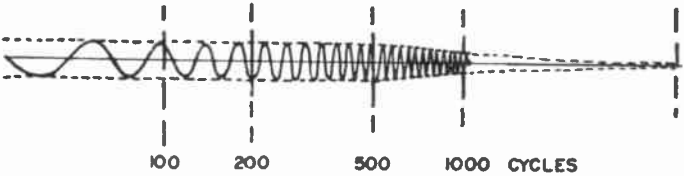


Fig. 39 Wave produced in groove with 500 cycle turnover.

At low frequencies, the amplitude of the undulations of the groove are great enough to cause "overcutting"; that is, one groove cuts completely over into an adjacent groove on the face of the recording disc. Another undesirable effect, referred to as "echo," takes place at amplitudes not quite great enough to cause overcutting. The "echo" effect results when the groove is cut close enough to an adjacent groove to deform the wall of the adjacent groove.

48. Turnover.—In order to eliminate the undesirable effects of cross-over and echo, special recording circuits have been devised which permit the creation of a constant velocity recording above a predetermined frequency, while all frequencies below it are cut constant amplitude. The frequency at which the recording characteristic changes from constant velocity to constant amplitude is known as the turnover point. Fig. 39 shows a graphical representation of the amplitude of the modulation in the groove of a recording, cut as described above.

In practice, the turnover point is usually between 300 and 800 cycles. A 500-cycle turnover point as shown in Fig. 40 is used very often.

There are a number of ways to secure a combination recording characteristic (constant velocity and constant amplitude). If a magnetic cutter is used, it is only necessary to add a small amount of resistance in series with the cutter. (See Fig. 41).

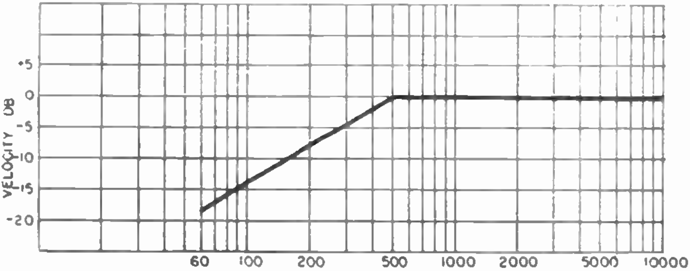


Fig. 40 Response of record cut with 500 cycle turnover.

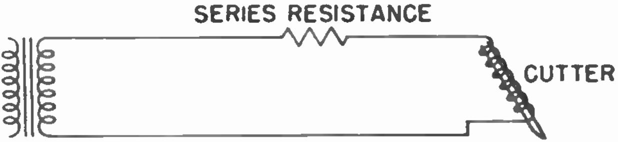


Fig. 41 Magnetic cutter circuit.

When a crystal cutting head is used, the cross-over frequency is determined by the impedance into which the cutter is coupled. As the impedance of the coupling circuit increases, the cross-over point of the crystal cutter decreases. (See Par. 22.).

49. Noise.—When a disc recording is played back, the reproduced sound is accompanied by a certain amount of background noise.

This background noise is of a high frequency nature. Almost all of it occurs at frequencies above 3,000 cycles.

The noise comes from three principal sources. Some of it is caused by grit in the material which forms the surface of the recording blank. In good instantaneous discs, this grit has been almost entirely eliminated. In some shellac pressings, grit is actually added as an abrasive so that steel styli are quickly ground to fit the groove. This protects the record and greatly extends its life.

Noise is also caused by dust which settles on a record. It may be avoided by keeping records stored in dust free containers when not in use.

Another type of noise is caused by irregularities in the cutting stylus. The cutting stylus cuts the groove in the record and at the same time, it polishes the walls of the groove. Under certain conditions, the stylus cannot properly accomplish this polishing action, and, therefore, rough groove walls result, which, in turn, are a source of noise during reproduction.

The level of the background noise remains almost constant with changes in the amplitude of the material recorded. From this, it is evident that if the level of the recorded sound is high, the sound will tend to "override" or mask the noise, making it unnoticeable.

The fact that almost all noise occurs at high frequencies indicates one of the advantages of constant amplitude recording over constant velocity. With constant velocity recording, the amplitude of the reproduced sound remains constant as the frequency increases, and the level of the reproduced sound approaches the level of the surface noise.

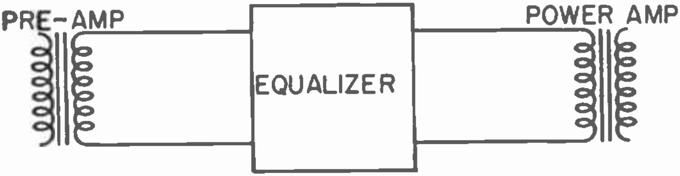


Fig. 42.

With constant amplitude recording, the output voltages generated at high frequencies are considerably greater than the noise voltages generated. If the amplitude at 1,000 cycles is the same for constant velocity and constant amplitude recording, then at 4,000 cycles, the amplitude of a constant amplitude recording will be four times as great as that of a constant velocity recording.

Properly used, constant amplitude recording will give noise reduction of as much as 10 db over constant velocity recording.

50. Pre-Emphasis.—The masking of the background noise which takes place when the level of the recorded sound is great enough has led to the development of an effective means of eliminating annoying, high frequency "surface noise." The action is similar to that of constant amplitude recording.

A filter is inserted between the pre-amplifier and the power amplifier (See Fig. 42) This filter changes the frequency response characteristics of the amplifying system and results in a constant rise in amplification as the frequency of the recorded sound increases.

In this way, the amplitude of the high frequency sound is increased to a point where it will mask the background surface noise.

51. **Disc Size and Turntable RPM**—The diameter of the disc and the speed of the turntable determine the rate at which the surface of the disc passes the cutting stylus. As the stylus moves toward the center of the disc, the actual diameter at which it is cutting decreases, and the rate at which the disc passes the stylus decreases.

Assume that a single high frequency tone is being recorded. As the stylus moves closer to the center of the disc, the linear distance from the beginning to end of a single cycle of the tone decreases as illustrated in Fig. 43. When this linear decrease is taking place, it is necessary for the stylus to move from side to side at ever sharper angles. During playback, the pickup needle must track these short bends in the wave, and as a result, there is a gradual attenuation of the playback response. This effect is greatest at high frequencies.

EFFECT OF LINEAL VELOCITY ON WAVE-FORM

R.P.M.	DIAM.	WAVE-FORM	COMMENTS
78	11½"		*The accompanying sketch illustrates a given wave-form well extended due to a high lineal velocity—good tone quality.*
78	4⅞"		*The same wave-form as above is here compressed by reduced lineal velocity resulting from the decrease of diameter—some loss of tone quality.*
33⅓	11½"		*At 33⅓ R.P.M. and 11½ inch diameter the lineal velocity is approximately the same as at 78 R.P.M. and 4⅞ inch diameter—again some loss of tone quality as compared with 78 R.P.M. at 11½ inch diameter.*
33⅓	5"		*This sketch illustrates why it is more difficult to record at small diameters and 33⅓ R.P.M. The wave-form is now so "squeezed" that no playing needle can possibly follow the short bends—reproduction bad or impossible.*

Fig. 43.

Because this "pinch" effect causes loss in high frequency response as the diameter at which a recording is made decreases, limitations are imposed on the minimum diameter at which a recording can be made. It is evident that, since the linear velocity of the surface of the disc passing the styus is greater at 78 RPM than at 33⅓ RPM, a smaller minimum diameter is permissible for 78 RPM recording, as shown in Fig. 43.

The diameter of the innermost groove for acceptable response characteristics is generally regarded as 7½" for 33⅓ RPM recording and 3¾" for 78 RPM recording. These dimensions have been adopted as standard by the National Assn. of Broadcasters.

52. **Recording Standards.**—Because of the many variables in the process of recording, many difficulties arose in the past in reproducing records from different sources. Records and transcriptions with vastly different characteristics are encountered. In order to eliminate the difficulties which arose from these variations in characteristics, the National Association of Broadcasters set up a group of recording standards which are widely used in the production of instantaneous recordings.

The outside diameter and the center hole diameter of records have been standardized. The innermost and outermost groove diameters, the stopping groove, the number of blank grooves before modulation occurs, the number of grooves per inch, the number of starting spiral grooves per inch, the "wow" factor, the maximum permissible record warp, the minimum label information, the recording turntable speed, and the frequency characteristics of both lateral and vertical recordings have also been standardized.

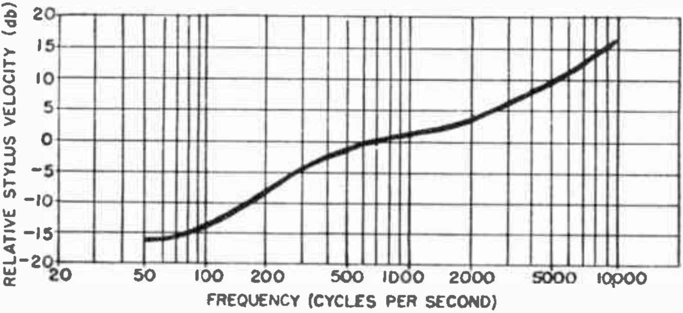


Fig. 44 Standard frequency characteristic..

Fig. 44 shows the frequency characteristics which have been adopted for lateral transcriptions. A deviation of ±2 decibels from the standard is permissible.

PRESSED RECORDS

53. Copies of a record can be made in two ways. If only a few copies are required, they may be made by re-recording. In re-recording the record to be copied is played back into a recording system and another recording is made. This process may be repeated several times to secure a number of copies.

The quantity of copies which can be made by re-recording is limited, and when a large number of copies is required, they must be made by a process known as "pressing".

54. Master Recordings.—In order to make pressings, a master recording is necessary. The master is often an ordinary instantaneous recording made on a special disc. Master discs, as they are called, are the same as ordinary instantaneous discs except that they are slightly larger and the base material is heavier. The larger disc is necessary because a blank area must be left on the edge of the master so that it may be gripped during processing.

Masters are also made on special wax discs. Wax discs require the use of special techniques and equipment. Wax masters were used before the advent of suitable lacquer discs, but in most applications they are being replaced by lacquer discs. The large commercial record producers still use wax masters to some extent. The wax master is better than the lacquer one in some ways, but the wax type is so delicate that in most instances, its disadvantages outweigh its advantages.

55. Processing the Master.—After the master has been cut, its surface is metalized so that it will conduct electricity. This is accomplished by a process known as "sputtering". The master recording is placed in a vacuum chamber where it is bombarded with pure gold. This bombardment is accomplished by creating a great potential difference between the gold and the disc. When a lacquer master is used, a connection is made to the base material (aluminum) at the center hole, and the potential charge is placed on it. When a wax master is processed, a metal disc is placed behind it, and the gold particles are intercepted and deposited on the surface of the wax master.

Two other methods are sometimes used to make the surface of the record conductive. They are, by dusting bronze powder on the disc, or by means of a chemical reaction. Sputtering is usually regarded as the best method of the three.

After the surface of the master has been made conductive, it is placed in an electroplating tank. In electroplating, the disc is given a coating of pure copper to build up a sufficiently heavy metal surface.

The copper surface and the master disc are then separated. The copper is reinforced and cleaned and becomes what is referred to as a "copper master". The copper master is given a nickel plating and is ready to be placed in the pressing machine.

When very large numbers of pressings are to be made or when the "nickel master" must be preserved, further processing is necessary. The nickel master is coated with a chemical compound. It is then placed in a nickel plating bath, and a plating is placed over the compound. It is next given a copper coating to strengthen the second nickel plating. The copper and the second nickel plating are then separated from the nickel master. The separation is made possible by the chemical compound with which the nickel master was coated when the second process began.

The second nickel and copper plate is a positive of the surface of the original master disc and cannot be used for pressing.

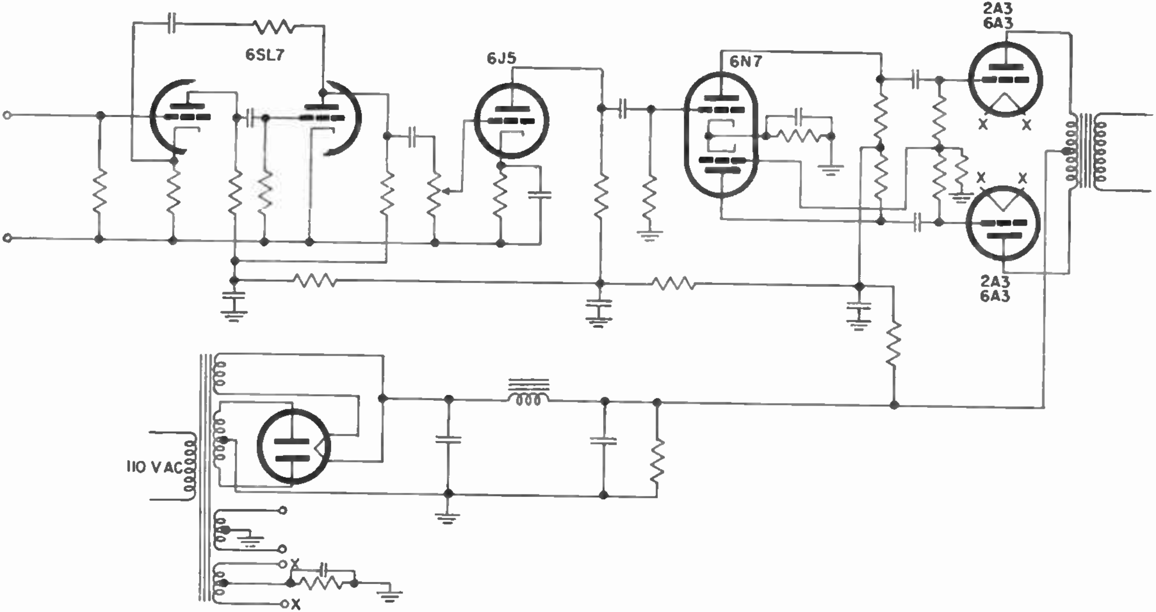


Fig. 45 Amplifier suitable for reproducing sound from recordings.

It is referred to as "mother". By repeating the process just described, a reversed copy of the mother is made. The reversed copy is referred to as a "stamper". It is used to make the pressed records. A number of stampers can be made from a single mother, making possible the production of huge numbers of pressed records.

56. Pressing Materials.—There are two types of pressed records. They are, those consisting of shellac and clay, and those made of vinyl acetate. The shellac record is widely used. Almost all commercial records are the shellac type. Vinyl acetate is used in the production of 16" broadcasting transcriptions. A few commercial records have been made using vinyl acetate.

The composition of shellac recordings contains a certain amount of abrasive material which results in considerable high frequency background noise. Vinyl acetate is almost entirely free of grit and therefore, gives very little high frequency background noise.

REPRODUCTION

57. There are a number of factors which must be given careful consideration if recordings are to be utilized to the fullest extent of their possibilities.

To utilize the complete frequency range which was recorded on the record, a suitable amplifying system is necessary. To prevent rapid wear of the recording, a carefully designed reproducing needle and arm are absolutely necessary.

58. Reproducing Amplifier. — The reproducing amplifier should have characteristics consistent with those of the recording amplifier. A good general purpose amplifier should have a response essentially flat from 50 to 15,000 cycles. The distortion of the amplifier output should be two or three percent at most. The power handling capacity of the amplifier should be at least 15 watts for optimum performance in an average room. Where greater coverage is desired, a correspondingly higher power is necessary.

It is important that the amplifier power supply ripple be kept to a minimum. This is especially important in amplifiers utilizing bass boost circuits. Fig. 45 shows the schematic diagram for a high quality, 15 watt amplifier suitable for record reproduction.

59. Reproducing Needles.—To minimize wear and secure the maximum useful life from a recording, a properly shaped needle must be used. A properly formed reproducing needle will also minimize background noise.

Fig. 46 illustrates a group of playback needles seated in the grooves of a recording. The needle at (1) is of a theoretically ideal shape. (2) and (3) are too sharp and will gouge the bottom on the groove. (4) is too blunt and will cause excessive wear on the walls of the groove, resulting in their eventual breakdown. (5) is a needle of satisfactory shape.

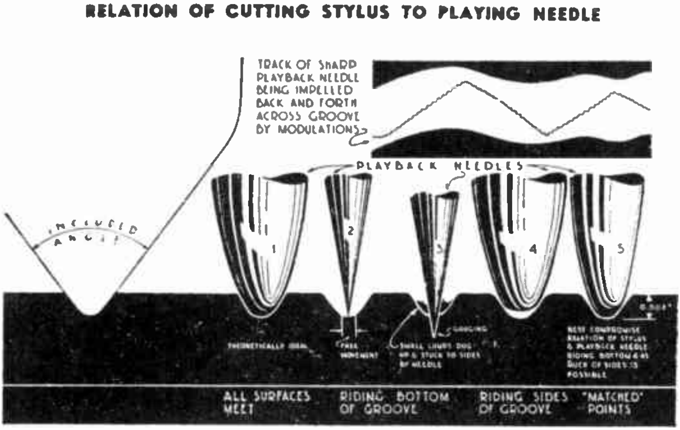


Fig. 46 Properly and improperly shaped playback needles.

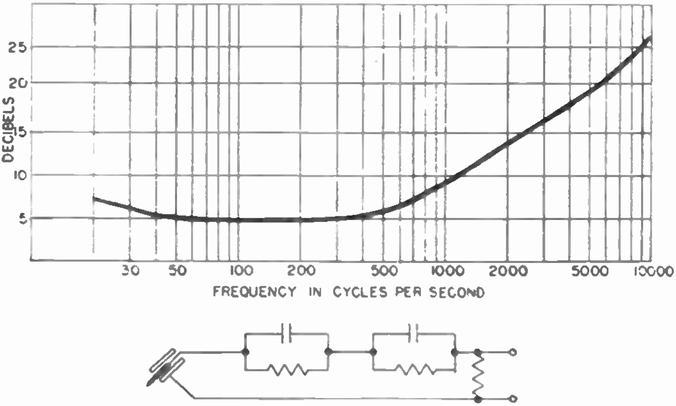


Fig. 47 Circuit and response curve of filter for use with crystal pickup when reproducing from records with 500 cycle turnover frequency.

Shellac pressing usually contains enough abrasive material to quickly wear a metal needle to the proper shape. Instantaneous recordings do not contain abrasive material, and because of this, it is particularly important that a needle of the correct shape be used with them.

Reproducing needles are made of a number of materials. Those made of steel are the most common. Steel needles have a comparatively short life. Diamond, sapphire and alloy are also used in the manufacture of reproducing needles. Diamond and sapphire needles will give satisfactory performance for a number of thousands of playings and when properly shaped and polished, they are superior to all other types. Their only disadvantage is that they are very delicate and may be fractured by a slight impact. A chipped diamond or sapphire needle will quickly ruin any type of recording.

60. Pickups.—Two types of pickup are widely used in the reproduction of sound from recordings. They are, crystal and magnetic pickups. Both of these units operate in a manner similar to the cutting head to which they correspond. Units of both types are available with varying response characteristics.

The pickup cartridge should be mounted in a suitably designed arm. Needle pressure should be left at the lowest value consistent with the design of the cartridge used. For optimum results, the arm should have an offset head to minimize tracking error, and side to side motion should be as free as possible.

61. Equalization.—When a recording which has pre-emphasized high frequencies is played back, a special problem arises. The amplitude of the high frequencies and of the low frequencies does not have the same proportions that it had in the original sound. To recreate this balance, equalization is necessary. It is accomplished through the use of a suitable de-emphasizing filter which attenuates the high frequencies the desired amount.

As a rule, the response characteristics of a pickup do not match the response characteristics of the recording with which it is to be used. If satisfactory reproduction is to be obtained, equalization of the pickup response characteristics should be provided.

An example of the need for equalization of this type is the crystal cartridge used to reproduce constant amplitude recordings having a 500 cycle turnover frequency. A response characteristic similar to that of Fig. 47 is necessary. It may be obtained by using the accompanying equalizing network.

Section 13

POWER SUPPLIES

1. The vacuum tubes in electronic equipment require voltages for their screen, plate and filament circuits. Filament circuits require low voltages at high currents. Either alternating or direct current may be used for filament supply depending upon the types of tubes employed. Filament voltages are obtained from batteries, generators, dynamotors or step-down transformers operating from the a-c power line. The filament source is generally referred to as the A supply.

The plate and screen circuits require d-c voltages. These voltages are obtained from batteries, generators, dynamotors, vibrator supplies, and transformers-rectifier supplies operating from the a-c line. In vibrator and transformer type supplies, rectifiers and filters are used to produce nearly pure d-c. before application to plate and screen circuits. These supplies are all referred to as B supplies.

In addition to A and B voltages, other potentials are sometimes required to operate electronic equipment. When a source of fixed grid-bias voltage is required, it is obtained in the same ways as those used to secure plate and screen voltages. It may be secured from the plate and screen supply or from a separate supply referred to as a C supply.

2. **Voltage Regulation.**—The output voltage of a power supply usually decreases as the current drawn from the supply increases. The term used when referring to this change in supply voltage, with variations in load current, is "voltage regulation". In electronics the voltage regulation of a power supply is usually stated as the difference between the no-load voltage and the full-load voltage expressed as a percentage of the no-load voltage. Thus if the output voltage of a power supply is 500 volts with no load and drops to 400 volts at full load, the voltage regulation is said to be 20 percent.

3. **A-C Power Supplies.**—The most common type of power supply used with electronic equipment utilizes the a-c power

line as an input source. In this type of supply, the a-c line voltage is applied to the primary of a transformer which steps up the voltage to a suitable value. The output of the transformer is applied to a rectifying system and then to a filter. The filter removes a-c ripple present in the output of the rectifier system. A bleeder or voltage divider is usually provided after the filter. The voltage divider makes it possible to obtain a variety of plate, screen or grid-bias voltages from the same supply. The power transformers used in these supplies usually have several secondary windings. One winding is used to obtain stepped-up voltage for plate and screen supply as described above. Other windings provide stepped-down voltages for the filament circuits.

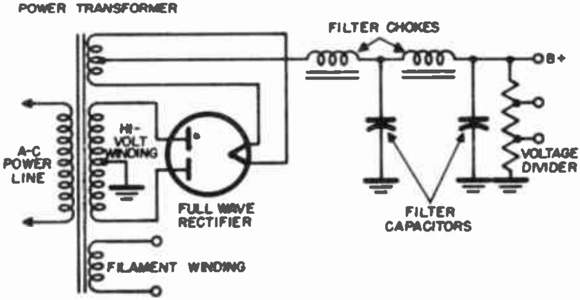


Fig. 1.—Typical a-c operated power supply circuit.

A typical a-c power supply circuit is shown in Fig. 1. It consists of a power transformer with plate and filament secondary windings, a rectifier circuit, a filter and a voltage divider.

4. **Rectifiers.**—Vacuum tube and dry metal rectifiers are generally used in power supplies for electronic equipment. High vacuum, mercury vapor and cold cathode vacuum tubes are employed. Dry metal rectifiers are used in small power supplies such as those used in receivers.

High vacuum rectifiers are used in power supplies having rated full-load currents of less than 250 millamperes. They are suitable for rectifying a wide range of voltages. However, their high internal resistance limits their use to applications where comparatively high internal voltage drop is not objectionable. High vacuum rectifiers possess several advantages which have made them very popular for use in low power circuits. Chief among these is the fact that they can stand considerable abuse, that their filaments are not easily damaged by short overloads, that they have a relatively high inverse peak voltage rating, and that they do not generate r-f interference.

Mercury vapor rectifiers have an internal voltage drop of approximately 15 volts which remains almost the same at all load currents. Thus they give excellent voltage regulation and are very efficient in high current applications. Their use has been limited, in many types of equipment, because of the r-f interference which they often produce. This interference is minimized by connecting r-f choke coils in their plate leads.

The cold cathode rectifier has the advantage of not requiring filament current. Its high internal voltage drop and low current capacity limit its use to small equipment in which the elimination of the rectifier filament source is desirable.

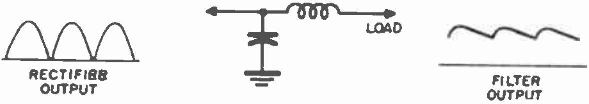


Fig. 2.—Capacitor input filter.

The most popular type of dry contact metal rectifier for use in electronic equipment is the selenium rectifier. Types are available for use in low, medium and high voltage supplies. Their important advantages are long life, low internal voltage drop and the fact that no filament voltage is required.

5. Filters.—The output of a rectifier system is pulsating direct current. This pulsating d.c. is usually thought of as d.c. with a.c. superimposed upon it. It cannot be applied to grid and plate circuits until the a-c component has been removed. This is accomplished by passing the pulsating d.c. through a suitable filter network. Such a network consists of a number of chokes and capacitors. Two types of filter networks, choke-input and capacitor-input, are generally used for this purpose. In some low current applications, resistors are substituted for chokes. Filters composed of resistors and capacitors are known as RC power filters.

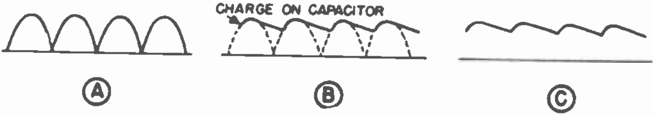


Fig. 3.—Action of filter capacitor.

6. Capacitor-Input Filter.—A single capacitor-input filter consists of a capacitor connected across the output of the rectifier, followed by a choke coil in series with the load as shown in Fig 2. The choke consists of a large number of turns of wire wound over a laminated iron core. Its purpose is to oppose current pulsations and produce a smoothing effect on the output of the rectifier. When the rectifier a.c. is approaching peak value, the capacitor charges as shown in Fig.

2. After the peak voltage as been reached, the rectifier output voltage begins to decrease. As the voltage decreases the capacitor, which has been charged at the higher peak voltage, begins to discharge, supplying current to the load. The action of the filter is illustrated in Fig. 3. A shows the output of the rectifier. The capacitor charges on the peaks and discharges in the intervals between them. As the capacitor discharges the current drops off slowly. This decrease in current is opposed by the inductance of the choke, which minimizes it and helps the capacitor to retain most of its charge. When the next peak occurs, the capacitor charges as before and the same action reoccurs. The output waveform of the filter is shown in Fig. 3C. Most of the a-c component of the rectifier output has been removed.

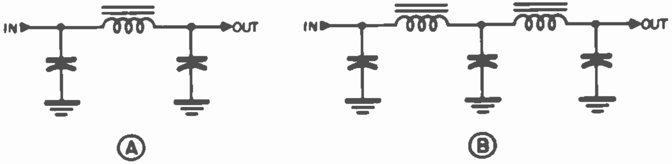


Fig. 4.—Single and dual section capacitor input filters.

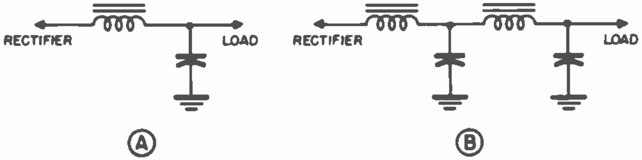


Fig. 5.—Single and dual section choke input filters.

If additional filtering action is desired, a second capacitor may be added after the choke as shown in Fig. 4A. To secure even greater filtering additional filter sections may be added as shown in Fig. 4B. A two section filter is suitable for most purposes although occasionally three or more are used.

7. **Choke-Input Filter.**—A choke input filter consists of a series choke followed by a capacitor connected across the load, as shown in Fig. 5A. As the rectifier output voltage varies from zero to its peak value, the choke opposes changes in current. This opposition results in a decrease in current fluctuations and greatly reduces the ripple current at the output of the filter. The capacitor charges during voltage peaks and discharges during the interval between them producing a further filtering effect. In this type of filter, the capacitor must charge through the choke during voltage peaks. Since the choke opposes changes in current flow, it tends to

limit this charging current so that the capacitor cannot charge to the full rectifier peak voltage as it would if it were connected directly across the rectifier output.

In the capacitor-input filter the capacitor charge approaches the peak voltage output of the rectifier, and for small output currents the filter output voltage is approximately equal to the peak rectifier output voltage. However, as the load current increases the capacitor must supply more current to the load, and the charge across it can no longer reach the peak voltage value. As a result, the filter output voltage falls as the load current increases. In a choke-input filter the choke limits the maximum charge on the capacitor to approximately the average rectified a-c voltage. Consequently, the output voltage of the choke-input filter is lower than that of the capacitor-input filter. In addition, the output voltage from this type of filter remains more constant with load current changes than does the output voltage of the capacitor-input filter. Capacitor-input filters are only satisfactory in applications where good regulation is not required or where the load current remains substantially constant, while choke-input filters are used in applications where load conditions vary and good voltage regulation is desirable.

8. The Input Choke.—The purpose of the input choke is to maintain the current through the filter as nearly constant as possible. In addition, it prevents the d-c output voltage from becoming greater than the average value of the a-c voltage at the input of the rectifier. There is a minimum inductance value below which the choke cannot accomplish its purpose. This minimum inductance has been termed "critical inductance". If the inductance of the choke is less than this critical inductance, the voltage at its output will rise above the average value of the alternating voltage input to the rectifier. As a result, the capacitor, following the choke, will charge to a value greater than the average value of the alternating voltage. Under these conditions, the filter will tend to act as a capacitor-input filter with resultant poor regulation and high peak current.

For a ripple frequency of 120 cycles, which is obtained when a full-wave rectifier is used with 60 cycle power, the value of critical inductance in henries can be approximated by dividing the load resistance of the filter by 1000. The load resistance is equal to the output voltage in volts divided by the output current in amperes. For ripple frequencies other than 120, the critical inductance may be found by multiplying the critical inductance obtained above by the ratio of 120 cycles to the ripple frequency in question.

In practice, the inductance of the input choke is usually made twice the critical value. This, called the optimum value, results in greater filtering while further increases in inductance have a negligible effect.

9. Swinging Chokes.—The optimum value of the input inductance of a filter varies with the load resistance. When the current drawn from the supply is low and the load resistance is high, the optimum inductance is high. As the current drawn by the load increases and the load resistance decreases, the optimum inductance also decreases. It is possible to design a choke whose inductance varies inversely with the current flowing through it so that both of the above conditions can be satisfied, Such a choke requires much less materials than a choke having a constant inductance high enough to satisfy the condition of minimum load current. A typical choke of this type might have an inductance of 20 henries at low currents falling to 5 henries at maximum load current. These chokes are called swinging chokes. The inductance values for a swinging choke may be determined by finding the optimum inductance at minimum load and the optimum inductance at maximum load using the method described in the preceding paragraph.

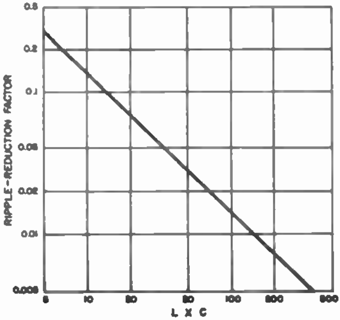


Fig. 6.—Ripple-reduction factors for choke input filters, 120 cycle ripple, L in henries and C in microfarads.

10. Choosing Values of L and C.—To determine the value of inductance and capacitance necessary to secure a desired percentage of ripple in the output of a choke-input filter, the value of the optimum inductance should first be determined using the method previously described. The value of capacitance may then be determined by dividing the product of the optimum inductance and the desired ripple percentage into 100. This will give an approximation close enough for practical purposes when the ripple frequency is 120 cycles. Thus if the optimum inductance is found to be 10 henries and the desired ripple percentage is 2 percent, the capacitance required will be 10 x 2 divided into 100 or 5 microfarads. For lower ripple frequencies, higher values of inductance and capacitance are required. For a 60 cycle ripple frequency, the required capacitance can be approximated by determining the optimum inductance and multiplying it by the desired ripple percentage and dividing the product into 400.

To obtain better filtering, additional filter sections may be added. The effect of an additional filter section may be determined by finding the ripple-reduction factor corresponding to the product of the inductance and the capacitance of the additional section in the chart of Fig. 6. The ripple in the output of the first filter section is then multiplied by the factor to find the ripple in the output of the additional section. Thus if the ripple in the output of the first section is 10 percent and the product of the inductance and capacitance in the additional section is 10, the ripple-reduction factor is 0.15. Multiplying the ripple in the output of the first section by 0.15 gives a ripple in the output of the additional section of 1.5 percent.

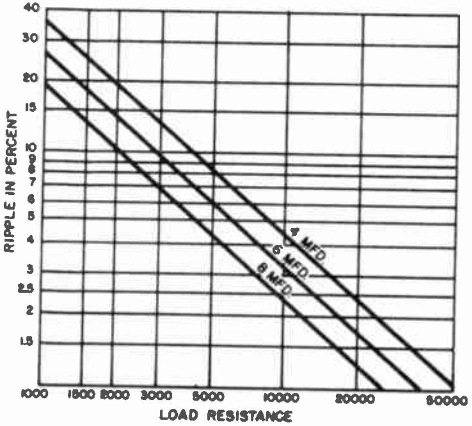


Fig. 7.—Percentage ripple across input capacitor, 120 cycle ripple frequency.

The capacitance required to approximate a desired percentage ripple with a filter consisting of a capacitor only may be determined from the curves of Fig. 7. The effects of additional filter sections may be determined in the same manner used to find the output ripple percentage of additional filter sections added after a choke-input filter.

Several other factors must be considered when choosing filter components. If the power supply is to be used with an audio-frequency or other low frequency amplifier, the reactance of the output filter capacitor must be much smaller than the impedance in the amplifier circuits. Output capacitor values greater than 8 mfds. are usually required to fulfill this requirement. In selecting filter components care should be taken to avoid resonance at the ripple frequency. If the product of the capacitance in microfarads and the inductance in henries of each individual filter section in a 60 cycle full-wave supply exceeds 3.5, this difficulty will be avoided. For 60 cycle halfwave rectification the product should exceed 25.

11. **Resistance-Capacitance Filters.**—In certain applications a resistance may be substituted for the choke in a filter. A resistor may be used when the current is very small or when a voltage dropping and filtering action may be combined. The ripple voltage across the output of a resistance-capacitance filter may be found if the ripple across its input is known by finding the ripple-reduction factor from the curves of Fig. 8 and multiplying the input ripple percentage by the factor.

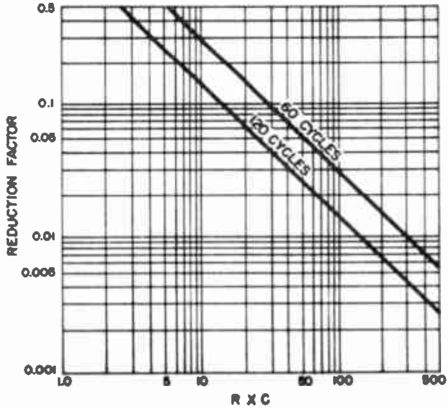


Fig. 8.—Ripple-reduction factors for RC filters, R in thousands of ohms and C in microfarads.

12. **Bleeder Resistors.**—A bleeder resistor is usually required across the output of a power supply. Bleeder resistors perform several functions. When the rectifier is of the filament type and the tubes operating from the supply are of the indirectly-heated type, the rectifier will begin to pass current before the other tubes. During the period before the load begins to draw current, the bleeder resistor places a load on the supply and prevents a high-voltage surge which might damage or shorten the life of components. In equipment where the load current varies from very small to large values, the bleeder improves the voltage regulation. In addition, the bleeder resistor discharges the filter capacitors after the supply has ben turned off, eliminating the danger of shock should it be necessary to repair or adjust the equipment.

13. **Voltage Dividers.**—Voltages less than the full output voltage of a power supply are often required in electronic equipment. These lower voltages are obtained from a voltage

divider resistor. A voltage divider may consist of a tapped resistor or two or more resistors in series. A typical voltage-divider system is shown in Fig. 9. The voltages available at the taps are dependent upon the supply voltage, the resistances of the various portions of the voltage divider, and the current drawn from the taps. If the current drawn from one tap changes, the voltages at all of the other taps will change. The currents drawn from all of the taps must therefore remain constant if the divider is to function properly. To design a voltage divider the voltages and currents required at each tap must be known. In addition to acting as a voltage divider, the resistor will draw current and act as a bleeder. In the arrangement of Fig. 9, the overall supply voltage is 450 volts and taps to supply 120 volts at 15 milliamperes and a bias voltage of 50 volts negative are provided. The value of resistor R1 is determined by finding the toal current through it and the voltage drop required across it. The voltage through R1 is equal to the sum of the bleeder current (15 ma.) and the current drawn from tap one, or 35 milliamperes. Applying Ohm's Law, resistor R1 should have a resistance of 8000 ohms.

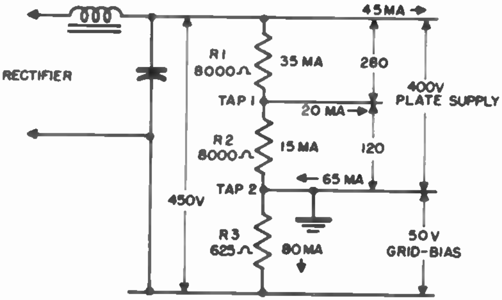


Fig. 9.—Voltage-divider system.

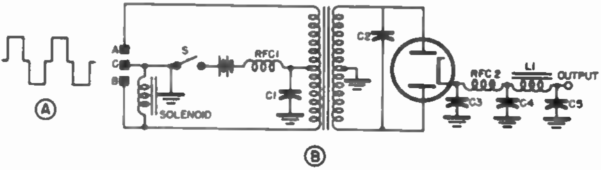


Fig. 10.—Simplified circuit of a vibrator supply.

Only the bleeder current passes through R2, so that its value must be 8000 ohms to secure a 120 volt drop. The return current from the high voltage end of the bleeder, the current from tap one and the bleeder current pass through R3. Therefore it must have a resistance of 625 ohms to secure a drop of 50 volts.

14. **Vibrator Supplies.**—Vibrator supplies are used to secure high voltage d-c from low voltage d-c sources. A simple vibrator supply circuit is shown in Fig. 10. It consists of a battery which provides a source of low voltage, direct current; a single-pole double-throw magnetically operated switch; a step-up transformer; and a rectifier and filter circuit. When switch S in the primary of the transformer is closed, the solenoid draws switch arm C down closing contact B. This completes the circuit through the lower half of the transformer primary and current flows through it. This action also shorts the solenoid winding, releasing the switch arm and permitting it to contact A, completing the circuit through the upper half of the transformer primary. Current flows through the upper half of the primary until the solenoid, which is no longer shorted, draws the switch arm down to contact B. This switching cycle keeps repeating as long as switch S is closed. This switching action produces an alternating current, in the primary of the transformer, with a wave shape as shown at A in Fig. 10. The a.c. flowing in the primary of the transformer induces a stepped-up voltage in the secondary of the transformer which is rectified and filtered in the usual manner.

Capacitor C2 in Fig 10 is called a timing capacitor or "buffer". When contact between the vibrator reed and one of the fixed contacts is broken, the magnetic field around the primary of the transformer collapses. This collapsing field induces high instantaneous voltages in the transformer secondary and results in sparking at the vibrator contacts. This condition is likely to cause insulating breakdown in the transformer and the contact sparking greatly reduces the life of the vibrator. Capacitor C2 serves to reduce these effects by absorbing the current surges. Its value is quite critical and must be carefully chosen.

Considerable r-f interference is generated in vibrator supplies. To prevent it from being radiated or passing into r-f circuits, choke coils RFC1 and RFC2 are employed. Additional suppression is obtained by connecting capacitor C1 from the primary centertap to ground.

The magnetically operated switch used in this type of supply is called a vibrator. Its construction is illustrated in Fig. 11. The coil is mounted above the vibrator contacts. The moving arm or reed is mounted between the fixed contacts and has moving contacts on each of its sides. On the upper end of the reed a bar of magnetic metal, called the armature, is mounted. The changing field around the coil causes the bar to vibrate from side to side alternately closing and opening each set of vibrator contacts. The fixed contacts are mounted so that they may move slightly to improve vibrator action and minimize contact wiping which results in contact wear. Vibrators are usually designed to operate at frequencies in excess of 100 c.p.s.

The vibrator supply described above utilizes an interrupter type vibrator and requires a vacuum tube rectifier in order to produce d.c. from the transformer output. Another type of vibrator known as a self-rectifying type does not require a separate rectifier. The circuit of this type of vibrator is illustrated in Fig. 12. Two sets of contacts are provided. One set performs the interrupting action in the primary while the other is connected in the transformer secondary. The primary and secondary contacts are synchronized so that when the voltage across the secondary is reversed, by the action of the primary contacts, the secondary contacts are switched to produce d.c. Although more compact, the self-rectifying vibrator

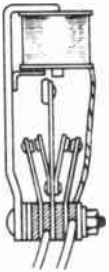


Fig. 11.—Vibrator construction.

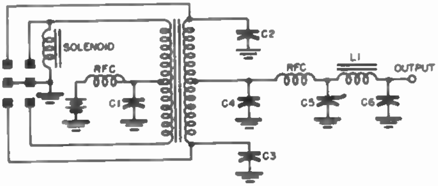


Fig. 12.—Vibrator supply employing self-rectifying vibrator.

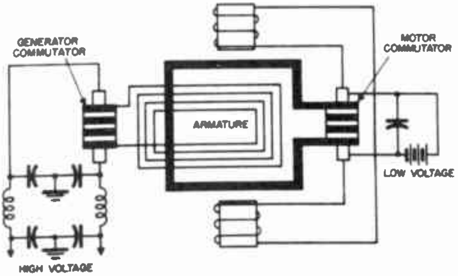


Fig. 13.—Diagram of dynamotor.

is more expensive and less dependable than the interrupter type.

15. **Dynamotors.**—Dynamotors are used to obtain high voltage d-c from low voltage d-c sources. A dynamotor consists of a motor and a generator constructed as a single unit. One field winding is used for both the motor and generator sections. Tthe rotating windings of the motor and the generator are wound on the same armature but are provided with separate commutators. The manner in which the various windings are connected is illustrated in Fig. 13. The motor armature winding consists of a small number of turns of heavy wire. The field winding is connected in parallel with the motor winding in the same way the field winding in an ordinary shunt-wound motor is connected. The generator armature winding consists of a larger number of turns than the motor armature winding and is wound with smaller size wire. A filter is provided for the high voltage output at the generator commutator. This filter is a combination audio and r-f filter. A capacitor is connected across the motor armature to suppress r-f interference resulting from commutator sparking.

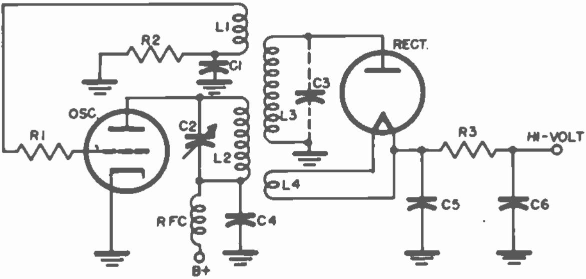


Fig. 14.—R-f power supply circuit.

16. **R-F Power Supplies.**—Certain types of electronic equipment, such as television receivers and oscilloscopes, require very high voltages at low currents. These voltages are sometimes produced by conventional transformer type supplies operating from the 60 cycle a-c power line. A conventional supply producing several kilovolts is quite bulky and expensive and the r-f high voltage supply has proved more satisfactory in many applications. This type of supply is lighter, more economical and less dangerous than the conventional 60 cycle supply.

The circuit of a typical r-f power supply is shown in Fig. 14. It consists of an r-f oscillator, a tuned transformer, a rectifier, and a filter network. The oscillator is of the tuned-plate grid-feedback type. The oscillator frequencies used range from

30 to 400 kc. The plate circuit of the oscillator is tuned to the desired operating frequency by means of variable capacitor C2. Feedback to the grid circuit is obtained by means of L1 which is coupled to plate coil L2. Grid-leak bias for class C operation is developed across R2-C1. Plate supply voltage for the oscillator is obtained from the plate supply used with the other circuits in the equipment or from a separate supply. C4 and RFC act as a decoupling filter to prevent r-f from being fed into the plate supply. Coil L3 serves as the secondary of a tuned voltage-step-up transformer. It has many more turns than L2 and is wound in the form of a number of pies to reduce distributed capacity and minimize insulation problems. In order to secure the highest possible L/C ratio, L3 is tuned by means of distributed capacitance only. A high L/C ratio is necessary in order to develop the highest possible voltage across L2. Filament voltage for the rectifier is obtained from winding L4 which consists of a few turns of heavy wire wound next to the high voltage secondary of the transformer. C6-R2-C5 filter the output of the rectifier. Supplies similar to that of Fig. 14 are capable of generating voltages as high as 10 kilovolts at currents up to 1000 microamperes. Using more complex circuits, it is possible to generate potentials in excess of 30 kilovolts using the same principles.

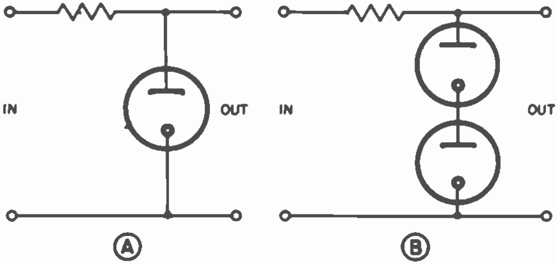


Fig. 15.—Gaseous voltage-regulator circuits.

17. Voltage Stabilization.—In order to perform properly many circuits require supply voltages which remain substantially constant regardless of load conditions. One method of stabilizing the output of a power supply is by means of gaseous voltage-regulator tubes. The gaseous voltage-regulator tube maintains a constant voltage drop across its terminals when provided with a suitable series-limiting resistor. Gaseous voltage regulators are designed to operate at specific voltages and are manufactured in a number of sizes. They may be connected singly or in series across the potential source. A series lmiting resistor is provided as shown in Fig.

15. The internal resistance of a gaseous-regulator tube decreases as the voltage across it increases. Thus as the supply voltage rises, the current through the regulator and the limiting resistor increases. This increases the drop across the resistor and maintains a contant voltage across the regulator tube. If the voltage decreases, the current drawn by the regulator tube decreases and the voltage drop across the series-limiting resistor is lower, again maintaining a constant voltage across the regulator tube.

Section 14

ANTENNAS AND TRANSMISSION LINES

PROPAGATION OF RADIO WAVES

1. The design and function of antennas is influenced by the nature and frequency of radio waves, and by the movement or *propagation* of radio waves between a transmitting antenna and receiving antenna. Knowledge of the characteristic behavior of waves during propagation permits more effective use of certain types of antennas for certain bands of frequencies.

2. Wavelength vs. Frequency.—Radio waves travel at a constant speed or *velocity* of about 186,000 miles per second, which is equal to about 300,000,000 meters per second. Since the velocity of any radio wave is constant regardless of its frequency, the relation between wavelength and frequency is expressed by the equation:

$$\lambda = \frac{300,000,000}{f}$$

where λ is in meters
f is in cycles per second

3. Frequency Bands.—Radio frequencies extend from about 30 kilocycles (30,000 cycles) to well over 30,000 megacycles (30,000,000,000 cycles). Since various frequencies within this wide range behave differently during propagation, it is convenient to divide them into groups or *bands* of frequencies for purposes of standardizing their identification.

Frequency Bands:	**Range of Frequencies:**
Low-frequency [l-f]	30 kc to 300 kc
Medium-frequency [m-f]	300 kc to 3000 kc
High-frequency [h-f]	3 mc to 30 mc
Very-high-frequency [v-h-f]	30 mc to 300 mc
Ultra-high-frequency [u-h-f]	300 mc to 3000 mc
Super-high-frequency [s-h-f]	3000 mc to 30,000 mc

Channels for f-m—between 88 and 108 mc—are in the very-high-frequency [v-h-f] band. Channels for television between 44 and 88 mc, and between 174 and 216 mc—are also in the v-h-f band. In practice, radio waves in the super-high-frequency [s-h-f] band are often known as *microwaves,* and identified in terms of wavelength rather than frequency.

4. Wave Energy.—All of the energy in a radio wave is evenly divided between two moving field: The *electrostatic* and the *electromagnetic.* The lines of force of the two fields are at right angles to each other in a plane which is perpendicular to the direction of travel. It is usual when discussing radio waves to describe the characteristics with reference to the *electrostatic* field.

5. Wave Polarization.—The polarization of a radio wave is determined by the plane of the electrostatic field with respect to the earth. When the plane of this field is perpendicular to the earth, the wave has *vertical* polarization; when the plane is horizontal, the wave has *horizontal* polarization. If a single wire or dipole is used to absorb energy from a passing radio wave, maximum signals are received when the position of the antenna corresponds to the polarization of the radio wave. Thus, a vertical antenna is used for the most efficient reception of vertically polarized waves, and a horizontal antenna is used for horizontally polarized waves. When both the transmitting and receiving antennas are located close to the ground, waves with vertical polarization provide a stronger signal than do equivalent waves which are horizontally polarized. When the transmitting antenna is several wavelengths above ground, waves with horizontal polarization provide a stronger signal *close to the earth* than is possible with equivalent waves which are vertically polarized. Except for radio waves in the very-high- and ultra-high-frequency bands, the original polarization of a radio wave is maintained during propagation.

6. Wave Reflection.—The phenomenon of reflection is an important characteristic of radio waves. As with light waves, the efficiency with which reflection of radio waves occurs depends upon the type and composition of the reflecting surface or object. Large, smooth, metal surfaces of good electrical conductivity are efficient reflectors. The surface of the earth is a good reflector of radio waves, particularly of those waves which are incident at small angles from the vertical or perpendicular. Layers of ions and electrons—which exist from 30 to 200 miles above the earth—also reflect radio waves in certain frequency bands.

7. Wave Refraction and Diffraction.—In passing through gaseous or ionized layers of the upper atmosphere, the direction of movement of radio waves is often changed obliquely; usually this refraction is downward in the vertical plane. Radio waves sometimes graze the edge of a large object in passing, which causes a diversion of part of the energy resulting in a bending or diffractive effect. The principal source of diffraction is the earth itself; and the effect is mainly confined to radio waves in the ultra-high- and super-high-frequency bands.

8. Modes of Propagation.—There are two principal ways in which radio signals travel between a transmitting antenna and a receiving antenna: (1) by means of a *ground wave,* which moves in close proximity to the earth and follows a direct or almost-direct path between the two antennas, and (2) by means of *sky waves,* which travel upward to the ionosphere region above the earth and are then reflected or refracted so that they return to earth. These two types or *modes* of propagation are shown in Fig. 1, although actual radiation takes place in *all* directions from an antenna. The ground wave is of practical use only within a limited distance from the transmitting antenna. Sky waves provide a means of long-distance radio transmission by utilizing certain reflecting layers of the ionosphere above the earth.

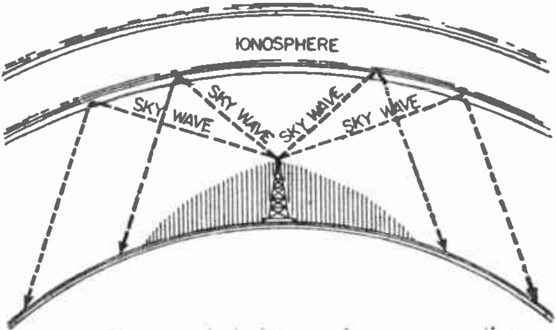


Fig. 1 The two principal types of wave propagation.

9. Ground Waves.—The part of the radiated energy which travels along or very near the surface of the earth, whether land or sea, is rapidly attenuated or decreased in strength. The rate of attenuation is proportional to the frequency of the wave and, accordingly, this type of ground wave is used chiefly by transmitters operating in the low-frequency and medium-frequency bands (from 30 to 3000 kc). The reception of broadcast stations during the daytime is entirely by means of this ground wave. Another type or component of the ground wave—known as the *direct wave*—travels directly from the transmitting antenna to the receiving antenna, providing that both antennas are within line-of-sight or optical distance of each other. Use of the direct wave is largely confined to operating frequencies higher than about 50 megacycles, at which frequencies the wave normally is not attenuated by the surface of the earth—although it may be refracted in such a manner that transmission is effectively extended *beyond* the line-of-sight or optical distance between two antennas.

10. Sky Waves.—Energy radiated upward—at any angle, or direction, above the horizon—continues on its path through space until it reaches an ionized region, known as the *ionosphere,* that exists from about 30 to 200 miles above the earth. There, many of the sky waves are reflected or refracted back toward the earth (Fig. 2) and produce signals at a receiving antenna which may be at a considerable distance from the transmitting antenna. Some of the sky waves may succeed in penetrating part or all of the ionosphere, and these waves are absorbed or otherwise lost for radio transmission purposes. This and the more important effect of reflection or refraction is due entirely to the nature of the ionosphere.

11. The Ionosphere.—The region of high atmosphere above the earth which permits the reflection or refraction of sky waves is actually composed of a number of distinct *layers* of free electrons (Fig. 3). These ionized layers are of different densities and accordingly exhibit different effects on sky waves of different frequencies. The density or amount of ionization is dependent upon ultraviolet radiation from the sun, which is sufficiently intense to disrupt the atoms in the air at such heights. Proceeding upward through the stratosphere and ozone region, the first layer of pronounced ionization—known as the *D region*—is encountered between heights of about 30 miles to 50 miles. This layer is important for long-distance transmission of waves in the medium- and low-frequency bands during the daylight hours, because such waves are then effectively reflected by the *D region*. Compared to higher layers, however, the amount of ionization is not sufficiently great to influence the paths of high-frequency waves. At heights between 50 miles and 90 miles lies another distinct layer of ionization—known as the *E region*—which provides reflection of radio waves at frequencies up to about 10 megacycles. Primarily useful during daylight hours, the *E region* provides excellent radio transmission at ground distances up to about 1500 miles or more. Between heights of about 100 miles and 200 miles above the earth is an important region of ionization, known as the *F region*. During daylight hours when the sun is high, there are *two* layers within the *F region*—the F_1 layer and the F_2 layer—whose exact height is widely variable, depending upon the season and the time of day. At night, the combined *F region* is between the approximate heights of 170 miles and 250 miles. This region is responsible for the reflection or refraction of radio waves in the high-frequency band (from 3 to 30 megacycles), providing long-distance trans-

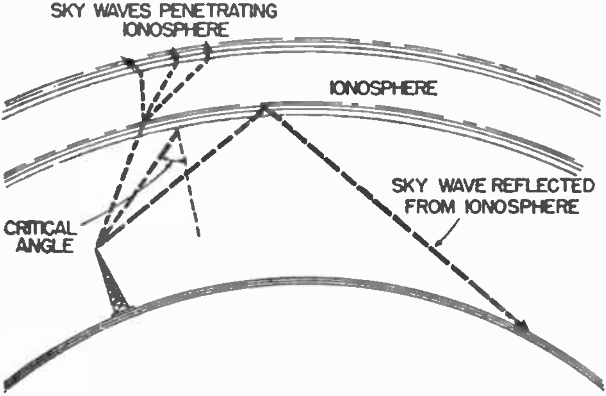


Fig. 2 Influence of ionosphere on sky wave propagation.

mission during night or day. It is important to note that the layers of ionization are subject to regular variations in height and ion density, from month to month, season to season, and year to year. Various solar and magnetic disturbances also produce continual changes in these important layers. Other, additional ionized layers—of a minor and usually spurious nature—appear occasionally, due to disturbed conditions in the upper regions of the atmosphere. Most prevalent of these is a layer at the height of the *E region*—known as the *sporadic E layer*—which often is so intensely ionized and continuous in occurrence as to provide excellent reflection of high-frequency radio waves. Although some of these transient layers provide good reflection of certain radio waves, many of the layers are just as likely to absorb waves. Because of the varying effect of the important D, E, and F regions plus the occasional minor layers of ionization, radio waves act differently at different frequencies, at different times of day, at different seasons of the year, and over different places on the surface of the earth.

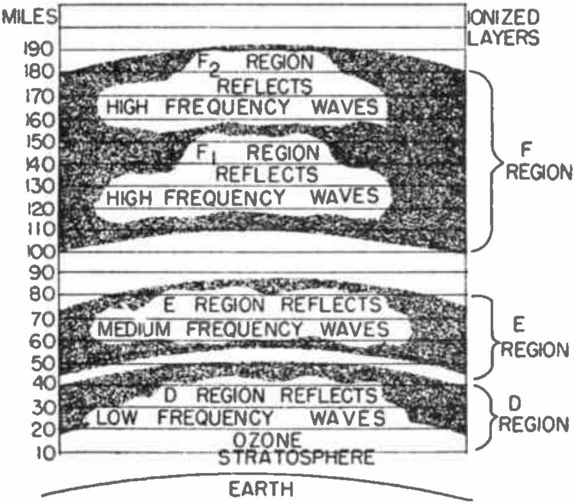


Fig. 3 Ionized reflecting layers above the earth.

12. Skip Distance.—The vertical angle which a radiated sky wave makes with a tangent to the earth is known as the *wave angle* or angle of radiation. The smaller this angle, the less refraction is required in the ionosphere to bring the wave back to earth, and the greater will be the distance between the transmitting antenna and the point where the wave returns to earth. As the wave angle becomes larger and larger (approaching the vertical) a *critical angle* is reached (Fig. 2) beyond which the sky wave will *not* be reflected or refracted back toward the earth but will penetrate and be absorbed by the ionosphere. Radiation at the critical angle represents the shortest possible ground distance over which transmission by normal ionospheric reflection or refraction can be accomplished. The region between the end of the useful ground wave and the beginning of wave reception due to ionospheric reflection or refraction is known as the *skip zone* (Fig. 4) within which region *signals are not normally received by any mode of propagation.* The entire distance between the transmitting antenna and the beginning of ionospheric wave reception is known as the *skip distance.* Since the extent of the useful ground wave is usually small compared to the *skip distance*, often the *skip zone* and the *skip distance* are almost equal. The higher the frequency of the sky waves, the greater is the *critical angle* and, therefore, the greater is the *skip distance.* When the sun is directly overhead, ultraviolet radiation produces the greatest density of the ionosphere, thus decreasing the *skip distance* at any given frequency. Conversely, the *skip distance* is greater at night than in the daytime. Seasonal changes in the ionosphere position and changes resulting from sunspot activity also are important factors in determining the *skip distance.*

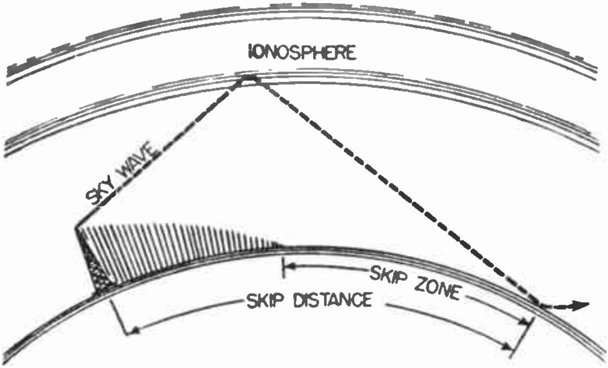


Fig. 4 Skip zone and skip distance.

13. Multihop Transmission.—Sky waves, after reflection or refraction by the ionosphere, return to earth *at an angle* which corresponds to the angle at which the particular waves strike the ionosphere. The waves may be reflected upward by the earth, travel again to the ionosphere, and again be reflected or refracted—returning to earth at a point far distance from the original radiating antenna. This may be repeated many times (Fig. 5), until the radio waves are absorbed or severely attenuated. By means of this process—known as *multihop transmission*—radio signals are propagated over enormous distances to provide extremely long-distance communication.

14. Fading.—The random rise and fall of intensity of a received radio signal—known as *fading*—is due to interaction between different components of the same radiation which, by virtue of traveling different paths from the transmitting antenna,

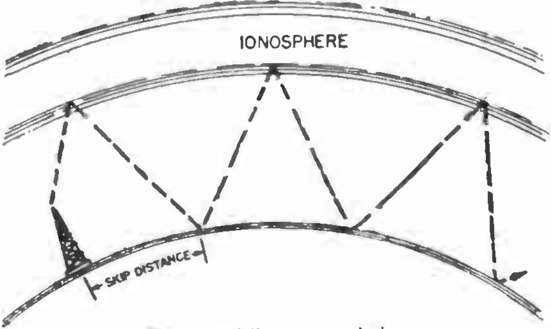


Fig. 5 Multihop transmission.

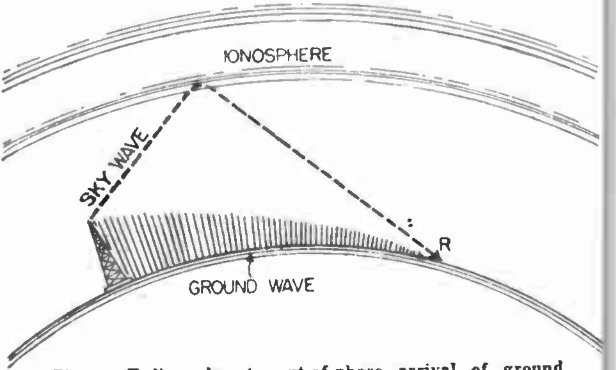


Fig. 6 Fading due to out-of-phase arrival of ground wave and sky wave.

arrive at the receiving antenna with varying phase relations hat tend to either cancel or reinforce each other. Since there s a continual change in the condition of the ionosphere, at one ins ant the components of the received wave may reinforce each o ier, while at a later instant their phase relation may be such that ieir combined effect produces a weak signal. When a strong gr und wave is radiated by an antenna (Fig. 6), at a certain distan : R it may be possible to receive both the ground wave and the sky wave; since these waves travel different paths, they are likel to be out-of-phase with each other and thus cause fading at poir R. Another cause of fading is the interaction of two or more omponents of the sky wave (Fig. 7), which may arrive at point R with varying phase differences and thus produce a signal at the receiver having continuously varying intensity. Violent changes in the ionosphere caused by sunspot activity—known as ionosphere storms—also produce fading at frequencies higher than about 2 megacycles.

15. Reduction of Fading.—Objectionable fading due to propagation effects can usually be minimized by radiating signals of high power at the transmitter, and by providing a receiver with automatic volume control. A better method used to overcome fading is known as *diversity reception.* In this system, two or more receiving antennas are spaced some distance apart but feed the same receiver. Thus, when fading occurs in one antenna circuit, another circuit provides a signal of sufficiently high intensity. The net result is an almost-continuous signal devoid of fading effects.

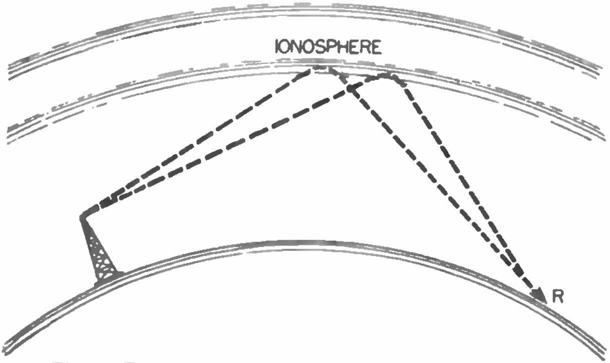


Fig. 7 Fading due to out-of-phase arrival of two sky waves.

BASIC PRINCIPLES

16. A radio antenna can be used either for radiating electromagnetic energy into space or for collecting or receiving electromagnetic energy from space. The characteristics of a given antenna are the same when it is used for either purpose, since the equivalence is an extension of the reciprocity theorem which applies to all electric circuits. Although much of the information on basic principles which follows is concerned with energy radiation, every type of transmitting antenna has a reciprocal function as a receiving antenna. Practical antennas fall into one of two distinct classes: (1) elevated or *Hertz* antennas, which operate some distance above the ground in either a horizontal or vertical position, and (2) vertical grounded or *Marconi* antennas, which operate with one end grounded in a vertical position. Elevated or *Hertz* antennas are used at frequencies higher than 2 megacycles, while vertical grounded antennas are restricted to use at fre-

quencies below 2 megacycles. The most elementary form of he *Hertz* antenna is the half-wave dipole in space.

17. Half-wave Dipole.—The *length* of a half-wave dipole etermines the resonant wavelength (or frequency) of the anten a. When properly excited by an RF signal of this resonant wa elength, standing waves of voltage and current are produced al ng the half-wave dipole (Fig. 8). There is a high voltage at e ch end of the dipole, low voltage at the center; there is low cur ent at each end of the dipole, high current at the center. Voltage nd current are inversely proportional. The maximum point o a standing wave is called a *loop;* and the minimum point is ca led a *node.* The presence of standing waves makes it possibl to build up strong electrostatic and electromagnetic fields, and ra iation of energy takes place at the resonant wavelength (or requency) of the antenna. This radiation is maximum in any direction perpendicular to the dipole, and is minimum in either direction lengthwise to the antenna as shown in Fig. 9. Howe er, the directional nature of this radiation is usually indicated raphically by means of *field patterns,* which are polar diagrams epresenting the field strength in either the horizontal plane (Fig. 10) or the vertical plane (Fig. 11) for a fixed antenna in space. erfect field patterns are difficult to obtain in practice, however because radio antennas are operated relatively close to the arth and the actual pattern is sometimes distorted and influence by various ground effects. These effects become of less import nce at shorter wavelengths (at higher frequencies).

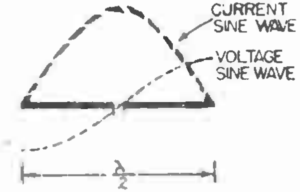


Fig. 8 Current and voltage distribution along a half-wave dipole.

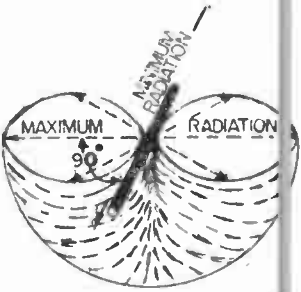


Fig. 9 Cross section of surf e pattern for a half-wave dip e in space (based on horizon and vertical field patterns dipole).

18. Electrical Length.—At resonant frequencies below a out 30 megacycles, the physical length of a half-wave dipole orresponds to its electrical length as given by the equation:

$$l = \frac{492}{f}$$

where l = length *in feet* for a half-wave dipole
f = resonant frequency *in megacycles.*

At resonant frequencies above about 30 megacycles, certain reflection effects cause the velocity of RF energy along the antenna to be always slightly less than the velocity of radio waves in free space. Accordingly, the *physical* length of a half-wave dipole is always less than the electrical length by a factor of 0.95, as given by the equation:

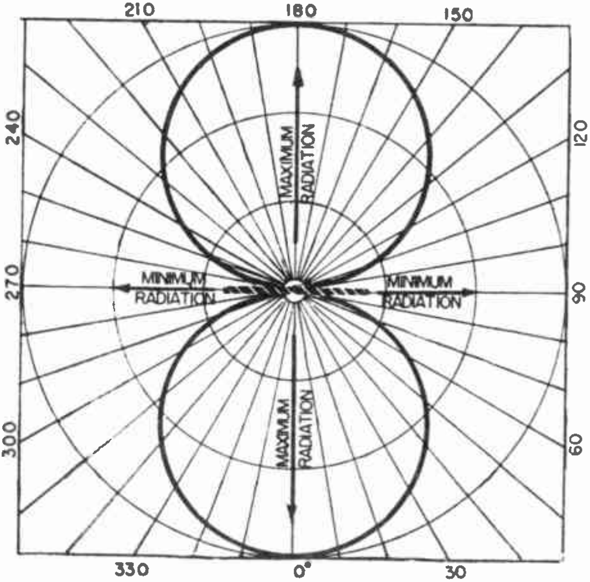


Fig. 10 Horizontal field pattern of horizontal half-wave dipole.

$$l = \frac{462}{f}$$

where l = length *in feet* for a half-wave dipole
f = resonant frequency *in megacycles.*

19. Loading.—When a dipole is slightly too short to resonate at a desired frequency, it may be effectively lengthened by inserting a sufficient amount of lumped inductive reactance at the point of highest current (Fig. 12a). When a dipole is slightly too long to resonate at a desired frequency, it may be effectively shortened by inserting a sufficient amount of lumped capacitive reactance at the point of highest current (Fig. 12c). This process is known as *loading* or lumped impedance tuning.

20. Antenna Impedance.—A half-wave dipole has a certa n impedance at every point along its length. The amount of i pedance at each point is determined by the voltage and curre t

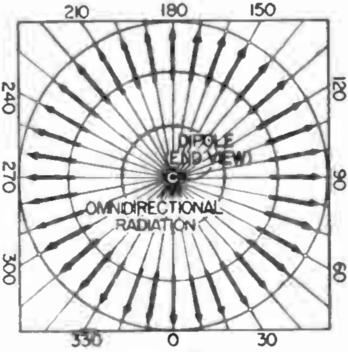


Fig. 11 Vertical field pattern of horizontal half-wave dipole.

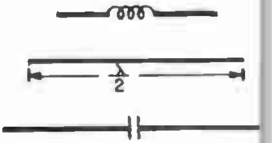


Fig. 12 Three antennas, a equal electrically to one-hal wavelength. Upper, Inductiv middle, Normal antenna without loading; lower, Ca pacitive loading to decreas length.

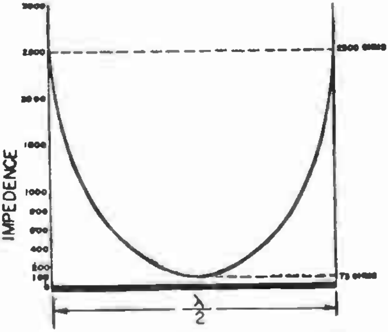


Fig. 13 Impedance along a typical half-wave dipole.

existing at that point (Fig. 13). Thus the lowest impedance c-curs where the current is highest, at the center of the dipole, nd usually is about 73 ohms. The impedance then rises uniformly toward each end of the antenna, where it is about 2500 ohms.

21. Polarization.—The position of a dipole in free space e-termines the polarization of the emitted radio waves. Th s, an antenna which is vertical with respect to the earth radiate a vertically polarized wave, while a horizontal antenna radiate a horizontally polarized wave. Similarly, the position of a receiv ng dipole should normally correspond to the nature of polarization of the desired radio waves for best reception.

22. Harmonic Resonance.—The *lowest* frequency at whic a half-wave dipole resonates is known as the *fundamental* frequency of the antenna. The same dipole could have two, three, four, five, or more standing waves on it simultaneously—representing the second, third, fourth, fifth, or higher harmonics; and thus it is possible for an antenna to resonate at integral harmonics of the fundamental frequency. The possibility of harmonic radiation can be considerably minimized, however, with proper feeding and coupling systems.

23. Long Radiators.—Another development of the basic *Hertz* antenna is the *long wire antenna*, consisting of a number of complete half-wave sections connected together and operated as a single "dipole" antenna. By the deliberate utilization of harmonic radiation, this antenna is intentionally employed at several different harmonic frequencies. An interesting property of the *long wire antenna* is that it tends to become more directional as the number of half-wave sections is increased.

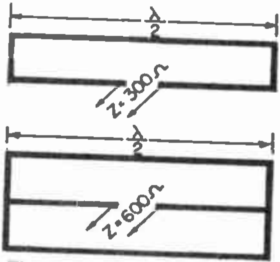


Fig. 14 Two types of folded dipoles providing high input impedance. Upper, Conventional folded dipole; lower, Three-element folded dipole.

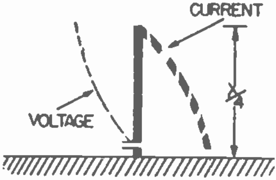


Fig. 15 Current and voltage distribution for a quarter-wave grounded Marconi antenna.

24. Wide-band Dipoles.—Television and other services require dipoles which, at resonance, transmit or receive a wide *band* of frequencies. The simplest way of obtaining this important characteristic is by constructing the dipole of relatively large diameter metal tubing. It is often more effective, however, to use a *folded dipole*, which also provides a higher impedance.

25. Folded Dipoles.—The low input impedance of 73 ohms of a single dipole is sometimes undesirable when the antenna must be fed by a transmission line with a higher impedance. A much higher input impedance—usually about 300 ohms—is provided by a folded dipole (Fig. 14a), which retains the radiation characteristics of a half-wave dipole and also responds to a wider band of frequencies. Spacing between the two parallel sections is ordinarily less than 3 or 4 per cent of the wavelength. The folded dipole behaves as two parallel dipoles, carrying equal currents in the same phase with similar reference directions. The voltage at the ends of the two dipoles is maintained equal by means of direct connections; thus the distribution of voltage along both "dipoles" is the same. Since the two "dipoles" are alike, equal currents accompany equal voltages. A three-element folded dipole (Fig. 14b) functions similarly. It provides an input impedance of about 600 ohms and thus accepts a wider band of frequencies.

26. Vertical Grounded Antennas.—Differing from all of the previously described types of elevated half-wave dipoles, these antennas have a length or vertical height of only a quarter wavelength and their operation requires a direct connection to ground. Use of the vertical grounded antenna—sometimes known as the *Marconi* antenna—is limited to the transmission of radio signals at frequencies less than about 2 megacycles. The most elementary form of the radiator (Fig. 15) consists of a vertical quarter-wave antenna which, when properly connected to ground and fed near that point of connection, transmits RF energy much in the manner of a half-wave (vertical) dipole. Current is maximum at the *base* rather than at the center of the vertical quarter-wave antenna, and current distribution is always such that current is zero at the top end of the grounded radiator. To resonate in this manner, the conducting antenna is provided with a suitable charge by the ground or by an equivalent metal structure or counterpoise. Detailed consideration of this type of radio antenna is given under heading, "Vertical Grounded Radiators."

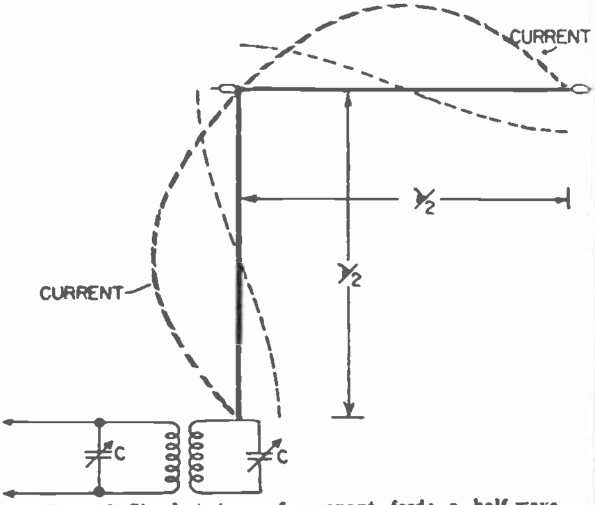


Fig. 16 Simplest type of resonant feed: a half-wave single wire with a voltage-fed antenna.

27. Field Patterns.—The variation of field strength around an antenna system is shown graphically by means of polar diagrams, known as *field patterns,* and these apply to both transmission and reception of RF energy. In the *horizontal* plane, these are simple circular charts which resemble the face of a compass with *zero* located at the center and the circumference indicated in angular degrees; computed or measured values of field strength are plotted radially. In the *vertical* plane, field strengths are somewhat similarly plotted but usually on a *semi*-circular polar chart. The resulting field pattern indicates the directivity of an antenna in the vertical plane in terms of the angle of radiation (or arrival) of radio waves with respect to the earth's surface.

28. Directivity.—The directivity of an antenna refers to the sharpness or narrowness of its field pattern in a particular plane. An antenna with a sharp pattern in the horizontal plane has good horizontal directivity. An antenna with a sharp pattern in the vertical plane has good vertical directivity. Points of the field pattern where radiation is zero are called *nulls,* and the curved section between any two nulls is called a *lobe.*

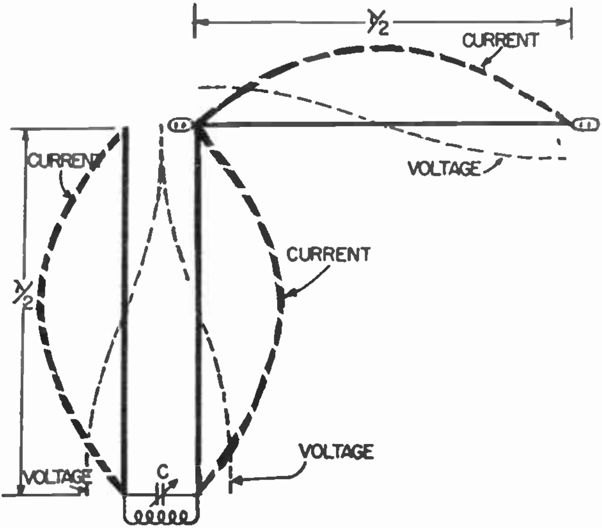


Fig. 17 Non-radiating resonant feed: a half-wave parallel wire with a voltage-fed antenna.

29. Power Gain.—This term is used to express the power *increase* of a given antenna over a standard, basic antenna—usually the half-wave dipole with the same polarization as the directional antenna under consideration. Power gain used in connection with directional antennas is usually measured in the optimum direction of the antenna system.

FEED AND COUPLING SYSTEMS

30. The process of supplying RF power to an antenna is known as *feeding* or exciting the antenna, and is accomplished by means of a suitable transmission line and coupling arrangement known as a *feed system.* The essential function of a feed system is to carry power from the transmitter to the radiating antenna with a minimum of loss.

31. Types of Feed Systems.—There are two types of feed systems: (1) resonant or tuned lines, and (2) non-resonant or matched lines. The resonant or tuned line is critical with respect to its length for a particular operating frequency, but is widely used in amateur radio since it provides a convenient method of multi-band operation with the same antenna and feed system. The non-resonant or matched line provides a maximum transfer of power when the impedances of the antenna, line, and transmitter are all properly matched, and operation is practically independent of the length of the matched line. The twisted pair, the shielded pair, the coaxial line, the parallel rod, and the open-wire line are forms of the non-resonant or matched feed line. Of the two types of feed systems, the non-resonant or matched line is far more efficient than the resonant or tuned line, and is therefore more widely used.

32. Resonant Feed Systems.—Tuned or resonant feed lines are simple and easy to adjust for maximum tranfer of power between the transmitter and the antenna. Essentially, such a line can be considered as simply a part of the antenna folded back on itself to prevent radiation. The line is resonated with the antenna at the desired frequency of operation, thus establishing standing waves on the feed line. No particular consideration is given to impedance values of the circuit. Simplest type of resonant feed is a single wire measuring a half wavelength between the transmitter output tank circuit and the input to a half-wave dipole (Fig. 16). Such an antenna is said to be voltage fed, because the feed line connects to a point of high voltage at one end of the dipole. The feed line need only be approximately a half-wave in length, since small errors in length can be corrected by adjustment of the variable condenser *C* in the output tank circuit. An important disadvantage of this simple feed system is that the half-wave single-wire feed line is actually a part of the radiating antenna and thus constitutes an effective loss in power. Radiation by the feed system is eliminated by using a half-wave parallel-wire line (Fig. 17), where the two wires are so close together that the field set up at any point on one wire is neutralized by the field set up at the same point on the second wire. The parallel-wire feed is tuned to exact resonance by means of tank condenser *C*. Since the two fields cancel each other, there is no radiation from the resonant feed line and all of the transmitter output reaches the voltage-fed dipole. Resonant feed lines for current-fed antennas are required to provide a high current at points where the feed connects to the radiating dipole, and either a quarter-wave parallel line (Fig. 18a) or a half-wave parallel line (Fig. 18b) can be used. In either case, opposing fields on the wires effectively cancel all radiation from the feed system. When the resonant feed is a quarter-wave (or an odd number of quarter-waves), there is a voltage maximum at the transmitter and the output tank circuit is parallel tuned. When the resonant feed is a half-wave (or any number of half-waves), there is a current maximum at the transmitter and series tuning is required. Feed lines may be extended to any desired length, providing that the feed line is properly resonated with the antenna and the transmitter.

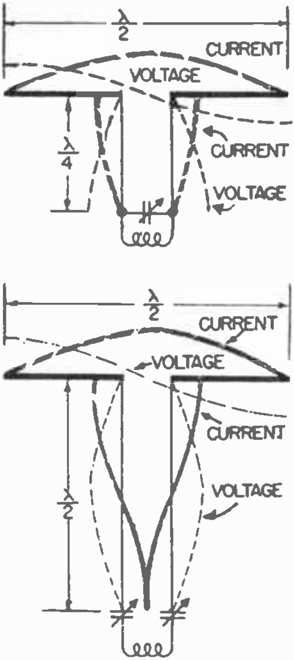


Fig. 18 Resonant fed line for current-fed antenna. Upper, Quarter-wave line with parallel tuning; lower, Half-wave line with series tuning.

33. Matched Feed Systems.—Maximum transfer of energy from the transmitter to the radiating antenna is achieved with a matched or non-resonant feed system, because no standing waves—with resulting loss of power—exist on the feed lines of such a system. In contrast with resonant feed systems, non-resonant or matched lines are terminated in the characteristic impedance of the particular line, and may be of any desired length. The input impedance of the radiating antenna is matched to the characteristic impedance of the line, and the output impedance of the transmitter is also matched to the impedance of the line. Such a matched feed system permits a greater conservation of available RF power, although it restricts the radiating antenna to a narrow band of operating frequencies. All commercial, broadcast, communications, and ultra-high-frequency feed systems are of the tuned or matched type, and use special kinds of wire for the actual transmission line. Parallel conductors—consisting of either two wires or two rods—are used at all medium and high frequencies. Coaxial cable is used at very-high frequencies, or when a low-impedance line is required; it is also widely used for the transmission of high power at medium frequencies. Twisted pair and shielded parallel pair are used for low-power transmission purposes.

34. Surge Impedance.—The characteristic or surge impedance of a transmission line depends upon a number of factors, chief among which is the spacing between conductors and their respective diameters. The impedance of a line must be of proper value to permit matching to the input antenna impedance as well as the output impedance of the transmitter. The wider the spacing and the smaller the diameter of the conductors, the greater will be the value of the surge impedance.

35. Parallel Rod or Parallel Wire.—Most important type of matched feed is the parallel-rod or parallel-wire transmission system, consisting of two fixed parallel conductors. These are found in a variety of forms. High-power and low- and medium-frequency installations are equipped with fairly heavy copper tubing; low-power and very-high-frequency installations are often equipped with parallel wires of small diameter, occasionally enclosed in plastic or other dielectric. The surge or characteristic impedance for various wire sizes and spacing is shown in Fig. 19 for air dielectric. Readings must be reduced by suitable correction factors for any dielectric other than air; for example, results are multiplied by 0.675 when the dielectric is polyethylene.

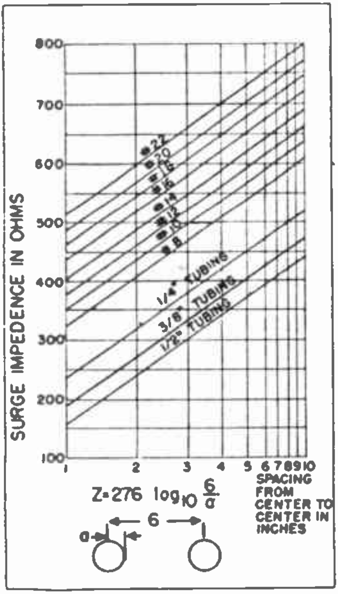


Fig. 19 Characteristic impedance of any two-conductor parallel-rod or parallel-wire transmission line, according to spacing and conductor size.

36. Coaxial Cable.—This type of transmission line is an extremely efficient conductor of RF power, and is widely used in commercial installations. The coaxial or concentric cable (Fig. 20) consists essentially of tubing or braided wire which a single conductor of copper is concentric to and enclosed within a larger copper tube or similar copper covering. The RF energy is confined to the *inside* of a coaxial line, and thus there is no less power due radiation. The outer conductor acts as a shield against stray noise or other undesirable electric fields. The surge or characteristic impedance for various sizes of inner conductor and for various inner spacings between outer and inner conductors is shown in Fig. 21 for air dielectric. Readings are reduced by suitable correction factors for dielectric other than air; for example, when polyethylene is used, the correction factor is 0.675. Air dielectric is universally used for all high-power and low- and medium-frequency operation; in damp locations, oxygen or nitrogen is sometimes introduced inside the coaxial cable in order to repel moisture. Small diameter *flexible* coaxial cable (Fig. 20c) is used for low-power purposes; this type consists of a stranded inner conductor, a plastic dielectric, a copper braid which acts as the outer conductor, and a suitable covering.

37. Twisted Pair.—This form of transmission line is used only under certain conditions in low-power installations. The twisted pair consists of two insulated *but not shielded* wires which are twisted upon each other to form a flexible line. While it is the most economical type of line with a low surge impedance between 50 and 150 ohms, it has considerable dielectric losses which limit its usefulness to frequencies well below 30 megacycles. It is a balanced line, but is not recommended for use at lengths greater than about 50 feet.

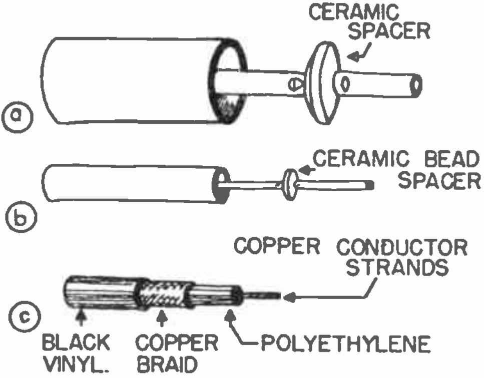


Fig. 20 Types of coaxial cable. a, High power medium-frequency type; b, High power high-frequency type; c, Low power high-frequency type, flexible cable.

38. Shielded Pair.—This form of transmission line is a variation of the flexible, low-powered coaxial cable. The shielded pair contains two insulated conductors surrounded and shielded by an outer conductor, usually consisting of copper braid, which is covered with rubber or other type of insulating material. Surge impedance values of this line are between 50 and 100 ohms. Although balanced and shielded, the shielded pair is not too efficient and its use should be limited to lengths not exceeding about 50 feet.

39. Impedance Matching.—Proper impedance matching depends upon connecting the transmission line to an appropriate point on the radiating antenna. Twisted pair and coaxial types of transmission line can match the input impedance of an antenna at a current loop—generally between 50 and 100 ohms—but in many cases it may be necessary to employ some form of impedance matching transformer between the transmission line and the antenna. Three circuit arrangements are used for accomplishing this result. In the first method (Fig. 22a) the feed line is simply spread or *fanned out* at the ends and attached to the radiating antenna part way out from the center; this is sometimes known as a *Delta-match transformer,* where the impedance of the transmission line is made to match the impedance of t e antenna. A more popular method (Fig. 22b) employs a quart -wave section connected to the points of the antenna to be fe ; then, the transmission line is connected directly to the prop r points along the quarter-wave section to obtain a proper im edance match. This arrangement is sometimes known as a *mat ing stub*. A third method of impedance transformation (Fig. 22), known as a *Q section*, consists of an open-wire section, the leng h of which is determined from the equation:

$$L = \frac{246}{f}$$

where L is *in feet*
f is *in megacycles*

At operating frequencies above 30 mc the above equation becom :

$$L = \frac{234}{f}$$

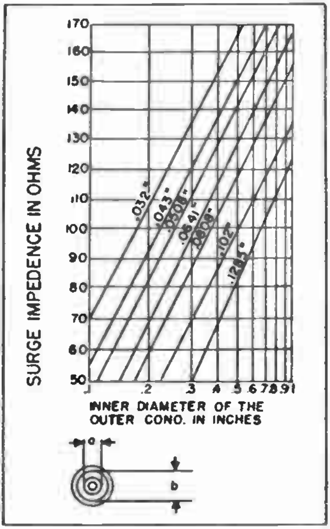


Fig. 21 Characteristic impedance of coaxial or concentric transmission line, according to the sizes of inner and outer conductors.

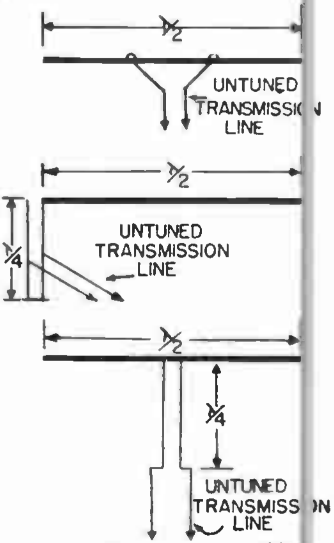


Fig. 22 Methods of matchin impedance of transmission lin to impedance of radiating an tenna. Upper, Delta-match middle, Quarter-wave stub lower, Q section or quarter wave transformer.

Either equation gives only the approximate length, since he quarter-wave section is always tuned after insertion between he transmission line and the radiating antenna. In most cases, the actual impedance of the transmission line is not too important, since the quarter-wave section is used to match practically any line impedance. The Q-section matching system is also used with antennas longer than a half wavelength.

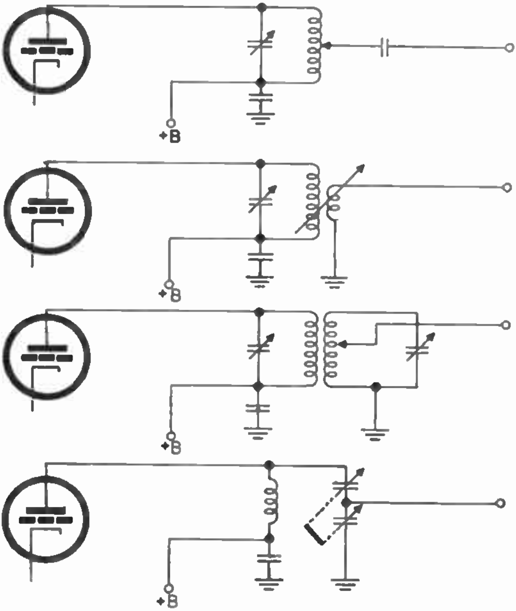


Fig. 23 Unbalanced coupling circuits for use with unbalanced transmission line.

40. Standing Waves.—If the current *loops* and current *nodes* are measured on a transmission line, the ratio of the loop current to the node current is found to be the same as the ratio of the line impedance to the terminating impedance. This is known as the *standing wave ratio,* which is a direct indication of the degree of mismatch along the transmission line of a feed system. If a transmission line is connected to the radiating antenna at a point where the impedance is matched (is resistive in nature), the line will have *no* standing waves along it—indicating *no* undesirable or spurious radiation by the feeder system. Absolute perfection, however, is often difficult to achieve; and, if the *standing wave ratio* is no greater than about *10-to-1* for a line more than several wavelengths long, the impedance match is considered to be sufficiently adequate for most practical purposes. Precise adjustment of quarter-wave stubs and matching sections often provides an improvement in the *standing wave ratio* of a non-resonant or matched transmission line.

41. Transmitter Coupling.—The manner in which the output of a transmitter is coupled either directly to the antenna, or through a transmission line to the antenna, is of considerable importance. There are three general methods of coupling, which are classified according to whether the output is balanced, unbalanced, or universal. A number of unbalanced coupling circuits are shown in Fig. 23; balanced coupling circuits are shown in Figure 24; and so-called universal or link coupling arrangements are shown in Fig. 25. Most coupling arrangements—with the exception of link coupling systems—are also used to resonate the transmitter circuits to which they are connected, and accordingly they are provided with one or more variable elements for tuning purposes. Since these arrangements provide a means of varying the coupling between two circuits, they can also be used to a limited extent in matching impedances.

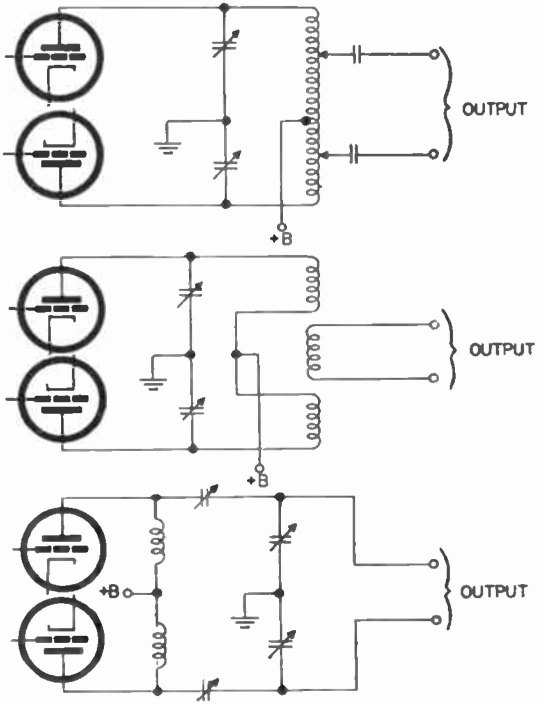


Fig. 24 Balanced coupling circuits for use with balanced transmission line

LONG WIRE ANTENNAS

42. An important development of the basic *Hertz* antenna is the *long wire radiator* consisting of a single wire of two or

more (usually several) complete half wavelengths. Sometimes known as the harmonic antenna, the long wire radiator provides multi-band operation at harmonic frequencies with a considerable

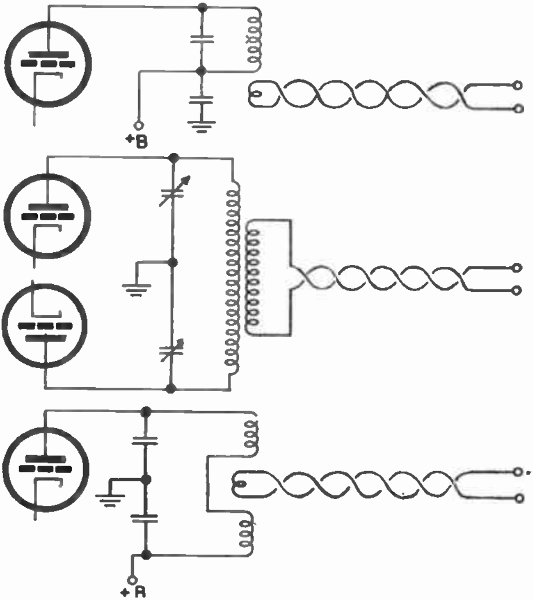


Fig. 25 Universal or link-coupling systems used to couple any type of transmitter to any antenna.

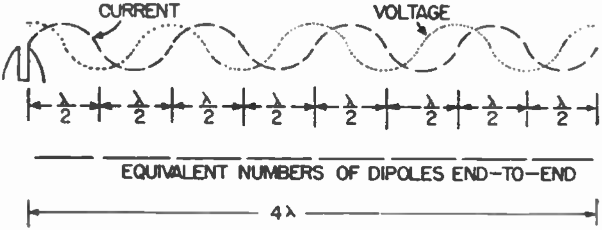


Fig. 26 Typical long-wire antenna of four wavelengths, showing current and voltage distribution when end-fed, and equivalent number of half-wave dipoles.

degree of directivity. Various combinations of long wire radiators constitute an important branch of directional arrays, which includes the *V antenna* and its variations, and the *rhombic antenna.*

43. Long Wire Radiators.—If the length of a long single wire is an integral multiple of a complete half wavelength, the antenna will be resonant when properly fed (Fig. 26) since an in egral number of standing waves of current and voltage are present long the length of the wire. Effectively, a long wire radiator co sists of a number of half wavelength dipole sections, placed e d to end, and excited in such a way that at any instant, current i adjoining half-wave sections flows in opposite directions. Thi out-of-phase condition is usually achieved by feeding the long wire radiator *at one end*.

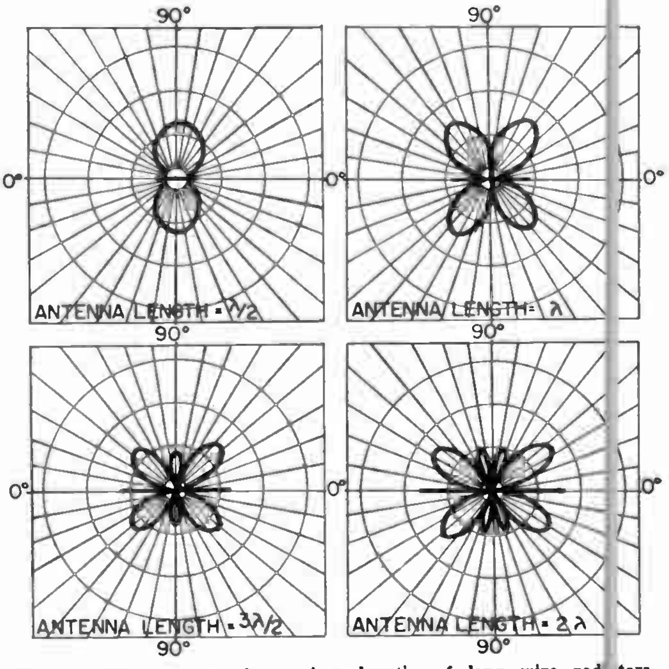


Fig. 27 Field patterns for various lengths of long wire rad tors, showing increase in directivity with increase in number of half-wave-length sections.

44. Directivity.—An important property of the lon wire radiator is that it tends to become more directional as the length of the wire is increased. Although maximum radiation om a *single* half-wave section is broadside to that section, wh n the antenna is a wavelength or more long (Fig. 27) the radiatio tends to concentrate more and more off the ends of the anten a despite the appearance of numerous minor lobes. The limit of extreme directivity is reached when the length of the radi tor is about 18 wavelengths, at which magnitude the antenna can b made resonant over a wide range of frequencies. A wire *long* than

about 18 wavelengths is impractical not only because of mechanical size but also because of skin-effect losses and unequal current amplitudes at adjacent current loops. The minor lobes associated with the field patterns of long wire radiators are seldom useful, and are sometimes suppressed or attenuated by combining them so that the undesired lobes effectively cancel each other.

45. Length of Long Wire Radiator.—The total length of a long wire radiator is not an *exact* multiple of a single-half-wave section, because *end effects* associated with radiation apply only to the extremities of the antenna—and *not* to intermediate half-wave sections. Accordingly, the complete length of a long wire radiator is given by the equation:

$$L = \frac{429\,(n - 0.05)}{f}$$

where L is the length *in feet*
n is the *number* of half-wave sections composing the complete antenna.
f is the resonant frequency *in megacycles*

46. The V Antenna.—This directional array is composed of two long wire radiators arranged horizontally in a V-shape (Fig. 28), which effectively combines the directional effects of each of the long wires with a pronounced increase in gain. The main lobes of each radiating wire are reinforced *only* along the line A-B that bisects the included angle between the two wires. Other lobes are eliminated or considerably minimized, thus producing a narrow-lobe bidirectional field pattern, as shown in Fig. 28. The two wires or sides of the V antenna are usually arranged so that the included angle Φ is *twice the angle of the major lobe of either wire* when used individually. If the length of each side is

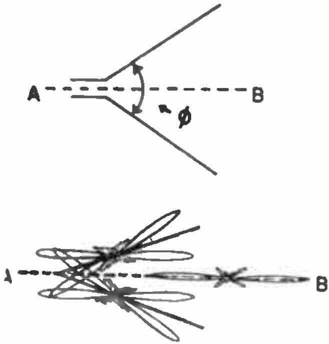


Fig. 28 The V antenna, and method by which field patterns of two long wire radiators are combined to produce highly directional V antenna field pattern.

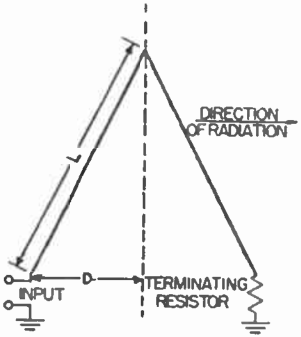


Fig. 29 Inverted V antenna.

one wavelength, the included angle Φ is about 90 degrees; for two wavelengths, the angle is about 72 degrees; for three wavelengths, the angle is about 60 degrees; and so forth. Gain is a function of the length of each side of the V antenna. In usual practice, this array is erected horizontally and *at least* a half wavelength above ground. Tilting the antenna plane *increases* low-angle radiation from the low end and *decreases* low-angle radiation from the high end of the antenna.

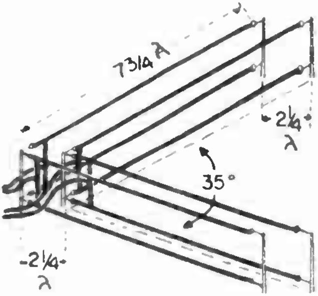


Fig. 30 Special communications type of V antenna.

47. Inverted V Antenna.—This long wire directional array is erected in a vertical or upright position (Fig. 29) perpendicular to the surface of the earth. The antenna is fed between one end and ground; the opposite end is terminated in a pure resistance R of about 400 ohms. When the dimensions of the antenna are such that the length L is a half wavelength greater than the dimension D, the field pattern is essentially unidirectional.

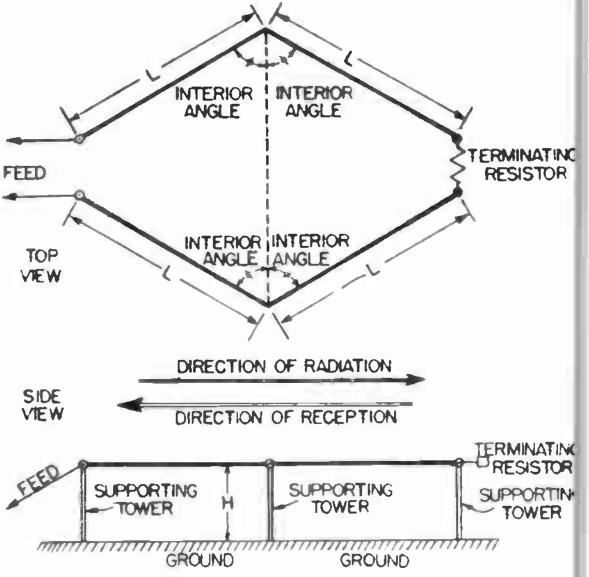


Fig. 31 The rhombic antenna.

48. Variations of V Antenna.—The gain of a single V antenna can be substantially improved by placing *two* V antennas parallel to, and a half wavelength above, each other. The V antenna can be made unidirectional by placing a V-shaped reflector behind the radiating antenna; the reflector must be in the same plane as the radiating antenna, and the separation between the reflector and radiator must be a multiple of a quarter-wavelength. One commercial type of V antenna (Fig. 30) consists of two radiating elements with respective reflectors.

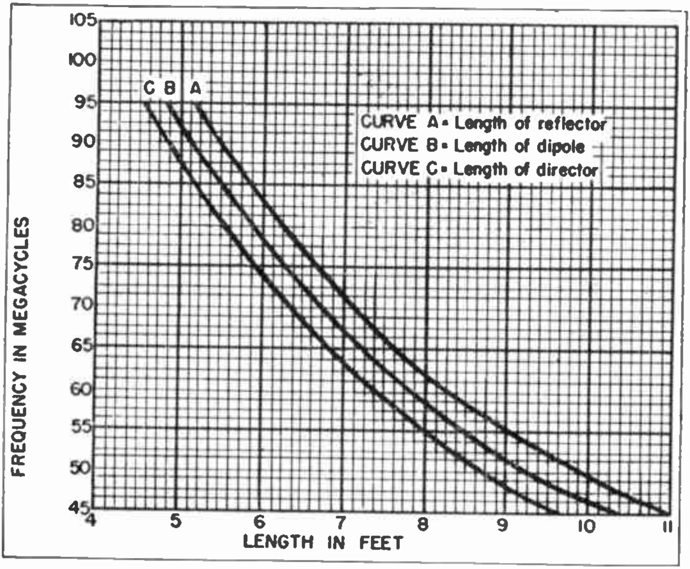


Fig. 32 A curve showing the length in feet of a dipole, a reflector, or a director for frequencies from 45 to 95 mc.

49. The Rhombic Antenna.—The horizontal rhombic antenna is a form of long wire directional array, which provides excellent directivity and high gain. Essentially, the rhombic antenna consists of four wires of equal length (Fig. 31) arranged in the shape of a diamond and suspended a half wavelength or more above the earth. Since the rhombic is ineffective as a radiator unless each wire is *at least* two wavelengths long, the antenna array is invariably of massive size—except at higher operating frequencies. The larger the antenna, the greater is the power gain. If the free end is *not* terminated with a resistance, the rhombic has a bidirectional field pattern. Usually the free end is terminated with a resistance of between 600 and 800 ohms, representing the characteristic impedance of the radiating an nna; the rhombic then functions as a non-resonant transmissio line *without* standing waves, and RF energy is radiated in onl one direction: toward the terminating resistance. The resistor dissipates about half the power fed into the antenna, without af cting the forward directional pattern. The gain and directivity of a rhombic antenna are functions of the length L of each sid , and the interior angle Φ, and the desired wave angle or vertical angle of fire. These important design dimensions are determi ed in detail by calculus; however, the length of each side and t e interior angle Φ can be given more simply by the following maximized equations:

$$L = \frac{0.37\,\lambda}{2 \sin^2 \Delta}$$

$$\Phi = \sin^{-1} \cos \Delta$$

where L is the length of each side *in wavelengths*
Φ is the interior angle *in degrees*
Δ is the wave angle *in degrees*

The height H of a rhombic antenna is assumed to be great than a half wavelength. As the height is increased above a half wavelength, however, the wave angle or vertical angle of fire s decreased. For maximum output, the optimum height H for a given wave angle is determined by the equation:

$$H = \frac{\lambda}{4 \sin \Delta}$$

where H is the height of the rhombic *in wavelengt* : . . . .
Δ is the wave angle *in degrees.*

Only the horizontal component of RF energy is radiated int space, and the degree of sharpness in the horizontal plane is pr narily dependent upon the length L of each side of the rhombic an enna.

HIGH-FREQUENCY PARASITIC ARRAYS

50. Directivity is an important and desirable character tic of high-frequency antenna systems. For transmitting purpo es, directional antennas concentrate RF energy in certain di ctions where the signal is desired and minimizes or prevents ra liation in other directions where it would be wasted or create inter erence. For reception purposes, directional antennas reject or discr minate against unwanted signals arriving from directions other th n that in which reception is desired. The simplest method of ob aining a unidirectional field pattern is by means of a *parasitic array*, which consists essentially of a conventional half-wave dipole associated with one or more of the two types of parasi c elements: *reflectors* and *directors*. The directivity—as well as the gain—of such types of arrays is roughly proportional to th number of parasitic elements employed. The size of a parasiti array is proportional to the operating wavelength. And for a given wavelength, a transmitting array and a receiving array are i entical in mechanical structure, although providing a reciprocal circuit function.

51. Gain and Directivity.—The *gain* of a parasitic array is the ratio of signal strength in the desired direction to the signal strength in the same direction which would be obtained with a single dipole without reflectors or directors. The *directivity* of an array refers to the shape of its field pattern in either the horizontal or vertical plane. A sharp or extremely narrow field pattern identifies a parasitic array with good directivity.

52. Polarization.—To transmit or receive signals which are polarized horizontally, all elements of a parasitic array are arranged and mounted in a horizontal position with respect to the surface of the earth. Vertically polarized signals are transmitted or received when all elements of a parasitic array are arranged and mounted perpendicular to the surface of the earth. For purposes of simplicity, the parasitic arrays which follow are considered in terms of the horizontal position.

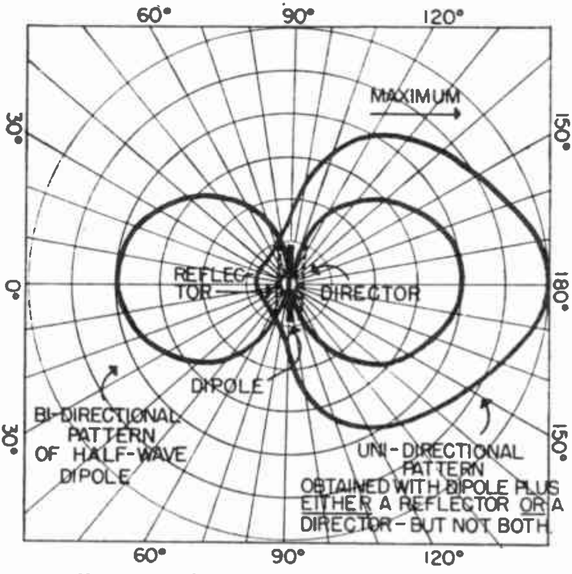


Fig. 33 Change in bi-directional field pattern of dipole when either a reflector or a director is added to the dipole.

53. Ground Effects.—The high-frequency antenna arrays discussed in this Section are considered to be operated in *free space,* which is effectively seven or more wavelengths above the earth where ground-reflection effects are either nonexistent or so slight that they can be ignored. If an array is located closer to the earth's surface, the field pattern in the vertical plane is influenced by a ground reflection factor according to individual circumstances.

54. Half-wave Dipole.—All types of parasitic arrays are based on the fundamental half-wave dipole operating in free space. The length of such a dipole is equivalent to an electrical half-wave. The actual length in feet is subject to a correction factor of .94, since the velocity of radio waves on or very near the surface of a metal dipole is less than the wave velocity in free space. Typical values of length for frequencies between 45 and 95 megacycles are shown graphically by *curve B* of Fig. 32. The field pattern of a half-wave dipole in free space is essentially bidirectional in the plane perpendicular to the dipole, with a horizontal cross-section (Fig. 33) shaped like a figure 8. This bidirectional pattern can be affected by the addition of either *reflectors* or *directors* to provide a unidirectional concentration of RF energy.

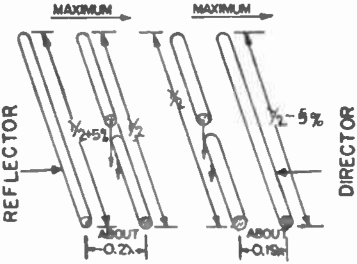


Fig. 34 Use of either a reflector or a director provides the same degree of directivity.

55. Reflectors.—A reflector is a metal conducting tube or rod placed parallel to and *behind* a half-wave dipole in a position *opposite* in direction to the desired field of maximum intensity. It is slightly longer than the half-wave dipole (usually about 5 per cent), and the reflector is mounted at a distance from 0.20 to 0.25 wavelength behind the half-wave dipole (Fig. 34). At wavelengths shorter than 1 meter, a spacing of a quarter-wave is generally employed. The reflector is not connected to the radiating or receiving dipole or its associated circuits. When the dipole radiator is energized, the resultant field induces a voltage in the reflector rod in such a direction as to produce a field opposite in polarity *but almost equal in magnitude* to the inducing field. *Two* kinds of radiation actually take place: that caused by the current in the radiating dipole, and that caused by the induced current in the reflector element. Very little RF energy travels beyond the reflector, since the two fields cancel when they are of opposite polarity. When RF energy from the reflector reaches the radiating dipole, however, the two fields are in phase, and they combine and mutually influence the field pattern in a forward direction (Fig. 33). The exact shape of the pattern depends upon the phase relation between the direct and the reflected high-frequency waves. The phase of the induced current in the reflector is controlled by

two factors: (1) the length or tuning of the element, and (2) the spacing between the dipole and the reflector. The reflector is normally tuned to a frequency slightly lower than the resonant frequency of the radiating dipole; thus, the reflector is slightly longer than the dipole, as indicated by the chart shown in Fig. 32. When used for reception of high-frequency signals, the parasitic element reacts on the receiving system through mutual impedance, and sensitivity is greatly improved in the forward direction.

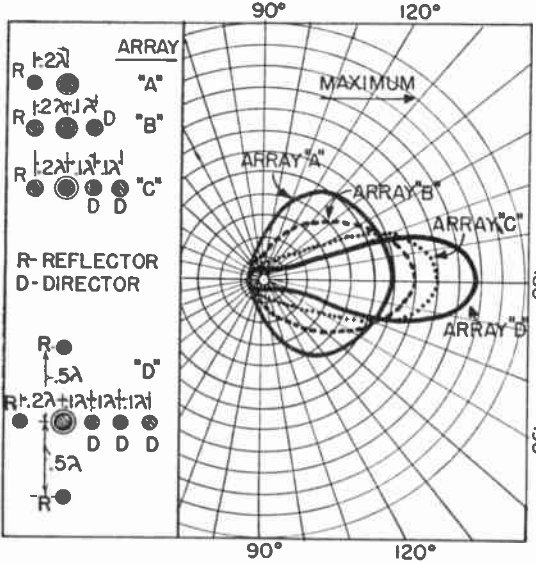


Fig. 35 Typical field patterns of four types of parasitic arrays.

56. Directors.—A director is a metal conducting tube or rod placed parallel to and *in front of* a half-wave dipole in the direction of the desired field of maximum intensity. It is slightly shorter than the half-wave dipole (usually between 4 and 5 per cent). The director is mounted at a distance from 0.10 to 0.15 wavelength in front of the half-wave dipole (Fig. 34). At wavelengths shorter than 1 meter, spacings up to a quarter wavelength are employed. The director is not connected to the radiating or receiving dipole or its associated circuits. When the dipole radiator is energized, the resultant field induces a voltage in the director so that there is a reinforcement of fields in a forward direction and a cancellation of fields in the opposite direction. This function of the director is very similar to that of the reflector, and the same field pattern is produced (Fig. 33) when either a director or a reflector is used with a half-wave dipole radiator. The phase of the induced current in the director is controlled by two factors: (1) the length or tuning of the element, and (2) the spacing between the dipole and the director. Normally the director is tuned to a frequency slightly higher than the radiating dipole; thus, the length of the director is less than that of the dipole, as indicated by the chart in Fig. 32. When used for reception, the parasitic element reacts on the receiving system through mutual impedance so that sensitivity is improved in the forward direction.

57. Multi-Element Arrays.—A single parasitic element (either a reflector or director) with a half-wave dipole constitutes the simplest type of parasitic antenna array; and since there are two variable factors involved—spacing between elements, and tuning of the parasitic element—a wide variety of unidirectional field patterns can be obtained. However, an even greater degree of directivity or gain is often desired, requiring the use of *two or more* parasitic elements with a single half-wave radiating or receiving dipole. Such antennas are known as ***multi-element parasitic arrays*** (Fig. 35), and usually consist of a number of elements arranged symmetrically with respect to the line and plane of greatest gain and directivity. Any number of directors can be used with a single half-wave dipole; and with these elements may be combined one to three reflectors. When four or more elements are used, the arrangement is often known as a *Yagi array*. With the addition of each parasitic element, the power gain of an antenna array increases 1.4 times; for example, if the power gain of a 4-element array is 5.0, the addition of another director would increase the gain to a value of 6.4, and so forth. Each director and reflector must be properly tuned and spaced—with respect to the half-wave transmitting or receiving dipole, and with respect to each other—in order to provide the desired degree of directivity. When necessary, a *folded dipole* may be used in place of the ordinary half-wave dipole; this arrangement provides an increase in antenna impedance to about 300 ohms permitting a coaxial feed line of more practical dimensions.

58. Array Construction.—Parasitic antenna arrays are mounted *at least* 7 wavelengths above, or remote from, ground in order to eliminate reflection effects due to the proximity of the ground. Elements of the array—whether the active dipole, or reflectors or directors—are mounted in a fixed position. When mobility of direction is desired, the entire array is moved without disturbing the relative positions of the dipole and parasitic elements. Antenna elements are generally constructed of conductive tubing of small diameter. At wavelengths less than 1 meter, however, metal rods can be used since microwave energy is confined entirely to the outside of such elements. Parasitic elements of large arrays are usually welded directly to a central conducting rod or tube in order to provide necessary regidity. Such a support does not interfere with the operation of the antenna array since it is perpendicular to the direction of the electric field. The active dipole, however, is not attached to such a support, because it must be fed at the center; suitable high-frequency insulation must be provided for this element of the parasitic array.

HIGH-FREQUENCY PHASED ARRAYS

59. When two or more dipoles are suitably arranged in the same plane and simultaneously operated in proper phase relationship, the individual dipole fields react upon each other in such a way that the *combined* field pattern provides an increase of field strength in a favored direction and a decrease or reduction in all other directions. Such an arrangement of two or more dipoles—known as a *phased array*—thus obtains a power gain in certain directions at the sacrifice or expense of a power reduction in other directions. Both the directivity and the gain are proportional to the number of activated dipoles. Since the length of each dipole is invariably a half wavelength, the size of the complete array is roughly proportional to the operating wavelength. For any given wavelength, a transmitting array and a receiving array are identical in mechanical structure although providing a reciprocal circuit function. When used for transmitting, phased arrays concentrate RF energy in certain directions where the signal is desired and minimizes or completely eliminates radiation in other directions where it would be wasted or create interference. When used for receiving, phased arrays reject or discriminate against unwanted signals arriving from directions other than that in which reception is desired.

60. **Gain and Directivity.**—The *gain* of a phased array is the ratio of signal strength in the desired direction to the signal strength in the same direction which would be obtained with a single dipole located at the geometric center of the array. Gain depends primarily upon the number and phasing of dipoles in the array. Essentially, the field pattern of all phased arrays is normally bidirectional—with maximum lobes usually forward and backward along a line perpendicular to the plane of the array. A unidirectional pattern is obtained by providing an additional element—a parasitic reflector—behind a phased array. The *directivity* of a phased array refers to the shape of its field pattern, and is given in terms of either the horizontal or vertical plane. A sharp or extremely narrow field pattern identifies an array with good directivity.

61. **Polarization.**—To transmit or receive signals which are polarized horizontally, all dipoles of a phased array are arranged and mounted in a horizontal position with respect to the surface of the earth. Vertically polarized signals are transmitted or received when all dipoles of a phased array are arranged and mounted perpendicular to the earth's surface. For purposes of simplicity, all phased arrays which follow are considered in terms of the horizontal position.

62. **Ground Effects.**—The high-frequency antenna arrays discussed in this Section are considered to be operated in *free space*, which is effectively seven or more wavelengths above the earth, where ground reflection effects are either non-existent or so slight that they can be ignored. If an array is located closer to the earth's surface, the field pattern in the vertical plane will be influenced by a ground reflection factor according to individual circumstances. Compensation must be made for such ground effects.

63. Principal Types.—There are four principal types of ph sed antenna arrays—the *co-linear,* the *broadside,* the *billboard,* and the *end-fire*—based on the geometric arrangement of the dipoles nd the directivity characteristics of the field patterns. In this or er, these principal types and their variations are discussed in he following paragraphs.

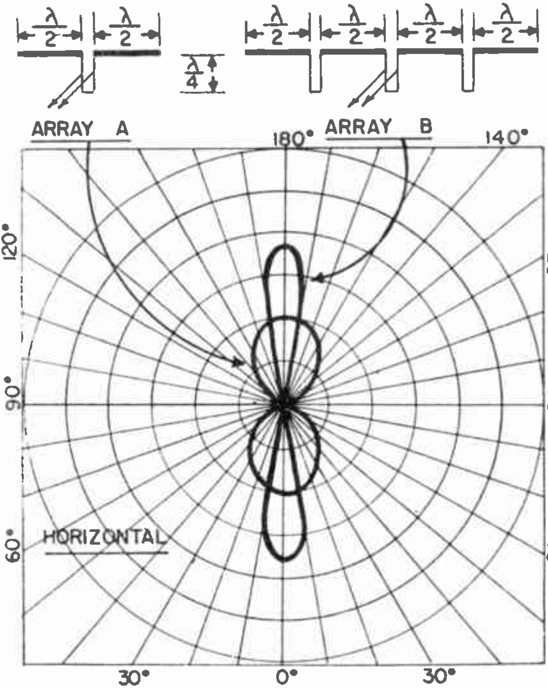


Fig. 36 Two types of co-linear phased arrays which provide greatest directivity in the horizontal plane.

64. Co-linear Arrays.—This basic type of phased array Fig. 36) consists of two or more half-wave dipoles arranged end-t -end along the same axis. Quarter-wave transmission-line section are used between dipoles to maintain all currents in phase, with a non-resonant feeder matched to one of the quarter-wave sections. ince an even distribution of RF energy is desirable, the feed fro the transmitter (or to the receiver) is usually connected to the c nter of a co-linear array—thus precluding the use of an odd-numb r of half-wave dipoles. When arranged in a horizontal positio the co-linear array provides directivity *only* in the horizontal pla e of its field pattern. Both the degree of directivity and the ar ount of gain depend primarily upon the number of dipoles, as s own by the typical field patterns of *Array A* and *Array B* in Fig. 36. A two-dipole phased array has a power gain of about 2.0 greater than an equivalent single half-wave dipole; a four-dipole array has a power gain of approximately 3.3. Although the co-linear array is essentially an arrangement *in width*, the array is sometimes used in a vertical position—when it is more popularly known as the *Franklin antenna*—to provide directivity only in the vertical plane of its field pattern. The physical size of such an array is limited, however, and transmission and reception is confined to vertically polarized waves. The co-linear array is far more useful in a horizontal position, producing a bi-directional field pattern.

65. Extended Double Zepp.—Only variant of the co-linear phased array is the *extended double Zepp*, which is used primarily by radio amateurs for operation on two wavelengths of harmonic relation. Similar to *Array A* of Fig. 36, the two dipoles of an extended double Zepp each have a length of 0.64 wavelength—instead of the conventional half wavelength. The additional length provides greater gain in *both* operating wavelengths, despite a sacrifice in directivity due to the appearance of parasitic and minor lobes in the field pattern. The phasing stub is shortened proportionately in order to maintain the entire array at resonance; usually this stub is about 0.11 wavelength.

66. Broadside Arrays.—This basic type of phased array consists of two or more half-wave dipoles, or two or more *pairs* of half-wave dipoles, arranged parallel to each other and in the same plane. With the dipoles in a horizontal position, a broadside array provides directivity *only* in the vertical plane of its field pattern. Both the degree of directivity and the amount of gain depend primarily upon the number and geometric arrangement of dipoles composing the array. There are a number of distinct major types—plus many minor varieties—of the broadside phased array. Simplest array is the *Lazy-H antenna.* The several kinds of *Sterba arrays* and *Bruce arrays* provide a field pattern with high directivity in the vertical plane — for radiation toward, *or*, reception from, the horizon. Multi-element broadside arrays, known as *stacked arrays*, provide any desired degree of directivity in the vertical plane, according to the number of dipoles and their arrangement in height.

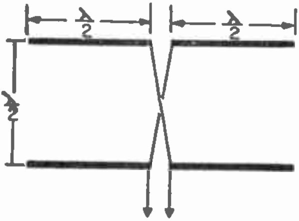


Fig. 37 The Lazy-H antenna, a 4-element broadside array.

67. Lazy-H Antenna.—This array consists of four half-wave dipoles arranged horizontally (Fig. 37) with all currents equal and fed in phase. Since the two upper dipoles and the two lower dipoles are separated by an electrical half wavelength, the feeder wire is transposed so that the polarity is always the same at opposite, corresponding points of either pair of parallel dipoles. RF energy moving up or down is effectively cancelled out. As a c nsequence, the field pattern is concentrated along a line which is b oadside, or perpendicular, to the plane of the array and thus i bidirectional. The array has a maximum gain of 5 or 6 over a s ngle half-wave dipole, with only a slight degree of directivity i the horizontal plane of the field pattern. Either a tuned line r a matched line with matching section is used to feed the antenna and tuning adjustments are the least critical of any type of ph sed array. The Lazy-H antenna is extremely popular for am teur operation where considerable gain is required without extrem directivity.

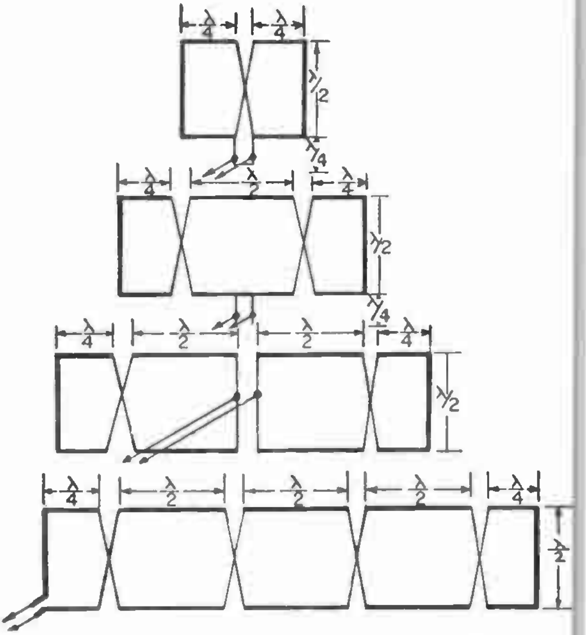


Fig. 38 Four types of the horizontal sterba array.

68. **Horizontal Sterba Arrays.**—An important variation o the broadside array is a system of phased *pairs* of half-wave di oles, known as the *horizontal Sterba array*. Each pair of hori ontal dipoles is arranged, one above the other, in the vertical plane with a separation of a half wavelength, resulting in two symme rical rows of half-wave dipoles. Each of the four "end" dipoles i bent at the center, and adjacent dipoles are then joined perman ntly; and all elements of the Sterba array are interconnected with ross-

over feeders so that currents are in phase. Four sizes of this array, each with a different method of feeding, are shown in Fig. 88. Teh feed is connected at any current maximum or between two opposite points of maximum voltage. Any type of tuned line or matched line is used to feed a horizontal Sterba array. The field pattern of the antenna is bidirectional and concentrated along a line which is broadside or perpendicular to the plane of the array. Both gain and directivity of the field pattern in the vertical plane are functions of the number of *pairs* of dipoles; however, an array consisting of six sections (six pairs of dipoles) is considered to be a practical limit. Since all sizes of the Sterba array represent closed circuits, it is a comparatively simple matter to apply a low voltage for ice and snow removal purposes.

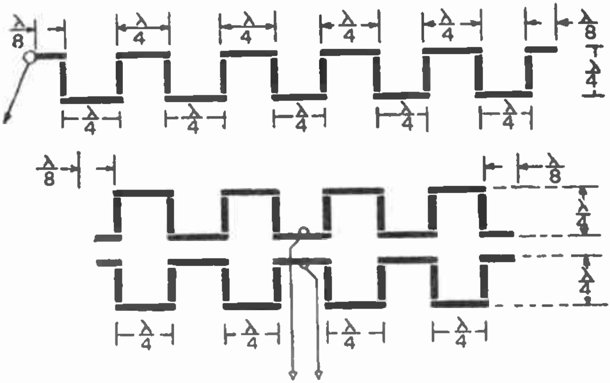


Fig. 39 Two types of the Bruce broadside array. Upper, End-fed array, unbalanced; lower, Center-fed, symmetrical array.

69. **Bruce Arrays.**—Another variation of the broadside array is a system of quarter-wave elements, known as the *Bruce array*. In its fundamental form, the array consists of any number of quarter-wave elements greater than six but not exceeding about 24. When these are arranged geometrically in one plane (Fig. 39a), currents in all horizontal elements tend to cancel each other, but currents in all vertical elements are in phase and thus exert a major influence on the field pattern. Both the directivity and gain are improved slightly through use of additional quarter-wave elements. Because such an array is fed at one end, however, current distribution throughout the array is not uniform. This proves to be a limitation of the fundamental type of Bruce array. A far more effective system actually consists of *two* Bruce arrays (Fig. 39b) arranged symmetrically and center fed, to provide a considerable improvement in vertical directivity. Bruce arrays transmit and receive only radio waves with vertical polarization. Space limitations usually restrict construction of such an array in a vertical position for radiating or receiving waves of horizontal polarization.

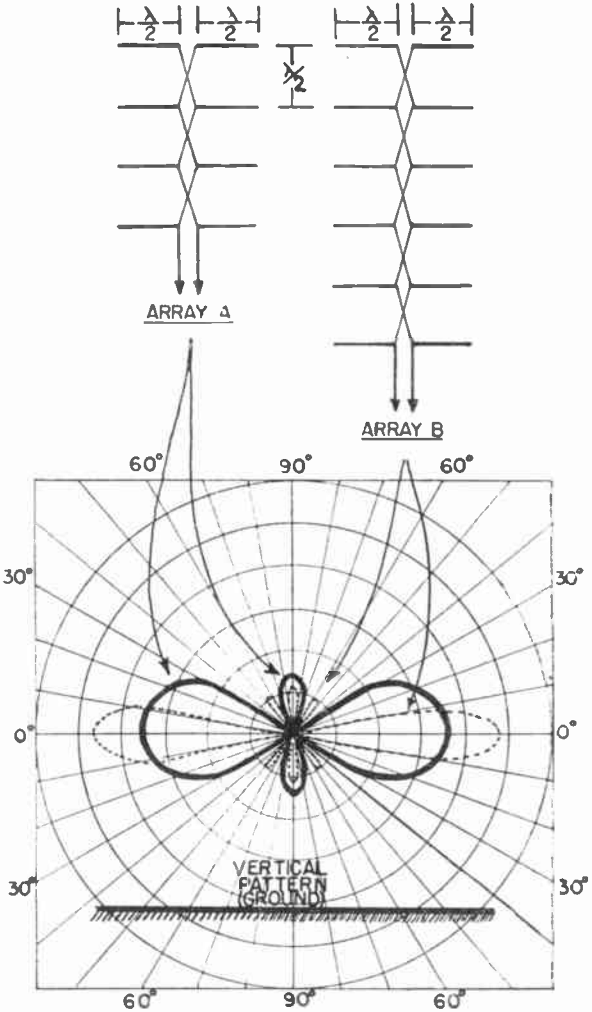


Fig. 40 Horizontal stacked arrays providing high directivity in the vertical plane. (No ground effect.)

70. Stacked Broadside Arrays.—A field pattern with extreme directivity and maximum gain at a low angle *in the vertical pl ne* is obtained by means of a multi-element broadside array, known as a *stacked array.* Such an array consists of two or more horizontal half-wave dipoles, or two or more *pairs* of horizontal half-wave dipoles, arranged one above the other in the same vertical plane, and operated with all currents in phase. The bidirectional field pattern is perpendicular to this vertical plane in the manner characteristic of all types of broadside arrays. Since the degree of directivity as well as the amount of power gain are both determined by the number of dipoles, the field pattern of a stacked array is extremely sharp or narrow *only* in the vertical plane. The greater the number of dipoles *in height,* the more directional is the field pattern in the vertical plane (Fig. 40) with no regard for the horizontal plane. Since high-frequency arrays are usually operated *at least* 8 wavelengths above the earth's surface, the vertical field pattern is influenced very little by ground effects. Power gain also is proportional to the height of a stacked array. Spacing between all pairs of dipoles is normally a half wavelength to simplify the problem of feeding the array. The necessary polarity relationships are preserved by transposing the transmission line between adjacent pairs of dipoles. Stacked arrays are fed either by resonant lines or by non-resonant lines and quarter-wave matching sections.

71. Unidirectional Phased Arrays.—Field patterns of all phased arrays are normally bidirectional, with RF energy concentrated along a line perpendicular to the plane of each array. In many high-frequency applications "back" radiation (or reception) serves no useful purpose; in some instances it is imperative that "back" radiation (or reception) be eliminated—either to minimize possible interference, or to increase the gain or directivity in the forward direction. This unnecessary or undesirable portion of the field pattern can be eliminated by placing individual parasitic reflectors, of proper length and spacing, behind each of the antenna dipoles in the manner described under "High Frequency Parasitic Arrays." Since phased arrays invariably consist of numerous dipoles, however, obvious difficulties arise in maintaining the correct spacing and tuning of a large number of reflectors. It is far more practical and efficient to use a *single* plane reflector, mounted at a fixed distance behind *all* of the active dipoles. Such a non-resonant reflector is usually constructed of either fine-mesh metal screening or closely spaced parallel wires. Thin sheet metal is sometimes used, but must be perforated to lower wind resistance. The frame and wire screen of the reflector often becomes the principal mechanical support for the entire phased array, when the radiating (or receiving) dipoles are mounted on quarter-wave metallic insulators which are short circuited at the reflector screen. Structural rigidity permits the use of radiating (or receiving) dipoles of large diameter when desired; such dipoles are less selective and allow operation over a wide band of frequencies. The screen or sheet reflector is mounted in a fixed position with respect to the array of dipoles, so that the plane of the reflector is parallel to the plane of the phased array; this distance is usually about a quarter wavelength, but may be as small as one-tenth wavelength on arrays of relatively small physical size. As in the case for individual reflector elements, the large screen reflector accepts RF energy from the activated dipoles and then *re*radiates this energy with such a p ase relation that the field combines with the field of each and e ery dipole—causing a reinforcement of RF energy in the forward direction (away from the reflector screen) and a cancellation of RF

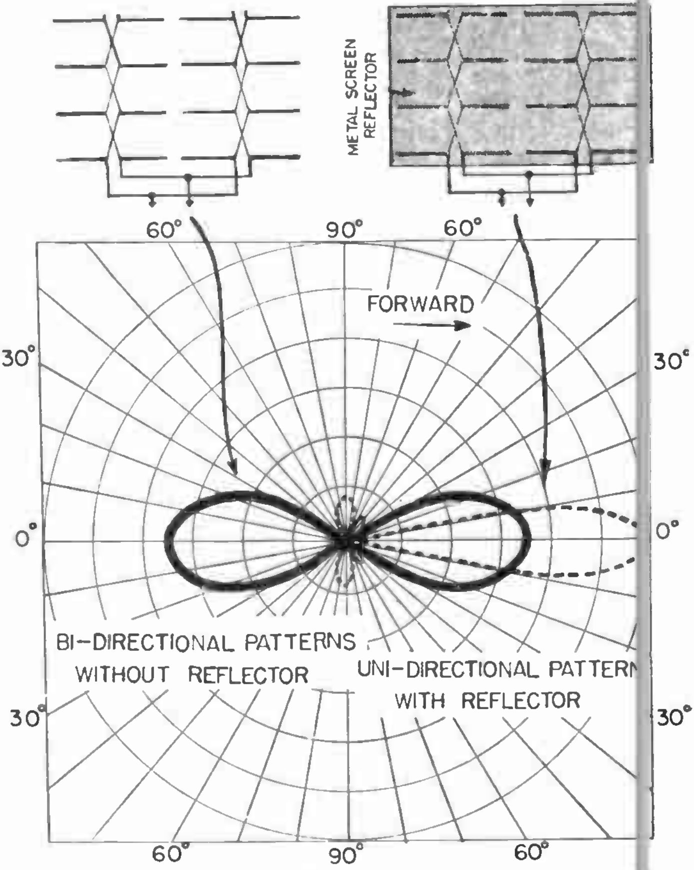


Fig. 41 Field patterns for the same multi-element antenna ar ay. A, Bi-directional pattern without a reflector; B, Uni-directional attern with metal screen reflector.

energy in the "back" direction. This produces a pronounced unidirectional effect in the forward direction. Using the same p ased array and the same power factors (Fig. 41), the addition of a screen reflector provides a unidirectional field pattern whi h is decidedly sharper (more directional) with a considerable inc ease in gain. Thus, the efficiency of a phased array is improved by eliminating "back" radiation (or reception) through use of a screen reflector. Because of structural difficulties, directors are rarely used with large phased arrays for unidirectional purposes.

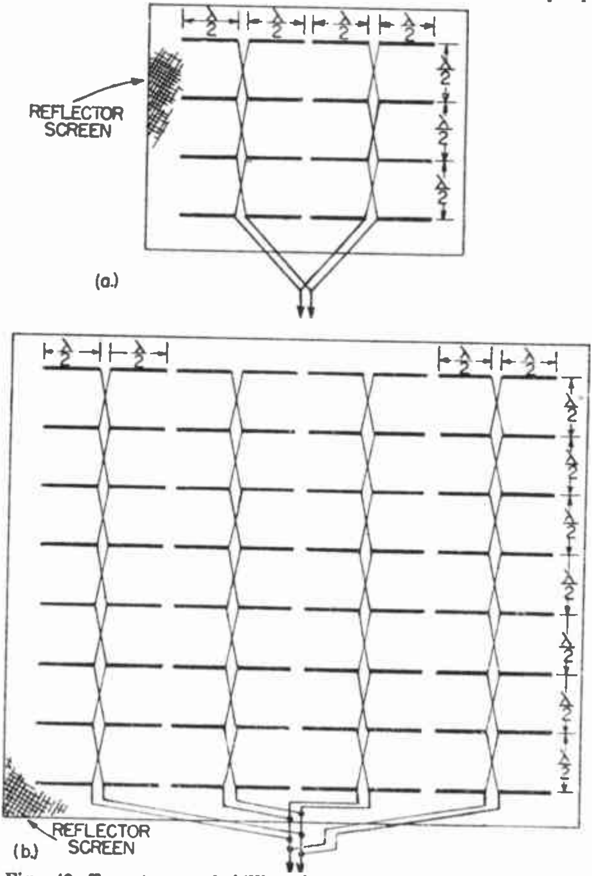


Fig. 42 Two types of billboard arrays used with reflecting screens. (a.) 16-element array has gain of 50, beam width of 15 degrees; (b.) 64-element array has gain of 100, beam width of 10 degrees.

72. Billboard Arrays.—This type of phased aray combines the directional features of both the co-linear array and the broadside array, plus a metal-screen reflector, to produce a unidirectional field pattern which is sharp in *both* the horizontal and vertical planes. Billboard arrays consist of at least 4 but rarely more than 64 half-wave dipoles (Fig. 42) mounted on a suitable metal-screen frame which also functions as a reflector. All dipole element are fed currents of equal magnitude and in the same phase. Essen ally an arrangement in width and height, the number of dipoles ssociated with each dimension influence the directional nature o the field pattern. The degree of directivity in the vertical pla e is determined by the *height* of the array: the number stacked alf-wave dipoles. The higher the stacks of parallel dipoles, the sh rper

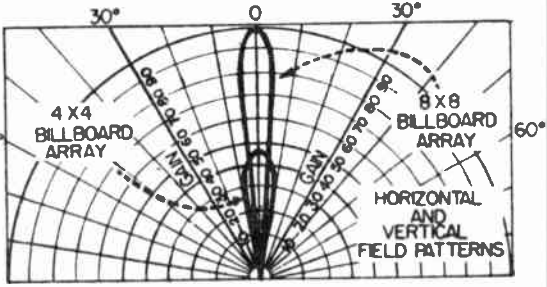


Fig. 43 Field patterns (main lobes only) of two large billboard arrays with high gain and high directivity.

is the vertical field pattern. Directivity in the horizontal lane is determined by the *width* of the array: the number of alf-wave dipoles arranged in co-linear fashion. The greater the umber of end-to-end dipoles, the sharper is the horizontal fiel pattern. Usually, the horizontal and vertical arrangements of d oles are equal in number; then the major lobe of the field patt n is essentially symmetrical about a line perpendicular to the pla e of the billboard array, and both the horizontal and vertical field patterns are identical (Fig. 43). Because of their large size billboard arrays are restricted in use to very short wavelengths. One popular type is the 4 x 4 array (Fig. 42a), which is use for radar and link-relay communications. The maximum limit the size of a billboard array is about 64 elements (Fig. 42b), hich provides a sufficiently narrow beam for radar contacts wit the moon and other astral bodies.

73. End-fire Arrays.—This type of array consists of o e or more pairs of parallel half-wave dipoles, which are fed cu rents of equal magnitude *but differing in phase.* With certain sp cings and with certain phase displacements, such pairs of dip les—known as *sections*—provide field patterns with pronounced irectivity. Since this directivity always lies in the plane of the ipole sections, such an arrangement is known as an *end-fire* rray. However, the antenna system is more popularly known as *flat-top array.* The actual field pattern of a flat-top array m y be either unidirectional or bidirectional, depending upon the s acing or separation and the phase difference of the two dipoles constituting each section. The degree of directivity is a functi n of the number of dipole sections, with a maximum limit of sections providing a field pattern sufficiently narrow for most practical purposes. Flat-top arrays are classified according to their types of feed. Center-fed arrays (Fig. 44) are usually preferred, because of their symmetry; a quarter-wave matching stub is used to connect the feeder to the array. End-fed arrays (Fig. 45) are less critical of adjustment, and often are more convenient to install.

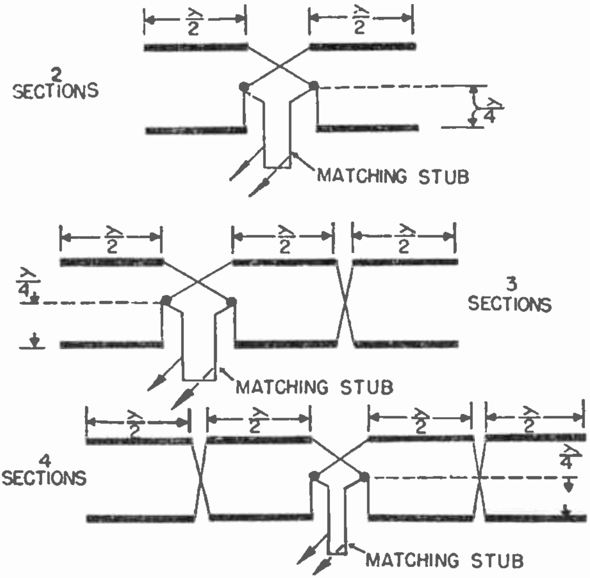


Fig. 44 Center-fed flat-top arrays (top view).

VERTICAL GROUNDED RADIATORS

74. At frequencies below about 2 megacycles, vertical grounded or *Marconi* antennas are generally used for the transmission of radio waves of high power intensity, because of the difficulty of elevating large structures above the ground as half-wave radiators. Vertical grounded radiators are essentially quarter-wave antennas, and provide non-directional field patterns useful for AM broadcasting and low-frequency communications services.

75. Basic Antenna.—The ground plays an important part in the operation of a vertical quarter-wave radiator, since the mirror or image effect of the ground (Fig. 46) permits the antenna to resonate at the same frequency as an *un*grounded half-wave antenna. This ground effect virtually completes the resonant length necessary to produce radiation, when the quarter-wave

antenna is fed at the grounded end with high current and low voltage. With maximum voltage at the top of the antenna and maximum current at the base, energy is radiated at a frequ ncy determined by the electrical length (vertical height) of the an-

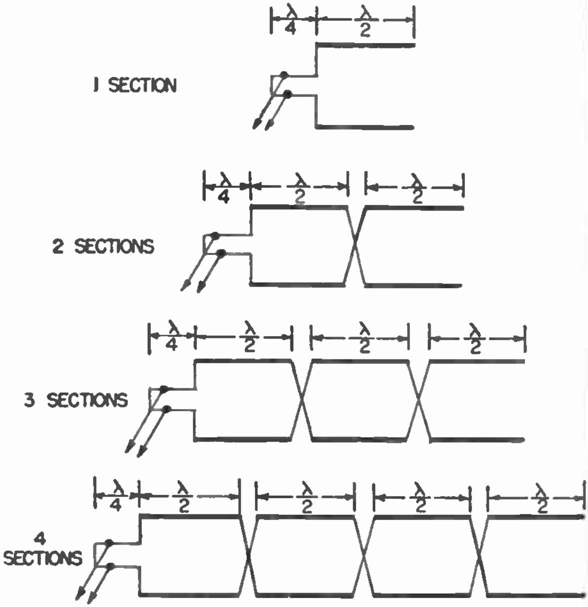


Fig. 45 End-fed flat-top antenna arrays (top view).

tenna. This resonant on- dition produces a fie l in the vertical plan as shown in Fig. 47, w ere maximum radiation kes place along the gr nd. The field pattern in the horizontal plane is i evitably affected — to ary- ing extents — by di fer- ences in the ground ar- acteristics surroun ing each antenna installa ion. The achievement of ef- fective, high-inten ity radiation is strongly de- pendent upon g od ground conductivity *and*

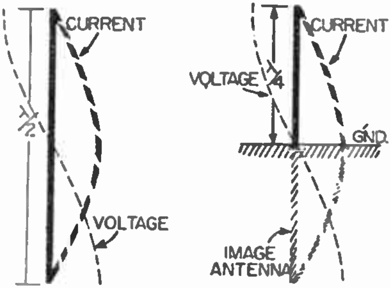


Fig. 46 Similarity between ungrounded half-wave antenna and grounded quarter-wave antenna, due to mirror or image effect of ground.

upon a low-resistance connection between the vertical antenna and ground.

76. Loading.—When a vertical radiator is slightly short *in electrical length* to resonate at a desired frequency, it may be electrically lengthened by inserting a sufficient amount of lumped inductive reactance—known as a *loading coil*—near the point of highest current (Fig. 49a). When a vertical radiator is slightly long *in electrical length* to resonate at a desired frequency, it

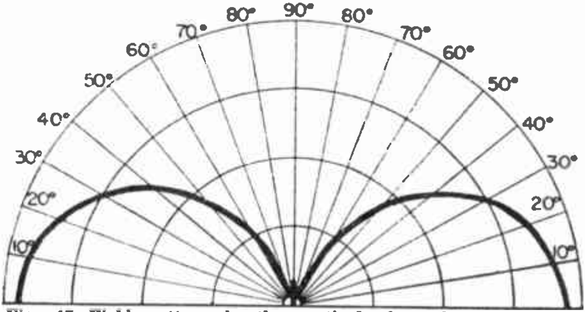


Fig. 47 Field pattern in the vertical plane for a grounded quarter-wave antenna, assuming a perfect ground.

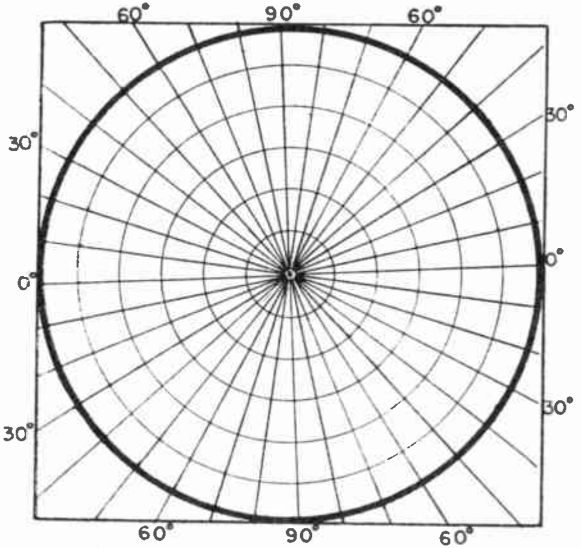


Fig. 48 Field pattern in the horizontal plane for a grounded quarter-wave antenna, assuming a perfect ground.

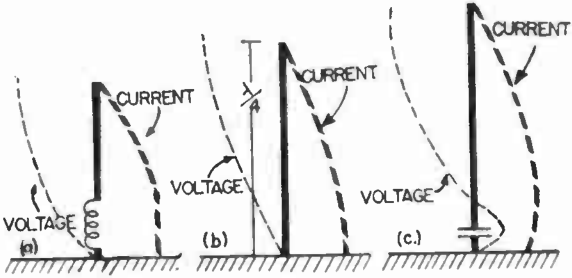


Fig. 49 Three vertical grounded antennas, all equal electrically to one-quarter wavelength. A, Inductive loading to increase length; B, Normal antenna without loading; C, Capacitive loading to decrease length.

may be electrically shortened by inserting a sufficient amount of capacitive reactance near the point of highest current (Fig. 49c.) This process is known as *loading* or lumped impedance tuning, and is frequently used with antennas for AM broadcasting.

77. Type Variations.—In some instances, because of cost considerations or because of height limitations imposed by airways traffic, it is necessary to radiate signals of equivalent power and frequency with a shorter wavelength. Although it is possible to load a short vertical antenna with a large value of series inductance in order to resonate the antenna at a desired frequency, excessive loading causes a considerable reduction in radiation resistance or impedance. It is more desirable to use either an *L-type radiator* or a *T-type radiator* (Fig. 50), both of which are essentially variations of the fundamental type of vertical grounded antenna. In the T-type, the two halves of the top horizontal portion of the antenna are effectively in parallel. Because of the relatively smaller currents in the horizontal sections of each of these antennas, maximum radiation is accomplished by the vertical or lower part of the L-type and T-

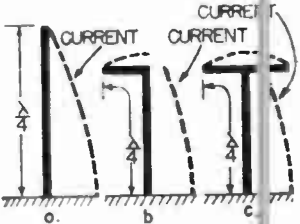


Fig. 50 Three types of ertical grounded antennas. A, Fundamental radiator; B, L-type radiator; C, T-pe radiator.

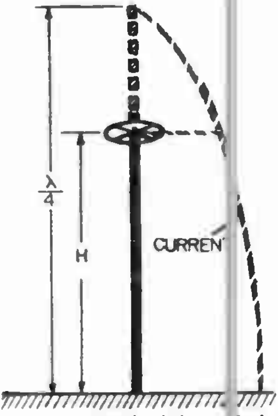


Fig. 51 Top-loaded ve ical radiator.

type radiators. Neither type, however, products an omnidirectional pattern in the horizontal plane. For maximum effectiveness, the vertical grounded radiator must actually be vertical and use, when necessary, a special type of loading known as *top loading.*

78. Top Loading.—When a vertical grounded antenna is provided with a *capacity top*—usually in the shape of a ring or spider—the radiator can be resonated at a longer wavelength (or lower frequency) than would be possible without the capacity loading. In other words, use of the capacity top permits the erection of short vertical radiators which, although considerably less than a quarter wavelength in height, function exactly as a fundamental quarter-wave antenna: providing maximum radiation. Increasing the top capacity of a radiator has the same effect as increasing the height of the antenna; current distribution in a top-loaded vertical radiator (Fig. 51) is the same as would be the case if the capacity top were removed and the antenna height H increased. Any horizontal radiation associated with the capacity top is negligible when compared with the high-intensity radiation produced by currents in the vertical or main section of the antenna. In a somewhat similar manner, it is also possible

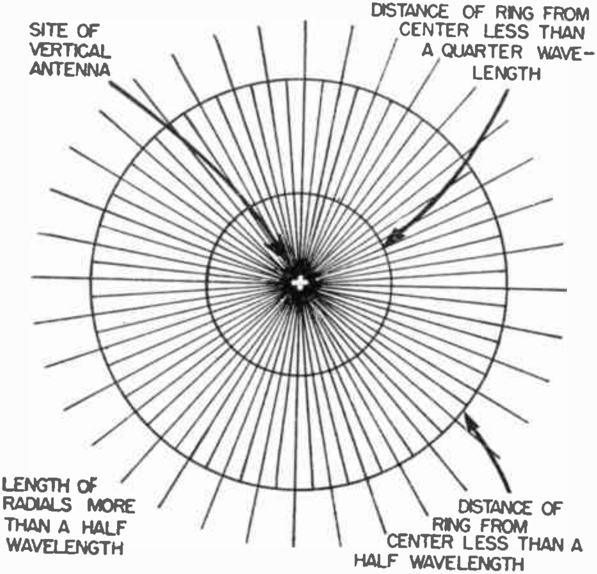


Fig. 52 Radial ground system for vertical grounded radiators.

to increase the effective height of a vertical radiator by m ans of *inductive* top loading.

79. **Ground Systems.**—The importance of a good, con uctive ground cannot be overemphasized in the operation of v rtical grounded antennas. Although the earth is often assume to be a perfect conductor, in practice it has resistance which may often be quite high and troublesome. Ground currents flowing through such a resistance constitute a definite power dissipa ion and consequent loss of antenna efficiency. Improving the gro und connection, therefore, reduces the loss of antenna power and thus increases the amount of radiated power. A radial gro und system (Fig. 52) provides one of the best possible ground onnections, and is widely used for AM broadcasting antennas. his ground system consists of heavy copper wires of more han a half wavelength extending out radially from the com non ground connection, with several concentric rings of similar wire or cable. Angular separation of radial wires is about 3 deg ees, and the wires are welded together at all joints to mini mize losses. A radial ground system is normally buried undergro und, but may be supported slightly above the earth's surface.

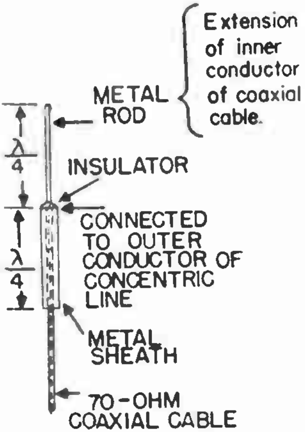


Fig. 53 Vertical coaxial radiator.

VERY-HIGH FREQUEN CY RADIATORS

80. Transmitting antenna for FM broadcasting, televi ion, communications, facsimile, and other services in the very-h gh-frequency band (30 mc to 300 mc) are usually require to provide omnidirectional r diation. For this purpose, a umber of distinct and un sual types of special radiators are used—ranging from a s mple coaxial dipole to such com plex types as the *turnstile, p lon,* and *cloverleaf* antennas.

81. **Vertical Coaxial R diators.**—Simplest omnidirec onal antenna is the vertical d pole fed by means of a coaxial cable. As shown in Fig. 53, this r diator consists of a quarter-wave section of open or exposed metal rod plus a tubular metal s eath or sleeve also measuring a quarter wavelength. The meta rod with the sheath form a complete half-wave radiator. Since here is no field within the sheath, the coaxial line runs up th ough the sleeve to feed the half-wave radiator at its center; thi arrangement eliminates any possibility of the coaxial line fun tion-

ing as a vertical radiator itself. Since the two feeder currents are balanced—one feeding the quarter-wave metal rod and one feeding the quarter-wave sleeve—there is substantially no high-angle radiation by the complete dipole. For best operation, the radiator should be mounted as high as possible. In a vertical position, radiation is vertically polarized with greatest intensity in a horizontal direction.

82. Ground Plane Antennas.—High-angle vertical radiation, which usually represents a power loss at high operating frequencies, is caused in large part by ground reflection or *re*-radiation effects. Thus, by attenuating or minimizing all *downward* radiation from a vertical coaxial antenna—through use of a *ground plane*—RF energy which would otherwise be lost is used to strengthen the horizontal radiation pattern. A ground plane antenna consists essentially of a vertical quarter-wave radiator fed by the *inner* conductor of a coaxial cable, and any one of several types of ground planes which is attached to the outer conductor of the coaxial cable. The ground plane is insulated from the vertical radiator, but elaborate precautions are not required as the voltage at the base of the vertical radiator is extremely low in value. One type of ground plane (Fig. 54a) consists of four quarter-wave rods mounted radially; although these rods do not constitute a plane surface, at very high frequencies their effect is much the same. A more efficient ground plane is the skirt—or wheel-type (Fig. 54b) consisting of six or more "spokes" or radial elements. A true ground plane (Fig. 54c) consists of a flat metal plate of any thickness but sufficiently large in area to prevent radiation downward toward the earth. By means of any type of ground plane antenna, RF energy is concentrated at a low angle, and the radiation pattern in the horizontal plane is circular or omnidirectional. Power gain is about 0.5 *less* than that of an equivalent single dipole. The radi-

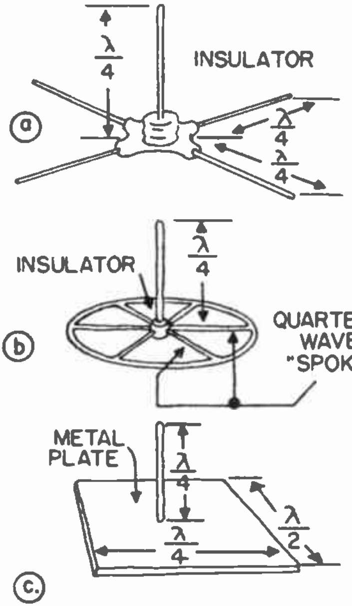


Fig. 54 Three types of ground plane antennas. A, Simulated plane of four rods; B, Skirt- or wheel-type plane; C, Metal plane.

ation resistance of a ground plane antenna is between 20 to 30 ohms, depending upon the type of ground plane construction nd other factors. Since this is not a standard impedance value for a coaxial line, the first quarter-wave section of feeder is usu lly selected to have a surge impedance of about 35 ohms, with the remainder of the line having about 75 ohms impedance. In his manner, the first quarter-wave section of the feed line is used as a matching transformer for the ground plane antenna.

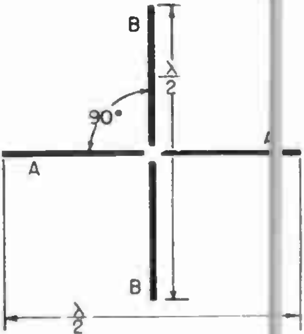


Fig. 55 Two half-wave dip es constituting one bay of a tu n-stile antenna.

83. Turnstile Antennas.—In order to obtain omnidirectional radiation with horizontal half-wave dipoles, a suitable arrangement of such elements is necessary which effectively combines the inherent directivity of each dipole to provide a circular radiation pattern in the horizontal plane. An arrangement of this type is the *turnstile antenna,* which is widely used for non-directional transmission. It provides relatively high power gain, due to

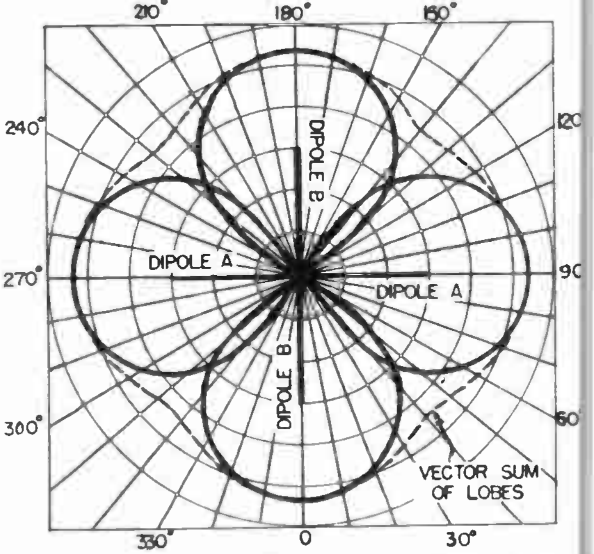


Fig. 56 Field patterns of two dipoles at right angles: when oper ted individually (solid lines); when operated simultaneously (dotted lin s).

energy concentration at a low angle in the vertical plane. The basic antenna consists of two horizontal half-wave dipoles (A and B of Fig. 55) crossed at right angles in the same plane, with their centers almost coinciding but not touching. The bidirectional field patterns for each dipole, when operated individually, are shown in Fig. 56. When the two dipoles are simultaneously fed equal currents *but differing in phase by 90 degrees,* the individual field patterns are combined; and the vector sum of all lobes is essentially omnidirectional, as shown by the dotted line in Fig. 56. Such an arrangement of two crossed dipoles, which produces an almost-circular radiation pattern, is known as a *bay* or unit. When a second, similar bay is placed a half wavelength above or below the first, and corresponding elements are fed currents with the same phase displacement, radiation in the vertical plane is minimized and a greater amount of RF energy is directed outward in the horizontal plane, but the gain is increased at the expense of unwanted vertical radiation. Additional bays of crossed dipoles, spaced at half-wave intervals and fed in phase quadrature, do not affect the shape of the horizontal radiation pattern but compress or modify the vertical pattern in such a way that maximum radiation is concentrated at a low vertical angle. A typical four-bay turnstile antenna (Fig. 57) has a radiation pattern in the horizontal plane which is almost constant in magnitude in all directions; the vertical radiation pattern (Fig. 58) indicates the low-angle directivity of such a 4-bay turnstile antenna. A high concentration of energy in the vertical plane requires a turnstile antenna consisting of a *minimum* of four bays. Since RF voltages and field intensities are zero at the vertical axis, the important center support of the antenna is constructed of metal. The necessary 90 degree phase displacement—between adjacent dipoles of each bay—is provided by either an external or coaxial feeder system. Fre-

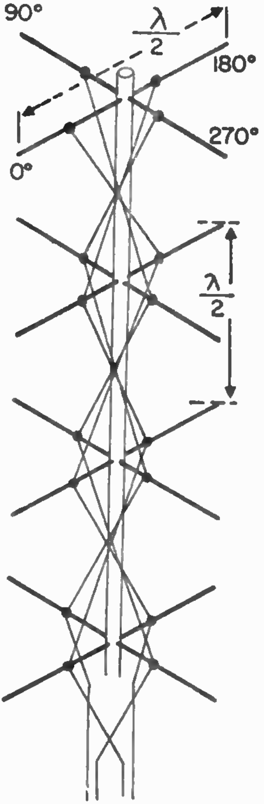


Fig. 57 **Four-bay turnstile antenna.**

quency of radiation is determined by the length of half-wave dipoles, which are tuned sharply to resonance.

84. Folded-Dipole Turnstile Antenna.—FM broadcas ing and television services require the use of a resonant ant nna capable of transmitting a relatively wide *band* of frequen ies. The basic turnstile, previously described, is inadequate for his purpose because it is composed essentially of half-wave dipoles which tune sharply to resonance. However, when these dipoles are replaced by *folded dipoles* having a characteristically b oad response, the resulting antenna *also* has a wide or broad frequency response—while retaining all other operating charact ristics of the basic turnstile antenna. In combination with a sui able phasing system, this arrangement of folded dipoles (Fig. 59) provides a band width many times greater than that of a s ngle FM channel. Another advantage of the folded-dipole tur stile antenna is its non-critical adjustment, permitting a shift in t ansmitter frequency of several FM channels without adjustin or returning the antenna. Vertical radiation is confined to a low angle, according to the number of bays. Radiation in the orizontal plane is omnidirectional. Field patterns are generally milar to those of the basic turnstile antenna.

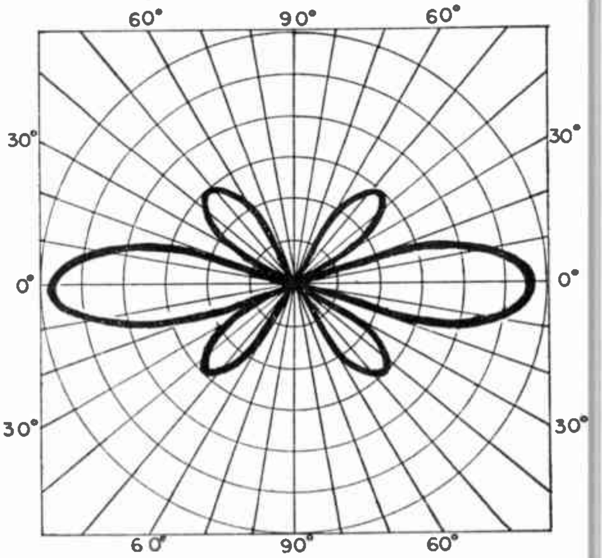


Fig. 58 Vertical radiation pattern of 4-bay turnstile antenna.

85. Super-Turnstile Antenna.—This broad band radiat r is another development of the basic turnstile antenna. Since it provides omnidirectional radiation at a low vertical angle and t ansmits an extremely wide band of frequencies (6 mc), the s per-turnstile antenna (Fig. 60) is ideally suited for FM broadcasting as well as television. Replacing the ordinary half-wave dipoles of the basic antenna, the super-turnstile is equipped with open sections of metal framework—known as *current sheets*—which have much the same electrical effect as solid metal sheets of the same size and shape without wind resistance. The open frame work is constructed of steel tubing, and vertical members are grounded at both ends. Each *bay* of the turnstile antenna consists of four *current sheets,* arranged in quadrature. When properly phased, the *current sheets* function as radiators much in the manner of ordinary dipoles. However, the particular shape of the *current sheets,* causes a widening of the frequency response for the antenna, so that it transmits a broad band of frequencies (about 6 megacycles). The super-turnstile usually consists of three or four *bays* in order to provide a sufficiently low angle of radiation in the vertical plane with the increased gain. In general, field patterns are similar to those of the basic turnstile antenna.

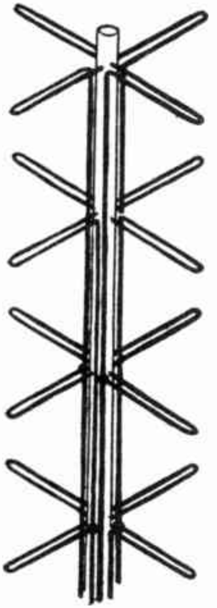


Fig. 59 Folded dipole turnstile antenna.

Fig. 60 Super-turnstile antenna.

86. Loop Radiators.—Several types of high-frequency radiators—known as the *square loop,* the *circular loop,* and the *cloverleaf antenna*—are essentially loop antennas, and function in accordance with the principles governing such a basic type of radiator. A loop radiator consists of one or more turns of conducting wire arranged in any symmetrical shape, generally square or circular (Fig. 61). Symmetry is important in order to maintain good electrical balance for obtaining desired radiation patterns. Both the square loop and the circular loop have almost-identical field patterns. In the horizontal plane (the plane of the loop), the field pattern is omnidirectional; in the vertical plane, the field pattern is bidirectional. Accordingly, for most high-frequency radiation, the loop antenna functions in a horizontal position. When identical horizontal loops are stacked vertically, radiation in the horizontal plane is highly concentrated—while retaining a circular or omnidirectional pattern in the vertical plane. Such an arrangement of square loops is know as the *square loop antenna* (Fig. 62), and consists of six or ore loops mounted on the same mast, each loop spaced a full v ivelength and fed in the same phase with approximately constant current distribution. To provide wide-band operation for FM and television services, each loop of the square loop antenna consists of four end-fed, interconnected arms—using conductors of large diameter. A vertical arrangement of circular loops, known as the *cloverleaf antenna* (Fig. 63), is composed of two or more stacked radiating units, each unit consisting of four circular loops arranged concentrically. One end of each loop is fed by a centrally positioned 3-inch coaxial pipe, which also provides structural support; opposite ends of the four loop are connected respectively to four vertical supporting members, hich also function as return feeders. Approximately constant cu rent, in the same direction and phase, flows through the four oops of a single unit, and the ring of uniform current produ es a circular radiation pattern about the axis of the antenna. Adjacent units of the cloverleaf antenna are spaced at a half avelength, and are therefore physically reversed. Thus RF c rent through each loop of every unit flows in the same directi n at any instant. This results in a directional pattern in the v tical plane, with the degree of energy concentration determin l by the number of units in the cloverleaf antenna. Radiation the horizontal plane is essentially omnidirectional.

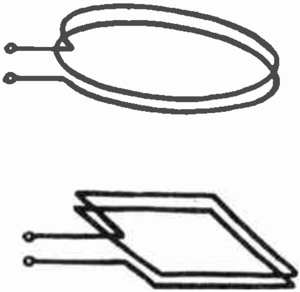


Fig. 61 Loop radiators: upper, Circular; lower, Square.

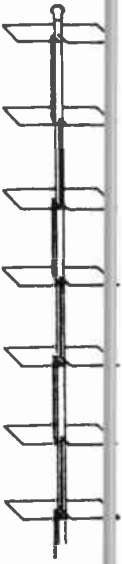


Fig. 62 Squar -loop antenna compo d of seven loop

87. Cylindrical Radiators.—This type of broad band adiator (Fig. 64) is essentially a vertical, cylindrical secti n of heavy metal tubing—having a length of approximately a avelength, and an inner circumference of a half wavelength- with a vertical slot by means of which the cylinder transmit RF energy. Sometimes known as a *slotted antenna* or *pylon antenna,* the cylindrical radiator is broadly resonant according to its length and inner circumference. The vertical slot—running the full length of the vertical cylinder—corresponds to a transmission line, since the edges have opposite polarity at any instant. When properly fed, RF energy travels horizontally *around* the inner circumference, because the difference in potential between opposite edges of the slot is greater than the difference of potential between the top and bottom of the cylinder. The vertical radiation pattern is not truly circular, due to the slotted opening in the cylinder; but for most practical purposes the radiation is sufficiently omnidirectional. The cylindrical radiator is constructed so that as many as eight sections may be stacked or attached together in order to provide a concentration of RF energy at small angles in the horizontal plane. A variation of the cylindrical radiator is the *rocket antenna* (Fig. 65) consisting of a metal cylinder with a metal bottom and an open top. Two such radiators may be joined at their open ends to form a *double rocket,* having greater directivity in the horizontal plane.

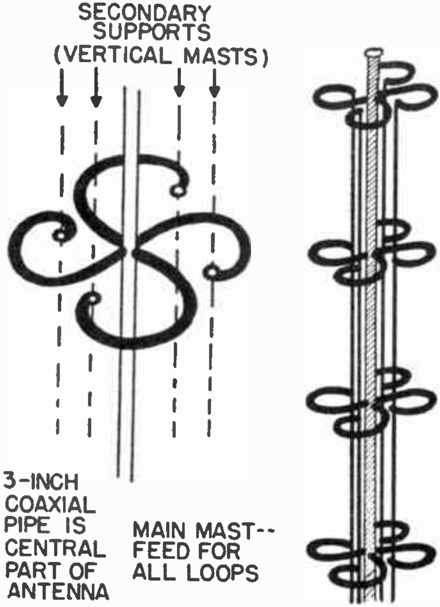


Fig. 63 Cloverleaf antenna.

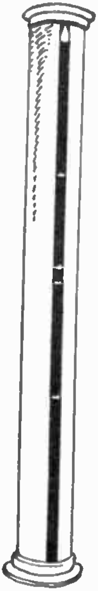


Fig. 64 Pylon radiator.

FM AND TELEVISION RECEPTION

88. Critical requirement for the satisfactory reception of FM

and television signals is a properly installed antenna system. No matter how well engineered, an FM receiver or television receiver is inefficient and often useless without a good ant nna installation. And a good installation means an *individual* in tallation, to fit the specific needs and solve the particular prob ems of each location. The two kinds of radio services, FM br adcasting and television, are both grouped together and given similar consideration for everal reasons. The two kinds of signals oc upy almost-adjacent portions of the elcetromag etic spectrum (Fig. 66), and the waves exhibit imilar characteristics during propagation and reception. Thus, similar type of antennas are sed to intercept either FM channels or telev ion channels. An important difference between the two kinds of channels, however, is the *w dth* of such bands of frequencies; television c annels (of 6 megacycles) are considerably v der than those used for FM broadcasting. Alth ugh some types of antennas are used for rece ving both FM and television signals, as a ge eral rule FM antennas are more selective than elevision antennas. Those having a wide or b oad frequency response—known as *wide-band antennas*—are capable of accepting several djacent channels when tuned to any one cha nel. In addition to band width, an important f ctor in the reception of either FM or telev sion waves is antenna *directivity,* since it provi es a means of eliminating unwanted signals, wave reflections, and interference. *Directivity* and *power gain* are obtained at ome sacrifice of *band width,* however, so that a compromise typ of antenna must usually be selected and installed—according t the individual requirements of each location.

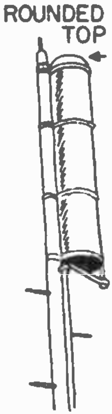


Fig. 65 Rocket radiator.

89. FM Reception.—Any one of the several basic typ s of dipole antennas is usually adequate for receiving FM si nals, but the antenna must be properly sited and oriented so that intercepts the signals of all FM broadcasting stations nor ally heard in the particular geographical region. For best rece tion, it is generally desirable to locate the receiving antenna *as high as possible* above surrounding objects and buildings, and a *remote as possible* from all kinds of electrical apparatus, fla hing signs, motors, and other possible sources of interference. If only one FM station is operating in the region, a *selective* ty e of antenna—such as a dipole with reflector, or dipole with di ector—is oriented in the direction of the FM station to provide aximum reception. If two or more FM stations are operati g in the region, a similar antenna is oriented in a compromi e or "average" direction so that it provides equally satisfactory eception of the desired stations; often this is in the direction c the weakest FM transmitter. When the stations are *widely* eparated in bearing, it may be necessary to install a *less direc onal* antenna; or, in extreme cases, individual dipoles may be used to receive each of the widely separated FM stations. Due to the wide range of operating frequencies contained within the FM broadcasting band (Fig. 66), it is often necessary to employ a *wide-band* type of receiving antenna—such as the folded dipole, or any of its variations—in order to produce a signal response reasonably uniform over the entire range of frequencies. An essential requirement of every FM antenna installation is that *it must provide signals of sufficient strength to operate the limiter stage of the FM receiver.* A good FM antenna installation also must provide:

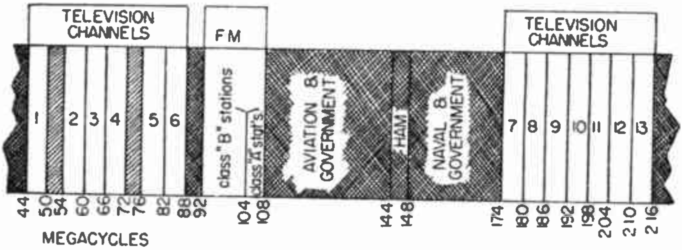


Fig. 66 Frequency chart of FM and television channels.

1. Signals free from noise or static interference.
2. Signals free from inter-station squealing and cross-talk.
3. Signals of constant strength, whether day or night.
4. Signals free from fading effects.

90. Television Reception.—There are many types of antennas suitable for receiving television signals, ranging from the simple and selective half-wave dipole to amazingly complex types of wide-band antenna arrays. Differences in the large number of types are characterized chiefly in terms of the *band width* or frequency response range of an antenna, or in terms of the *directivity* and *gain* of the field pattern. But there are so many variations within these categories, that it is usually possible to obtain a *selective* antenna having any desired degree of directivity or shape of field pattern, or to obtain a *wide-band* antenna capable of intercepting all channels within either *or both* of the two television frequency bands. Choice of the proper type of receiving antenna is primarily influenced by the specific requirements and characteristics of each location or site. In general, the antenna should be erected *as high as possible* in an attempt to provide a line-of-sight transmission path between the one or more television stations and the receiving antenna. If only one station is operating in the region, a *selective* antenna—such as a dipole with reflector, dipole with director, or a more directive array—is oriented in the direction of the desired television station *or* in a direction which provides the brightest and least distorted image on the picture tube of the receiver. If two or more stations are operating on channels in the low-frequency television band (44 to 88 mc), a *less selective* antenna—such as a folded dipole, or wide-band array—is oriented in a suitable compromise or "a erage" direction which provides equally satisfactory receptio of the desired stations. To receive two or more stations opera ing on channels in the high-frequency band (174 to 216 mc), a roportionately smaller but similar type of antenna is installed. The reception of *all* television channels (1 to 13) *with a single antenna* is possible only through use of one of the special t pes of wide-band multi-channel antennas. To favor weak signal or to minimize interference, a highly directive (or selective) antenna is sometimes employed; and almost any desired shap of field pattern can be obtained with a suitable combination or arrangement of antenna elements. Such special field patterns are required in many cases in order to provide the television rec ver with signals of sufficient strength for good visual reproduc ion. In metropolitan areas and industrial districts, where telev ion reception is likely to be marred by reflected waves or "gh sts" and other kinds of interference, it is sometimes necessar to install *individual* highly directive antennas for reception of *ach* television station. Many types of distortion or interference—due to flashing signs, diathermy machines, elevator motors, and ther electro-mechanical devices—can be minimized or eliminated with either a directional antenna system or a transmission line co sisting of coaxial cable. The essential purpose of a televisio antenna system is *to provide adequate, "ghost"-free, interfe ence-*

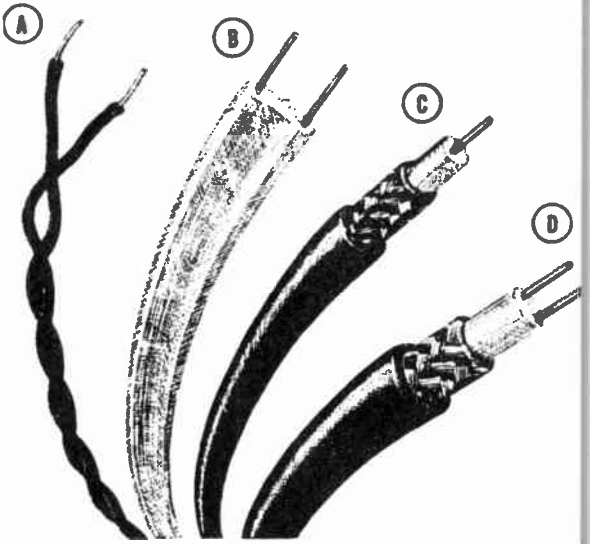


Fig. 67 Principal types of transmission lines used with F and television antennas. A, Twisted pair; B, twin-lead ribbon C, co-axial cable; D, Shielded parallel pair.

free reception of all desired television channels. The step-by-step details of a complete television installation are given, following a discussion of transmission lines and the principal types of FM and television receiving antennas.

91. Transmission Lines.—As in all high-frequency antenna installations, the proper choice of a feeder system or transmission line between antenna and receiver is necessary to good reception. All of the basic principles concerning feed and coupling systems apply to FM and television antennas, but a number of specific types (Fig. 67) are particularly suited for these specialized installations. *Twisted pair* consists of two insulated copper wires twisted upon each other to form a flexible line; although economical, it cannot be used at lengths greater than a few wavelengths because of high dielectric losses. A more popular type is the *twin-lead ribbon,* which is a two-wire parallel conductor enclosed and insulated by means of a plastic ribbon of polyethyline; although available with low surge impedance values, the 300-ohm twin-lead ribbon is widely used because of its ability to match directly the impedance of a folded dipole antenna. *Coaxial cable,* with the center conductor spaced and insulated from the outer shield by neoprene or polyethyline, is an extremely efficient transmission line for installations in "noisy" locations; it is an unbalanced line, with an impedance rating of about 50 ohms. *Shielded parallel pair* is similar to the coaxial cable in appearance and in impedance value; it is a balanced line, and is effectively shielded from stray electric fields encountered in "noisy" receiving locations. Regardless of the type of transmission line used, it is imperative that (1) the impedance of the feeder system is matched to the impedance of the receiving antenna, and (2) the impedance of the feeder system is matched to the input impedance of the receiver. In general, it is desirable to keep the transmission line—between antenna and receiver—as short as possible to minimize power losses.

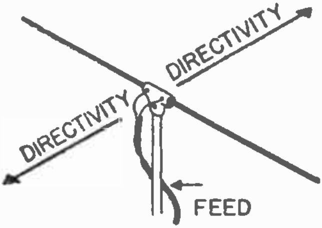


Fig. 68 Basic dipole or doublet antenna.

92. Basic Dipole.—Simplest—and most economical—receiving antenna for either FM or television signals is the horizontal *half-wave dipole* (Fig. 68). This antenna is *selective,* because it is tuned or resonant—at a frequency determined by the length of the dipole. It is not sharply tuned, however, so that it normally accepts several frequency channels without introducing degeneration of high-frequency side-band components. The actual band width accepted by a simple dipole is largely a function of the diameter size of the conducting rods. A rod diameter of less than a half-inch restricts use of the antenna to a single frequency channel; thus, dipoles are invariably constructed of larger-diameter conductors — despite a somewhat proportionate sacrifice in power gain. For example, a dipole with rods of sufficiently large diameter may be used to receive all or most of the channels (1 to 6) of the low-frequency band; but the resulting reduction in gain is a serious drawback to the use of such an antenna. Some compromise is necessary, because of the inherent selectivity of the half-wave dipole. Thus, it is only used effectively in areas of relatively high signal strength. Since it has a center impedance of only 73 ohms, installation of the dipole with a standard 300-ohm transmission line requires the use of a quarter-wave matching section. Although the antenna has a bi-directional (figure-eight) reception pattern, the two main lobes are not sufficiently sharp or narrow to be of much practical value; thus, the half-wave dipole has only a slight directivity. Despite its limitations, the antenna is used effectively for the reception of only two or three adjacent frequency channels—when wide-band response is not desired or required. It is noteworthy, however, that the fixed dipole forms the basis for a wide variety of other types of antennas and arrays, all of which

Fig. 69 Tunable dipole.

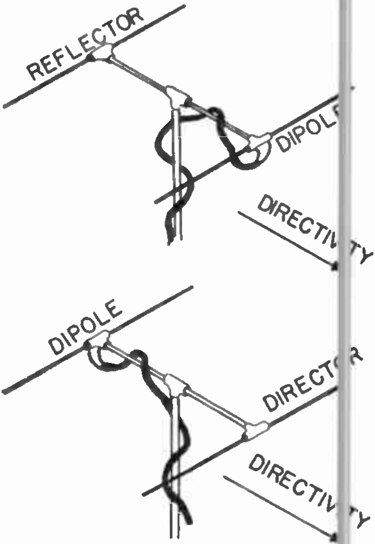


Fig. 70 Use of a parasitic element w th basic dipole to provide unidirecti al reception. Upper, Dipole and reflec r; lower, Dipole and director.

retain some component of the inherent selectivity of the basic half-wave dipole.

93. Tunable Dipole.—This simple variation of the basic half-wave dipole overcomes a tuning restriction imposed by the *fixed* elements of a conventional dipole antenna. By means of telescoping end-sections, the *tunable dipole* (Fig. 69) can be adjusted to resonate at any desired frequency in the wide range between about 50 and 850 mc. This permits maximum-signal interception of either FM or television signals on any specific frequency channel.

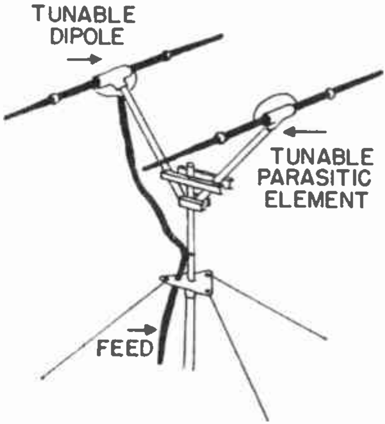


Fig. 71 Two-element tunable parasitic array.

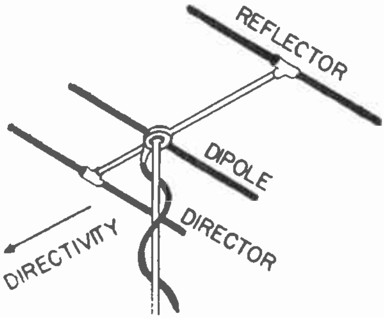


Fig. 72 Three element parasitic array: a reflector and a director with half-wave dipole.

94. Simple Dipole Arrays.—The bidirectional field pattern of a basic half-wave dipole permits reception from both the front and rear of the antenna. Often this is undesirable, since either of the wide major lobes may allow the reception of reflected waves, noise intereference, or other unwanted signals. The increased directivity of a *unidirectional* field pattern not only insures the rejection of many of these unwanted signals but also provides a gain increase in the forward direction. Simplest method of producing a unidirectional field pattern is by means of a two-element parasitic array — consisting of either a *dipole with reflector,* or a *dipole with director.* When a half-wave dipole is properly operated in conjunction with either a a reflector (Fig. 70a) or a director (Fig. 70b), the directivity of the forward reception pattern is sharpened, there is an increase in gain or signal strength, "back" reception is effectively cancelled or eliminated, the band width of the system is reduced, and the input impedance of the dipole is lowered. Both types of two-element parasitic arrays are widely used for FM and television reception, with the dipole-reflector arrangement pro ing the most popular. A variant of this type of antenna is the *tu ble parasitic array* (Fig. 71), consisting of two adjustable element —a dipole, and a parasitic rod which can be used as either a refle tor or director. Since the length of each element as well as the spacing between the two elements are both variable, this ype of adjustable parasitic array can be used to provide recep ion patterns of any desired shape and magnitude, at any des red operating frequency.

95. Three-element Array.—When both a reflector an a director are combined with a half-wave dipole in a para itic array (Fig. 72), the resulting highly directional antenna -dinarily provides sufficient selectivity to eliminate the most difficult or persistent "ghosts." A three-element array of this type is designed for maximum power gain at only *one* frequen y of operation. At resonance, the band width—without degene ative effects—is about 8 megacycles. The reception pattern in the lane of greatest directivity is shown in Fig. 73.

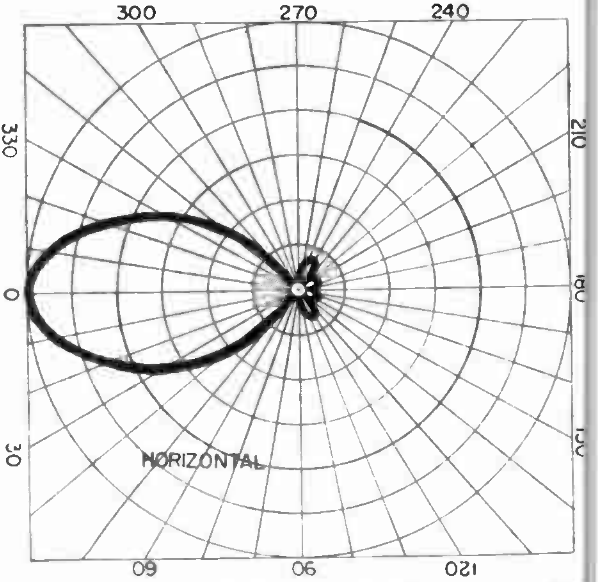


Fig. 73 Horizontal field pattern for three-element fixed parasitic array.

96. Stacked Doublet Antenna.—This type of antenna consists of two half-wave dipoles, stacked one above the other in a vertical plane (Fig. 74). Compared with a *single* dipo or doublet, this arrangement provides a bidirectional receptio pattern with increased gain in the horizontal plane and with a somewhat proportional decrease in gain in the vertical plane. Thus, the main lobes—forward and backward—are sharper in the horizontal plane, and ground reflection effects are virtually eliminated. The stacked doublet antenna has a medium-broad frequency response, but it is only installed in areas of average-high signal strength.

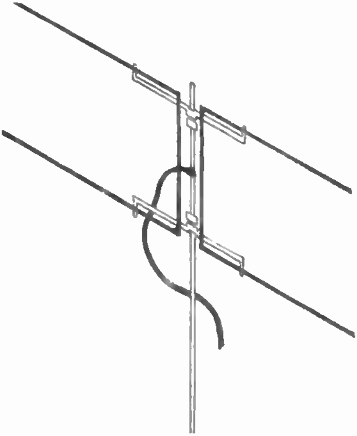


Fig. 74 Stacked doublet or H-type antenna.

97. Double Doublet Array.—This variation of the stacked doublet requires only the addition of two reflectors behind each of the two half-wave dipoles in order to produce a highly concentrated *unidirectional* reception pattern. Because of high gain, the double doublet array (Fig. 75) provides good reception of fairly low signal strength and in localities extremely remote from transmitting stations: often well beyond the horizon.

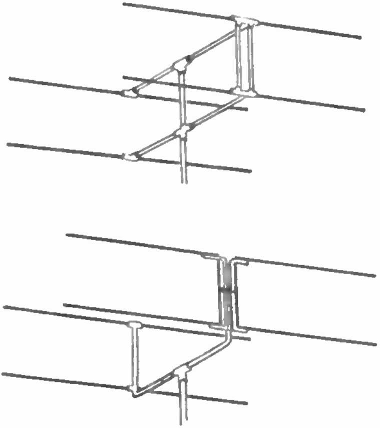


Fig. 75 Two types of the double-doublet antenna.

98. Adjustable V Antenna.—A distinct variation of the dipole-type receiving antenna consists of a half-wave dipole *with movable arms or elements.* The dipole is fed at its center, and pivoted in such a way that each arm can be adjusted to any angle above the horizontal (Fig. 76). The adjustable V antenna is used primarily for FM reception in congested city and industrial areas, where multi-path wave reception is commonplace. FM waves are horizontally polarized at the time of transmission, and normally they retain this polarization during propagation and until they are intercepted. In urban or metropolitan districts, however, these waves are often reflected by large buildings and other structures before reception. Due to this multi-path transmission, the waves acquire a *vertical* component of polar ation—in addition to the horizontal component. The combination of vertical and horizontal components effectively "raises" the angle of polarization above the horizontal plane, so that a maximum ignal can only be intercepted when the receiving dipole is opera ed in an angular position which corresponds to the oblique angle of wave polarization. In practice, the two arms of the dipole are merely adjusted for maximum reception of a desired FM sig al, as determined by aural test and comparison. The shape of he reception pattern varies considerably, according to the angular positions of the two arms of the receiving dipole, but the pattern is always bidirectional. When reception from only *one* direc on is desired, a parasitic reflector—which is similarly adjustab —is placed behind the receiving dipole (Fig. 77), thus provid ng unidirectional reception of FM waves.

Fig. 76 Adjustable V antenna

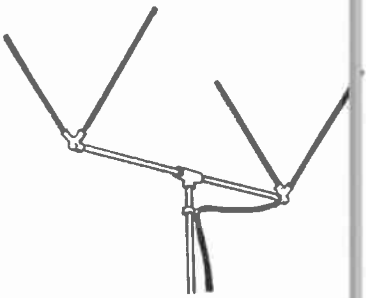


Fig. 77 Adjustable V antenna with reflector unit.

99. Extended V Antenna.—This wide-band antenna is u ed for FM and television reception in congested city and ur an locations, where polarization effects—due to multi-path wave transmission—are most pronounced. The extended V ante na (Fig. 78) provides compensation for this polarization distort on, and has a frequency response sufficiently broad to accept all FM and television frequency channels. The V-shape of the antenna represents a *Delta match* connection, by which the antenna is properly matched to a 300-ohm transmission line.

100. Folded Dipoles.—All the types of receiving antennas previously described are characteristically *selective,* because t eir operation is based on a tuned or resonant half-wave dipole. For adequate reception of a great many channels *or all channels* of the FM band or either television band, a less selective and ess directive type of antenna is required—which has uniform response over a wide range of frequencies. These are kn wn as *wide-band antennas,* and range in size and complexity f om a single folded dipole to elaborate multi-element arrays of w ich a few are capable of intercepting *all* FM and television frequency channels with the same degrees of directivity and power gain. Most types of *wide-band* antennas are developments or improvements of the *folded dipole* which, by itself, constitutes the simplest type of wide-band receiving antenna. The *basic* folded dipole (Fig. 79) is constructed of large-diameter metal tubing,

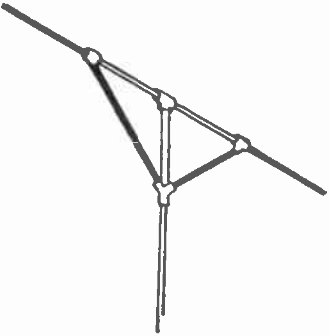


Fig. 78 Extended V antenna.

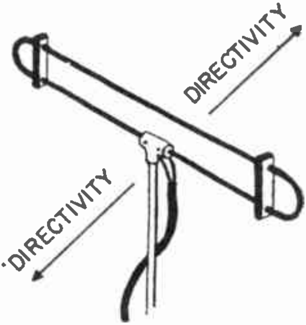


Fig. 79 Simplest wide-band antenna: the folded dipole.

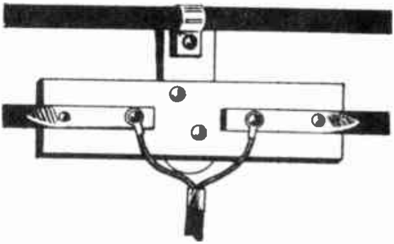


Fig. 80 Method of connecting feeder to folded dipole.

has a bidirectional (figure-eight) reception pattern with wide lobes, and is somewhat similar in other respects to a conventional dipole. The outstanding characteristic of the single-loop folded dipole, however, is its impedance rating of 300 ohms—which allows an almost-perfect match to a standard 300-ohm transmission line (Fig. 80). When the receiver input impedance is also 300 ohms (the usual case), a single size and type of lead-in can be installed the entire distance between the antenna and the receiver, without the need of a matching section; then, since the entire antenna system is perfectly matched and tuned, all energy accepted by the antenna reaches the receiver with no loss of signal strength, and any possibility of noise interference pick-up is minimized considerably. Much like an ordinary dipole, the *length* of a folded dipole determines the frequency to which it is tuned; but this dimension—a half wavelength—is by no means critical, due to the characteristic broad frequency response of the folded dipole.

101. Folded Dipole with Reflector.—Extensive applications of the basic folded dipole are limited, because this antenna lacks sufficient directivity to discriminate effectively against unwanted signals and interference. By providing the single dipole with a conventional parasitic reflector, the resulting two-element array (Fig. 81) has a *unidirectional* field pattern—with a much narrower beam and an increase in gain or signal strength in the forward direction, and with no "back" reception due to wave cancellation. Such use of a parasitic reflector has a compressive effect on the band width or frequency response of the folded dipole; but this is usually overcome by constructing the two-element array with conductors of slightly larger diameter. This antenna is extensively used for FM reception, particularly in areas of low signal strength and in locations near sources of noise and other interference.

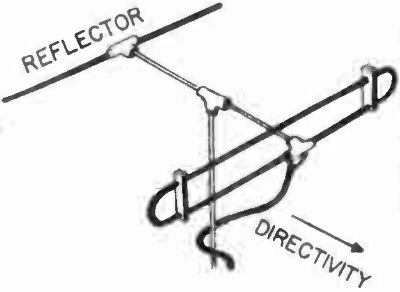


Fig. 81 Use of reflector behind folded dipole provides unidirectional wide-band reception.

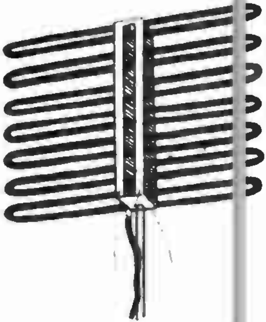


Fig. 82 Stacked array of folded dipoles for wide-band FM reception.

102. Array of Folded Dipoles.—This stacked array of folded dipoles (Fig. 82) is a unique type of wide-band FM antenna, with maximum gain concentrated at a low angle in the horizontal plane of the reception pattern. There is pronounced discrimination against ground reflections as well as high-angle reception on all channels of the FM broadcasting band. In this manner, directivity is achieved with an array having a broad frequency response. The reception pattern in the vertical plane is essentially omnidirectional.

103. Duo-band Antenna. — The unconventional dipole arrangement of this wide-band receiving antenna (Fig. 83) provides the same directional coverage of both television bands, as well as the FM broadcasting band. The antenna consists of a relatively thin half-wave dipole—*resonant at 70 megacycles*—

mounted parallel and close to a thicker half-wave dipole—*resonant at 128 megacycles.* The ends of the short, thick dipole are connected *by means of inductive loops or rings* to mid points along the thin dipole; in addition to feeding the short dipole, these two inductive loops also provide structural support for the long, thin dipole. For reception in the low-frequency television band: the antenna functions as a wide-band *folded dipole* resonant at about 70 megacycles, since the thin dipole is tuned to this frequency and the thick dipole is effectively end-loaded by means of the inductive loops. For reception in the high-frequency television band: both dipoles are resonant at the center of the band with all currents in phase, since the long, thin dipole is tuned to a third harmonic of the center frequency and the short dipole is end-fed by means of the inductive loops. A matching stub permits use of a standard 300-ohm transmission line, with no loss of power due to mismatching. In general, the directivity of this receiving antenna remains substantially the same for *both* television bands. This important characteristic is evident by comparison of the reception pattern at 70 mc (Fig. 84) with the reception pattern at 195 mc (Fig. 85).

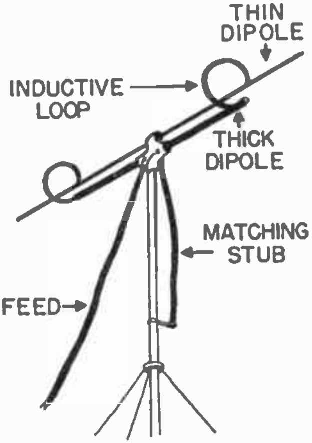


Fig. 83 Duo-dipole antenna.

104. Bat-Wing Antenna.—An important modification of the folded dipole, known as the *duoband* or *bat-wing antenna* (Fig. 86), operates with equal effectiveness on each of the thirteen television channels (as well as the FM channels)—and thus exhibits essentially the same directivity, gain, band width, and other reception characteristics on any channel, *regardless of frequency*. This is accomplished with a conventional folded dipole broadly tuned to the center of the low-frequency television band (44 to 88 mc), *plus* a wide-band half-wave dipole resonant at 180 megacycles, connected to the terminals of the transmission line *in parallel* with the large folded dipole. The short modifying elements protrude forward at an angle of 50 degrees, accounting for the "bat-wing" appearance of the antenna. For reception of television channels in the low-frequency band, the antenna functions as any conventional folded dipole—with a bidirectional field pattern (Fig. 87). For reception of television channels in the high-frequency band, however, there is a pronounced directional effect (Fig. 88) produced by the resonant modifying elements at the center of the antenna. Increased directivity in the forward direction is achieved by placing a three-element parasitic array behind the antenna (Fig. 89), resulting in an essentially unidir ctional field pattern for television channels in the low-freque cy band (Fig. 90), as well as the high-frequency band (Fig. 91).

105. Double-V or Fan Antenna. — Complete coverage of *all* FM and television channels is accomplished with the *double V antenna* (Fig. 92), the *fan antenna* (Fig. 93), or any of he several variations based on the number and arrangement of

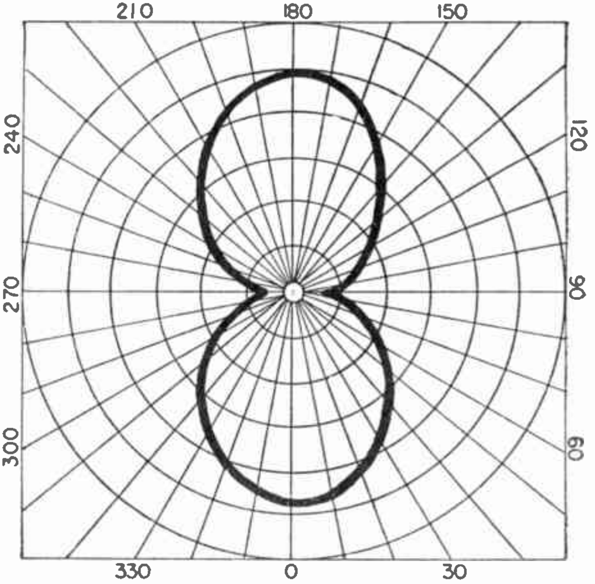


Fig. 84 Horizontal field pattern of duo-dipole antenna at a frequency of 70 mc.

"fanned" elements. Maximum reception is perpendicular to he major axis of these antennas and, accordingly, the horizon al reception pattern is bidirectional (Fig. 94a). The shape of this pattern is considerably influenced, however, at higher televis on frequencies (Fig. 94b). There are sharp *nulls* off the e ds of the wide-band antennas, which prove useful in the el nination of spurious reflections originating at some point bey nd the transmission line. In the vertical plane, the reception p ttern is essentially omnidirectional—regardless of the freque cy of operation. An important characteristic of these wide-b nd antennas is their *fixed* impedance rating—of 300 ohms—which is maintained practically constant throughout the entire operat ng range of frequencies. This condition results in increased fficiency of the entire antenna circuit, with a maximum trans er of energy between the antenna and transmission line to the eceiver.

106. Omnidirectional Antennas.—In some areas where several transmitters are separated by large angular distances, it may be difficult or impossible to orient conventional types of FM receiving antennas—all of which possess at least a slight amount of directivity. A possible solution to this reception problem is an omnidirectional antenna (Fig. 95) consisting of two crossed half-wave dipoles. For all practical purposes, this antenna has no directivity in the horizontal plane (Fig. 96) and such a characteristic may be put to good advantage in locations where several FM signals must be received from widely different directions. However, this type of antenna cannot discriminate against unwanted signals, and it is likely to accept reflected signals or "ghosts," waves with polarity distortion, noise interference, or other unwanted signals. For this reason,

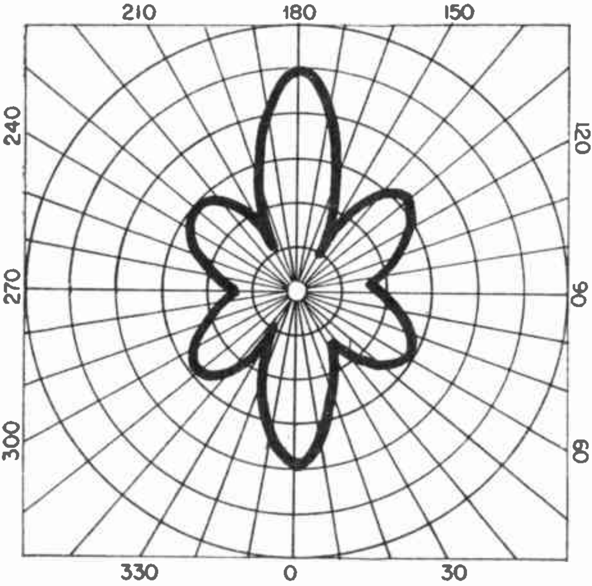


Fig. 85 Horizontal field pattern of duo-dipole antenna at a frequency of 195 mc.

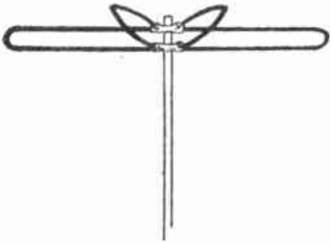


Fig. 86 Bat-wing antenna.

use of the omnidirectional antenna is restricted to FM recept on in areas of high signal strength; it is *not* recommended for he reception of television channels.

107. Rotatable Antenna.—Since optimum or perfect rec ption of an FM or television station is only achieved when he receiving antenna is oriented in the true direction of the particu ar transmitter, *ideal* reception of a dozen FM channels and a

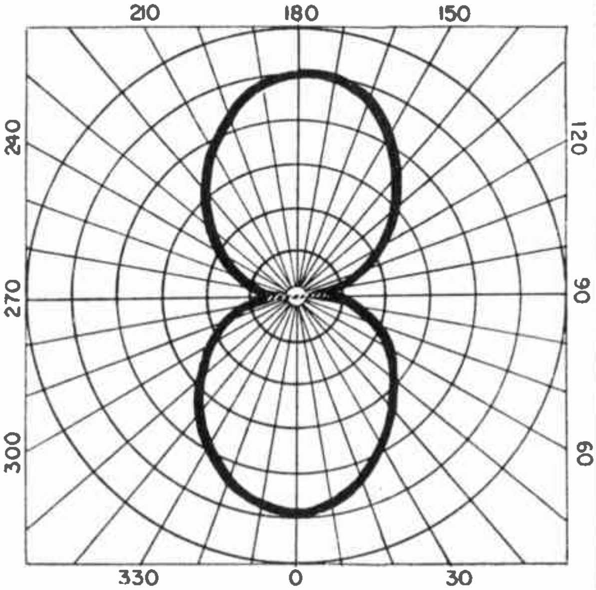


Fig. 87 Field pattern of bat-wing antenna at a frequency of 80 mc.

half-dozen television channels would ordinarily require m ny individual receiving antennas. A more practical solution to his *potential* reception problem is a *rotatable antenna,* which can be oriented in the direction of any desired station, thus provid ng peak performance at all times. One type of rotatable ante na (Fig. 97) consists of two wide-band dipoles, mounted at r ght angles to each other. The longer dipole is broadly tuned or reception of television channels in the low-frequency band; he shorter dipole is broadly tuned for reception of the high- equency channels. The entire dipole assembly is motor dri en, and can be rotated in azimuth, in either direction, from a emote control box at the receiver. In operation, the dip les are rotated or oriented in the direction of a desired stat on. Results are observed directly (visually) on the picture tube of

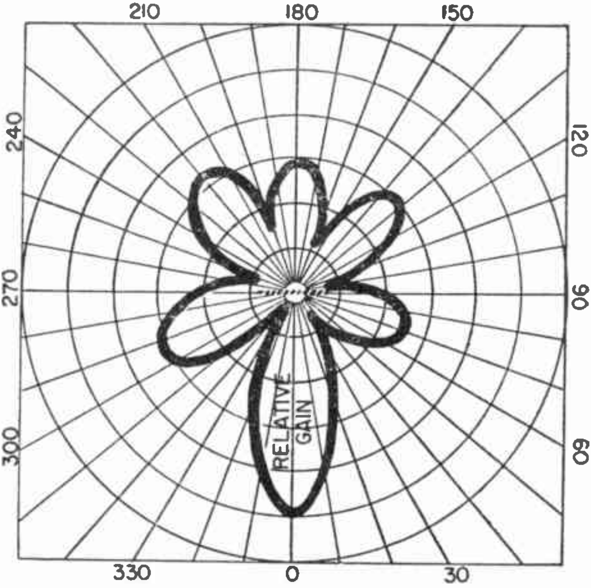


Fig. 88 Field pattern of bat-wing antenna at a frequency of 180 mc.

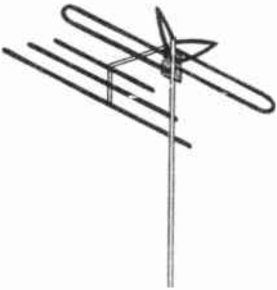


Fig. 89 Bat-wing antenna with reflector unit attached.

the television receiver, thus providing an indication of accurate orientation.

108. Installation Procedure for Television Antenna.—A detailed step-by-step procedure covering the siting, orientation, and complete installation of a television receiving antenna is given in the following appropriate order. The outline is general, and is *not* intended to cover exceptions or extreme details of the procedure.

1. *Initial Analysis of Site.* Several days prior to commencement of work; visit proposed site of installation (a suburban residence, about 5 miles from large city). At site: note likely or possible roof location for antenna. Note presence of any tall or large buildings in immediate vicinity. Note presence of any

large buildings or obstacles blocking direct path between transmitting station and the proposed site of installation. Estimate necessary height of receiving antenna, and possible need for directional array (a dipole with reflector). Determine owner's

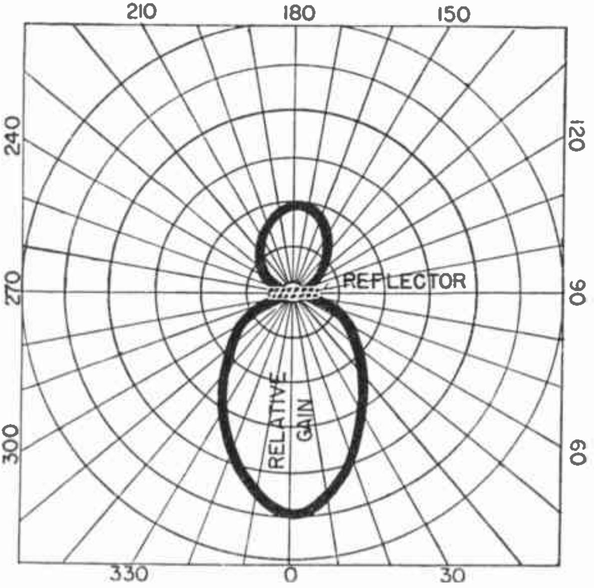


Fig. 90 Field pattern of bat-wing antenna with reflector unit attached at a frequency of 80 mc.

preference as to interior location of television receiver. Estimate approximate distance of transmission-line route—from set location to farthest corner of roof.

2. *Preparation of Gear.* Based on above information: Prepare extra-sufficient length of twin-lead ribbon (impedance: 300 ohms) for lead-in. Prepare quarter-wave matching section if one is required to match transmission line to dipole (73 ohms). Quarter-wave matching section consists of 30-inch length of 150-ohm twin-lead ribbon. Prepare half-wave dipole for operation at wavelength of television station. Prepare reflector of proper length to operate behind dipole—in case directivity is needed.

The following chart is useful in determining *the length in* inches of an active dipole, a reflector, and a director for operation at a specific television channel:

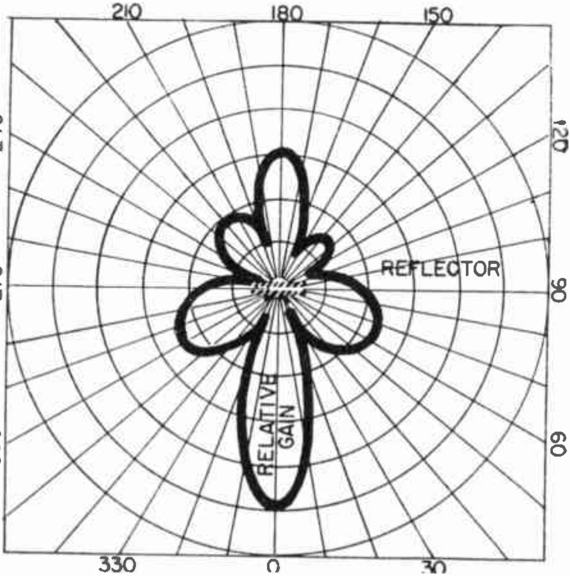
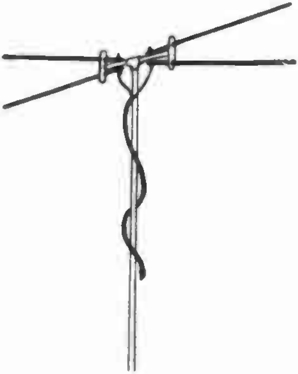


Fig. 91 Field pattern of bat-wing antenna with reflector unit attached at a frequency of 180 mc.

TV Channel No.	Freq. band	Dipole length in inches	Reflector length in inches	Director length in inches
1	44- 50 mc	118″	130″	106″
2	54- 60 mc	106″	116″	96″
3	60- 66 mc	88″	97″	79″
4	66- 72 mc	80″	88″	72″
5	76- 82 mc	70″	77″	63″
6	82- 88 mc	65″	71″	59″
7	174-180 mc	30″	33″	27″
8	180-186 mc	29″	32″	26″
9	186-192 mc	28″	31″	25″
10	192-198 mc	27″	30″	24″
11	198-204 mc	26″	29″	23″
12	204-210 mc	25″	28″	22″
13	210-216 mc	24″	27″	21″

3. *Preliminary Preparations.* At site of installation: place television receiver at previously established location. Check receiver for possible damage. Check operation of receiver. Outside the house: assemble single half-wave dipole on suitable antenna mounting pole. Connect one end of matching section to

two center terminals of antenna. Connect opposite end of matching section to slack end of coil of twi-lead ribbon. T ke dipole assembly, matching section, and lead-in coil to roof; s-sistant carries necessary tools, coil of twisted pair, and equipm nt



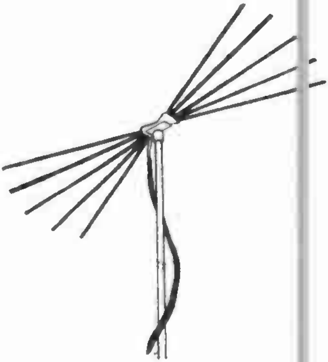


Fig. 92 Double-V antenna.

Fig. 93 Fan multi-channel ante na.

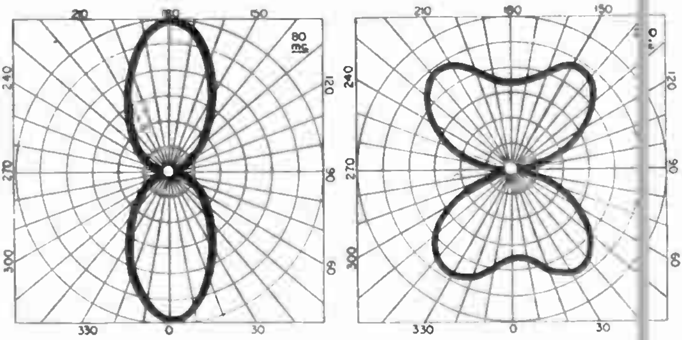


Fig. 94 Horizontal field patterns of fan antenna. Left, At frequen y of 80 mc; right, At frequency of 200 mc.

for battery operated communications system. With port ble dipole antenna left on the roof, run lead-in *loosely* from oof to interior location of television set, following a proposed lea -in route. Connect slack end of twin-lead ribbon to input termi als of receiver. Run loose length of two-conductor covered ire between roof and receiver. Connect wires to portable earph ne-and-speaker sets of local battery telephone system. With assistant at receiver, establish communication between roof and receiver.

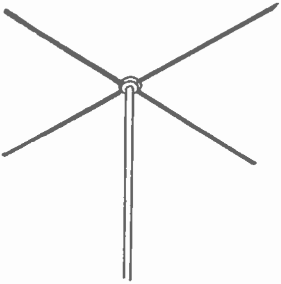


Fig. 95 Omnidirectional FM antenna.

4. *Siting the Antenna.* Determine the best roof site experimentally, using two-man coordination system. Assistant switches receiver to channel of television station in operation; he observes all changes in intensity of image on tube as dipole on roof is moved from point to point. On roof: hold dipole assembly upright, with dipole in horizontal position. Test the desirability of various location—in terms of signal strength and picture quality observed at television receiver.

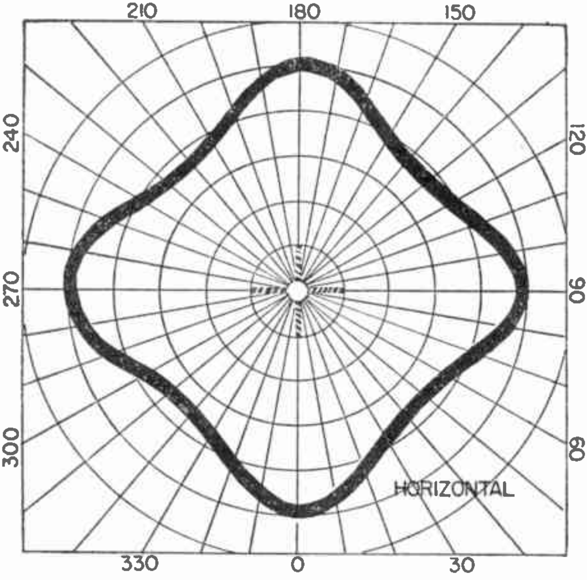


Fig. 96 Horizontal field pattern of the omnidirectional antenna.

Explore all likely and accessible parts of roof. Re-test best locations. Then: select best site for erection of receiving antenna. Attach mounting bracket for antenna pole support. Place antenna assembly in upright position. Do *not* mount antenna permanently;

pole must be free to rotate.

5. *Orientation.* For best reception: dipole must be broadside to direction of television station; image must be clear and bright, with no trace of "ghosts" or noise interference. Use previous, two-man coordination system to orient antenna. Rotate antenna assembly in mounting bracket, to determine best bearing—in terms of signal strength and picture quality observed at receiver. When brightest picture image is obtained at one bearing of antenna: *proceed to sub-paragraph 7 below.* If pictures are distorted by interference: suppress noise at source, elevate antenna, or install coaxial transmission line. If "ghosts" are present on picture tube: install an antenna with greater directivity. If pictures are weak, and snowy or "spotted": install an antenna with greater directivity.

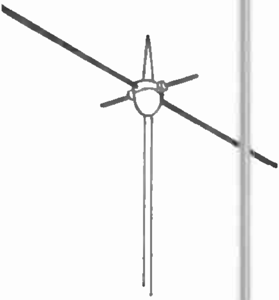


Fig. 97 Motor-driven rotatable antenna.

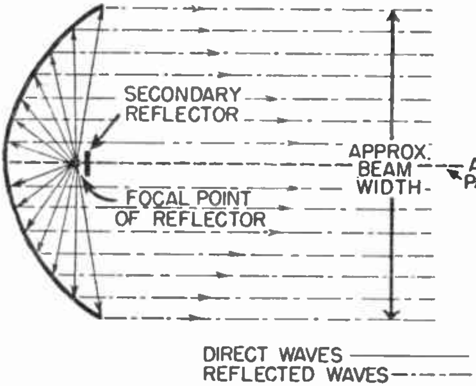


Fig. 98 Reflecting action of parabolic surface.

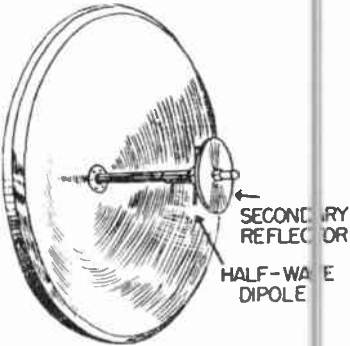


Fig. 99 Rotational parabola.

6. *For Greater Directivity.* Remove existing antenna assembly and return to ground. Detach single dipole from antenna frame, then replace with dipole and properly spaced reflector. Reflector is mounted *behind* center-fed dipole. On roof: place new antenna assembly in mounting bracket. Again using two-man coordination system: orient antenna, as before. Best bearing position results in sharp, clear picture—with no "ghost" or other interference present.

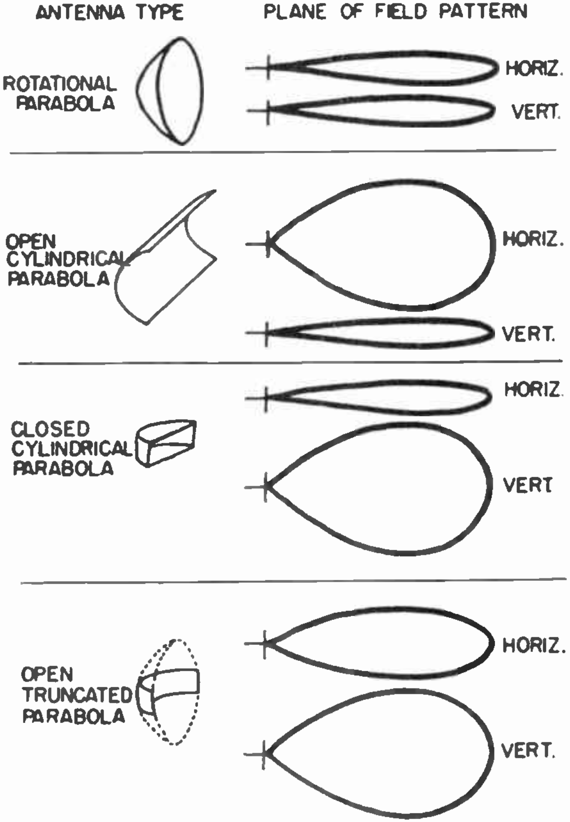


Fig. 100 Special types of parabolas, with comparative field patterns.

7. *Conclusion.* Mount antenna array in fixed position; tighten all mounting nuts and bolts; guy antenna assembly if necessary.

Install lead-in permanently, using stand-off insulators where ne essary; avoid sharp bending of twin-lead ribbon. Install lightn ng arrestor. Recheck operation of receiver. Furnish owner w th practical instructions on operation of set, assisting owner in actual operation of television receiver.

MICROWAVE ANTENNAS

109. Antennas used for the transmission and reception of microwaves (frequencies higher than about 300 megacycles) differ markedly in both physical and electrical aspects from those operating at lower frequencies.. This is due to the nature of u-h-f-waves, which exhibit many of the characteristics of infrared light waves. They can be reflected by plane surfaces, much as light waves are reflected by mirrors. They can be focused with metal lenses; they can be diffracted by slits in metal surfaces; and they are propagated in almost-straight lines between transmitting antenna and receiving antenna. By the usual laws of reciprocity, an identical antenna may be used for either transmission or reception. Both function in free space—at least 10 wavelengths above ground—and there is no influence of the field pattern by ground effects. Practically all types of microwave antennas have pronounced directional characteristics. Antennas with *parabolic reflectors* constitute an important group of microwave antennas, because of the wide variety of reflector sha es and sizes which are used to provide almost any kind of di ctional field pattern. Other types of directional systems are: he *corner reflector,* the *metal lens antenna,* and the electromagne ic horn.

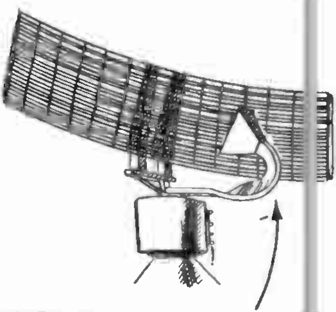

WAVEGUIDE FEED WITH ELECTR O-MAGNETIC HORN RADIATOR.

Fig. 101 Truncated parabola.

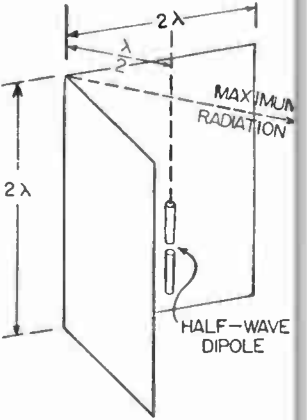


Fig. 102 Corner reflector.

110. **Parabolic Reflectors.**—Since microwaves have char cteristics similar to those of light waves, the parabolic reflec or

is an obvious directional device for radiating or receiving an extremely narrow (highly directional) beam of energy. The operation of such a reflector follows a simple law of optics: light is reflected by a smooth mirror surface in such a way that the angle made between the incident wave and the surface is equal to the angle made between the reflected wave and the surface. When the reflector is a spherical mirror partially surrounding a source of energy located at its focal point, a concentrated beam of parallel waves is produced (Fig. 98) following the law of light reflection. Conversely, when a directed beam of energy (from a microwave radiating antenna) is intercepted by a spehrical mirror, all waves are reflected so that they converge at the focus of the reflecting surface. As a means of concentrating all energy within the spherical mirror, a small *secondary* reflector is generally used directly behind the focal point, as shown in Fig. 98. The *focal point,* or *focus,* of a spherical mirror is a point along the *axis* of the reflecting surface; the distance between the surface and focal point is known as the *focal length of the mirror,* and is equal to one-half the radius of the spherical mirror. The simplest type of spherical reflector for microwave operation is the paraboloid or *rotational parabola* (Fig. 99), which is the surface generated by the revolution of a parabola about its axis. The sourcs of RF energy—at the focus of the reflector—may be a half-wave dipole, an open waveguide, or an electromagnetic horn; to preserve the concentric nature of the field pattern, the radiating dipole or other device is normally fed directly through the center of the reflector. Construction difficulties normally limit the physical size of a parabolic reflector, but it should have a diameter of *at least* 10 wavelengths in order to provide good directivity. Since a rotational parabola is

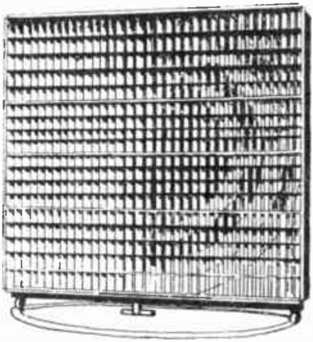


Fig. 103 Metal lens antenna.

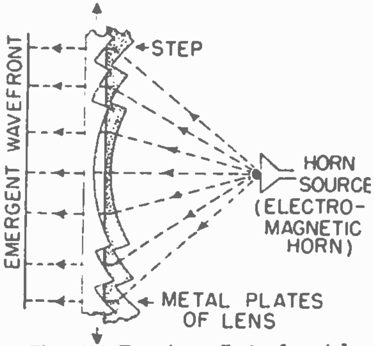


Fig. 104 Focusing effect of metal plates of "stepped" construction.

circular in shape when viewed along its axis, the field pattern in both the horizontal plane and the vertical plane are almost identical.

111. Other Parabola Types.—When high directivity is desired in only *one* plane of a field patern, or, when a particular shape of field pattern is required, special types of parabolic reflectors are used. (Fig. 100). A *cylindrical parabola* has a parabolic surface in only *one* dimension, and thus has a focal *line* instead of a focal point. The antenna provides directivity in only one plane, according to its position in space; the plane of greatest directivity is always perpendicular to the length of the cylinder. Often the open ends of a cylindrical parabola are covered or closed to effect a slight increase in power gain. *Truncated parabolas* (Fig. 101) are equivalent in shape to narrow sections removed from a conventional rotational parabola. Although similar in function to a cylindrical parabola, a field pattern with higher gain is provided by a truncated parabola. By altering the physical shape of any type of parabolic reflector, almost any shape of field pattern can be obtained. Often parasitic elements are added to parabolic reflectors to exert a further influence in the shaping of the field pattern in a particular plane, or for a particular transmitting or receiving purpose. Parabolic reflectors are usually constructed of sheet metal, presenting an unbroken surface for the reflection of microwave energy. To lower wind resistance, however, the metal may be perforated, or, the entire reflector may be composed of closely spaced, parallel metal strips (Fig. 101). Reflectors are fed at the focal point of the parabolic surface. Most common methods employ either a half-wave dipole or an electromagnetic horn associated with a waveguide system.

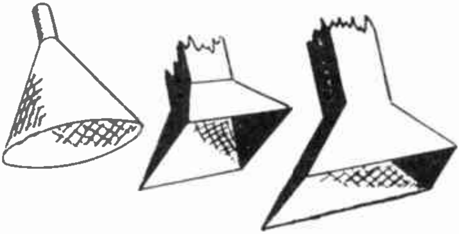


Fig. 105 Electromagnetic horns; Left, Conical type; center, Pyramidal type; right, Rectangular type.

112. Corner Reflectors.—Microwave energy can be concentrated in a directive beam by means of a relatively simple device (Fig. 102) known as a *corner reflector*. This antenna consists of two flat conducting planes which meet at an angle of 90 degrees to form a corner. Bisecting this angle, a half-wave dipole is located parallel to the reflecting planes and at a distance of a half wavelength from the corner. The reflecting planes are constructed of sheet metal, mesh screen, or closely spaced parallel wires; each plane measures *at least* two wavelengths in height and in width. An important characteristic of the corner reflector is that it exhibits very marked polarization effects. To transmit or receive horizontally polarized waves, the corner reflector must be arranged so that the half-wave dipole is situated in a horizontal position. For vertically polarized waves, the corner reflector must be turned 90 degrees.

113. Metal Lens Antenna.—This elaborate array provides extremely sharp beams of microwave energy by utilizing the focusing effect of a large number of specially shaped, closely spaced metal plates (Fig. 103). When used as a radiator, this unique lens receives divergent waves from a point source—usually an electromagnetic horn—in the rear of the array. As they travel between the parallel conducting plates, the microwaves actually *gain speed.* By a suitable geometric arrangement of the metal plates, outer paths are made slightly longer than paths near the center of the array; in this way, outer waves are accelerated in such a manner that the waves are effectually focused and emerge from the array in a narrow, parallel beam (Fig. 104). The "stepped" construction of the metal plates provides uniform transmission over a wide band of frequencies, for carrier telephone, television, facsimile, and other wide-band microwave services. An identical array is used as a highly directional *receiving* antenna, where it funnels microwave back into an electromagnetic horn and waveguide system for detection and amplification of the signal. Field patterns less than one-tenth of a degree in width can be obtained with a metal lens antenna.

114. Electromagnetic Horns.—Horn radiators are used for microwave transmission, because the physical dimensions of electromagnetic horns—which must be large compared to the operating wavelength—are extremely practical in the super-high-frequency band. The function of all horn radiators is similar to that of acoustic horns, with the exception that the *throat* of an electromagnetic horn must be larger: more comparable to the wavelength of operation. There are three basic types of horns, as shown in Fig. 105. *Conical horns* are coaxial, and generally fed by means of round waveguides. *Pyramidal horns,* fed by rectangular waveguides, provide a radiation pattern with essentially the same directivity in both horizontal and vertical planes. *Rectangular horns,* also fed by rectangular waveguides, are widely used to provide directional radiation in only one plane. The shape of any field pattern is largely a function of the *aperture* of the electromagnetic horn.

Section 15

METERS AND TEST EQUIPMENT

METERS FOR DIRECT CURRENT

1. The most practical and widely used instrument for measuring direct current is the permanent-magnet *moving-coil meter*. It is essentially a sensitive microammeter, but, when equipped with suitable shunts, the instrument can be used to measure milliamperes or amperes; thus, DC microammeter, milliammeter, and ammeter are basically identical. A few other basic types of meters can be used to measure direct current, but their use is severely restricted because of the decided advantages of the moving-coil instrument. Current meters are always connected *in series* with the line or circuit being measured. For this reason, any voltage drop across

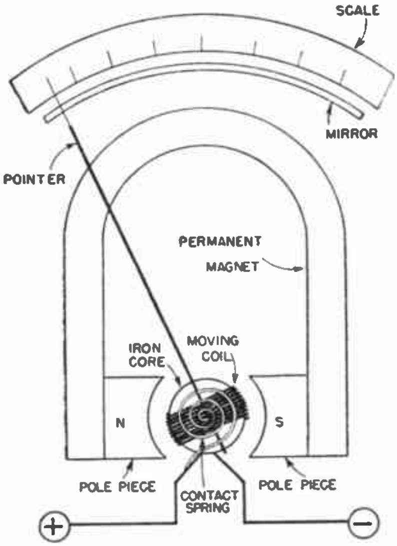


Fig. 1 Principle of the moving-coil meter.

the meter represents a voltage loss in the circuit Therefore, the power consumption of a current meter must be small in comparison with the power available in the circuit in order to obtain accurate readings.

2. Moving-Coil Meter.—Operation of this instrument—sometimes known as the d'Arsonval meter—is based on a mechanical force exerted between a moveable coil and a fixed magnet which causes a pointer to move across a suitable scale. In the strong field of a permanent magnet, a coil is placed so that it can rotate on a spindle mounted in jewelled bearings. To this spindle are attached two small spiral springs and the pointer. The hairsprings tend to oppose any movement or change from the static position of the coil, and they also serve as flexible joints to conduct current to and from the coil. When current flows through the coil, it produces a magnetic field at an angle to the field of the permanent magnet, thus creating a *turning force* which tends to rotate the coil and move the pointer across the scale. The degree of this turning force is proportional to the amount of direct current applied to the coil; when this turning force is equal to the mechanical opposition of the spiral springs, the pointer will stop somewhere along the scale. Since the magnetic field is uniform in the air gap between the pole pieces and the soft-iron core, the deflection of the pointer is proportional to the amount of applied current. In this manner, the moving-coil meter provides *linear* measurement, and the scale divisions—regardless of the current range—are always uniformly spaced (Fig. 3). This instrument is probably the most important type of electrical measuring instrument, because the sensitive microammeter movement is also used as the basis of many other types of indicating devices: such as the DC voltmeter, ohmmeter, AC rectifier-type meter, and vacuum-tube voltmeter. In general, this meter is extremely effective and can be obtained with almost any degree of desired sensitivity. It has low power consumption, rugged mechanical construction, and very high accuracy.

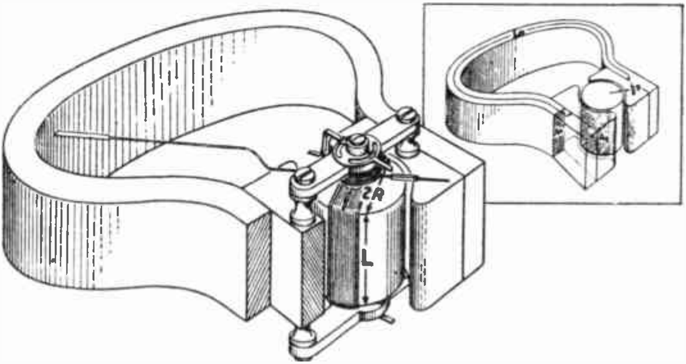


Fig. 2 Construction of the moving-coil meter.

3. **Sensitivity.**—The sensitivity of a direct current meter is determined by the amount of current required to operate the moving element of the meter. The *sensitivity rating* is the number of microamperes or milliamperes of current which must be applied to the coil to obtain a full-scale deflection of the pointer. For example, a meter having a sensitivity rating of 500 microamperes will require 500 microamperes for full-scale deflection. The meter requiring the least amount of current for full-scale deflection is considered the most sensitive. In using DC measuring instruments, strict attention must be paid to the polarity indicated on each of the two input terminals of the meter. Only when these external connections are correct will the meter register properly. Any reversal of polarity will jam the needle against the stop pin, and may seriously damage the coil windings or other parts of the meter.

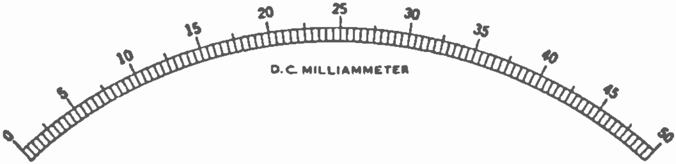


Fig. 3 Linear scale, typical of the moving-coil meter.

4. **Damping.**—For a brief period after current is applied to a moving-coil meter, the normal inertia of the coil and resilience of the spiral springs will permit the pointer to oscillate about the true scale indication. This oscillation is considerably reduced by means of electrical damping. In DC meters this is accomplished by winding the coil on a light aluminum frame, which is then placed over the core of the meter between the pole pieces of the permanent magnet. Any movement of the coil assembly sets up small eddy currents in the aluminum frame; this field interacts with the strong field of the permanent magnet and opposes any motion of the coil, and thus restrains any oscillation of the pointer.

5. **Use of Shunts.**—Since a DC moving-coil meter is basically a microammeter, the coil is small and delicate, light in weight, with little inertia, and is constructed of wire so fine that it is incapable of carrying more than a few hundred microamperes. In order to use this accurate meter (Fig. 4a) to measure large current (milliamperes, or even amperes), most of the current must be by-passed or shunted around the meter so that only a small and definite percentage of the total current is allowed to pass through the coil. This is accomplished by using a *shunt* or low-resistance path, in parallel with the moving coil of the meter (Fig. 4b); the current then divides according to the resistance of the shunt as compared with the resistance of the coil. By providing a shunt resistor across the coil, the range of a DC meter can be extended to any desired full-scale value. Shunt resistance values are determined by the sensitivity and resistance of the moving-coil

meter, and values are computed by applying Ohm's Law for parallel circuits.

$$R_s = \frac{R_m}{n - 1}$$

where R_s = resistance of shunt
R_m = resistance of meter
n = multiplying ratio.

Most types of commercial moving-coil milliammeters and ammeters are equipped with *internal* shunts, inside the meter case, and the scales are generally calibrated to read the rated amperage of the shunt. Ammeter shunts are so constructed that they will not be injured by high peak or pulse currents of short duration, and provisions are made for dissipation of considerable heat. Shunts are usually made of metal having a low temperature coefficient of resistance, to minimize any resistance variation with changes in temperature. The shunt used to extend the range of a DC moving-coil meter (Fig. 4b) should not be confused with the multiplier or series resistor (Fig. 4c) used to convert the moving-coil microammeter to a DC voltmeter.

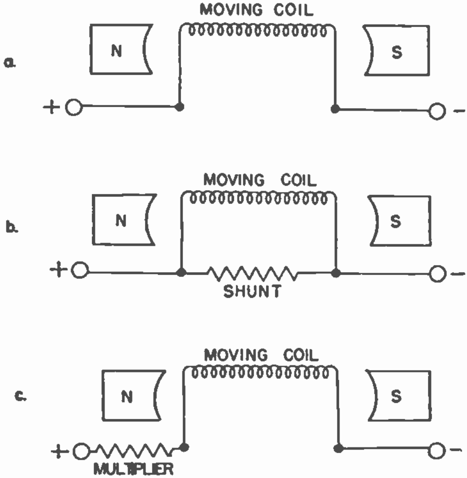


Fig. 4 Equivalent circuit of the moving-coil meter.

6. Multi-Range DC Meters.—A microammeter or milliammeter need not be restricted to a single range of current measurement. By using several shunt resistors and a suitable switching circuit, a *single* meter can measure direct current over several different ranges, thus eliminating the need for a number of individual meters. For example, using the proper values for three separate shunt resistors, a DC microammeter (scale 0 to 500) forms the basis of a typical multi-range circuit (Fig. 5). With switch in position 1, the shunt resistor R_1 permits DC measurements in the range 0 to 1.5 ma; with switch in position 2, the meter range is 0 to 15 ma; with switch in position 3, the meter range is 0 to 150 ma. Since the moving-coil meter is a linear measuring device, the three ranges are indicated on the same scale (Fig. 6). Most multi-range DC meters have ranges in multiples of 5 or 10, so that the same scale may be adapted easily for reading all ranges. These multi-range meters are used extensively as combination meters for radio servicing and other test work.

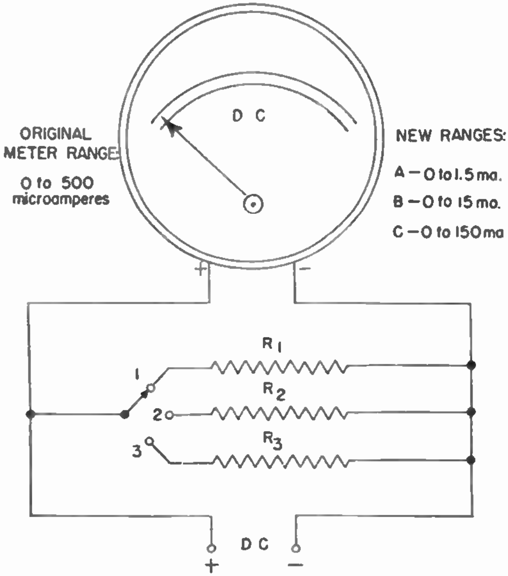


Fig. 5 Typical multi-range direct current meter.

Fig. 6 Typical linear scale of multi-range DC milliammeter.

7. Other Instruments.—Direct current can also be measured by some types of AC instruments, such as the moving-iron or moving-vane meter, the electrodynamometer, and one or two others. However, use of these instruments for DC purposes is extremely limited, because they all compare unfavorably with the DC moving-coil meter which is much more accurate and sensitive, consumes less energy, and is free from magnetization errors.

DC VOLTMETERS

8. All practical DC voltmeters are of the moving-coil or d'Arsonval type, and have basically the same movements as those used in DC microammeters and milliammeters. For operation as a voltmeter, a current-limiting resistor is connected permanently in series with the sensitive moving coil, and the instrument becomes a high-resistance measuring device. DC voltmeters are always connected *in parallel* with the circuit or source of voltage being measured, and consume relatively small power.

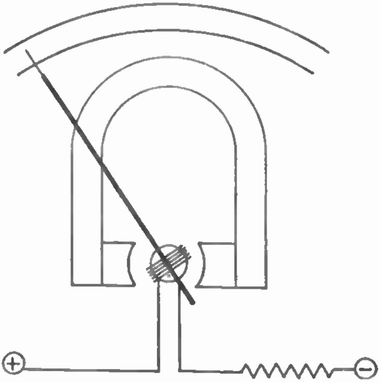


Fig. 7 A DC voltmeter is essentially a current-operated moving-coil instrument with a series resistance.

9. **The Moving-Coil Meter.**—Operation of this instrument as a DC voltmeter is essentially the same as for a DC microammeter, and the general features of construction of both types of meters are almost identical. Principal components of a moving-coil instrument are shown in Fig. 20. A coil of fine wire, usually rectangular in shape, is mounted on pivots in the field of a permanent magnet with a pointer attached to the moveable coil assembly When current is applied to the coil windings, the magnetic effect causes the coil to turn or rotate, thus moving the pointer across an appropriate scale and giving an indication of the current. Current is applied to each end of the coil through hairsprings, which also serve to regulate movement of the coil assembly and restore it to a static position when current ceases to flow.

The degree of pointer deflection is proportional to the amount of current in the coil, and this *linear* measurement is indicated by uniformly spaced divisions of the scale (Fig. 3). The moving-coil instrument becomes a DC voltmeter when it is placed across a source of voltage so that it measures the amount of current flowing through a known value of fixed resistance in series with the meter (Fig. 4b). As long as this resistance remains constant, current measurements will be proportional to the actual voltage and the meter is calibrated in volts accordingly. Such a resistor—known as a *multiplier*—is usually enclosed in the case of the instrument (Fig. 7). The resistor has a high value in order to limit the amount of current flowing through the sensitive coil; this protects the meter from damage and restricts the consumption of power from any circuit under measurement. The moving-coil type of instrument is the only effective means of measuring DC voltage. The voltmeter has rugged mechanical construction, and very high accuracy.

10. Sensitivity.—The sensitivity of a DC voltmeter is determined by the amount of current which must be applied to the moving coil to obtain a full-scale deflection of the pointer. However, the reciprocal of this current value is used as the *sensitivity rating* of a voltmeter, as expressed in *ohms-per-volt*. For example, if 1 milliampere or $\frac{1}{1000}$ ampere is required for full-scale deflection, a DC voltmeter is rated as 1000 ohms-per-volt; this means that when it is used as a 0-100 voltmeter, the resistance of the instrument is 100,000 ohms. The sensitivity rating of a DC voltmeter is always greater than unity, and the more sensitive the DC voltmeter the higher the ohms-per-volt numerical value. Since a voltmeter should not influence in any way the circuit or the source of voltage across which it is connected, it must appear as an extremely high value of resistance—as indicated by a high ohms-per-volt sensitivity rating. In using a DC measuring instrument, strict attention must be paid to polarity. The meter will register properly when external connections are correct, and any reversal of polarity may seriously damage the coil windings or other parts of the voltmeter.

11. Damping.—For a brief period after voltage is applied to a moving-coil voltmeter, the inertia of the coil and the resilience of the spiral springs permit the pointer to oscillate about the true scale indication. This oscillation is minimized by either of two kinds of electrical damping. In the general method, the coil is wound on a light aluminum frame, which is placed over the core of the meter between the two pole pieces of the permanent magnet; any movement of the coil assembly will set up eddy currents in the frame, which will interact with the strong magnetic field of the permanent magnet, opposing any motion of the coil and thus acting as a brake to keep the pointer from oscillating. In another method, used by voltmeters of extremely high sensitivity, the coils are *not* wound on metallic frames in order to minimize weight; instead, a resistor in parallel with the moving coil provides constant damping with only a slight sacrifice in sensitivity.

12. Multipliers.—The series resistor or multiplier establishes the maximum range of a DC voltmeter. Any value of voltage can be measured directly, providing such a value does not exceed the voltage required to produce a full-scale deflection of the pointer. If a higher voltage is to be measured, a larger resistor is required to drop the excess volts; if a lower voltage is to be measured with greater accuracy, a smaller resistor is required. When the meter sensitivity and resistance are known, the range of a DC voltmeter may be changed by varying the value of the multiplier, according to Ohm's Law.

$$R_p = [E\,R_v] - R_m$$

where R_p = resistance of multiplier
R_v = ohms-per-volt rating of meter
R_m = resistance of meter
E = desired maximum voltage range.

The resistance value of a new multiplier is generally selected so that the existing scale readings of the voltmeter can be multiplied by a convenient factor to obtain the correct voltage. Multiplier resistors are usually made of metal having a low temperature coefficient of resistance to minimize resistance variation with changes in temperature.

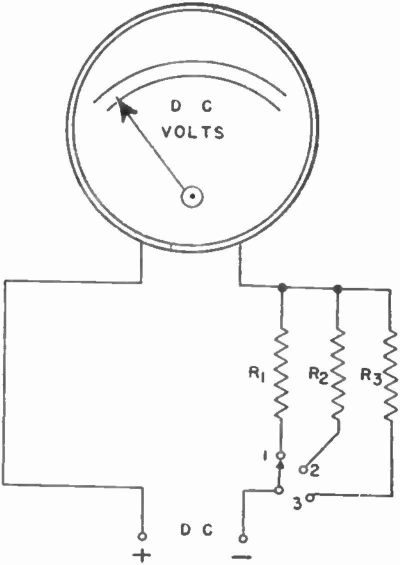


Fig. 8 Typical multi-range DC measuring circuit for three voltage ranges.

13. Multi-Range DC Voltmeters.—One DC voltmeter need not be restricted to a single range of voltage measurements. By using several multipliers and a suitable switching circuit, a single instrument is used to measure DC voltages over a wide range, thus eliminating the need for several individual voltmeters. Using appropriate values for three multiplier resistors, a DC voltmeter (range 0 to 0.3 volts) forms the basis of a typical multi-range circuit (Fig. 8); with switch in position 1, the multiplier R_1 permits measurements in the range 0 to 3 volts; with switch in position 2, the meter range is 0 to 150 volts; with switch in position 3, the meter range is 0 to 300 volts. The linear characteristic of moving-coil meters is put to good advantage in multi-range instruments, since scale divisions for different ranges are similarly spaced (Fig. 9); range scales are usually in convenient multiples of 5, 10, 50, or 100. Multi-range circuits are used extensively in many types of combination meters for radio servicing and other test work.

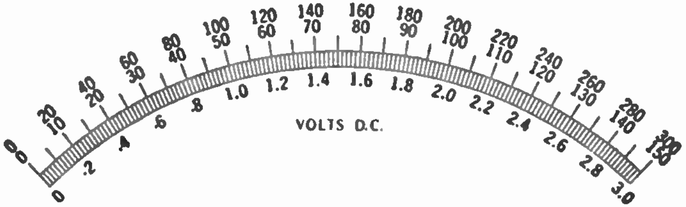


Fig. 9 Linear scale used for multi-range DC voltage measurements.

14. Other Instruments.—DC voltage can also be measured by some types of AC instruments, such as the moving-iron or moving-van meter, the electrostatic voltmeter, the electrodynamometer, and others. However, use of these instruments for DC purposes is extremely limited, because they all compare unfavorably with the DC moving-coil voltmeter which is much more accurate and sensitive, consumes less energy, and is free from magnetization errors.

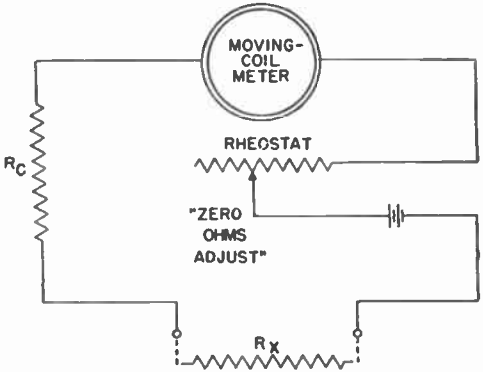


Fig. 10 Circuit of basic ohmmeter.

OHMMETERS

15. An ohmmeter is an instrument for measuring the DC resistance of a circuit or circuit element, with a scale indicating results directly—in terms of *ohms* or *megohms*. There are several types of ohmmeters, all of which employ the basic DC moving coil meter with a self-contained source of power. They function according to the fundamental relationship of DC current, voltage, and resistance, as expressed by Ohm's Law. Ohmmeters cannot be used for accurately measuring wide ranges of resistance, however; and indicated results are usually approximate. When extreme accuracy is required, resistance is measured by means of a bridge measuring device.

16. **Series Ohmmeters.**—The most common type of ohmmeter consists essentially of a DC moving-coil milliammeter, one or more current-limiting resistors, and a source of low voltage. These elements are so arranged (Fig. 10) that the resistance to be measured is connected *in series* with the meter and the voltage source; then, the amount of current flowing through the meter is determined by the value of the resistor R_x. For a very small value of resistor R_x, there is almost maximum current in the series circuit causing almost full deflection of the pointer; for larger values of R_x, less current flows, and there is less deflection of the pointer. The amount of current flowing through the meter is inversely proportional to the value of the resistor R_x. Because of the fundamental relationship between resistance, voltage, and current—expressed by Ohm's Law—the scale of the meter is calibrated in *ohms,* thus giving a direct indication of resistance measurement. Since the unknown resistance R_x is connected *in series* with the meter and voltage source, this instrument is known as a *series ohmmeter.* Operation of this ohmmeter requires a fixed source of voltage, usually a dry-cell battery, and sufficient series resistance to limit the maximum current through the meter to the amount needed for full-scale deflection. Such a full-scale deflection corresponds to the *zero*-ohms division at the right end of the scale, and occurs only when the terminals of the ohmmeter are shorted [when $R_x = 0$]. As larger and larger values of resistance R_x are connected between the two measuring terminals, there is a corresponding decrease in the amount of pointer deflection until, for extremely high resistor values, there is almost no perceptible movement of the pointer from its static position at the left end of the calibrated scale. This scale (Fig. 11) differs from most measuring instruments, since it is graduated in ohms from right to left and covers an exceptionally wide range from *zero* to *infinite* resistance. The scale is decidedly non-linear, however, and accurate readings can be obtained *only* in the intermediate range or central portion of the scale. Since the voltage and the

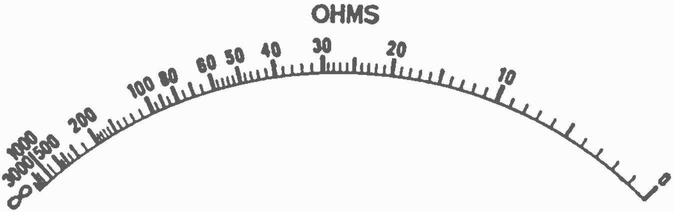


Fig. 11 Scale of typical series ohmmeter.

internal resistance of the battery change with age and thus influence the accuracy of measurements, part of the current-limiting resistance of the series circuit (Fig. 10) is made variable to compensate for such variations. This rheostat—known as the "zero-ohms adjustment"—supplements the current-limiting action of fixed resistor R_c, and provides precision control of current flowing through the meter.

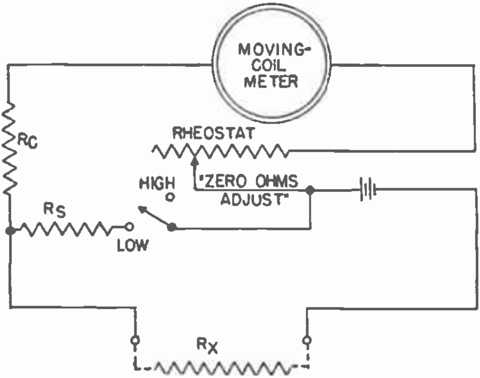


Fig. 12 Multi-range ohmmeter.

Prior to using the series ohmmeter, the two measuring terminals are shorted $[R_x = 0]$ and the rheostat is adjusted so that the pointer coincides with the *zero*-ohms division of the calibrated scale; this insures maximum current in the circuit—a requirement for accurate readings—regardless of the actual voltage or the internal resistance of the dry-cell battery. Although the range *limits* of a series ohmmeter cannot be altered, certain sections can be moved or shifted to the intermediate range or magnified central portion of the scale *for greater accuracy* by means of increasing or decreasing the value of the current-limiting resistor R_c, connecting additional shunt resistors across the moving-coil meter, increasing the battery voltage, or by utilizing *combinations* of these methods. Such modified circuits use meter scales with more appropriate calibrations, so that resistance values in the desired range occupy the central portion of the meter scale.

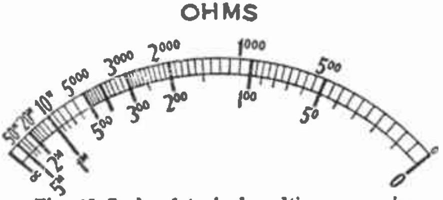


Fig. 13 Scale of typical multi-range series ohmmeter.

17. Multi-Range Ohmmeters.—Although the *total* range of a series ohmmeter extends from *zero* to *infinite* resistance (Fig. 11), the calibration is not linear, and readings near the extreme ends of the scale are erroneous and misleading. Only the intermediate range or central portion of the scale has sufficient accuracy for reliable measurement, because it is least affected by the characteristic non-linearity of this type of instrument. By effecting a change in the scale calibration, through circuit design, a different section of the scale can be brought into the expanded and highly accurate intermediate range to obtain more accurate measurement. In practice, this is known as "shifting" the intermediate range. To provide an existing series ohmmeter with a "lower" intermediate range, a shunt resistor R_s is connected across the indicating meter (Fig. 12) so that the pointer deflection for *any* value of unknown resistance R_x is proportionately *smaller* than if the shunt resistor R_s was not connected. By using a switch, the shunt resistor is removed from the circuit whenever desired; thus the ohmmeter is provided with two effective ranges (Fig. 13). To obtain a "higher" intermediate range for a series ohmmeter, the DC voltage is increased to a fixed value sufficiently large to cause maximum current to flow through the meter and high-resistance circuit.

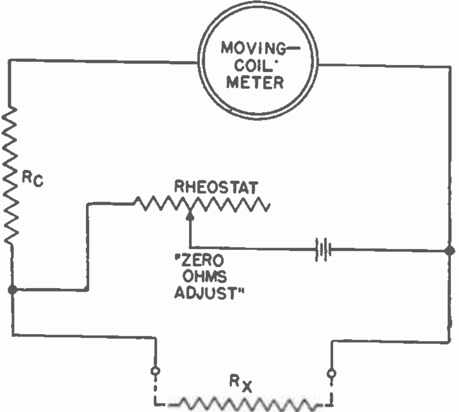


Fig. 14 Circuit of shunt ohmmeter.

18. Shunt Ohmmeters.—This instrument consists essentially of a DC moving-coil milliammeter, a current-limiting resistor, and a source of low voltage. These elements are so arranged (Fig. 14) that the resistance to be measured is connected *in shunt* with the meter and *also* with the source of voltage. Direct current flowing in the parallel circuit is divided between the unknown resistance R_x and the meter with its current-limiting resistor R_c. Thus, the amount of current flowing through the meter—and therefore the actual deflection of the pointer—is proportional to the value of the resistor R_x. The scale of the meter is calibrated in *ohms* for direct indication of resistance measurement and reads from left to right. Since the unknown resistor R_x is connected

in shunt with the meter and with the source of voltage, this instrument is known as a ***shunt-ohmmeter.*** Prior to use, when ***no*** resistance [R = infinity] is connected across the terminals of the ohmmeter, *all* of the direct current flows through the moving coil of the meter. Fixed resistor R_c limits this current to the maximum value required for full-scale deflection; the rheostat provides additional control as well as a means of compensating for variations in the voltage or internal resistance of the battery. With ***no*** resistance connected to the two measuring terminals, the rheostat is adjusted so that the pointer (at full-scale deflection) coincides with the maximum-range division mark on the scale.

The maximum range of a shunt ohmmeter is always a finite value of resistance—usually 10, 20, or 30 ohms—and appears at the right end of the calibrated scale. With the ohmmeter adjusted, it measures accurately any unknown value of resistance within the range of the instrument. If a too-large resistor is connected between the two measuring terminals, there is no effect on the open-circuit condition of the meter and the pointer remains at full-scale deflection. When any *low* value of resistor R_x is connected, this resistance provides a shunt or parallel path, which draws current from the meter branch of the circuit and thus causes a decrease in the amount of pointer deflection. A short circuit of the terminals [R = 0] draws *all* of the current from the meter branch of the parallel circuit and, without deflection current, the pointer stops at *zero* ohms at the left end of the scale. Although an accurate instrument, the shunt ohmmeter is useful only for measuring low values of resistance.

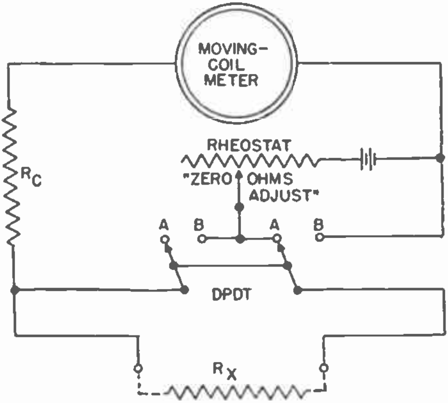


Fig. 15 Series-shunt ohmmeter.

19. Combination Series-Shunt Ohmmeters.—Series ohmmeters are widely used to measure all medium and high values of resistance, but they usually are unsatisfactory for low-resistance measurements because of the heavy current they require for operation. Somewhat conversely, shunt ohmmeters are inadequate for measuring high resistance, but they are accurate and useful instruments for low-resistance measurements. When the two types are combined in a circuit with a single meter (Fig. 15), their respective advantages can be more effectively utilized. The combination series-shunt ohmmeter uses a *double* scale (Fig. 16), since the series scale [A] reads from left to right, and the shunt scale [B] reads from right to left.

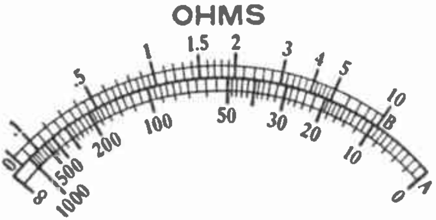


Fig. 16 Scale for combination series-shunt ohmmeter.

20. Differentially-wound Ohmmeters.—The moving coil of this high-precision ohmmeter consists of two windings at right angles to each other, and each winding produces a separate magnetic field. The effect of one field moves the pointer up-scale; that of the second field moves the pointer down-scale. Measurement of resistance is according to an almost-linear scale. In its commercial form, the ohmmeter is equipped with three scale ranges (Fig. 17) for continuous readings from zero to 3000 ohms with extreme accuracy. It is not a rugged or portable ohmmeter, however, and its use is largely restricted to experimental and development laboratories.

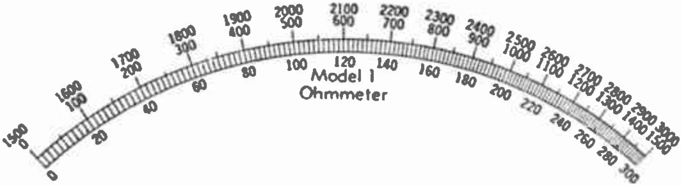


Fig. 17 Scale of laboratory ohmmeter.

21. Meggers.—This is a special type of ohmmeter for measuring very high resistance, usually on the order of *megohms* or millions of ohms. Although primarily a device for determining the insulation resistance of cables, the megger is useful for leakage tests and similar measurement work with transmission lines. It consists essentially of a moving-coil type of meter and a small hand-driven DC generator (Fig. 18) which are mounted together in the same portable case. The meter coil consists of two separate windings, rigidly fixed at right angles to each other, and pivoted so they can turn freely in the field of a permanent magnet. There are no controlling springs; current reaches each winding through flexible copper ligaments, almost without torsion. The coil assembly literally floats between jewelled bearings and, during periods of inoperation, the pointer may assume any position on the scale. When the DC generator is operated, one coil winding is energized directly through the series resistor R_c, and the resultant magnetic field causes a turning force in one direction. The second coil winding is energized through the unknown resistor R_x, which causes a turning force in the opposite direction. Consequently, the entire coil assembly rotates until the two opposing magnetic forces are equal and balanced, thus moving the pointer

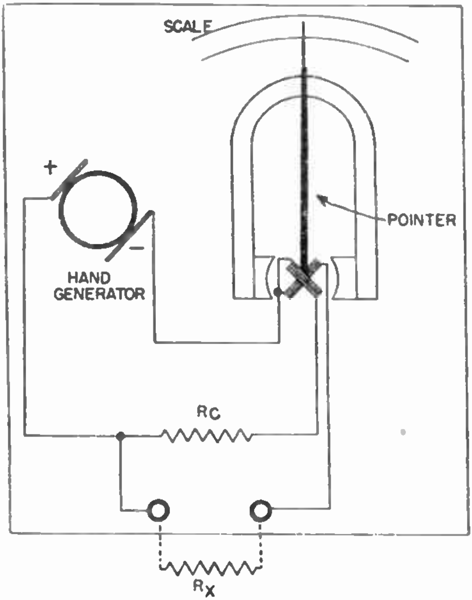


Fig. 18 The Megger consists of a DC generator and moving-coil meter for measuring high values of resistance.

so that it indicates the ohmic value of resistor R_x directly on a suitable scale. The use of an additional shunt resistance and switch, within the instrument, permits two operating ranges (Fig. 19) for greater accuracy. The megger is a true ohmmeter, capable of measuring very high resistance independently of any fluctuations in the DC voltage.

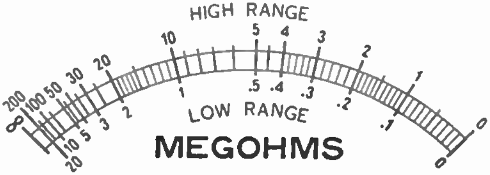


Fig. 19 Typical range scale for a Megger.

METERS FOR ALTERNATING CURRENT

22. An important factor in the measurement of alternating current is the *frequency* of the current, or the *frequency range* of the currents, to be measured. Instruments for low-frequency measurement—such as the moving-vane and dynamometer type—are effective only at frequencies less than about 1000 cycles. For measuring current at higher frequencies, rectifier-type instruments are used, which operate anywhere within the audio-frequency range up to about 35,000 cycles. For measurements at radio frequencies, special meters are required. Current meters are always connected *in series* with the line or circuit being measured. For this reason, any voltage drop across the meter represents a voltage loss in the circuit. Therefore, the power consumption of a current meter must be small in comparison with the power available in the circuit in order to obtain accurate readings. The sensitivity of an AC meter depends upon the amount of current required to cause mechanical action; thus the instrument requiring the least amount of current is considered to be the most sensitive.

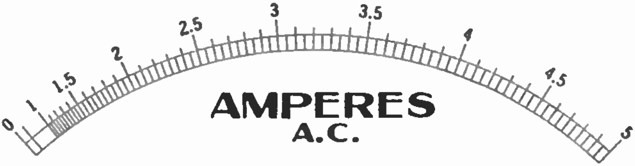


Fig. 21 Compressed quadratic scale, typical of the moving-vane ammeter.

23. Moving-Vane Meter.—This is an electromagnetic instrument—sometimes known as the moving-iron or iron-vane meter—in which a mechanical force is caused by the mutual repulsion between two highly magnetized iron strips, one fixed and one moveable, located in the electromagnetic field of a stationary or fixed coil. Principal components of the moving-vane instrument are shown in Fig. 20. An electromagnetic coil—consisting of a few turns of large-diameter, insulated copper wire—is contained in a circular-type sheath to the inside of which is affixed a strip of soft iron. By means of pivots, a spindle is mounted lengthwise through the geometrical center of the coil. Another, shorter strip of soft iron is attached to an arm of the spindle, and this element constitutes the moving vane. The pointer is attached to the opposite side of the spindle; and a small weight W (or a spiral spring) is attached to one side of the spindle (Fig. 20) so that the static position of the pointer is at the *zero* scale marking. When alternating current is applied to the coil, both the fixed iron strip and the moveable iron vane are magnetized. Even though their polarity is reversing rapidly, according to the frequency of the alternating current, the two soft-iron plates always retain the same polarity with *respect to each other*. Since the two plates are similarly magnetized, they repel each other, and movement of the iron vane causes the pointer to swing across the calibrated current scale.

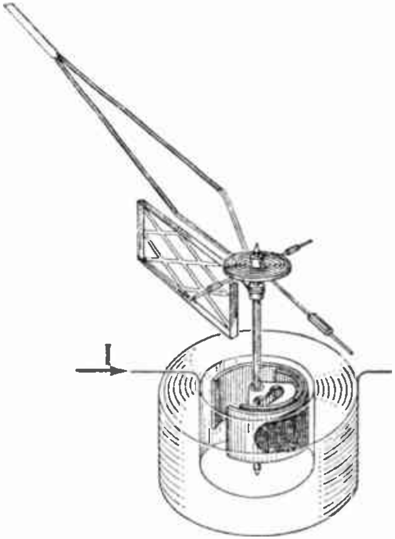


Fig. 20 Principle of the moving-vane meter for current measurements.

The amount of pointer deflection is approximately proportional to the square of the current being measured. Thus, a quadratic scale is used, with additional compression at the low end of the scale to compensate for minor instrument errors. The range of a moving-vane meter can be extended by using a *current transformer* to step down the high current to be measured so that it falls within the range of the existing meter; *or*, the range can be extended by connecting a suitable shunt resistor across the magnetic coil as in the case of DC meters. *Effective* values of alternating current are indicated by the moving-vane instrument. Although the meter is free from errors due to heating effects and is relatively inexpensive, it requires an extremely high current for energizing the electromagnetic coil. Because of this lack of sensitivity, as well as certain frequency errors, the moving-vane meter is impractical for accurate AC measurements at frequencies much above 600 cycles. The instrument is used mainly in high-amperage power circuits where, because of its nature of operation, it can function as either a DC ammeter or an AC ammeter.

24. Dynamometer-type Ammeter.—This is an electrodynamic instrument—sometimes known as the electrodynamometer—in which a mechanical force is caused by the reaction between the magnetic field of a moveable coil and the magnetic field of a fixed coil. Principal components of the instrument are shown in Fig. 22. The fixed coil consists of two sections, between which a shaft or spindle, mounted on pivots, contains the moveable coil and a suitable pointer. The moveable coil is energized through two spiral springs which also control the motion of the spindle and pointer. The fixed and moveable coils are connected in series (Fig. 23), but an inductive shunt is connected across the termi-

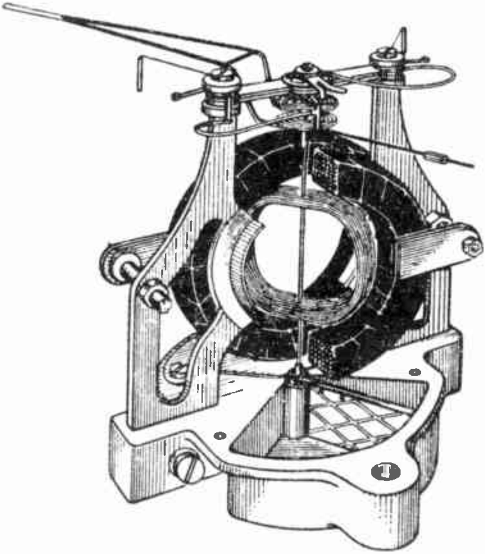


Fig. 22 Principle of the dynamometer-type instrument.

nals of the moveable coil so that only a *part* of the normally heavy current to be measured passes through the moving coil. When current is applied to the dynamometer-type meter, two distinct magnetic fields are produced. Since the axis of the magnetic field around the moveable coil is not parallel to the axis of the magnetic field around the fixed coils—due to action of the spiral springs—the two magnetic fields attempt to align themselves, and thus create a mechanical force. This turning force is proportional to the strength of the magnetic fields which, in turn, are proportional to the value of current flowing through the respective coils. Therefore, movement of the spindle and pointer is roughly proportional to the square of the applied current, and a modified quadratic scale is used (Fig. 24). Polarity reversals of alternating current come at the same instant *in both coils,* and therefore the direction of the mechanical or turning force is independent of alternations of the applied current. Accordingly, the instrument can also be used to measure direct current; but it is not as sensitive or accurate as the conventional DC meter. The range of a dynamometer-type ammeter is extended by using a *current transformer* to step down the high current to be measured so that it falls within the range of the existing meter. Because of inductive effects of the coils, the instrument is practical for AC measure-

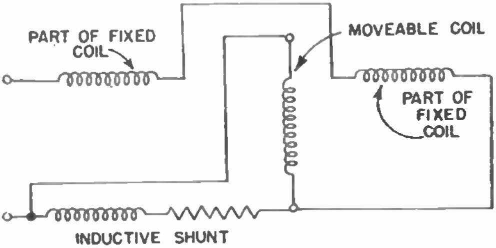


Fig. 23 Equivalent circuit of dynamometer-type ammeter.

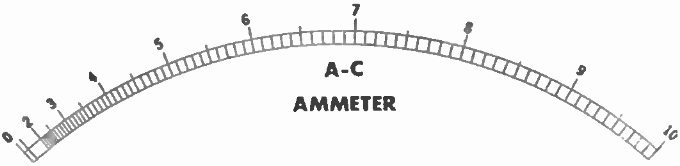


Fig. 24 Modified quadratic scale, typical of the dynamometer type of AC ammeter.

ments only at frequencies less than about 1000 cycles. Chief use of the meter is in high-amperage power circuits, where it indicates *effective* values of alternating current. The same basic movement is used in the dynamometer-type AC voltmeter and also is used in wattmeters.

25. Current Transformers.—The current range of either a moving-vane or dynamometer-type meter can be extended by means of a shunt resistor, as in the case of DC meters. Usually, however, the range is extended by means of a *current transformer* having a suitable step-down ratio to permit measurements of high values of alternating current. The secondary winding of the current transformer is connected to the existing ammeter and the primary winding is connected in series with the circuit being measured (Fig. 25). By means of this transformer, alternating current in the circuit is stepped down so that it falls within the range of the existing meter. Thus, the step-down ratio of the transformer becomes the multiplying ratio applied to the current indications on the scale of the meter.

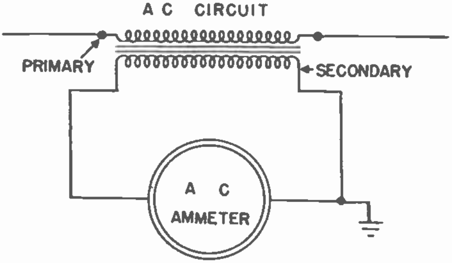


Fig. 25 Method of using current transformer to extend range of AC meter.

26. Rectifier-type Instrument.—When a suitable AC rectifying device is used with the highly sensitive DC moving-coil meter, the *combination* permits reliable measurements of low values of alternating current at any of an extremely wide range of frequencies. Since it requires only a limited amount of current from the circuit being measured and is substantially independent of frequency, the rectifier-type instrument is particularly useful in audio-frequency circuits. Although usually contained in the same meter case (Fig. 26), the rectifier and the DC meter have separate functions in the measurement of alternating current. Purpose of the rectifier is to provide the moving-coil meter with a direct current which is almost directly proportional to the alternating current being measured. The most common type consists of *four* unidirectional elements—either copper-oxide discs, or crystal diodes—arranged in a bridge circuit for full-wave rectification (Fig. 26).

When alternating current is applied to the rectifier at points A and B, the polarity at point C is always negative and that of point D is always positive; thus, the flow of current between points C and D—through the meter—is always in one direction, regardless of the nature or frequency of the alternating current. Since a bridge so connected enables rectification of each half cycle of the applied AC wave, the device is called a full-wave rectifier. Operation of the DC moving-coil meter is conventional but the scale is calibrated in AC milliamperes with approximately uniform or linear scale divisions (Fig. 27). The accuracy of readings is influenced by limitations of the rectifying unit, since the characteristics of the rectifier change with temperature, conditions of overload, frequency of operation, and other conditions. For this reason, accuracy is usually stated as plus or minus 5 percent of the full-scale reading of the milliammeteer. The rectifier-type

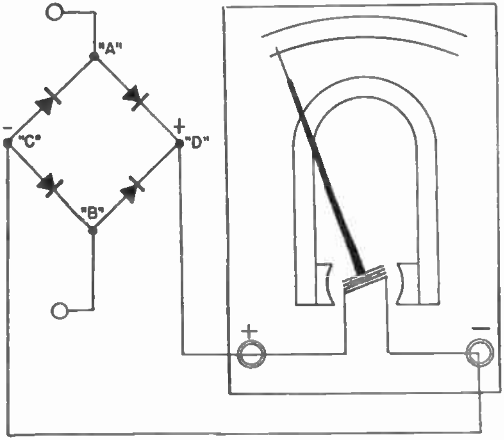


Fig. 26 Used for measurements of alternating current, the rectifier-type instrument consists essentially of an AC rectifier and a DC moving-coil meter.

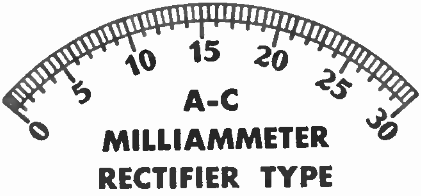


Fig. 27 Almost linear scale used with rectifier-type instrument for measuring alternating current.

instrument indicates the *average* value of applied alternating current, and therefore it is susceptible to errors due to variations in the applied wave form. Accordingly, the rectifier-type meter should be used to measure *only* the type of AC wave form originally used for calibration—as indicated on the scale or the meter case. In most instances, when the instrument was originally calibrated for an AC *sine wave,* the scale is inaccurate for measuring non-cinusoidal values of alternating currents. However, the rectifier-type meter is an extremely valuable instrument, when used with a recognition of its various limitations. It offers the only practical means of measuring minute values of alternating currents. In general, the sensitivity of the rectifier-type instrument is more than 50 times greater than either the dynamometer-type or the moving-vane meters.

27. Multi-Range Rectifier-type Instruments.—The current range of an AC rectifier-type meter is extended by means of a shunt resistor which, when connected in parallel *with the complete instrument,* provides a low-resistance path for a proportionate part of the alternating current being measured. Such shunts are precision, wire-wound, non-inductive resistors in order to limit the introduction of any additional inductance into the circuit. Shunt resistors are always connected on the AC line side of the rectifier, so that most of the alternating current flows through the parallel resistance and not through the rectifier and DC meter. By using suitable values of shunt resistors and a switching circuit, a *single* rectifier-type instrument can measure alternating currents over several different ranges, thus eliminating the need for a number of individual instruments. For example, using the proper values for two shunt resistors, a rectifier-type milliammeter (scale 0 to 100) is used for AC measurements on two additional ranges (Fig. 28). With switch in position A, the normal range of the milliammeter provides direct readings from *zero* to 100 ma; with switch in position B, the added shunt resistance permits current readings in the range *zero* to 250 ma; with switch in position C, the range is *zero* to 500 ma. Since the rectifier-type instrument approximates very closely a linear measuring device, the three

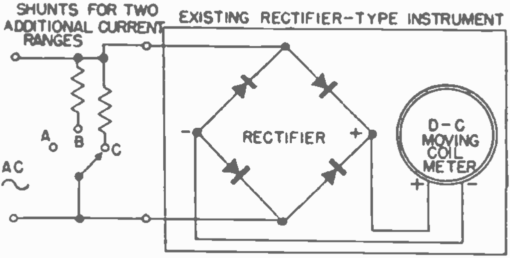


Fig. 28 Typical circuit of multi-range rectifier-type instrument, using additional shunt resistance to increase the range of existing alternating current meter.

current ranges are indicated on the same scale (Fig. 29). Most multi-range AC rectifier-type meters have ranges in multiples of 5 or 10 so that the same scale may be adapted for reading all ranges. Multi-range instruments are used extensively in many types of combination meters for radio servicing and other test work.

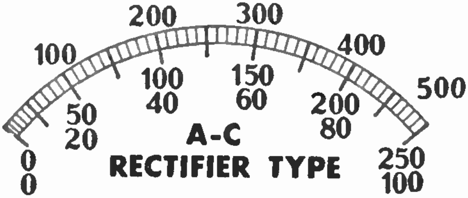


Fig. 29 Almost linear scale, typical of multi-range AC rectifier-type instrument.

28. Damping.—For a brief period after current is applied to an AC meter, the normal inertia of the moving element and the resilience of the spiral springs will permit the pointer to oscillate about the true scale indication. This oscillation is considerably reduced by means of *damping.* In the moving-vane or dynamometer-type ammeters, either magnetic damping, air damping, or a combination of both are used. With magnetic damping, a small aluminum vane is mounted on the shaft or spindle of the moving element, and turns between the poles of a small permanent magnet (Fig. 30); the motion of the vane between the poles of the magnet sets up eddy currents, creating a field which interacts with the field of the permanent magnet and thus opposes any motion of the aluminum vane. With air damping, a vane is attached to the

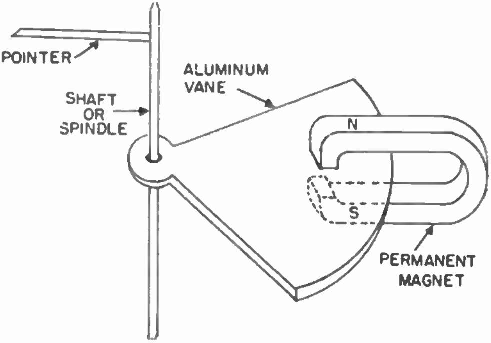


Fig. 30 Principle of magnetic damping in AC meters.

shaft or spindle of the moving element and moves in a closed air chamber (Fig. 31); when there is sufficiently small clearance between the moving vane and the walls of the chamber, any motion is opppused by constriction of air in the chamber. Damping of DC meters used in AC rectifier-type instruments is accomplished by winding the coil on a light aluminum frame so that any movement of the coil assembly sets up eddy currents, creating a field which interacts with the field of the permanent magnet and opposes motion of the coil assembly.

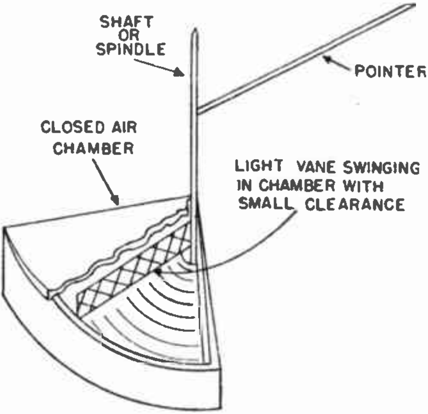


Fig. 31 Principle of air damping in AC meters.

A-C VOLTMETERS

29. The type of instrument best suited for AC voltage measurements depends primarily upon the *frequency* of the voltage, or the *frequency range* of the voltages, to be measured. Low-frequency voltmeters—such as the moving-vane, the electrostatic, and the dynamometer type— are effective only at frequencies less than about 1000 cycles. At higher frequencies, particularly in the audio-frequency range, AC voltages are measured with rectifier-type instruments. For measurements at radio frequencies, special meters are required. AC voltmeters are always connected *in parallel* with the circuit or source of voltage being measured. The most effective instruments represent a high value of resistance, and therefore consume relatively low power. In considering the sensitivity of AC voltmeters, the instrument requiring the least amount of current for deflection is considered to be the most sensitive.

30. Moving-Vane Voltmeter.—This is an electromagnetic instrument—sometimes known as the moving-iron or iron-vane voltmeter—in which a mechanical force is caused by the mutual repulsion between two highly magnetized iron strips, one fixed and one moveable, located in the electromagnetic field of a stationary or fixed coil. Principal components of this voltmeter are similar to those of the moving-vane ammeter (Fig. 20); the essential difference between the two being the nature of the winding. Since a voltage-measuring instrument must have a high resistance, the coil of the moving-vane voltmeter is wound with many turns of extremely fine wire. When this instrument, with its non-inductive series resistor or multiplier, is connected across a source of AC voltage, the amount of current flowing through the meter is determined by the *effective* value of the AC voltage. As current is applied to the coil, both the fixed iron strip and the moveable iron vane are magnetized; and despite rapid reversals of polarity, according to the frequency of the AC voltage, the two soft-iron plates always retain the same polarity *with respect to each other*.

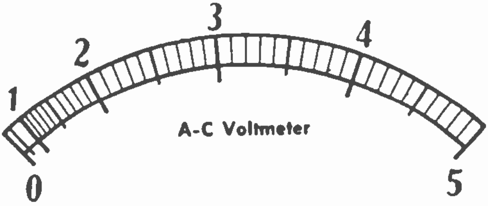


Fig. 32 Compressed quadratic scale, typical of the moving-vane AC voltmeter.

Thus, when the two plates are similarly magnetized, they repel each other, and movement of the iron vane causes the pointer to cross a calibrated scale. Since deflection of the pointer is approximately proportional to the square of the current flowing through the coil, results are indicated on a compressed quadratic scale which is calibrated directly in AC volts (Fig. 32). The range of a moving-vane voltmeter is usually extended by using a *potential transformer* to step down the high voltage to be measured so that it falls within the range of the existing meter. The range can also be extended by connecting a suitable *multiplier* in series with the electromagnetic coil, as in the case of DC voltmeters; but such resistors must have a higher power rating, since the AC moving-vane voltmeter requires considerably more current than a DC voltmeter for normal operation. In addition to this lack of sensitivity, the moving-vane voltmeter is limited as to frequency variation. This limitation becomes severe at frequencies above 100 cycles, and introduces a substantial error in readings. Accordingly, moving-vane voltmeters for use at frequencies between about 100 cycles and 600 cycles are especially calibrated for operation at a *specific* frequency in that range. The instrument is used mainly in high-voltage power circuits where, because of its nature of operation, it can function as either a DC voltmeter or an AC voltmeter.

31. Electrostatic Voltmeter.—This instrument is radically different from all other types of meters, since it is the only kind that functions because of a *stationary* electric charge instead of the more usual *moving* electric charge. When a stationary charge is applied between two parallel plates, one fixed and one moveable, the difference of polarity creates an electrostatic *force of attraction* between the two adjacent plates. Since one plate is free to move, a deflection takes place which is a measure of the potential difference between the two plates. This action is, in general, unaffected by the frequency of the AC voltage being measured because, even though their polarity is reversing rapidly, the two plates always retain the same *difference in polarity* regardless of the frequency of the applied voltage. Accordingly, it is also possible to measure DC potentials with this instrument.

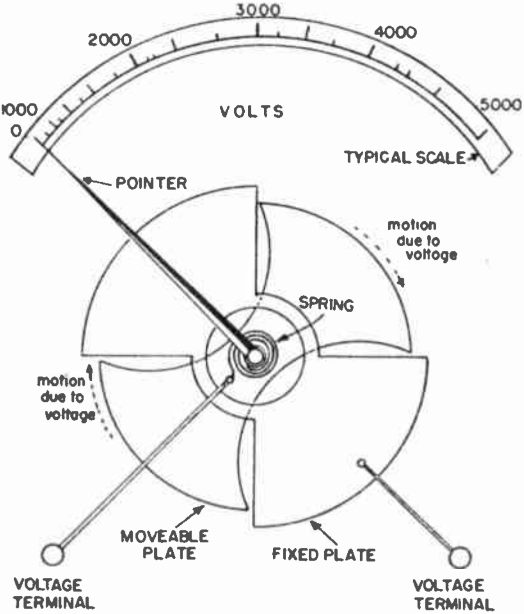


Fig. 33 Principle of electrostatic voltmeter, with typical non-linear scale.

Principal components of the electrostatic voltmeter are shown in Fig. 33. No coils or magnets are required. In both appearance and electrical function, the plates closely resemble a precision variable condenser. The moveable plate is mounted on a shaft or spindle, to which is also attached a pointer and two spiral springs to control movement of the pointer. As it turns on the spindle, the moveable plate is always parallel and very close to, but not touching, the fixed plate. When a potential difference is applied to the meter (Fig. 33), the dissimilar polarities of the two plates produce an electrostatic force which tends to rotate the moveable plate in a clockwise direction about the spindle, thus moving the pointer across the scale. The extent of this movement is determined by the magnitude of the voltage applied to the instrument. Since deflection of the pointer is not directly proportional to the amount of the applied voltage, however, the scale is non-linear and has considerable compression at the low end of its range (Fig. 33). This lack of sensitivity is characteristic of the electrostatic voltmeter and, for this reason, use of the instrument is normally restricted to measurements of very high voltages —at power frequencies and up to about 500 cycles. The effectiveness of the voltmeter, in this respect, is due to its high resistance and negligible power consumption at such low frequencies. The principle of the electrostatic voltmeter is also used in a special type of meter, known as the *electrostatic ground detector,* which indicates the voltage between ground and any wire of a high- or low-voltage transmission circuit. For high-frequency voltage measurements, however, the electrostatic voltmeter is not recommended, because it introduces capacitive effects which unbalance or otherwise disturb the operating conditions of the circuit being measured.

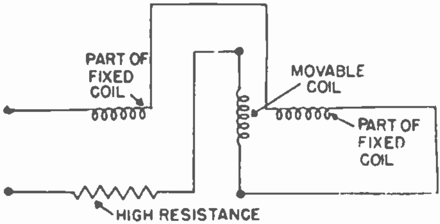


Fig. 34 Equivalent circuit of dynamometer-type AC voltmeter.

32. Dynamometer-type Voltmeter.—Operation of this instrument—sometimes known as the electrodynamic voltmeter—is based on a mechanical force caused by the reaction between the magnetic field of a moveable coil and the magnetic field of a fixed coil. Principal components of the instrument (Fig. 22) include a fixed coil of two sections, between which a shaft or spindle, mounted on pivots, contains the moveable coil and a suitable pointer. To provide the high resistance needed for measuring voltages, the moveable coil is wound with many turns of extremely fine wire, and the fixed and moveable coils are connected in series with a non-inductive current-limiting resistor (Fig. 34). When placed across a source of AC voltage, the amount of current flowing through the meter is determined by the *effective* value of the AC voltage. This current—which usually does not exceed about 0.1 ampere—

is conducted in and out of the moving coil by means of two spiral springs, which also control the motion of the coil. The flow of current through the complete circuit of the dynamometer-type voltmeter produces two distinct magnetic fields. Since the axis of the magnetic field around the moveable coil is not parallel to the axis of the magnetic field around the fixed coils—due to action of the spiral springs—the two magnetic fields attempt to align themselves and thus create a mechanical force. This turning force is proportional to the strength of the magnetic fields which, in turn, are proportional to the value of current flowing through the coils.

Movement of the pointer is almost proportional to the square of the current flowing as the result of the applied voltage; accordingly, the meter uses a modified quadratic scale. Since polarity reversals of alternating current come at the same instant *in both coils* the direction of the mechanical or turning force is independent of alternations of the applied AC voltage. For this reason, the instrument can be used to measure DC voltage; but it is not as sensitive as the conventional DC voltmeter. An existing dynamometer-type voltmeter is converted into a multi-range instrument, by tapping the non-inductive series resistor at proper points and bringing out leads to new terminals. For example, a voltmeter with a full-scale reading of 300 volts can have a 150-volt scale by employing only one-half of the total resistor value, and a 75-volt scale by employing only one-quarter of the resistor; since the reductions are proportional, a single scale (Fig. 35) is used for readings on all ranges. When the dynamometer-type voltmeter is used in high-voltage power circuits, the range of the instrument is usually extended by using a *potential transformer* to step down the high voltage to be measured so that it falls within the range of the existing meter. The range can also be extended by connecting a suitable *multiplier* in series with the circuit, as in the case of DC voltmeters; but such resistors must have a much higher power rating, since the AC dynamometer-type voltmeter requires much more current than a DC voltmeter for normal operation. Although it is an accurate instrument, the dynamometer-type voltmeter is only practical at frequencies less than about 1000 cycles because of inductive effects of the fixed and moveable coils. The basic dynamometer movement is also used in wattmeters.

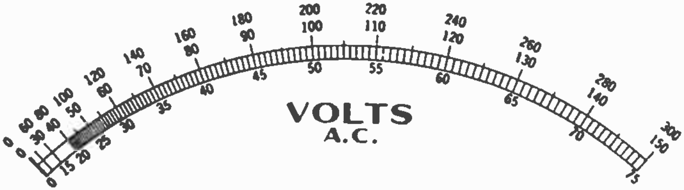


Fig. 35 Modified quadratic scale, typical of the dynamometer type of multi-range AC voltmeter.

33. Potential Transformers.—The range of an AC voltmeter can be extended by means of a multiplier or series resistor, as in the case of DC meters; however, when the operating frequency is less than about 500 cycles, it is more practical to extend the range of an AC voltmeter by means of a *potential transformer* (Fig. 36) having a suitable step-down ratio to permit measurement of high AC voltages. The secondary winding of the potential transformer is connected to the existing voltmeter, and the primary winding is connected in parallel with the circuit being measured. By means of this transformer, voltage across the AC circuit is stepped down so that it falls within the range of the existing meter. Thus, the step-down ratio of the transformer becomes the multiplying ratio applied to the voltage indication on the meter.

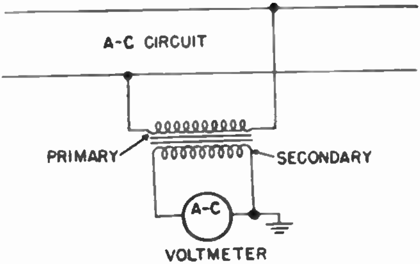


Fig. 36 Method of using potential transformer to extend range of AC voltmeter.

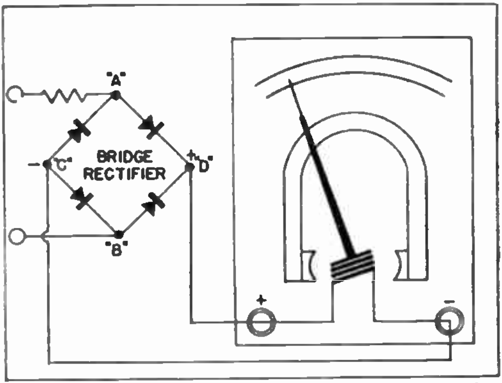


Fig. 37 When used to measure AC voltages, the rectifier-type instrument consists essentially of a current-limiting resistor, an AC rectifier, and a DC moving-coil meter.

34. Rectifier-type Voltmeter.—All of the desirable features and characteristics of the current-operated rectifier-type instrument can be retained for *voltage* measurements merely by providing the current instrument with a suitable series resistance. In such a combination, the series resistor permits a flow of alternating current directly proportional to the applied AC voltage, after which the AC rectifier and the DC moving-coil meter function in the conventional manner. To provide a direct indication of the quantity being measured, the approximately linear scale of the meter is calibrated in terms of the applied AC voltage. Although usually contained in the same meter case (Fig. 37), the series resistor, the rectifier, and the DC meter have separate functions in this process of AC voltage measurement. The most common type of AC rectifier consists of *four* uni-directional elements—either copper-oxide discs, or crystal diodes—arranged in a bridge circuit. When alternating current is applied by the rectifier at points A and B, the polarity at point C is always negative and that of point D is always positive—regardless of the nature or frequency of the alternating current—and the flow of current through the DC meter is always in one direction. Since the rectifier-type instrument requires only a limited amount of power for operation, the voltmeter is particularly useful for audio-frequency measurements. The accuracy of readings is considerably influenced by limitations of the AC rectifying unit, since the rectifier characteristics change with temperature, conditions of overload, frequency of operation, range of operation, and other factors. When a high value of series resistance is used, the scale is linear; but when a small value of series resistance is used the varying resistance of the rectifier causes a radical departure from linearity, and the scale is so severely compressed near the low end as to be almost useless.

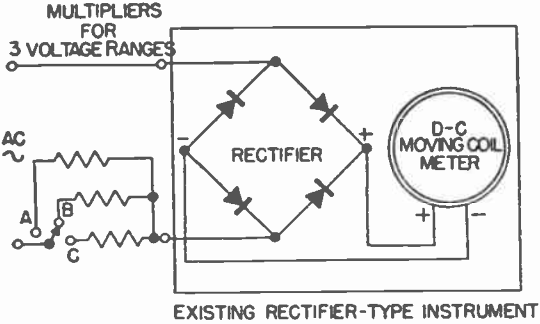


Fig. 38 Typical circuit of multi-range rectifier-type instrument, using suitable multiplier resistors with an existing AC voltmeter.

Readings may be seriously affected by frequency errors when the rectifier-type voltmeter is used above 10,000 cycles, because series resistors are not ordinarily designed for use above that frequency. Since this instrument measures the *average* value of the applied AC voltage, it is susceptible to errors due to variations in the applied wave form; and it should be used to measure *only* the type of voltage wave form originally used for calibration—as indicated on the scale or the meter case. In most instances, when the instrument was calibrated originally with a *sine wave*, the scale is inaccurate for measuring non-sinusoidal values of AC voltage. However, when the rectifier-type voltmeter is used with a recognition of its various limitations, it is an extremely valuable measuring instrument. The sensitivity of the rectifier-type voltmeter is more than 50 times greater than either the dynamometer-type or moving-vane voltmeter.

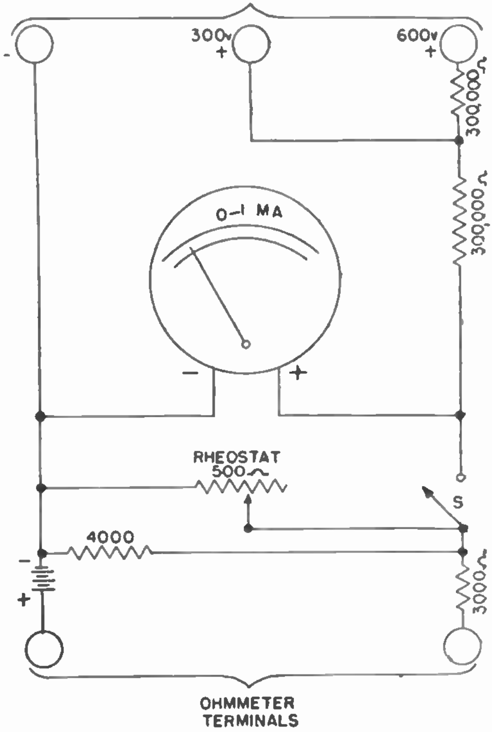


Fig. 39 Typical volt-ohmmeter.

35. Multi-Range Rectifier-type Voltmeters.—The range of an AC rectifier-type voltmeter can be extended by means of a multiplier resistor connected *in series* with the AC line side of the rectifier. By using suitable values of multiplier resistors and a switching circuit, a *single* rectifier-type instrument can measure AC voltage over several different ranges (Fig. 38), thus eliminating the need for individual instruments. A common scale is accurate for all voltage ranges *above* approximately 50 volts. At lower ranges, however, the resistance of the instrument varies according to the amount of current and a common scale is inadequate, unless a special compensating network of resistors is connected across the input of the instrument.

COMBINATION METERS

36. A wide range of current, voltage, and resistance measurements can be obtained with a single meter, when either a switching circuit or plug-in arrangement permits the use of appropriate shunt and multiplier resistors to cover the required ranges. In most cases, the highly sensitive DC moving-coil meter—with or without a rectifier—forms the basis of such combination measuring instruments.

37. Volt-Ohmmeter.—A dual-purpose measuring instrument of the simplest type is the *volt-ohmmeter* which, as its name implies, is a combination of ohmmeter and DC voltmeter. The circuit of a typical instrument (Fig. 39) employs a DC milliammeter (range 0 to 1 ma) with suitable mulitplier resistors for DC voltage readings on two ranges at a sensitivity of 1000 ohms-per-volt *plus* a self-contained 4½ volt battery and suitable shunt resistors for accurate resistance readings up to about 100,000 ohms. The scale of the meter (Fig. 40) is calibrated directly in ohms, and volts, according to these ranges. Input terminals—for either voltmeter or ohmmeter operation—consist of plug-in or tip jacks. Thus, only a single switch S is required; when open, the circuit functions as a voltmeter; when closed, the circuit measures resistance. Other types of volt-ohmmeters can be used to provide a wider variety of ranges, but their fundamental operation is the same. Because of their small size and simplicity of design, volt-ohmmeters are usually contained in pocket-size cases for extreme portability and, therefore, greater usefulness.

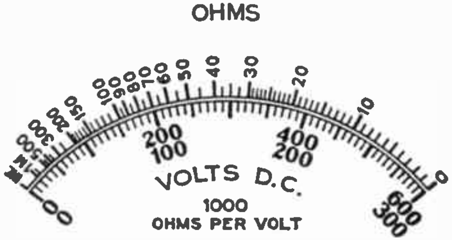


Fig. 40 Volt-ohmmeter scale.

38. Multi-Range AC/DC Volt-Ohm-Milliammeter. — Since the AC rectifier -type instrument contains a DC moving-coil meter, by means of a simple switch the DC meter can also be used independently of the AC rectifier. Thus, a *single* meter of high sensitivity provides readings of both direct and alternating currents as well as DC and AC voltages. With appropriate shunt and multiplier resistors connected in a suitable switching circuit, the resulting combination instrument measures a wide range of current, voltage, and resistance. The multi-range scale of a typical AC/DC volt-ohm-milliammeter (Fig. 41) includes a conventional scale for resistance, a linear scale for all values of DC voltage and current, a compressed almost-linear scale for low-range values of AC voltage and current, and a more linear scale for all higher values of AC voltage and current. Although the measuring circuits of such combination meters are somewhat complicated by multiple-contact switching systems, the meter functions, in each of its various applications, according to basic and fundamental principles.

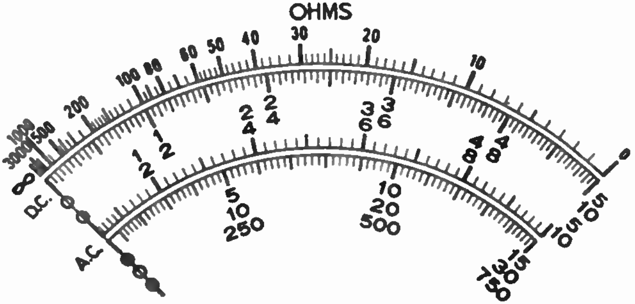


Fig. 41 Multi-range scale of an AC-DC volt-ohm-milliammeter.

POWER METERS

39. Instruments for measuring electric power are known as *wattmeters*. Since the amount of power consumed in a circuit is dependent upon both the voltage and current, a wattmeter measures both of these quantities *at the same time* and then, by a combining process of multiplication, produces a *single* deflection which is indicative of the power consumed. DC power is measured directly; but the wattmeter indicates the *average* value of power in AC circuits due to the partial influence of the power factor or phase angle. *Power-factor meters* are used to indicate the percentage difference between the voltage and current alternations in an AC circuit. *Watthour meters* are instruments for measuring energy: the product of power and time.

40. The Wattmeter.—Operation of this instrument is based on the principle of the dynamometer-type of AC meter where a mechanical force is caused by the reaction between the magnetic field of a moveable coil and the magnetic field of a fixed or stationary coil. Principal components of the wattmeter (Fig. 42) include a fixed coil of two sections, between which a shaft or spindle, mounted on pivots, contains the moveable coil and pointer. The fixed coil is the current-measuring element of the wattmeter; this coil is wound with very heavy wire and is connected *in series* with one side of the line or circuit being measured (Fig. 43). The moveable coil is the voltage-measuring element; this coil is

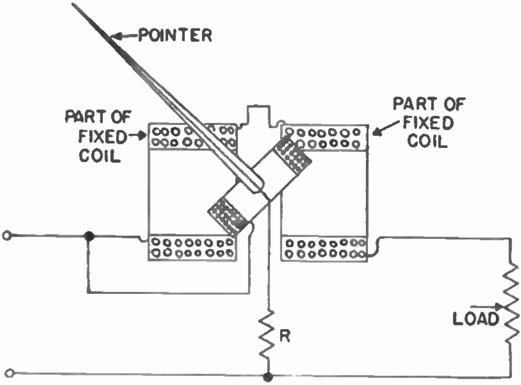


Fig. 42 Principle of dynamometer-type wattmeter.

wound with many turns of extremely fine, high-resistance wire and, with a non-inductive current-limiting resistor, is connected *in parallel* with the line or circuit. Any voltage across this section of the meter causes a flow of current which is conducted in and out of the moveable coil by means of two spiral springs.

The load current flowing through the fixed coil produces a magnetic field with an axis at right angles to the magnetic field produced by current flowing through the moveable coil. Reaction between the two magnetic fields develops a mechanical force which turns the moveable coil and pointer. The amount or degree of this turning force is, therefore, determined by the amount of *current* flowing through the fixed coil and the amount of *voltage* across the high-resistance moveable coil. Deflection of the pointer is proportional to the *product* of this current and voltage, and, when suitably calibrated, a linear scale is used for direct readings

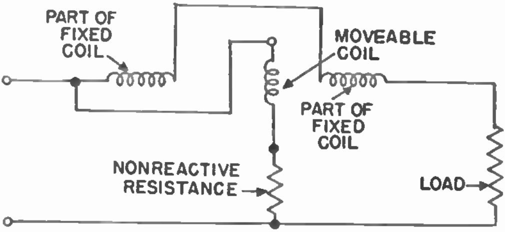


Fig. 43 Equivalent circuit of dynamometer-type wattmeter

of power measurements in watts (Fig. 44). Because of its inertia, the moveable coil cannot follow rapid changes or polarity reversals of voltage and current; thus, when the wattmeter is used for AC single-phase measurements, the scale indicates the *average* power in watts. For measurement of power in other than single-phase AC circuits, much more elaborate wattmeters or a combination of wattmeters are required.

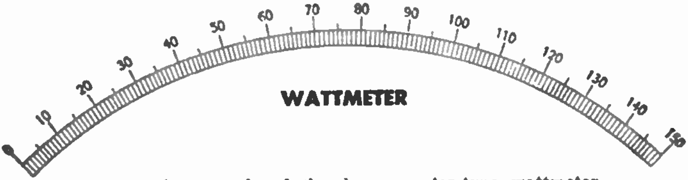


Fig. 44 Linear scale of the dynamometer-type wattmeter.

41. Power-Factor Meter.—In AC circuit measurements, the percentage difference between the current and voltage alternations is expressed as the *power factor* of the circuit. It is this quantity by which the product of the *effective* voltage and *effective* current is multiplied in order to obtain the *true power* in watts taken from the AC circuit. The nature of the circuit load—whether inductive, resistive, or capacitive—determines the phase lag or lead of current with respect to voltage which, in turn, determines the power factor. This percentage factor is indicated directly by the power-factor meter (Fig. 45) which consists essentially of a fixed coil

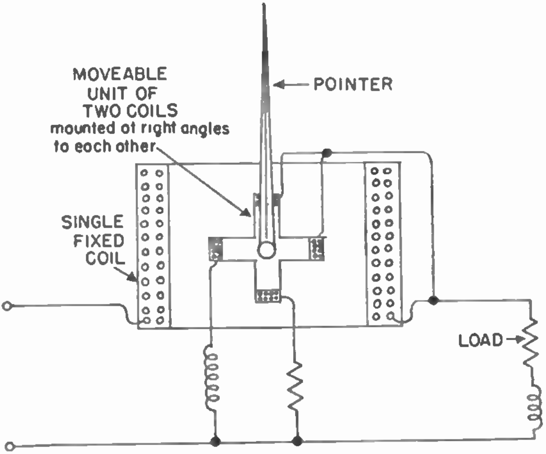


Fig. 45 Principle of power-factor meter.

connected in series with one side of the circuit, and two moveable coils, mounted on a shaft or spindle at right angles to each other and connected across the circuit. There is a high resistance in series with one of the moveable coils, and current in this coil is always in phase with the *voltage* of the circuit. Because of the inductance in series with the second moveable coil, the current in this coil always lags 90 degrees behind the circuit *voltage*. The two coils tend to maintain this phase relationship, and any change—due to phase differences between current and voltage in the circuit being measured—causes a compensating movement of the two coils and, therefore, a deflection of the pointer.

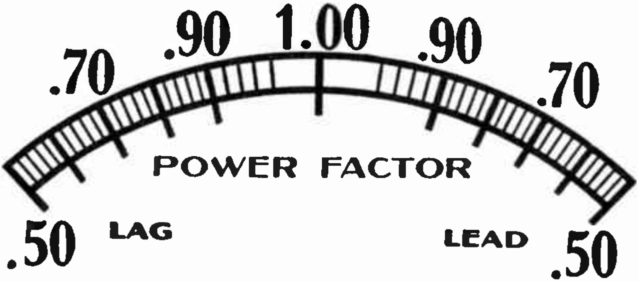


Fig. 46 Scale for power-factor meter.

The measured phase angle is indicated on the scale (Fig. 46) in terms of the *percentage* lag or lead of the current with respect to the voltage, which represents the power factor of the circuit. When the scale of the same meter is graduated in equal angular intervals, the instrument is known as a *phase meter*.

42. Watthour Meter.—This instrument measures energy: the product of power and time, and is universally used to record the consumption of electric power. The meter consists essentially of a small motor whose instantaneous speed is proportional to the amount of power passing through it, and whose total revolutions during a given time are proportional to the total energy or *watthours* consumed during that period of time.

RF CURRENT METERS

43. For AC measurements at high frequencies, electrothermal instruments are usually employed. The *hot-wire meter* is the simplest type, but is difficult to adjust and has other limitations. Far more satisfactory is the *thermocouple-type meter*, consisting of a thermal junction and a DC moving-coil meter. These are the *only* instruments which can be used for measuring radio-frequency currents in antenna and transmission circuits with any degree of accuracy.

44. Hot-Wire Meter.—Operation of this meter is based on the *expansion* of a specially prepared wire, which results when such a wire is heated by the electric current to be measured. Although heat is generated by this process, the principle of operation concerns only the resulting *effect* of such heat. In the basic movement of a hot-wire meter (Fig. 47), a thin high-resistance wire is stretched between the two supports A and B, and a silk thread is connected between the mid-point X of the wire and a spring having sufficient tension to hold the thread taut. The pointer, mounted on pivots, is also attached to the thread, so that it indicates *zero* on the scale—unless movement of the thread permits the pointer to cross the scale. When the current to be measured passes through the wire between points A and B, heat is generated and the wire expands; this expansion relieves tension on the spring, and movement of the thread permits movement of the pointer. The greater the amount of current flowing through the wire, the greater the heat and expansion of the wire, and the greater the deflection of the pointer. The heating effect is proportional to the square of the applied current, and therefore calibration of the scale follows the square law (Fig. 48) with additional compression at the low end of the scale to compensate for heating losses and other effects. Since the generation of heat is independent of polarity, the hot-wire meter can be used for measuring either direct or alternating current. Since no coils or magnets are used, there are no resonance or frequency-error

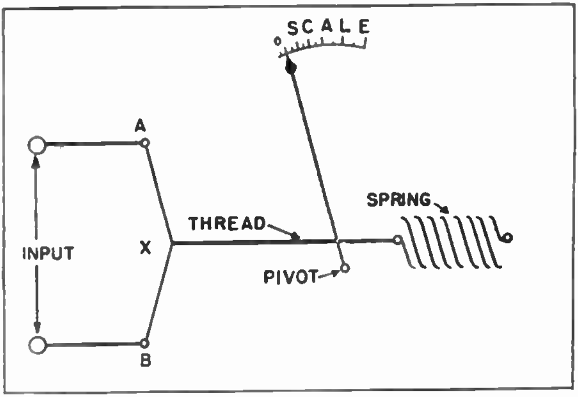


Fig. 47 Basic movement of the hot-wire meter.

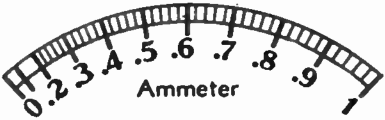


Fig. 48 Cramped non-linear scale, typical of hot-wire meter.

effects and, when equipped with the proper type of wire and suitably calibrated, the meter can be used over an extremely wide range of frequencies. These advantages are offset, however, by the weaknesses of the instrument. It is slow acting and insensitive, often requiring the consumption of a considerable amount of current in order to generate sufficient heat to obtain a reading. The *zero* setting is usually indefinite because of difficult and precise adjustments, which must be made frequently. The accuracy of the hot-wire meter is extremely low, and it is generally unsuitable for measuring small currents or for use as a voltmeter.

45. Thermocouple-type Meter.—Operation of this instrument is based on the potential developed by the junction of two wires of dissimilar metal, when such a junction—known as a *thermocouple*—is heated by the electric current to be measured. This thermocouple and a conventional DC moving-coil voltmeter or millivoltmeter constitute the essential components of the complete electrothermal instrument (Fig. 49), but the thermocouple is usually considered as a separate accessory of the meter. There are several types of thermocouples, all of which are composed of two wires of unlike material—such as iron and copper-nickel alloy, constantan and copper, constantan and manganin, or other combinations. The two wires are of equal length and are brought to a junction at, or very near, a high resistance which becomes heated with application of an external current. When heat is applied to the junction, there is a difference in temperature between the junction and the opposite or "cold" ends of the wires at A and B. This difference in temperature produces a low DC voltage which can be measured by the sensitive moving-coil voltmeter.

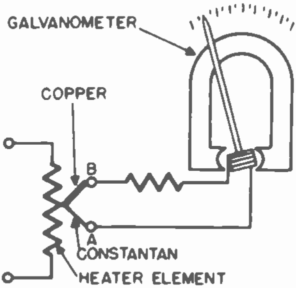


Fig. 49 The thermocouple instrument consists essentially of a thermocouple element and a low range DC moving-coil voltmeter.

The deflection of the meter is proportional to the temperature difference between points A and B, which is proportional to the temperature of the junction *and* of the high-resistance heater. Since the temperature of the heater is proportional to the square of the current flowing through the resistance, the *amount* of this current determines the deflection of the meter. Therefore, the meter is calibrated in terms of current, using a non-linear square-law scale (Fig. 50) with a slight compression at the low end of the scale to compensate for slight heat losses of the thermocouple. Since the generation of heat is independent of polarity, the thermocouple-type instrument can be used for measuring either direct or alternating current. The basic or contact type of thermocouple (Fig. 51a) is adequate for low-frequency measurements of alternating currents. At high frequencies, however, the separate-heater type is used (Fig. 51b), where the junction is held near but is actually insulated from the heater by means of a small glass bead of high thermal conductivity; this arrangement eliminates errors due to electrostatic capacity effects between the meter and ground, but decreases the sensitivity of the instrument.

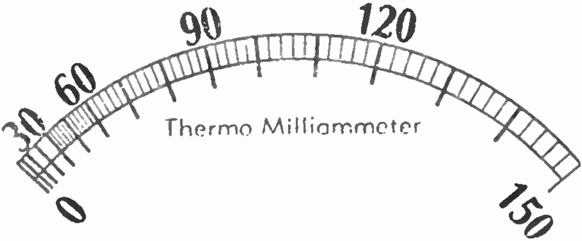


Fig. 50 Compressed square-law scale, typical of thermocouple instrument.

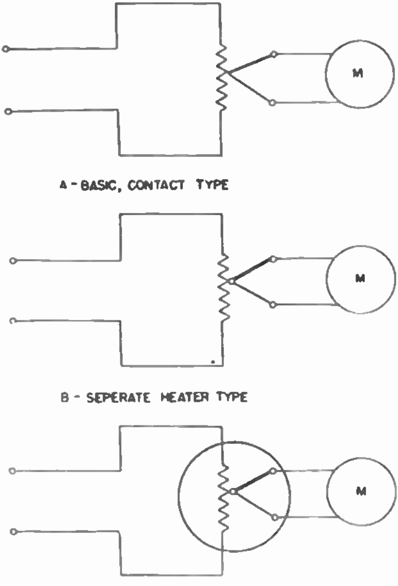


Fig. 51 Principal types of thermocouples.

When the heater and junction of the thermocouple are enclosed in an evacuated bulb (Fig. 51c), losses due to heat conduction are eliminated, and the sensitivity and reliability of the instrument are greatly improved. The vacuum thermocouple is useful for measurements of small alternating currents of only a few milliamperes. In all thermocouple-type meters, however, the temperature of the heater increases as the square of the applied current increases; therefore, any appreciable overload causes the heater to burn out. Also, because of their delicate costruction, all thermocouple-type meters must be handled carefully. Despite these limitations, the thermocouple-type meter is suitable for current measurement at high frequencies which are entirely beyond the capabilities of any other type of meter.

VACUUM-TUBE VOLTMETERS

46. The measurement of many circuits—particularly radio circuits, where the amount of power is small—requires a meter which draws practically no current from the circuit, thus giving a true indication of circuit operating conditions. The vacuum-tube voltmeter not only satisfies this requirement but can be used to measure either DC voltage or AC voltage at any frequency up to several hundred megacycles. These characteristics are common to all of the several types of vacuum-tube voltmeters, and make them the most important instruments for measuring voltage at radio frequencies.

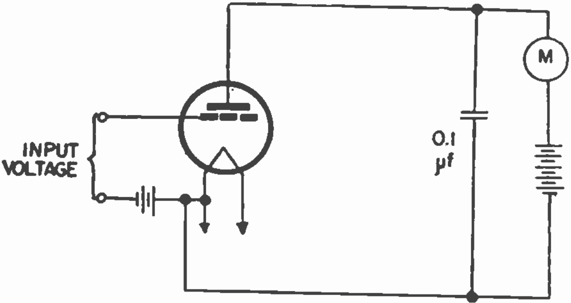


Fig. 52 Basic circuit of triode vacuum tube voltmeter.

47. Basic Triode Circuit.—The vacuum-tube voltmeter consists essentially of a vacuum-tube detector circuit used in conjunction with a DC moving-coil meter. Operation of the circuit is based on the *proportional* change in DC output current due to application of a signal or input voltage. In a typical circuit arrangement (Fig. 52), a conventional triode is operated as a plate detector. The grid of the tube is biased near the cut-off point of the plate-current/grid-voltage curve (Fig. 53) so that an unknown AC voltage applied to the grid causes an increase in plate current during positive half cycles which is far greater than the negative decrease in plate current during negative half cycles. The result-

ing change or net increase is a measure of the applied voltage, and this change is read on a DC milliammeter or microammeter calibrated directly in AC voltage. By means of a suitable bypass condenser, the meter is protected from any alternating currents that may be present in the plate circuit. Since a steady plate current is present at all times, it is usually desirable to balance out this current so that the full range of the meter may be utilized. This neutralization is accomplished in several ways, one of which is shown in an improved triode circuit of Figure 54. A pentode is often connected as a triode and used for plate detection, because the pentode has a lower input capacitance, lower interelectrode capacitance, and is equipped with a grid cap on the

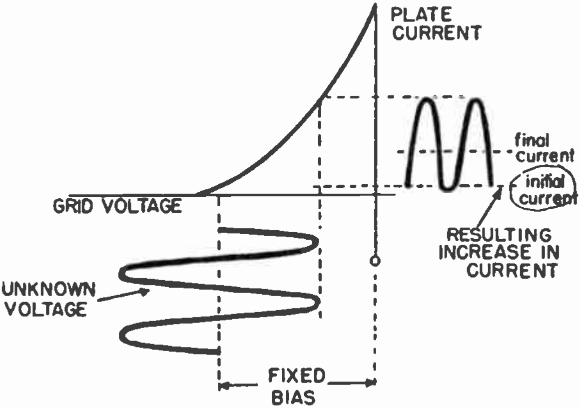


Fig. 53 With the vacuum tube biased just above cut-off, only positive half-cycles of the applied voltage cause an increase in the DC plate current.

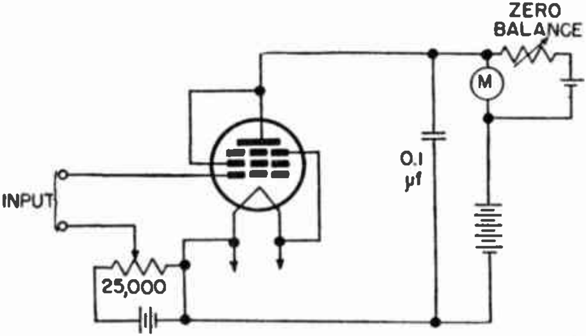


Fig. 54 Improved circuit of triode vacuum tube voltmeter, with balance control.

top of the envelope so that the tube can be used with a probe when desired. Since the behaviour of the voltmeter depends upon the critical value of the grid bias, this voltage is usually controlled with a potentiometer (Fig. 54) for precise adjustment. The input resistance of a vacuum-tube voltmeter is extremely high, and the plate load of the tube is low so that it does not influence the input resistance. The input capacitance is usually on the order of only a few micromicrofarads. Most types for RF measurements use either a 100 or a 200 microampere linear scale.

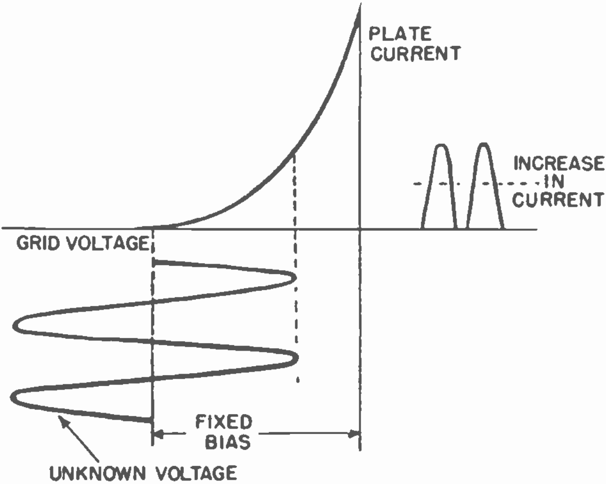


Fig. 55 In the peak vacuum tube voltmeter, the tube is biased well beyond cut-off so that only the positive peak portions of the applied voltage cause an increase in the DC plate current.

48. Peak Voltmeter.—A vacuum-tube voltmeter can be used to indicate peak values of the applied AC voltage, merely by adjustment of the grid bias to a negative value well *beyond* the cut-off point (Fig. 55) on the plate-current/grid-voltage curve for the particular tube. When an unknown AC voltage is applied to the grid, there is an increase in DC plate current *only* during extremely positive peak portions of the applied voltage. The instrument can be made even more sensitive to peak values of the applied AC voltage, by adjusting the grid bias to a value *slightly less* than the crest of the AC voltage, so that current flows in the plate circuit for very brief intervals during each voltage alternation.

49. Reflex Voltmeter.—The circuit of this instrument—known as a reflex or self-biased voltmeter—operates according to the plate detection principle. Although essentially the same as the basic triode circuit, the grid bias voltage is obtained from a resistor R_c in the cathode of the tube (Fig. 56). This biasing arrangement tends to compensate automatically for any changes in the operating voltages or tube characteristics. However, the instrument has a slightly lower sensitivity, due to degenerative effects when plate current flowing through the cathode resistor increases

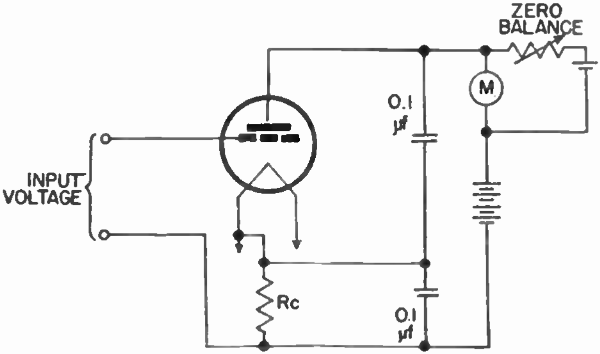


Fig. 56 Circuit of reflex voltmeter.

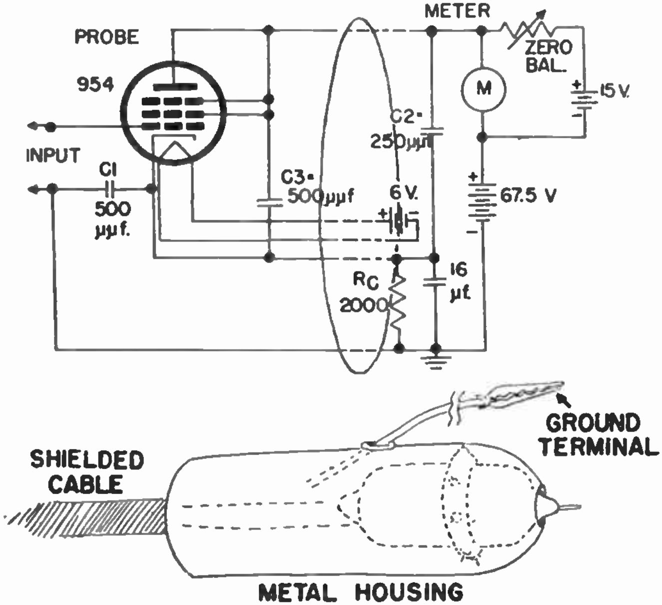


Fig. 57 Reflex voltmeter with acorn-tube probe.

the voltage drop—and thus the grid bias. Like other plate-rectification voltmeters, the input resistance of the reflex voltmeter is very high. The reflex circuit is particularly adaptable to probe arrangements, and is also used in conjunction with a DC amplifier to provide an instrument capable of measuring a wide range of voltages.

50. Reflex Voltmeter with Probe.—For measurements at high frequencies, it is necessary to keep the input leads of a vacuum-tube voltmeter as short as possible in order to minimize input capacitive effects. A more practical arrangement is to bring the grid connection of the tube directly to that portion of the device being measured, by means of a cable extension, thus effectively eliminating the leads and their troublesome effects. A small or miniature tube and a few components are encased in a small, shielded assembly—known as a *probe*—which provides plate rectification of AC voltages at the exact point of contact in the circuit of the device being measured. The rectified output of the tube is then applied to the main part of the vacuum-tube voltmeter circuit via the same flexible cable that supplies the necessary tube operating voltages. The reflex voltmeter circuit is admirably adapted to use with such a probe. In a typical circuit (Fig. 57) a type 954 acorn tube functions as a self-biased triode plate detector, with the grid terminal serving as the actual signal probe. Mica condensers C_1 and C_2 are used to by-pass high frequencies, and thus prevent any AC voltage from being built up at either the cathode or the plate. Operation of the reflex circuit is conventional, but use of a probe provides much greater accuracy. With this arrangement, the reflex voltmeter can be used for AC measurements at frequencies as high as 50 megacycles.

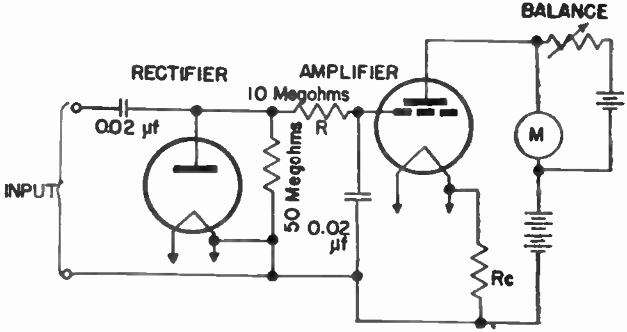


Fig. 58 Rectifier-amplifier voltmeter.

51. Rectifier-Amplifier Voltmeter.—This instrument provides DC amplification of the rectified signal before final application to the DC meter, and thus differs from the basic vacuum-tube voltmeter. As its name implies, *two* tubes are used in the rectifier-amplifier voltmeter: the *rectifier* which is usually a diode but can be a triode functioning as a diode, and the *DC amplifier* which can be a triode, tetrode, or pentode. Principal advantage of adding the stage of amplification is the considerable increase in sensitivity, which permits measurements of almost microscopic values of AC voltage in extremely delicate circuits—such as those used in radio. The use of a DC amplifier also provides greater stability, much wider range, and higher input impedance. These important advantages are made possible by separating the two circuit functions, so that both rectifier and amplifier operate at greatest efficiency. In a typical circuit (Fig. 58), the diode provides half-wave rectification, as the input condenser charges up to slightly less than the peak value of the applied voltage being measured. The voltage drop across the coupling resistor R is applied directly to the grid of the triode amplifier, which is normally maintained negative by the cathode resistor R_c, and the DC output current is applied to a balanced milliammeter or microammeter.

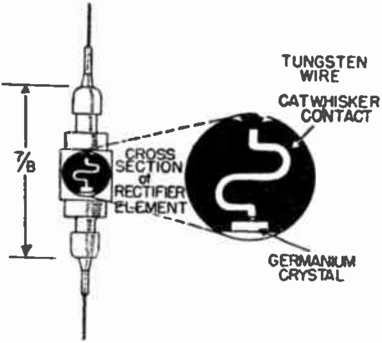


Fig. 59 Germanium crystal diode.

52. Rectifier-Amplifier Voltmeter with Probe.—For measurements at high frequencies, much of the general effectiveness of the rectifier-amplifier voltmeter (Fig. 58) is lost due to serious capacitive effects introduced by the leads of the instrument when connected to the circuit under measurement. These unwanted effects can be reduced by using extremely short leads between the circuit and the vacuum-tube voltmeter; but this is often impractical, because of the size of the voltmeter or the inaccessibility of parts of the circuit or device. A more adequate arrangement is to bring the AC rectifier directly to the portion of the circuit or device being measured, by means of a cable extension. This rectifier and a few components are encased in a small, shielded assembly—known as a *probe*—which provides rectification of AC voltages at the exact point of contact in the circuit being measured. The rectified output of the probe is then applied to the DC amplifier in the main part of the voltmeter circuit via a suitable flexible cable. If a diode vacuum tube (Fig. 58) is used as the rectifier, the size of the probe is determined by the size of the tube employed; and the flexible cable must provide a diode filament supply in addition to, and well insulated from, the two signal wires. Although this type of probe was once popular, the diode vacuum-tube rectifier has largely been replaced by the more modern *crystal diode* (Fig. 59). The germanium crystal diode is a compact, miniature rectifier—measuring only ¼-inch in diameter and about ⅞-inch in length—which consists essentially of a tungsten-wire catwhisker in fixed contact with a small square of germanium crystal. No voltage, other than the signal itself, is required for crystal operation. For this reason, and because of its small size and high sensitivity, the crystal diode is extremely desirable as a probe rectifier. The physical size of the probe can be made very small, the flexible cable need consist only of two unshielded wires, and the complete circuit of such a rectifier-amplifier voltmeter is considerably simplified (Fig. 60).

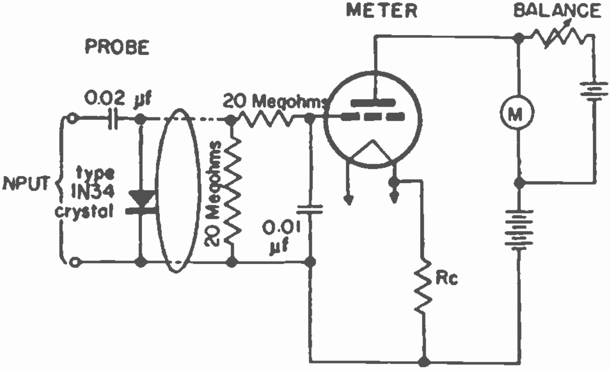


Fig. 60 Rectifier-amplifier voltmeter, using crystal diode.

53. Balanced Push-Pull DC Voltmeter.—When the requirements of a vacuum-tube voltmeter include extreme sensitivity and high stability over a wide operating range, it is often preferable to use the circuit of the balanced push-pull DC voltmeter (Fig. 61). Two tubes of similar type are employed, with their cathodes coupled together by a large value of resistance R_c. This resistor prevents degeneration and increases the stability of the circuit without effecting the sensitivity. Because of the balanced condition of the circuit, the *zero* adjustment for the meter is very stable.

POWER LEVEL METERS

54. The output power level of radio receivers and amplifiers is measured by means of *output meters.* Instruments for indicating the power being carried by voice-frequency communications circuits are known as *power level meters,* sometimes called db meters or VU meters. Widely used in circuit measurements of power level is the term *decibel,* or *db,* which is a ratio indication of the gain or loss of an amplifier or any other device. The *decibel* is also used to indicate the power level in a circuit with respect to a *zero* or standard reference level.

55. Output Meters.—A rectifier-type AC voltmeter and a fixed value of load resistance are the essential components of an output meter, which is sufficiently sensitive for measuring low output values in the range of audio frequencies. When such a meter is connected to the output of a radio receiver or amplifier circuit *with a load resistance that matches the source of power,* voltage readings across the fixed load resistor are proportional to the actual output power of the circuit (Fig. 62) and the scale of the meter is calibrated directly in watts or in decibels. Since the load resistance must match the power source in order to obtain accurate readings, the output meter is usually equipped with a variety of resistance multipliers and a suitable switching arrangement (Fig. 63). In this manner, the instrument is capable of providing a wide range of power measurements.

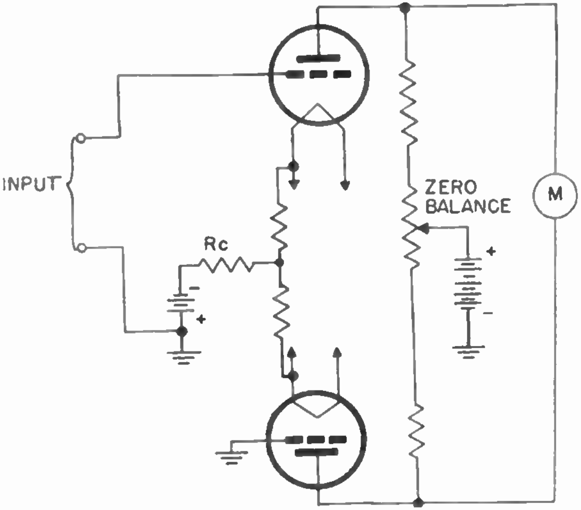


Fig. 61 Balanced push-pull DC voltmeter.

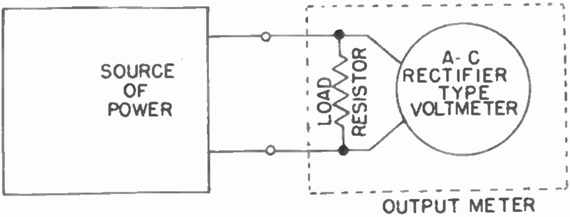


Fig. 62 Principle of output meter.

56. Power Level Indicators.—This instrument is fundamentally an AC rectifier-type voltmeter connected in series with a fixed value of load resistance. When the power level indicator is bridged across an audio-frequency transmission line or communications circuit, the potential drop across the fixed load resistor is proportional to the power level of the line or circuit. The series resistance is high, so that the shunting effect of the meter and consequent loss of circuit power is negligible. Power level measurements are indicated on the scale of the instrument in terms of the power dissipated in the load resistance. Accordingly, the scale can be graduated and marked either in watts or in db or VU. With a db or decibel scale, the instrument is more popularly known as a *db meter.* With a VU scale, the instrument is known as a *VU meter.*

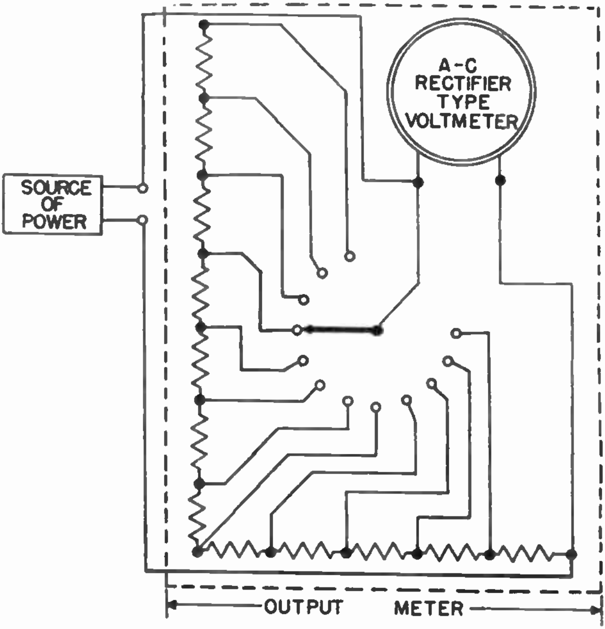
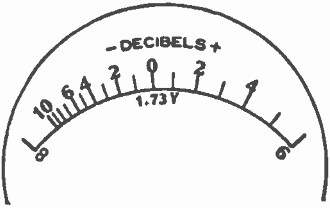


Fig. 63 Circuit of multi-range output meter for power measurements.

57. Db Meters. This type of power level indicator is equipped with a db or decibel scale (Fig. 64), and is calibrated in decibels with respect to a *zero* reference level. Meters of this type usually employ a reference level of 6 milliwatts at 500 ohms, which is th equivalent of 1.73 AC volts across a 500-ohm load; and this is the *zero* point at the center of the scale (Fig. 64). When the power level of the circuit being measured rises above the established reference level, the potential drop across the load resistance of the instrument increases by a proportional amount and this is indicated on the scale of the meter as a *plus db* value.



When the power level is below the established reference level, the resultant indication on the scale of the meter is a *minus db* value.

58. VU Meters.—This type of power level indicator, equipped with a special scale (Fig. 65), is universally accepted as the standard instrument for monitoring the power level in voice-frequency circuits, such as those used in telephony and radio broadcasting. The VU meter operates essentially the same as a db meter, but is calibrated with respect to a standard reference level of 1 milliwatt at 600 ohms, using a series resistance of 3600 ohms. The VU scale always contains two related ranges (Fig. 65); the lower scale is a conventional decibel scale, the upper scale stresses percentage use of the circuit facilities or the radio transmitter. When used for monitoring wire lines or other circuits, a VU scale is used with these two ranges interchanged for ease of observance. This type of power level indicator has largely superseded the db meter, not only for purposes of monitoring but for measurement of noise level and other audio-frequency power.

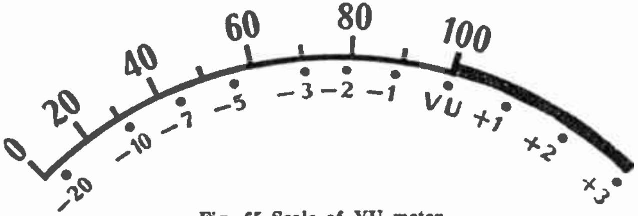


Fig. 65 Scale of VU meter.

TUBE CHECKERS

59. A number of different types of instruments have been developed exclusively for testing and checking the condition of vacuum tubes. Used in connection with the servicing and maintenance of radio and electronic equipment, these tube-testing devices vary considerably in physical size and circuit complexity depending primarily upon the number of *test functions* performed by each instrument. Most important of these functions are the *emission test* and the *dynamic transconductance test*. Other functions, less frequently encountered, include the *static transconduct-*

ance test, the *cathode-leakage test,* the general *short-circuit test,* the *open-element test,* and the *gas test.* Any one, or a combination, of these various functions may be performed by a single tube checker using, generally, the same indicating meter for all tests with appropriate switching and circuit arrangements. When AC operated, tube checkers are usually provided with some means of controlling the input or line voltage for greatest accuracy of readings.

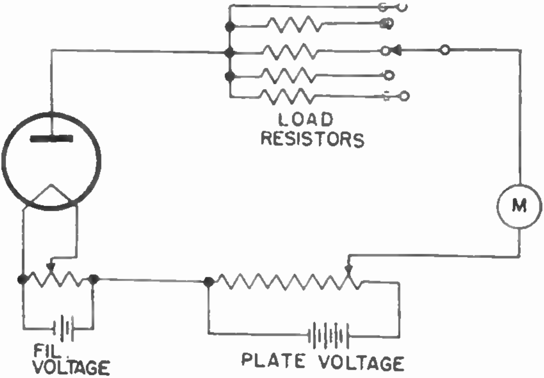


Fig. 66 Basic circuit for diode emission test.

60. Emission Test.—An important indication of the condition of a vacuum tube is obtained by a comparative check of the filament or cathode emission, since a pronounced lower-than-normal emission *or* a complete lack of emission invariably indicates the tube has reached the end of its useful life. The basic circuit for testing emission consists of a DC moving-coil milliammeter and a series load resistor connected in the plate circuit of the vacuum tube under test (Fig. 66) with suitable voltages provided for operation of the filament or heater and the plate only. With a diode inserted in this circuit, the amount of plate current flowing through the load resistance and the meter is determined entirely by the electron emission within the tube. If, by comparison, this deviates severely from the normal operating characteristics of the diode, then the tube is defective. Deflections of the current meter

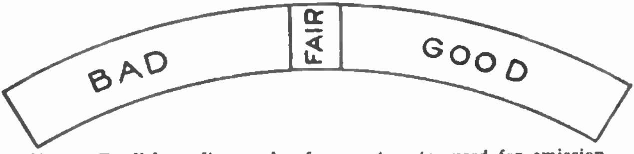


Fig. 67 English-reading scale of current meter used for emission test.

are considerably simplified by use of an English-reading scale (Fig. 67) giving a direct indication of the condition of the tube under test. The load is essentially a current-limiting resistor, and therefore suitable values are provided so that the range of the meter can be varied according to the type of tube being checked. Following this same procedure, triodes, tetrodes, and pentodes can be tested for emission by connecting *all* grid electrodes to the plate—and operating the tube as a diode (Fig. 68). Such a test, however, reveals *only* the condition of the electron emitter, and fails to indicate or identify many other faults which may be present in the tube. Thus, the emission test does not constitute a check of the tube under operating conditions simulating those of actual practice.

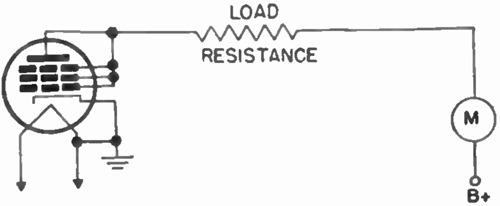


Fig. 68 Pentode connection for emission test.

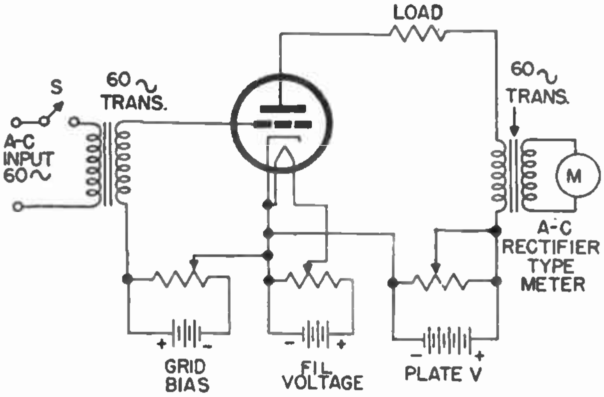


Fig. 69 Basic circuit for dynamic transconductance test.

61. Dynamic Transconductance Test.—The most accurate indication of the condition of any amplifier tube is an appraisal of the tube's transconductance—also known as mutual conductance—under operating conditions approximating those of an actual circuit. Transconductance— in *mhos*—is a figure of merit denoting the ability of a vacuum tube to amplify, and essentially represents the relative increase in plate current as a result of a given increase in applied grid voltage. For tube-checking purposes, this relative increase in plate current is used to indicate the transconductance of the tube under test; and any pronounced deviation from the rated or normal transconductance for a specific tube is indicative of either a defective or ineffective tube. The basic circuit for the dynamic transconductance test (Fig. 69) first provides, with the switch S open, normal DC operating voltages for the tube under test; and since the output consists only of direct current, there is no indication on the AC milliammeter. When the switch S is closed, a known value of AC voltage—obtained through a step-down transformer from a 60-cycle power source—is superimposed on the grid bias of the tube, and the resulting AC component of the plate current is applied to the AC rectifier-type milliammeter through a suitable transformer. The amount of this alternating current represents an increase (above *zero*) due to the increase in grid voltage and, therefore, represents the relative transconductance of the tube under test. The meter is unaffected by the DC component of the plate current and, for purposes of tube-testing, provides an accurate measurement of transconductance under *dynamic* conditions. The AC milliammeter is sometimes calibrated directly in *mhos*—for transconductance. Since the *magnitude* of the current determines the desireability of a tube as an amplifier, the milliammeter is more often equipped with an English-reading scale (Fig. 67).

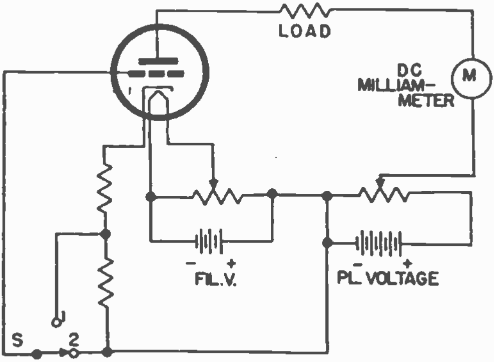


Fig. 70 Basic circuit of the "grid shift" or static transconductance test.

62. Static Transconductance Test.—In principle, this test —also known as the "grid-shift test"—is similar to the dynamic transconductance test described above, with a suitable meter indicating the relative transconductance of any amplifier tube under test. In the static test, however, the necessary change in negative grid bias is effected by a change in DC voltage—and the resultant change in the plate circuit of the tube is indicated by means of a DC milliammeter (Fig. 70). The required values of grid bias are obtained by tapping the DC voltage drop across one or both of the cathode resistors. With the switch S in position 1, the DC milliammeter will read a low value of plate current; and with the switch S in position 2, the decrease in grid bias will permit the flow of a higher value of plate current. The difference between the two plate-current readings is proportional to the relative transconductance of the tube under test and, accordingly, the DC milliammeter can be calibrated directly in *mhos*—for transconductance. Since the *magnitude* of current determines the desirability of an amplifier tube, however, the milliammeter is more often equipped with an English-reading scale (Fig. 67) indicating either "Good," "Fair," or "Bad" conditions of the vacuum tube. The static transconductance test is adequate for some purposes, but measurements made under static conditions impose limitations not encountered in the dynamic test and are, as a result, not too accurate.

63. Cathode-Leakage Test.—A common cause of ineffectiveness likely to be developed in all indirectly heated vacuum tubes is a partial or complete short circuit between the heater and cathode, and this condition is detected by means of the cathode-leakage test. The basic circuit for this test (Fig. 71) provides two operating conditions for the tube under test. With the switch S closed, the vacuum tube functions in a conventional manner; and the normal DC plate current is indicated by a DC milliammeter. When the switch S is open, the cathode of the tube is disconnected from the circuit. Thus, if there is *no* leakage between heater and cathode, there will be *no* current flowing in the plate circuit. However, if there is a partial or complete leakage path between heater and cathode, an amount of plate current will flow as indicated by the DC milliammeter. The greater the plate current, the greater the leakage between heater and cathode. The cathode-leakage test provides an extremly accurate indication of this undesirable condition.

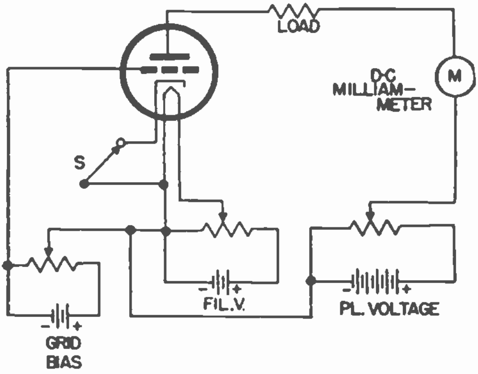


Fig. 71 Basic circuit for Cathode-Leakage Test

64. General Short-Circuit Test.—In addition to the important cathode-leakage test described above, some tube checkers provide a means for detecting short circuits between other electrodes of the tube under test. Since any such short circuit generally results in an excessive flow of current, the simplest method of detecting shorts is by the use of a neon lamp in the plate circuit as a visual warning device. This may fail to identify the exact electrodes causing the trouble, but for practical purposes such specific information is not important because the tube under test has been proven defective and must be replaced. More elaborate tube checkers are equipped with individual electrode-control systems, which permit the exact location of short circuits between any two electrodes of the tube under test.

65. Open-Element Test.—This test is effectively an emission test of *each* of the individual elements or electrodes of a vacuum tube, and uses the same circuit (Fig. 68) as the total emission test previously described. After all grids of the tube have been connected to the plate—usually by means of convenient switches—the plate current for *total* emission is noted. Then, each of the electrodes, *in turn,* is switched out of the circuit, while observing the effect on the plate-current reading of the milliammeter. Under normal conditions, there is a slight change in the amount of plate current when this is done. However, if no change is indicated when an electrode is switched in and out of the testing circuit, then such an electrode is considered to have an open circuit — and is defective. This individual test of each electrode is often necessary, since an open element does not necessarily result in a low plate-current reading during the total emission test.

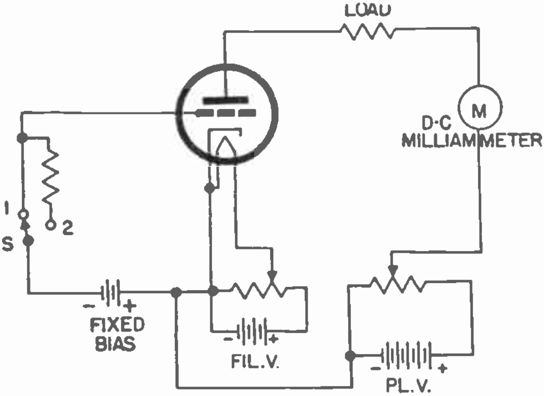


Fig. 72 Basic circuit for gas test.

66. Gas Test.—In all but rectifier tubes, the presence of any gas is extremely undesirable, since the resulting ionization within the tube permits an excessive flow of grid current, destroys the cathode, and has other damaging effects. This condition of a vacuum tube is detected by means of a circuit (Fig.

72) which utilizes any flow of grid current *due to gas* as an indication of the presence of such gas. With the switch S in position 1, the tube functions in a conventional manner with a value of plate current indicated by the DC milliammeter. With the switch S in position 2, a large value of resistance — usually about 500,000 ohms — is introduced in the grid circuit of the tube under test. If there is current flowing in the grid circuit—due to gas in the tube—a voltage is developed across this series resistor. This voltage causes a decided change—either negatively or positively—in the grid bias of the tube, resulting in a decided change in the value of plate current as indicated by the milliammeter. If there is no current flowing in the grid circuit of the tube, the presence of the grid resistor has no effect on the plate current: an indication that there is no gas in the tube under test.

67. **Vacuum-Tube Analyzers.**—When all, or a great many, of the above test functions are accomplished in a single, large, versatile tube-testing device—often with provision for many other circuit measurements—the instrument is known as a *vacuum-tube analyzer.* It is usually equipped with individual control of voltages applied to the electrodes or elements of the tube to be tested. When AC operated, the instrument is provided with some means of controlling the input or line voltage.

CONDENSER METERS

68. There are a number of distinct types of condenser meters, depending upon the functions performed and the degree of accuracy of indicated readings. An instrument for checking only the condition (but not the capacity) of a condenser is correctly identified as a *leakage tester,* although known commercially as a condenser checker, capacity tester, condenser analyzer, and by various other names. An indication of the effective value of a condenser in microfarads is given by a *capacity meter.* A more accurate measurement of capacitance is given by a precision *microfarad meter.* Capacity can be measured with extreme accuracy by means of a bridge measuring device known as a capacitance bridge.

69. Leakage Testers.—These devices are used only to check the condition of a condenser in terms of its most frequently encountered troubles: the presence of any leakage and whether the condenser is open-circuited or short-circuited. After an appropriate DC charging voltage has been applied to, and then removed from, the condenser under test, the required information is given by means of a suitable meter, a neon glow tube, or some other indicating device. If the full DC charge remains on the condenser, there is no appreciable leakage. If considerably less than the full DC charge remains on the condenser, there is some leakage present—and the fixed value of current passing through the indicating device is a measure of that leakage. A short-circuited condenser produces a brief current discharge through the indicating device, but only until the potential on both sets of condenser plates have been equalized. Since an open-circuited

condenser is effectively uncharged during application of the DC voltage, there is no discharge through the indicating device. A circuit based on a modified ohmmeter (Fig. 73) is commonly used as a leakage tester, with the initial DC charging voltage provided by the ohmmeter battery. The various conditions of charge on a condenser are indicated on the highest range of the meter scale often using a very large series resistance and higher voltage to extend the highest range of the meter. Another method of testing condenser leakage employs a relaxation oscillator and a neon-tube indicator (Fig. 74), where the condenser under test, after initial charge, is permitted to discharge through a neon tube until the voltage falls below the value necessary to keep the lamp lit, when the condenser C_x is again charged to a sufficiently high

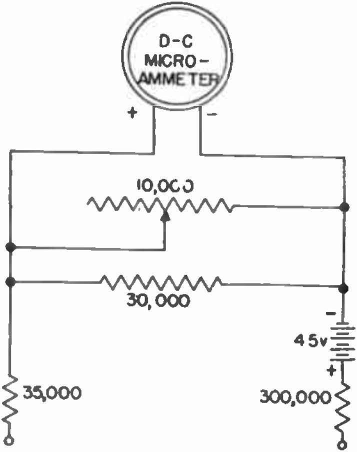


Fig. 73 Modified ohmmeter circuit for testing condenser leakage.

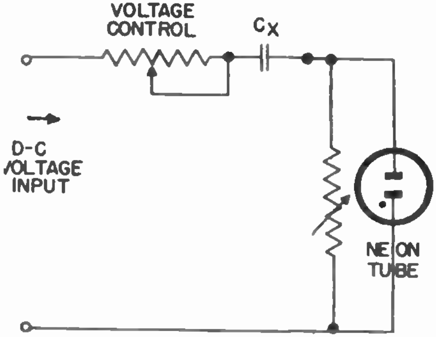


Fig. 74 Circuit of neon leakage tester for condensers.

value to cause the neon tube to glow. The actual speed of such circuit action depends entirely upon the ability of the condenser under test to charge and discharge, and thus the on-off frequency of neon flashes is indicative of any leakage present in the condenser; the higher the leakage, the more often will it cause flashing of the neon tube; in the case of a good condenser, the flashes may be several minutes apart. Any leakage tester provides only *approximate* indications of the condition of the condenser under test, primarily because the condenser is not being tested at its correct operating voltage.

70. **Capacity Meters.**—A fairly accurate indication of the effective value of a condenser *in microfarads* is provided by this instrument, which measures the approximate reactance of a condenser under test when it is inserted in a series AC circuit (Fig. 75). The meter consists essentially of an AC rectifier-type milliammeter in series with an AC potential and an adjustable current-limiting resistor or potentiometer. Prior to operation, the switch S is placed in position 1—so that the condenser C_x is not in the circuit—and the line voltage is adjusted so that the AC milliammeter reads full scale. When the switch S is then placed in position 2, the flow of alternating current in the series circuit is reduced by the reactance (approximate impedance) of the condenser being measured. Since this reactance is determined by the capacity value of the condenser. the reduction of current is inversely proportional (approximately) to the effective value of the condenser *in microfarads.* Accordingly, the AC milliammeter is calibrated in terms of microfarads for direct readings of capacitance. The capacity meter is also used to indicate leakage, since any leakage path through the condenser permits an excessive flow of current overbalancing any reasonable or normal value of capacity. The range of a capacity meter can be extended—to read smaller values of capacitance—by connecting appropriate resistors in shunt with the indicating meter. Although adequate for many testing purposes, the capacity meter is not sufficiently accurate for precision measurements of capacitance.

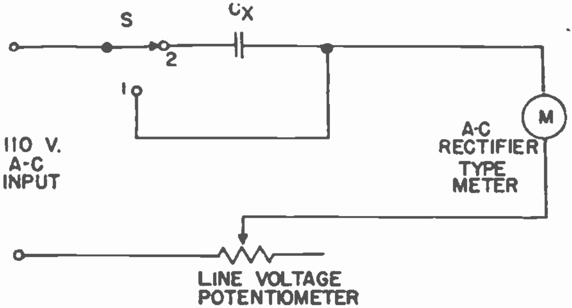


Fig. 75 Basic circuit of capacity meter.

71. **Precision Microfarad Meter.**—This electrodynamic-type meter provides a direct and highly accurate measurement of

capacitance when used with an AC voltage of stabilized frequency. The microfarad meter (Fig. 76) consists essentially of a large fixed coil, and two moveable coils which are mounted on a shaft or spindle at right angles to each other. In series with one of the moveable coils is a known value of capacitance C_o; and the application of a suitable AC voltage *of fixed frequency* causes a resultant current in this coil which produces a magnetic field tending to move the coil into the plane of the fixed coil—and thus indicate *zero* on the scale of the meter. When the condenser C_x is connected in series with the other moveable coil, the flow of current through this coil produces a magnetic field causing a mechanical turning effect in the opposite direction. This opposing

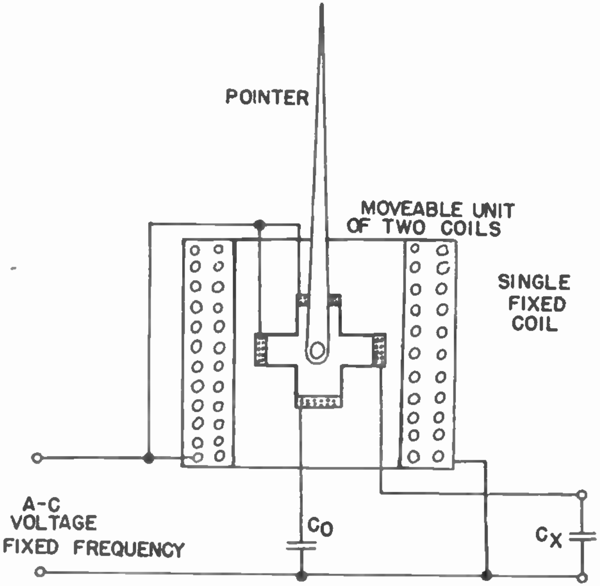


Fig. 76 Principle of precision microfarad meter.

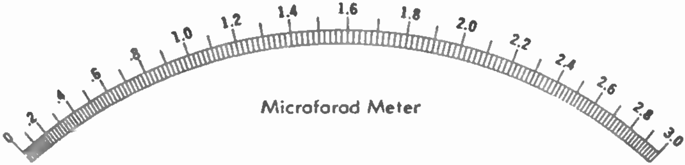


Fig. 77 Linear scale, typical of the precision microfarad meter.

effect is proportional to the amount of capacitance represented by C_x at the fixed frequency of operation, and the value of the unknown condenser is indicated directly in microfarads on a linear scale (Fig. 77). The applied AC voltage must be large enough to cause the moveable coils to turn in their pivots. Accurate readings require use of the microfarad meter at the exact frequency for which it was originally calibrated.

INDUCTANCE METERS

72. An instrument known as an *inductance tester* is used to check the condition (but not the inductance) of coils, filter chokes, and transformer windings. Actual measurement of inductance involves a more tedious process, closely related with the operating frequency of the coil or inductive component. The "Q" or figure of merit of a tuning coil is indicated by a resonating instrument known as a *Q meter.* Direct and more accurate measurement of inductance requires use of a bridge measuring device known as an *inductance bridge.*

73. Inductance Testers.—This device is essentially an ohmmeter, and is used both for checking continuity and for measuring the DC resistance of filter chokes, transformer windings, and other low-frequency inductances. Although it can be used for checking the continuity of high-frequency coils, it has no other practical use in testing coils associated with tuned circuits.

74. Q Meters.—The "Q" or figure of merit of a coil or other inductive element normally operating at a high frequency is expressed by the ratio $\frac{\text{reactance}}{\text{resistance}}$ but a Q meter provides direct measurement of this important characteristic under dynamic conditions of circuit resonance. Essentially, the operation of this instrument is based on a comparison of voltages at the resonant frequency for which the coil to be measured was originally designed. The basic circuit of the Q meter (Fig. 78) consists of a variable-frequency generator G with a controlled output voltage, a low-range vacuum-tube voltmeter V_A measuring the output voltage of the generator across a low value of resistance R, a precision tuning condenser C, and a high-range vacuum-tube volt-

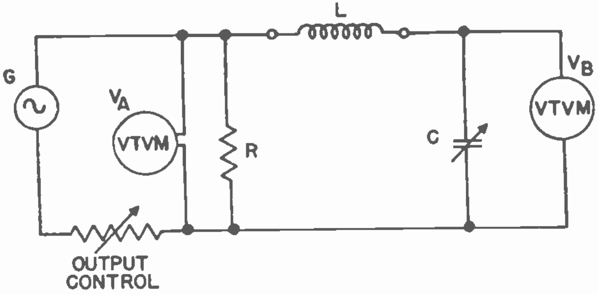


Fig. 78 Basic circuit of the Q meter.

meter V_B connected across the variable condenser. To measure the "Q" of an unknown inductance L, the generator G is first adjusted to the frequency for which the coil was designed, and the amount of RF output voltage across the resistor R is adjusted to any fixed value which can be indicated conveniently on the range scale of the voltmeter V_A. With the inductance L and the condenser C forming a parallel circuit, the variable condenser is adjusted for resonance and the resulting voltage across the parallel resonant circuit is measured by the output voltmeter V_B. The relative value of "Q" for the coil is then determined by dividing the latter reading with the initial V_A reading, as expressed by the equation:

$$\text{“Q”} = \frac{\text{Voltage of } V_B}{\text{Voltage of } V_A}$$

For example, if the initial voltage across resistance R is 0.03 volts and the voltage across the tuned parallel circuit is 3.0 volts, then the relative Q of the coil is $3 \div 0.03 = 100$. When a fixed value of voltage at V_A is used for all measurements of "Q", voltages indicated at V_B will always be proportional to the relative value of "Q" and, accordingly, the scale of the vacuum-tube voltmeter V_B is often calibrated for *direct* indications of "Q" on a special scale.

BRIDGE MEASURING DEVICES

75. Extremely accurate measurements of resistance, capacitance, or inductance are provided by means of special balanced networks which operate on the principle of the *Wheatstone bridge.* There are numerous varieties of bridge measuring devices, ranging from precise but cumbersome laboratory equipment to modern, portable forms designed for rapid field measurements.

76. **Resistance Bridge.**—The circuit of the fundamental Wheatstone bridge provides the most accurate means of measuring DC resistance. This device consists essentially of two *fixed* resistors R_A and R_B—known as the "ratio arms", a calibrated *variable* resistor R_s—known as the "resistance standard", and the unknown resistance R_x; all of which are connected in a bridge circuit (Fig. 79) with a source of DC voltage, appropriate switches, and a sensitive indicating meter—such as a galvanometer or DC moving-coil meter calibrated to indicate both positive *and* negative current. Measurement of the unknown resistance depends upon establishing a *balanced* condition of the bridge such that no difference of potential exists between points A and B, and thus no current flows through the meter. In order to obtain this condition, the ratio of any two adjacent resistors must be equal to the ratio of the other two resistors, as expressed by the proportion:

$$\frac{R_A}{R_s} = \frac{R_B}{R_x}$$

If all four resistors are equal in value, voltage drops across each resistor will be the same, points A and B in the circuit will be at the same potential, and no current will flow through the meter. If the unknown resistor R_x is larger or smaller than R_s, points A and B will not be at the same potential, and current flow will

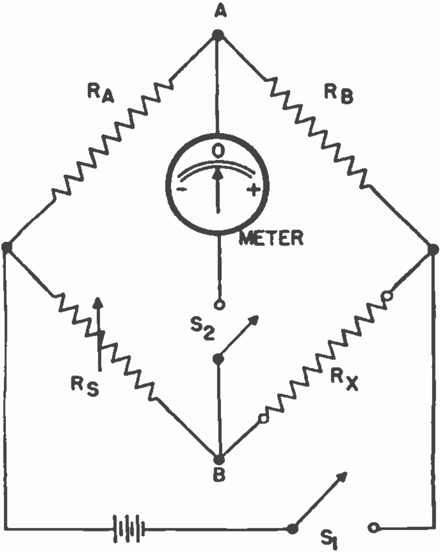


Fig. 79 Wheatstone bridge for measuring resistance.

be indicated by the galvanometer; and the resistor R_s must be varied until its value is equal to R_x in order to balance the bridge. The range of the bridge is extended by providing various fixed ratios between the resistors R_A and B_B; thus, if R_B is twice as large as R_A, the bridge is balanced only when resistor R_s is half the value of the unknown resistance R_x. However, the greatest sensitivity is obtained when these two resistors (R_s and R_x) are somewhat similar in value. In operation, switch S_1 is closed first, and values of resistance are selected for approximate balance with the unknown resistance R_x, after which switch S_2 is closed for final adjustment of R_s to obtain a precision balance in terms of the meter indications. This procedure prevents possible damage to the sensitive galvanometer due to heavy current flow when the bridge is *not* balanced. After proper balancing, the value of the unknown resistor R_x is determined directly from the calibrated variable resistance standard R_s— with due consideration of the ratio established between resistors R_A and B_B. This measurement is expressed by the equation:

$$R_x = \frac{R_B\ R_S}{R_A}$$

where all values are in *ohms*.

77. Capacitance Bridge.—Accurate measurements of capacitance are obtained by means of an AC type of Wheatstone bridge —known as a *capacitance bridge*—which provides a direct comparison of an unknown capacitance with a condenser of known value. The basic circuit of this bridge measuring device (Fig. 80) is similar to the resistance bridge previously described, both in appearance and operation; except that the power source of the capacitance bridge is an AC audio-frequency oscillator, and headphones or telephone receivers are used to determine a balanced condition of the bridge circuit. Measurement of an unknown capacitance C_x depends upon a balance of circuit impedance, so that no difference in potential exists between points A and B. Usually the two resistors R_A and R_B are equal in value, and the bridge circuit is balanced merely by varying the value of condenser C_s until either a null or minimum tone is heard in the headphones. After proper balancing, the value of the unknown capacitance C_x is determined directly from the calibrated condenser standard C_s. This is expressed by the equation:

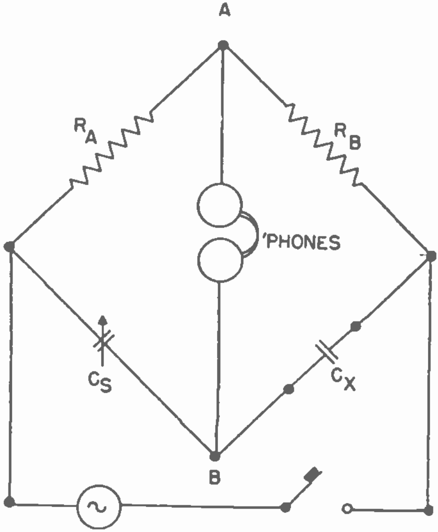


Fig. 80 Capacitance bridge.

$$C_x = \frac{R_A C_S}{R_B}$$

where R values are in *ohms*, C values are in *farads* or *microfarads*.

Apparent inversion of the above resistance ratio is due to the fact that the impedance of a condenser is *inversely* proportional to its capacitance.

78. Inductance Bridge.—Accurate measurements of inductance are obtained by means of an AC type of Wheatstone bridge —known as an *inductance bridge.* Like all bridge measuring devices, it provides a direct comparison of an unknown inductance with an appropriate coil of known value. The basic circuit of the inductance bridge (Fig. 81) is similar to the resistance bridge previously described, both in appearance and operation, except that an AC audio-frequency oscillator is the source of power, and headphones are used to determine a balanced condition of the circuit. Measurement of an unknown inductance L_x depends upon a balance of circuit impedance, so that no difference in potential exists between points A and B. The range of the bridge is extended by providing various fixed ratios between the resistors R_A and R_B. The bridge circuit is balanced by varying the value of the coil L_s until either a null or minimum tone is heard in the headphones. After proper balancing, the value of the unknown inductance L_x is determined directly from the calibrated inductance standard L_s—with due consideration of the ratio established between resistors R_A and R_B. However, the greatest sensitivity is obtained when these two resistors are equal in value. Bridge measurement of the unknown inductance is expressed by the equation:

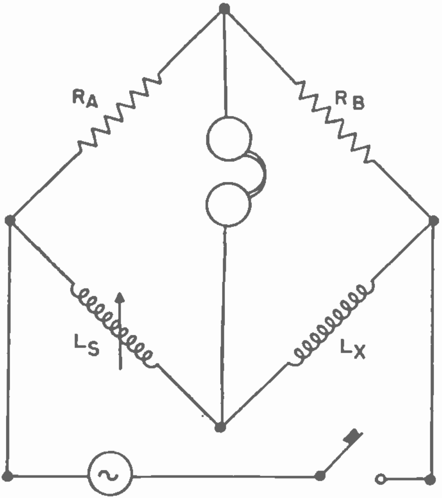


Fig. 81 Inductance bridge.

$$L_x = \frac{R_B L_s}{R_A}$$

where R values are in *ohms*,
L values are in *henries*
or *millihenries*

RF SIGNAL GENERATORS

79. Essentially a variable oscillator with a controlled output voltage, the RF signal generator is an important instrument capable of producing oscillation at any required radio frequency with any required magnitude from 1 to about 250,000 microvolts. Nucleus of the generator is a vacuum-tube oscillator, which functions according to any one of the several basic types of oscillator circuits. A wide range of radio frequencies is obtained by utilizing harmonics of the original RF oscillation. Most types of oscillators are continuously modulated with a fixed audio frequency—usually about 400 cycles—to provide audible assistance in making tests or measurements. Signal generators are equipped with suitable attenuator networks for varying the intensity of the RF oscillation according to the requirements of the circuit or device under test. These instruments require elaborate shielding in order to prevent undesirable radiations and to stabilize operation of the vacuum tube oscillator stage.

80. **Electron-Coupled Oscillators.**—Because of their favorable stability characteristics, oscillators of this type are often used in signal generators. A tetrode vacuum tube is used in this type of oscillator (Fig. 82). The cathode, grid, and screen grid are connected in what is effectively a Hartley series-fed circuit with the necessary feedback supplied by coupling through the electron stream of the tube. The frequency of oscillation is determined by the resonant frequency of the tuned circuit LC. The electron stream is also the coupling medium between the oscillator and the output load of the plate circuit. Since the screen grid is at RF ground potential, it serves as an effective shield between the output load and the oscillator. The output circuit L_0C_0 is tuned to the resonant frequency of the oscillator; or, for frequency multiplication, the output circuit is tuned to a frequency which is a multiple or harmonic of the oscillator frequency.

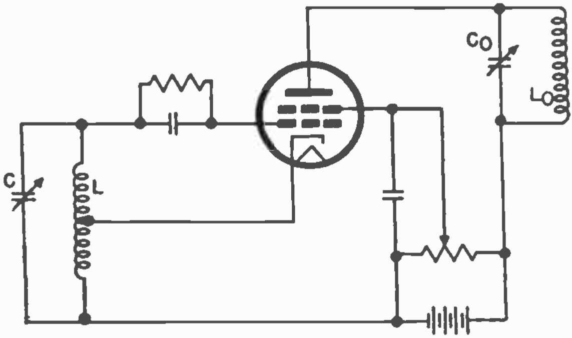


Fig. 82 Electron-coupled oscillator.

81. **Harmonics.**—The types of oscillators used in RF signal

generators are *not* required to produce an undistorted output since a good deal of signal distortion can be tolerated at such high frequencies without affecting test measurements. When the signal generator is required to operate over a wide range of radio frequencies, distortion is often purposely introduced in order to provide a signal composed of multiple or harmonic frequencies in addition to the natural or fundamental frequency. The *order* of a harmonic frequency is the number of times it is greater than the fundamental frequency, and the *strength* of harmonic signals diminishes as the *order* increases. The *third* harmonic and the *fifth* harmonic of a fundamental frequency are most often utilized by RF generators to extend the operating range of the instrument. This is accomplished by providing a tuned circuit which resonates at the desired harmonic frequency and not at the fundamental frequency. For example, if the fundamental frequency of an oscillator is 100 kc, a frequency of 300 kc can be obtained from the same circuit by means of a tuned circuit which resonates at the third harmonic frequency; similarly, a frequency of 500 kc can be obtained from the same circuit by utilizing the fifth harmonic of the fundamental frequency.

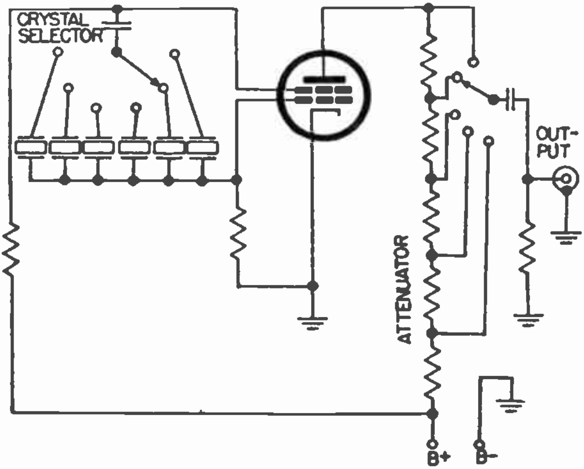


Fig. 83 Crystal controlled signal generator.

82. Crystal Control.—For some purposes, a crystal controlled signal generator is superior to one employing a self-excited oscillator. Accuracy of calibration and ease of adjustment are the chief advantages of the crystal controlled signal generator. The oscillators used in these instruments are usually of the untuned type. A group of output frequencies is ordinarily made available through the use of six or more crystals, any one of which can be selected by using a switch provided (Fig. 83). The output of these oscillators is rich in harmonics, further increasing the number of frequencies available.

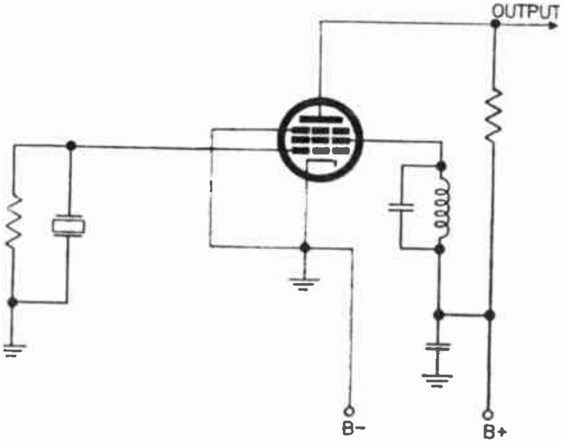


Fig. 84 Crystal calibrator circuit.

83. **Calibration Crystal.**—Many signal generators are equipped with an internal crystal oscillator. This oscillator is used to check and adjust the calibration of the instrument. Instruments so equipped combine the accuracy of crystal control and the flexibility of the self-excited oscillator. Fig. 84 is a simplified schematic diagram of a typical crystal calibrator circuit.

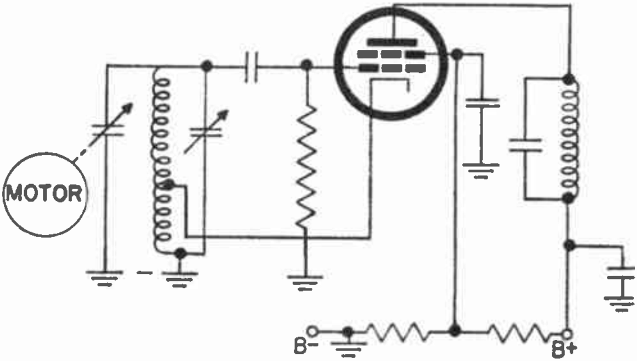


Fig. 85 Sweep generator using motor-driven rotating condenser.

84. **Modulation.**—Since the output of a radio-frequency signal generator is not audible, the oscillator is usually modulated

with an audio frequency signal of fixed value—generally 400 cycles—to permit aural tests and circuit measurements. Separate AF oscillator tubes can be used to provide the RF oscillator with the necessary modulating signal, or any of the RF oscillator tubes can be designed so that they effectively modulate themselves usually by using grid leaks composed of large values of resistance and capacitance.

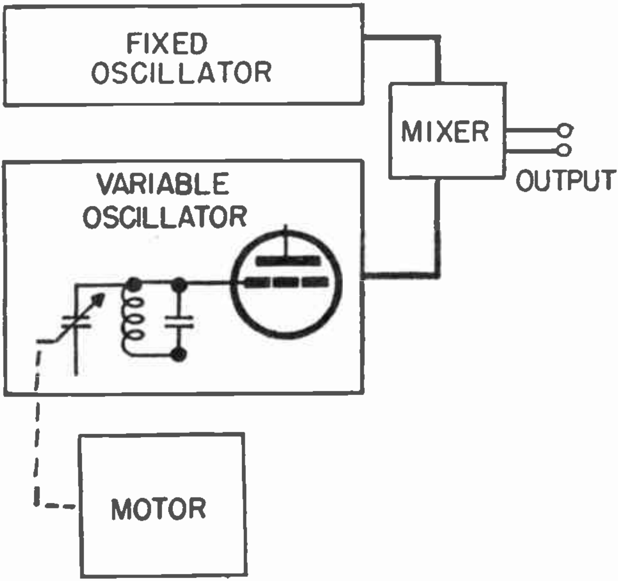


Fig. 86 Sweep generator using dual oscillator and a mixer.

85. Wobbulator.—The usefulness of a signal generator is greatly increased by the addition of frequency sweep or frequency modulation. If it is so equipped, it can be used with an oscilloscope for visual receiver alignment and to study the band width characteristics of many circuits. Various methods are used to secure a frequency swept signal. The simplest is through the use of a rotating motor-driven condenser. The condenser is connected across the tank circuit of the oscillator in the signal generator as shown in Fig. 85. The frequency at which the signal is swept or modulated is dependent upon the speed of the motor. In practice, it is usually in the neighborhood of 60 cycles per second.

This system has an important disadvantage. The deviation (in cycles per second) of the signal increases with the operating frequency of the oscillator and cannot be controlled except by changing the value of the rotating condenser.

86. Beat Oscillator.—In some signal generators, this fault is overcome by adding another oscillator. The rotating condenser is connected across the tank circuit of this oscillator. The output of the oscillator, and of the basic oscillator in the generator, is fed into a mixer stage as shown in Fig. 86. The output of the mixer stage contains the desired frequency swept signal.

The center frequency of the sweep generating oscillator remains constant. Tuning takes place in the basic oscillator. The deviation of the generator's output signal is always the same regardless of the frequency in use.

87. Reactance Tube.—Most frequency swept signal generators now being manufactured utilize a reactance tube circuit. The reactance tube method is more flexible, lighter, and more compact than the rotating condenser. A typical circuit is shown in Fig. 87. The reactance tube and its associated components are shunted across the tank circuit of the oscillator in the signal generator. The AC power line is often coupled to the grid of the reactance tube and controls the rate, or frequency, of the sweep. Since an oscilloscope is invariably used with frequency swept signal generators, the AC power line provides an excellent synchronizing medium.

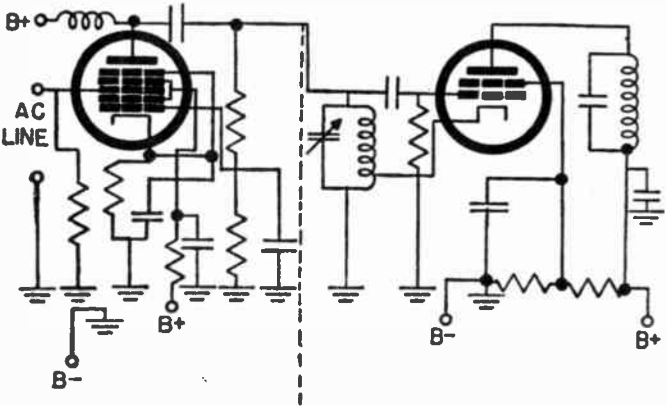


Fig. 87 Reactance tube sweep modulator.

AF SIGNAL GENERATORS

88. Tests and measurements of many types of audio-frequency equipment—such as amplifiers, modulators, and other voice-frequency apparatus—require a source of controlled audio-frequency oscillation with very little or no harmonic content. This is supplied by an AF signal generator which produces oscillation at any required audio frequency—from about 15 to 60,000 cycles—with an output that remains substantially constant. At such frequencies, few of the basic oscillator circuits are practical, mainly because of the large size and cost of inductive and capacitive components required for the tuned circuits. Therefore, special types of audio oscillator stages are used to provide signals of required magnitude and frequency. These signal generators are equipped with suitable attenuators for controlling the intensity of the AF output signal.

89. Resistance-tuned or RC Oscillator.—This type of audio-frequency oscillator (Fig. 88) is essentially a two-stage resistance-coupled amplifier with regenerative coupling between output and input provided by a resistance-capacitance network. This network—consisting of R_1C_1 and R_2C_2—determines the frequency of oscillation, and the circuit is ordinarily tuned by varying the values of condenser C_1 and C_2. The lamp LP is used as the cathode resistor for the first tube in order to stabilize the amplitude of oscillation, since it provides inverse feedback in combination with resistor R_3. Operation of the resistance-tuned or RC oscillator is independent of changes in supply voltages, tube characteristics, and values of circuit components.

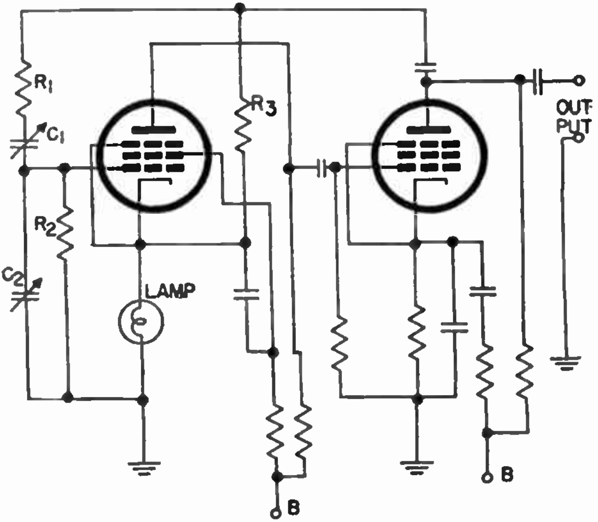


Fig. 88 Resistance-tuned or RC oscillator.

90. Wien-bridge Oscillator.—A frequency-selective Wien bridge is used as the resistance-capacitance feedback network in this type of AF oscillator (Fig. 89). Such use of the Wien bridge prevents the circuit from oscillating at other than the required audio frequency, because of the degeneration and phase shift which the bridge circuit provides. Oscillation takes place only at the frequency which permits the voltage across resistor R_2 to be in phase with the output voltage of the second vacuum tube, and for which frequency the positive feedback exceeds the negative feedback voltage. Voltages of any other frequency are attenuated by the high degeneration introduced by the bridge circuit so that the feedback voltage is inadequate to sustain oscillation. The series network R_1C_1 *plus* the parallel network R_2C_2 determine the frequency of audio oscillation, and the lamp LP is used to stabilize the amplitude of oscillation. Operation of the Wien-bridge oscillator is independent of changes in supply voltage, tube characteristics, and component values. An extremely wide range of audio frequencies can be produced by this oscillator, and frequency stability is excellent.

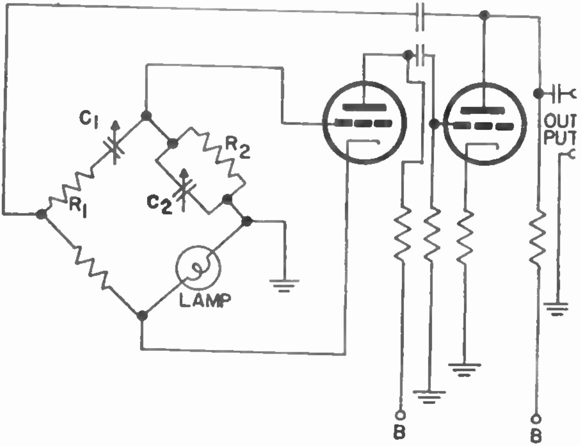


Fig. 89 Wien bridge oscillator.

91. Phase-Shift Oscillator.—This is a special type of resistance-capacitance-tuned oscillator which operates with only a single tube and a simple phase-shifting feedback network (Fig. 90). Three resistance-capacitance sections are used to provide the necessary phase shift, and the tube functions as a straight amplifier. Since the reactance of a condenser varies with frequency, the three sections provide a *total* phase shift of 180 degrees *at only one frequency.* Each section contributes a phase shift of about 60 degrees, so that the complete circuit provides the necessary conditions for sustained oscillation. The frequency of oscillation is determined by *all* RC component values—C_1R_1, C_2R_2, C_3R_3—any one or more of which may be variable for tuning purposes. In order to increase the frequency, either the resistance or capacitance must be *decreased.* To decrease the frequency, either the resistance or capacitance must be *increased.*

92. Bridge-type Phase-Shift Oscillator.—Another type of phase-shift oscillator (Fig. 91) employs a bridge arrangement of capacitance and resistance to accomplish a 180-degree phase shift.

The bridge components R_1, R_2, R_3, C_1, C_2, C_3 are so proportioned in value that at only one frequency is the output voltage—across resistor R_4—exactly 180 degrees out of phase with the voltage at the plate of the amplifier tube. The reactance of the bridge condensers changes sufficiently with a change of frequency that at only one frequency is a phase shift of 180 degrees produced.

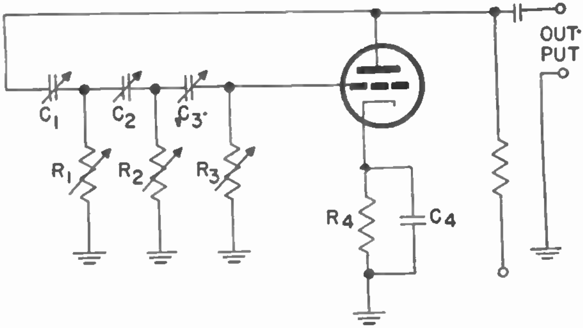


Fig. 90 Phase-shift oscillator.

93. Heterodyne Oscillator.—This is a distinct type of audio-frequency oscillator, which combines the output frequencies of two RF oscillators—one of fixed frequency, the other adjustable—and then, by crystal or detector-tube mixing and appropriate filtering, produces a *difference* signal at the required audio frequency. Known as etiher a beat-frequency oscillator or a heterodyne oscillator, the signal generator employs from three to five or six tubes and at least two RF filter networks (Fig. 92). Signals

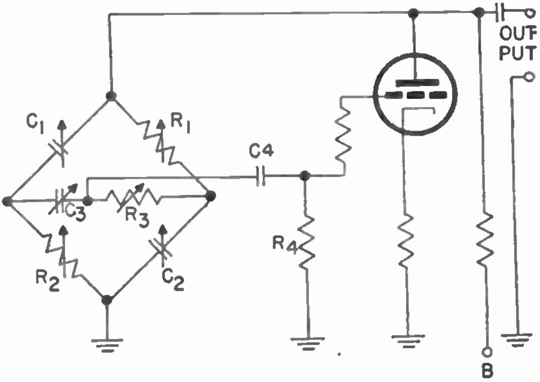


Fig. 91 Bridge-type phase-shift oscillator.

from the two RF oscillators—operating at a frequency between 100 and 500 kc—are applied at the same time to a crystal detector (or vacuum-tube detector), the output of which consits of the two original (RF) frequencies, a *sum* (RF) frequency, and a *difference* frequency in the audio range. Only this difference frequecy is desired, and this signal is amplified and then applied to a suitable attentuator or isolating network. Principal advantage of the heterodyne audio-frequency oscillator is its wide and continuous range—from a few cycles to several megacycles. However, the instrument must be calibrated and checked frequently with a suitable frequency standard.

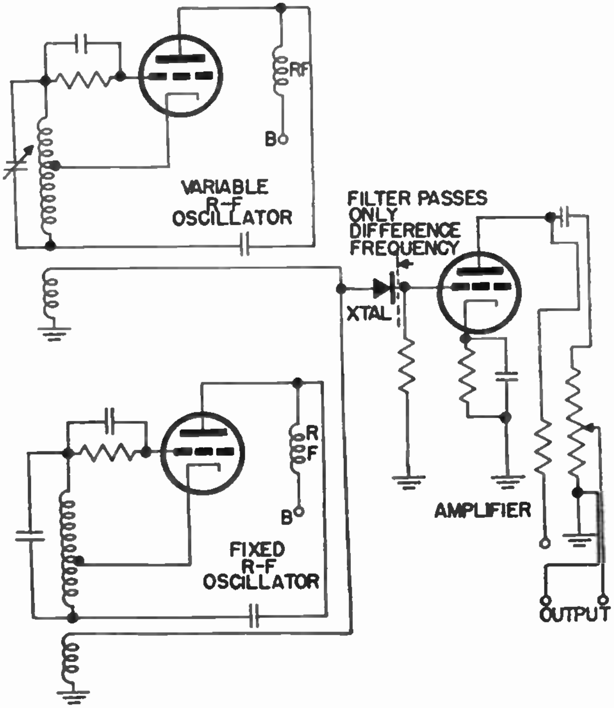


Fig. 92 Heterodyne oscillator.

SIGNAL TRACERS

94. An instrument for checking the stage-by-stage progress of a signal through a communications circuit is known as a *signal tracer*. Essentially a special type of vacuum-tube voltmeter uum tube voltmeter. For testing signals at all frequencies below 100 kc, the signal tracer uses an *untuned* amplifier circuit with a

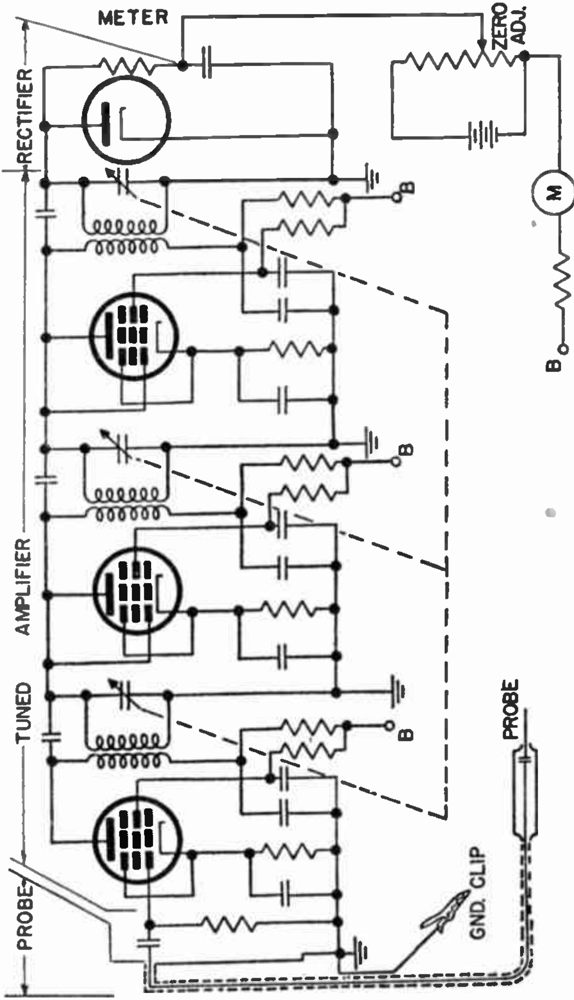


Fig. 93 Typical circuit of tuned signal tracer for checking RF voltages.

equipped with a probe, it is ideally suited for testing the minute signal voltages encountered in radio receivers and audio amplifiers. The instrument differs from conventional types of vacuum-tube voltmeters since it provides three or more stages of amplification *before* rectification of the AC signal voltage—thus affording a very high degree of sensitivity. For testing radio-frequency signals, the signal tracer uses a *tuned* amplifier circuit with a vac-

vacuum tube voltmeter. When both kinds of signal-tracing circuits are employed in a dual-purpose instrument, the device is known as a *multi-channel signal tracer.*

95. Tuned Signal Tracer.—For tracing radio-frequency signals, a shielded probe and a *tuned* amplifier circuit are used with a vacuum-tube voltmeter (Fig. 93). The complete instrument provides not only amplification but also high selectivity, so that it can distinguish between voltages of different frequencies,—such as the weak RF signal and the relatively strong oscillator signal of a superheterodyne receiver. A simple probe is used; and a well-shielded cable conducts the RF signal to the input of the amplifier circuit. The combined input capacitance is usually between 50 and 100 micromicrofarads. Because of the need for stability and precision tuning, each of the three or more stages of the tuned amplifier is adequately shielded and all supply voltages are well filtered. Operation of the vacuum-tube voltmeter is conventional. The amplified RF signal is applied to a diode, or a triode operated as a plate detector, and the rectified output is ordinarily of sufficient magnitude for direct application to a suitable DC millammeter or microammeter. However, an elaborately calibrated output indicator is not necessary, because a signal tracer is used only to obtain *relative* values of RF signals.

96. Untuned Signal Tracer.—For tracing audio-frequency signals, a shielded probe and an untuned amplifier circuit are used with a vacuum-tube voltmeter (Fig. 94). The complete instrument provides high amplification over a wide range of frequencies with a minimum of distortion effects. A simple probe is used; and a shielded cable conducts the low-frequency signal to the input of the first amplifier stage. Input capacitance is unimportant at audio frequencies; and because of the high input resistance of the vacuum tube, there is a minimum loading of the circuit under test. The three or more amplifier stages are resistance coupled to eliminate frequency discrimination and the entire circuit is designed for stable operation. The function of the vacuum-tube voltmeter is conventional. The amplified AF signal is applied to a diode, and the rectified output current is ordinarily of sufficient magnitude for application to a DC milliammeter. Since a signal tracer is used only to obtain *relative* values of audio-frequency signals, an elaborately calibrated output meter is unnecessary.

97. Multi-Channel Instruments.—Inclusion of the complete circuits of both a *tuned* signal tracer and an *untuned* signal tracer in a dual-purpose instrument—known as a *multi-channel signal tracer*—permits simultaneous tracing of both radio-frequency and audio-frequency signals with a single piece of test equipment.

DISTORTION ANALYZERS

98. There are two principal types of test instruments for detecting and indicating the presence of distortion in audio-frequency circuits. Those giving quantitative measurement of dis-

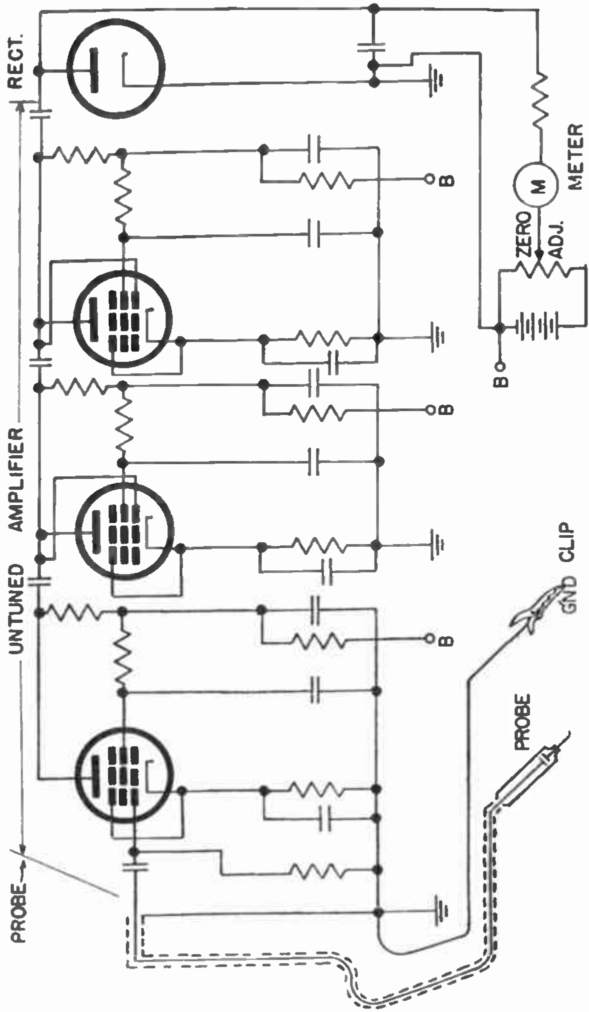


Fig. 94 Typical circuit of untuned signal tracer for checking AF voltages.

tortion, with the fundamental frequency suppressed, are generally known as *distortion meters.* More elaborate instruments for measuring the exact magnitude of any harmonic content — in order to compute the *total* amount of distortion—are known as *wave analyzers.*

99. Distortion Meters.—Using the fundamental-suppression

method of detecting distortion, these meters consist essentially of a *rejection* filter which is tuned to the fundamental frequency, and a suitable voltmeter for indicating all distortion voltages which pass through the filter (Fig. 95). Either of two filter systems may be used to suppress the fundamental frequency and pass any distortion voltages. In one instance, a Wien bridge (Fig. 96) provides complete fundamental frequency suppression without producing attenuation of other frequencies, and the selective filter can be made variable over a wide range of frequencies —from about 50 to 15,000 cycles. Another filter system—somewhat more conventional—is a parallel-tuned circuit (Fig. 97) consisting of a coil L in parallel with two condensers C_1 and C_2. Such a parallel network rejects the fundamental frequency to which it is tuned, but passes all other frequencies which appear as a voltage at the indicating device. Although any type of AC voltmeter can be used to indicate distortion voltages, the most

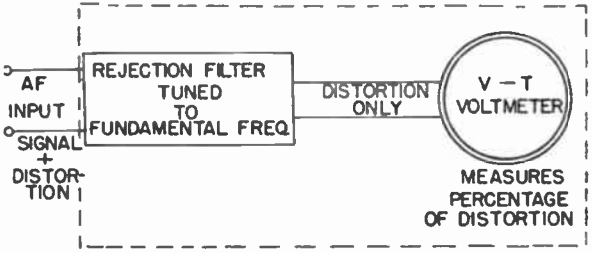


Fig. 95 Principle of distortion meter using fundamental frequency suppression.

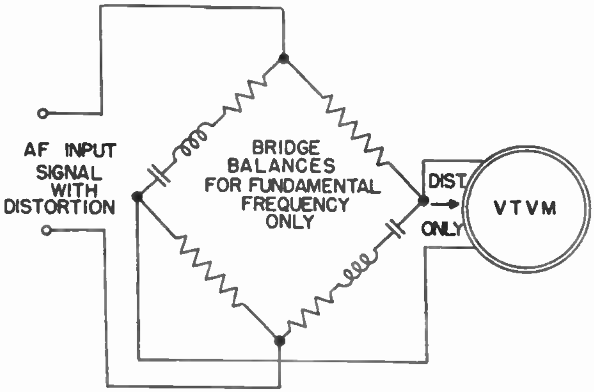


Fig. 96 Bridge-type filter to suppress fundamental frequency.

accurate distortion meters use a vacuum-tube voltmeter for this purpose.

100. Wave Analyzers.—This instrument provides definite information concerning the exact nature of any harmonic distortion by classifying any harmonics present in an audio-frequency circuit and then measuring the magnitude of any such harmonics. The AF signal is applied to a sharp pass filter (Fig. 98), which is adjustable to pass any desired frequency and reject all other frequencies. The vacuum-tube voltmeter indicates the actual magnitude of any single harmonic to which the sharp pass filter is tuned. In this way, voltage readings may be obtained for any single harmonic present in the circuit or equipment under test. Total distortion can be computed from this information, since the *total* distortion is equal to the square root of the *sum* of the squares *of all harmonic voltages present.*

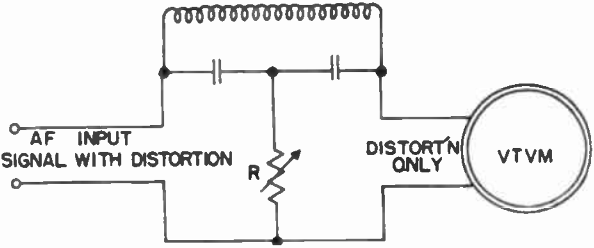


Fig. 97 Parallel-tuned filter to suppress fundamental frequency.

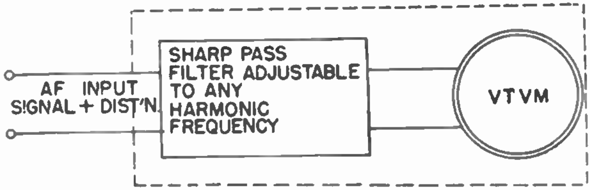


Fig. 98 Principle of wave analyzer.

TEST SPEAKERS

101. This instrument is used primarily to check the condition of an existing speaker in a radio receiver or low-power sound amplifier circuit. Since the procedure requires direct substitution for the existing speaker, the test speaker is provided with a wide range of equivalent values for the speaker field and for the voice coil. By careful selection of these values, the test speaker very effectively simulates the characteristics of the original speaker and, when properly connected in the circuit, the test

speaker gives an obvious aural indication of the condition of the original or existing speaker.

102. **Universal Dynamic Type.**—This portable speaker—sometimes known as a multi-test speaker—is a dynamic speaker with a wide range of suitable resistance and inductance, so that the speaker can be substituted in any circuit under test. To provide the least amount of distortion, the speaker is equipped with a universal output transformer, so that the speaker can be matched properly to the output tubes of the circuit under test. The instrument includes a universal field coil with a suitable switching arrangement, which provides resistance values equivalent to all such resistance values used in standard practice. Also part of the test speaker is a universal voice-coil transformer, which supplies any standard value of impedance for the voice coil of a dynamic speaker. Thus, provision is made for matching the test speaker to all tvpes of output tubes and output transformers.

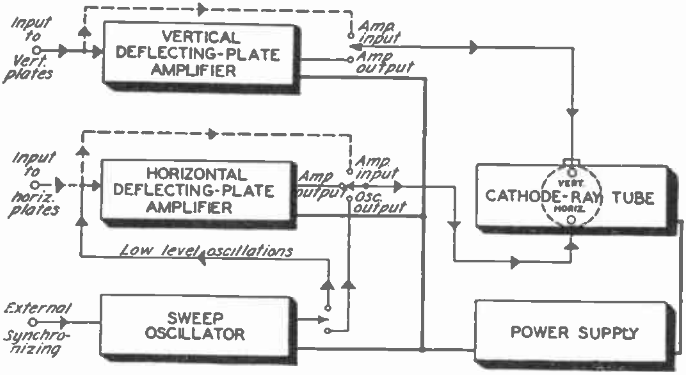


Fig. 99 Principal components of a typical cathode-ray oscilloscope.

OSCILLOSCOPES

103. The cathode-ray oscilloscope is an important and versatile test instrument, which provides a visual representation of one electrical quantity as a function of another on the screen of a cathode-ray tube. The great usefulness of the oscilloscope lies in its ability to portray graphically the fluctuating conditions of voltage and current in a circuit with negligible delay, with no frequency discrimination, and with very little disturbing effect on the circuit to which it is connected. Operation of the instrument is based on the formation and control of a beam of electrons. Since electrons have very little mass, the oscilloscope responds at much higher frequencies than any other electrical indicating or measuring device. Principal components of the oscilloscope (Fig. 99) include a cathode ray tube, a sweep oscil-

lator, signal amplifiers for each of the two pair of deflecting plates, and an adequate power supply for operating all of these components. A suitable switching arrangement permits use of the signal amplifiers only in cases where the incoming signal is sufficiently high so as not to require amplification. The sweep voltage—or time base—from the sweep oscillator is normally applied to the horizontal deflecting plates, and the signal under observation to the vertical deflecting plates of the cathode ray tube.

104. Cathode-Ray Tube.—Heart of a test oscilloscope is the important cathode-ray tube. This is a special type of vacuum tube (Fig. 100) in which electrons emitted by a heated cathode are focused and formed into a narrow beam of very high velocity, and are then controlled in direction and allowed to strike a fluorescent screen—thus causing a brief glow of light, depending upon the relative position of the electron beam. The electronic process of forming, focusing, accelerating, controlling, and deflecting the electron beam is accomplished by these principal *elements* of the cathode-ray tube: *the electron gun*, consisting of a heated cathode, grid, and from one to three focusing and accelerating anodes; *the deflecting plates*, for controlling the direction of the beam emanating from the electron gun; *a fluorescent screen*, for observing light images and patterns produced by the high-speed motion of the electron beam; and, *an evacuated glass bulb*, for containing all of the above elements of the cathode-ray tube. The characteristic shape of the tube resembles that of a closed funnel with a long neck for the electron gun, and flared out to a flattened end or "face" which is coated *on the inside* with phosphor for the viewing screen.

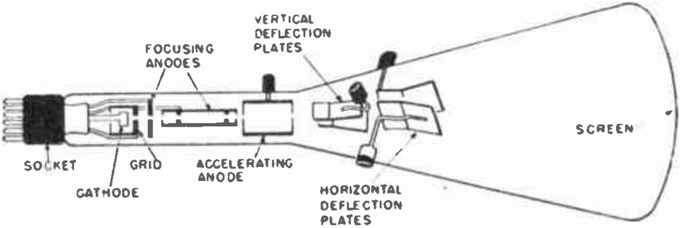
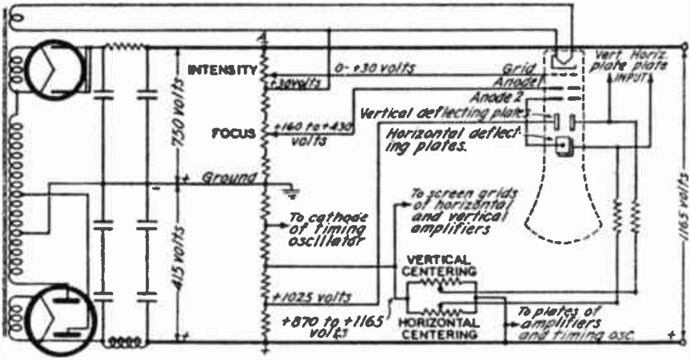


Fig. 100 Cathode-ray tube.

105. The Electron Gun.—This element of a cathode-ray tube provides a concentrated beam of electrons moving nearly parallel to each other and having a very high velocity. The cathode is a metal cylinder and, when properly heated, emits a shower of negative electrons which are attracted toward the focusing and accelerating anodes because these anodes are at a positive potential with respect to the cathode. In order to reach these anodes, however, the electrons are forced to pass through the negative grid electrode—a cylindrical piece of metal, nearly closed at one end by a baffle with a tiny circular opening—which concentrates the electrons and forms them into a beam. Electrons leaving the grid opening are strongly attracted by the positive charge on the focusing and accelerating anodes and, since these anodes are small cylinders, the electron beam passes through them and eventually reaches the fluorescent screen. The electron beam is focused in the same manner as a light beam is focused by a lens. Thus, by varying the epotential on the focusing anode or anodes, the spot of light on the screen can be brought to a fine optical focus. The accelerating anode causes electrons in the narrow beam to move at an even greater speed toward the fluorescent screen.

106. Deflecting Plates—After the high-speed electron beam has been produced by the electron gun and before the beam reaches the viewing screen, the *direction* of the beam is influenced by either or both pairs of deflecting plates—one pair in the horizontal plane or x-axis, and one pair in the vertical plane or y-axis. The two pairs of plates are mounted at right angles to each other, and in such a position that the electron beam passes between each pair of deflecting plates. Since all electrons are negatively charged and have substantially no weight or inertia, any positive charge on any one, or both, of either pair of deflecting plates exerts a force of attraction on the beam. This causes a change in direction of the beam, the extent of which is dependent upon the magnitude of the positive charge. In this way, the spot of light moves across the fluorescent screen in proportion to the force exerted by the horizontal and vertical deflecting plates. The application of any recurrent wave shape to the deflecting plates causes a motion of the beam which is sufficiently rapid as to appear on the screen as a continuous line, circle, or other closed pattern, because of the persistence of human vision. A return path is provided for electrons to "leak off" the screen, and eventually reach the cathode via the inside of the



NOTE: All voltages positive with respect to ground.

Fig. 101 Simplified diagram of power and control-voltage requirements of typical cathode-ray tube.

glass tube. A type of conducting graphite is painted on the inside of the glass envelope to assist in this purpose. Although somewhat lengthy to describe, the entire process of electron movement from cathode to screen is accomplished in a few millionths of a second—because of the high speed of the accelerated electrons—and any change of potential on either the horizontal or vertical deflecting plates, or both at once, causes an almost instantaneous influence or change in the appearance of the spot, pattern, or image on the screen.

107. Control of Electron Beam.—The various electrodes of a cathode-ray tube require operating potentials ranging from a few volts to a few thousand volts (Fig. 101). Power supplies for a cathode-ray tube invariably have the *positive* side of the output grounded, so that most of the high voltage is developed below ground. The last anode of the electron gun is usually at or near ground potential, and the cathode of the tube is operated at a relatively high potential with respect to ground. The voltage on the grid of the tube is adjustable by means of a BRILLIANCE or INTENSITY control. Focus of the electron beam is obtained by varying the voltage on the first or focusing anode of the electron gun; this is commonly known as the FOCUS control. A suitable balancing network for each of the two sets of deflecting plates provide a means of adjusting the spot on the screen to any desired static position; controls for this purpose are known as VERTICAL CENTERING or a HORIZONTAL CENTERING for their respective action in the power and control circuit of a cathode-ray tube. Since the limiting factor in the life of a cathode-ray tube is usually the life of the fluorescent screen, care in adjusting the INTENSITY control will prolong the useful life of the tube.

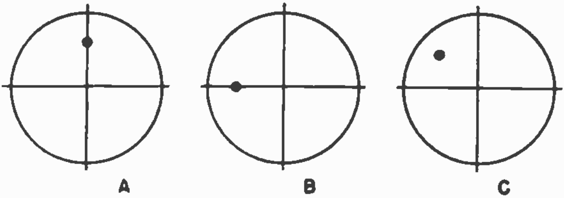


Fig. 102 Position of electron beam, with various fixed or DC potentials on deflection plates. A, Positive potential on upper vertical plate only; B, positive potential on left horizontal plate only; C, same positive potential on both horizontal and vertical deflection plates.

108. Motion of Electron Beam.—When a fixed or DC potential is established between the vertical deflecting plates *with no charge across the horizontal plates,* the electron beam moves up or down only in a vertical plane with respect to the center of the viewing screen. If the upper plate is more positive than the lower plate (of the vertical pair) the electron beam moves up to some fixed position proportional to the amount of DC voltage across the two vertical deflecting plates (Fig. 102a). When a similar fixed or DC potential is established between the horizontal deflecting plates ***with no charge across the vertical plates,*** the electron beam moves to some fixed position in the horizontal plane with respect to the center of the screen and according to the amount of DC voltage across the two horizontal deflecting plates (Fig. 102b). When *both* of the above horizontal and vertical potentials are applied across their respective deflecting plates *at the same time,* the electron beam is acted upon by two forces at right angles to each other and it moves to a fixed position (Fig. 102c) determined by the vector sum of the magnitudes of the two DC potentials. More practical examples of electron-beam movement can now be considered (Fig. 103). When a sine wave is applied only to the vertical deflecting plates of a cathode-ray tube, the electron beam is swept back and forth across the tube screen—causing a bright vertical line to appear on the screen (Fig. 103a). When a sine wave is applied only to the horizontal plates, a bright horizontal line is observed on the fluerescent screen (Fig. 103b). When two sinusoidal waves of the same frequency and the same phase are applied to *both* pairs of deflecting plates *at the same time,* the movement of the electron beam will be proportional to the vector sum of two forces acting at right angles to each other (Fig. 103c). Any of various voltages applied to one or both sets of deflecting plates causes a proportional deflection of the electron beam and thus a corresponding movement of the spot on the viewing screen. In general practice, the voltage wave of *unknown* shape or amplitude is usually applied to the horizontal deflecting plates, and a locally generated wave of known shape—called the sweep voltage—is applied to the vertical plates of the tube. When the sweep voltage is of proper shape and frequency with respect to the unknown voltage wave, it provides a uniform time rate of deflection is one direction—from left to right—which is known as a *time base.* This time scale is usually linear, and the frequency of its sweep (horizontally) across the face of the tube has a definite integral relation with the frequency of the wave shape which is being applied to the vertical deflecting plates.

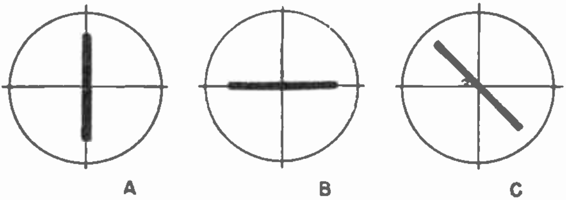


Fig. 103 Position of electron beam, with AC potential applied across pairs of deflecting plates. A, AC potential on vertical plates; B, AC potential on horizontal plates; C, Same AC potential on both pairs of deflection plates.

109. Sweep Oscillators.—The most conventional form of sweep voltage is the saw-tooth wave form (Fig. 104) which, when applied to the horizontal deflecting plates of the cathode-ray tube produces a horizontal movement of the electron beam that is ideally suited for true reproduction of the wave form of an *unknown* signal applied to the vertical deflecting plates. During the time the trace crosses the screen from left to right, the saw-tooth wave is substantially linear. In order to repeat this linear trace continuously—at the frequency, or harmonic or subharmonic frequency, of the unknown wave form—the electron beam must return quickly to the sart of the trace, and repeat the process. The time of this return or *fly-back* is not instantaneous, but any small amount of lost time is not important since it represents only a fraction of the total time of the full linear trace. A sweep voltage of this shape (Fig. 104), at any desired frequency and with any desired amplitude, is generated by a separate component of the test oscilloscope, known as the sweep oscillator (Fig. 99). Most saw-tooth oscillators are based on the fundamental principle of charging a condenser through a resistance from a constant source of potential to obtain an exponential charging curve that is suitably linear for an oscilloscope time base. After charging to a predetermined level, the condenser is quickly discharged, and the entire process is re-

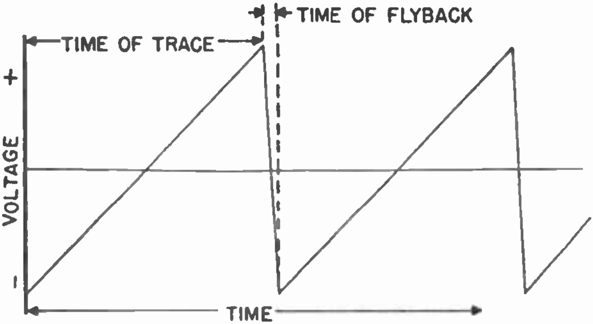


Fig. 104 Saw-tooth wave.

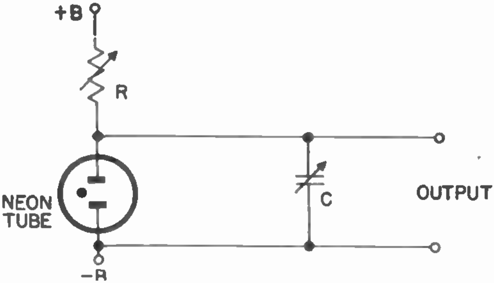


Fig. 105 Gas-filled diode used as sweep oscillator.

peated at a frequency determined by the time constant of the RC circuit.

The simplest type of sweep oscillator (Fig. 105) employs such a resistance-capacitance combination, with a constant source of voltage to charge the condenser and with a gas-filled *diode* to discharge the condenser. The gas-filled diode has the property of passing almost zero current until a certain value of voltage is reached, which is sufficiently large to cause ionization of the gas within the tube. This is known as the *striking voltage.* Ionization results in heavy current flow, and the condenser continues to discharge until a specific value of low voltage is reached —known as the *recovery voltage*—when the gas-filled tube deionizes, and the condenser begins to charge again. The entire process is repeated, over and over, at a frequency determined by the RC components of the circuit. This charge-and-discharge action (Fig. 106) is somewhat equivalent to a controlled oscillation that takes place between the two limits of ionization, thereby producing a saw-tooth wave form with a "slope" determined by the exponential charging curve of the condenser in the circuit. The fly-back portion of the sweep takes place when the condenser is suddenly discharged due to ionization of gas within the tube. The recurrent frequency of this saw-tooth voltage is controlled by the adjustable resistor (Fig. 105). The same principle of operation is applicable when a gas-filled *triode*—also known as a *thyratron*—is used in place of the diode to control the saw-tooth oscillations. Use of a thyratron, however, stabilizes operation of the sweep oscillator, since the addition of a grid electrode

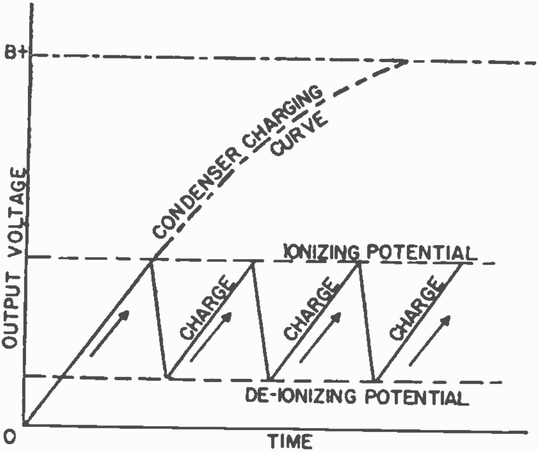


Fig. 106 Saw-tooth oscillation produced by charging and discharging a condenser.

permits more rigid control of the action of the gas-filled tube. Another advantage of the thyratron is that the grid electrode can be used for purposes of synchronizing the sweep voltage with the signal voltage under observation, so that the resulting pattern or image on the screen remains fixed and does not move or wander about.

110. **Deflecting-Plate Amplifiers.**—An amplifier is associated with the horizontal deflecting plates of an oscilloscope for the purpose of supplying the plates with voltage signals of sufficient amplitude. A direct connection, or suitable switching arrangement, between the sweep oscillator and this amplifier circuit (Fig. 99) provides control of the voltage used as the time base. When other than a linear time base is desired (for certain measurements), the external oscillator is connected to the horizontal deflecting amplifier. Most of the signal voltages to be examined or measured are not of sufficeint amplitude for application to the vertical deflecting plates. To build these signal voltages up to the required amplitude, one or more stages of amplification are incorporated in the oscilloscope (Fig. 99). Used for this purpose are either Class A resistance-coupled amplifiers, or, in some cases, video or so-called wide-band amplifiers. The gain of these amplifiers is controlled by means of precision adjustments.

111. **Oscilloscope Calibrators.**—One of the variety of functions performed by a cathode-ray oscilloscope is the measurement of peak-to-peak voltages, according to their actual appearance on the screen of the tube. Measurements by visual estimation, however, are likely to be erroneous or at least approximate. The amplitude of such wave forms can be measured far more accurately by direct comparison with semi-standard wave forms of known amplitude, when both known and unknown wave forms appear side-by-side on the screen of the tube. These semi-standard wave forms are provided by a special type of square-wave generator, known as an *oscilloscope calibrator* or a voltage calibrator.

Operation of this generator is conventional and the output is essentially a square wave whose amplitude is continuously variable from *zero* to *100* volts, as indicated by a calibrated dial on the test instrument. Both the unknown signal and the calibrating square wave are applied to the vertical deflecting plates of the cathode-ray tube, and the amplitude of the calibrating signal is adjusted so that it matches the desired peak or peaks of the unknown signal. When the known and unknown signals have been properly aligned, their amplitudes are the same, and the value of this voltage amplitude is read directly from the dial setting of the calibrated square-wave generator.

SQUARE-WAVE GENERATORS

112. Square waves are used to determine the reproductive faithfulness of an audio-frequency amplifier by means of a *simultaneous* examination of both the amplitude response and the phase shift inherent in the circuit under test. When these square waves, which are extremely rich in odd-order harmonics, are passed through an AF amplifier in the manner of a conventional

test signal, any apparent distortion in the *output* square-wave signal—as viewed on a cathode-ray oscilloscope—is an accurate indication of the reproductive nature of the amplifier. Essentially a test signal, these square waves originate in a test instrument called the *square-wave generator,* which consists of an electronic wave-shaping circuit and suitable isolation amplifiers. With the single exception of the multivibrator circuit which produces a wave that is *almost* square in shape, square waves are generated or produced by special types of circuits known as *limiters* or *clippers.* These wave-shaping circuits constitute the heart of the square-wave generator.

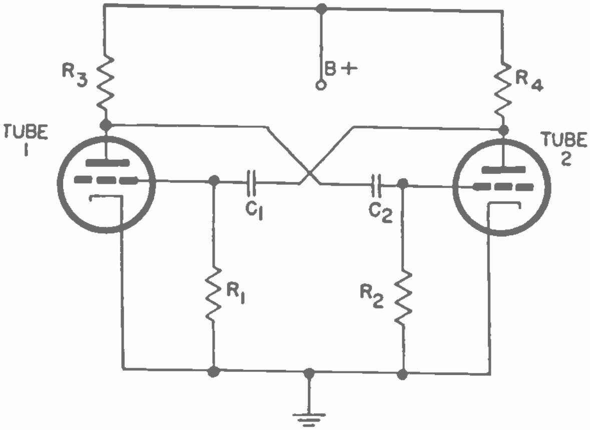


Fig. 107 Multi-vibrator circuit.

113. Multivibrators.—The multivibrator is essentially a two-stage resistance-coupled balanced amplifier in which the output of the second tube is coupled to the input of the first tube (Fig. 107). Since each tube of the circuit introduces a phase shift of 180 degrees—or a total of 360 degrees—the second tube supplies an input voltage to the first tube which has the proper phase to sustain oscillation in the circuit. When proper operating voltages are applied to this circuit, currents flow in the plate circuits of the tubes and, as the plate voltages of the tubes increase, charges are built up on condensers C_1 and C_2. Although it is called a "balanced" circuit, a perfect balance is impossible to achieve because of various random or transient electric effects. Initially assuming that tube 1 draws slightly more current than tube 2, this minor difference is sufficient to bring about a cumulative increase in the circuit unbalance. Thus, when tube 1 becomes more positive, there is also an increase in the voltage drop across resistor R_3 and a decrease in the plate voltage of tube 1. This causes a decrease in the grid voltage of tube 2, due to the presence of condenser C_2 which tends to maintain its charge at a more-or-less constant value. The decrease in the grid voltage of tube 2 reduces the plate current of tube 2. Therefore, any initial increase in the plate current of tube 1 is accompanied by a decrease in the plate current of tube 2. This regenerative switching action continues until the plate current of tube 2 is reduced to zero and the plate current of tube 1 is increased to its maximum value. However, in order to entirely cut off the flow of plate current in tube 2, the grid of that tube must be driven negative well beyond the point of cut-off. Since the negative bias on the grid is determined by the charge on condenser C_2 and since this charge leaks off through resistor R_2, the grid of tube 2 does not remain at a negative voltage but gradually returns to zero as the condenser C_2 discharges. As soon as the cut-off point is reached, plate current begins to flow in tube 2, and a *second* regenerative switching action takes place. This switching action is similar to the first with the exception that the plate current in tube 2 is increasing while that of tube 1 is decreasing, and finally ends with tube 2 carrying maximum current and no current flowing in tube 1 due to cut-off. The condition is momentary, however, since the switching action repeats continuously, first with one tube and then with the other, at an extremely fast rate of operation. This circuit action of the multivibrator is illustrated graphically by the wave forms in Fig. 108. The plate circuit of either tube provides a square-wave form,

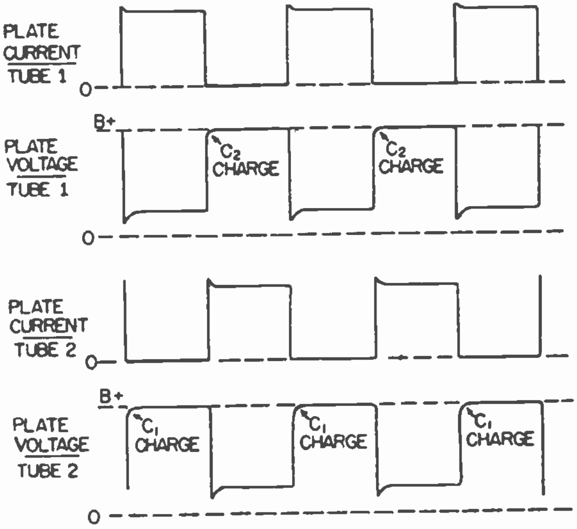


Fig. 108 Square-wave forms produced by multi-vibrator circuit.

which may be coupled out of the circuit by suitable capacitive means.

114. Overdriven Amplifiers.—A square-wave output voltage is produced by a single-stage triode amplifier when it is operated under unusual conditions which include an excessively large sine-wave voltage applied to the grid of the tube. This results in severe distortion, as the grid is driven *alternately* far beyond the cut-off point and then far into the saturation region. Two forms of limiting or clipping take place, however, during this action of the grid (Fig. 109). As the grid goes positive, the plate current rises quickly to its greatest possible value—until the saturation region is reached. As the grid attempts to go more positive, grid current is drawn by the tube and the high impedance driving source is incapable of effecting further increase in the grid voltage. Thus, as the wave continues, the plate current remains constant at its maximum value—until the grid voltage has proceeded in its cycle and returns to the region of normal conduction. Once this point is reached, the plate current falls rapidly and is reduced to almost *zero* as the cycle reverses and the grid moves in a negative direction beyond the cut-off point. As the grid goes more negative, the output signal remains constant near the zero value of plate current until the grid voltage has completed another half cycle. As this entire process is repeated continuously, the large-amplitude sine-wave grid voltage is effectively converted into a square wave. Limiting or clipping in the region of saturation, due to the flow of grid current, is known as *saturation limiting.* Limiting or clipping at the cut-off point of the tube characteristic curve is known as *cut-off limiting.*

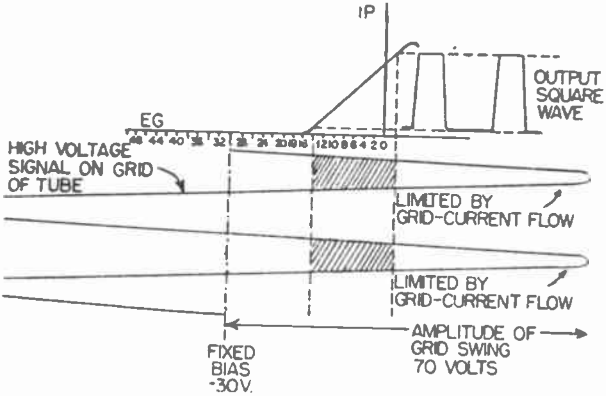


Fig. 109 Principle of overdriven amplifier.

115. Double-Diode Limiters.—Most types of limiters consist of a single diode or triode vacuum tube, and their clipping or limiting function is restricted to the removal of only *one* extremity of a wave form. In this general category are the series diode, the parallel diode, the triode with grid limiting, the triode with cut-off limiting, and other types. Not all of these are practical for the generation of square waves, however, because in such instances *two* limiters are usually required in order to provide clipping or limiting of *both* positive and negative extremities of the waves.

One of the few double-limiting arrangements which has proven successful is the comparatively simple circuit (Fig. 110) of the *double-diode limiter.* The tubes are connected in parallel with the load, which is assumed to be a very high impedance so that the output current is negligible. By means of the fixed voltage E_1 in the cathode of tube 1, this diode is made to conduct *only* when the input voltage exceeds the positive value of E_1, thus limiting the positive half cycles of the applied voltage to the value of E_1. By means of the fixed voltage E_2, the second diode is made to conduct only when the input voltage exceeds the negative value of E_2, thus limiting the negative half cycle of the wave. When either diode conducts, current flows through the tube and through the series resistor R across which practically the entire input voltage is developed. The output voltage of the double-diode limiter is about equivalent to the very low voltage drop across the two tubes. This circuit represents probably the simplest method of producing a square wave from a sine-wave voltage.

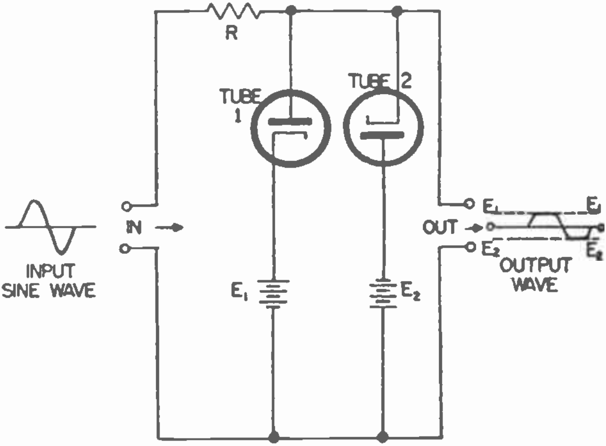


Fig. 110 Double-diode limiter, with typical waveforms.

116. Triode Combination Limiter.—A combination of two different types of triode limiters *with only a single vacuum tube* is used to convert a sine-wave voltage into a high-amplitude square-wave voltage. The circuit of this combination limiter

(Fig. 111) provides two clipping or limiting functions, which are substantially independent of one another. When a large value of resistance—about 1 megohm—is inserted in series with the grid of the triode, a high voltage drop is developed across the resistor R by the flow of grid current during positive half cycles of the input voltage. This voltage drop opposes the negative input voltage, and thus limits the input grid voltage during positive half cycles. This procedure is known as *grid limiting*. Despite partial compression, the amplitude of the input signal is sufficiently high to hold the grid of the triode amplifier *beyond* cut-off for the greater part of the *negative* swing. This procedure—known as *cut-off limiting*—removes the negative extremity of the wave, and the final output voltage, across the load resistor R_L, is a square wave.

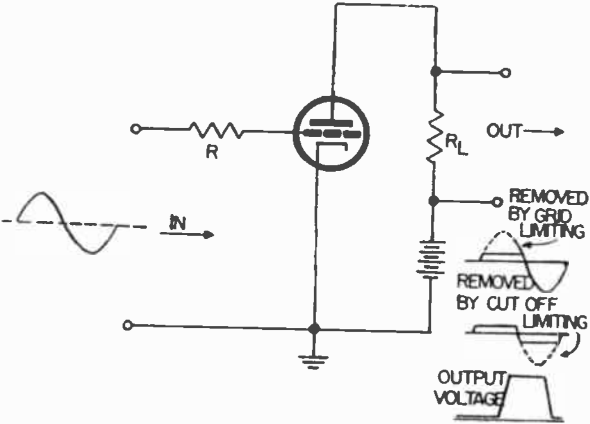


Fig. 111 Square wave produced by grid limiting plus cut-off limiting in triode tube.

FREQUENCY METERS

117. Frequency measuring instruments and devices—particularly those used to determine *radio* frequencies—constitute a distinct class of test equipment, because of the importance and critical nature of such measurements wherever radio-frequency waves are transmitted and received. Although there are only two basic types of RF meters—the *absorption wavemeter*, and the *heterodyne frequency meter*—there are a large number of variations and, in addition, several combination instruments which perform related test functions. Every type of frequency meter must be properly calibrated, however, and this introduces the primary and secondary standards of frequency with which the meters are compared—directly or indirectly—in order to provide accurate measurements. The requirement of precise calibration is extremely important in all frequency-measurement work.

118. Absorption Wavemeter.—This is the simplest type of meter for determining the wave length or frequency of RF oscil-

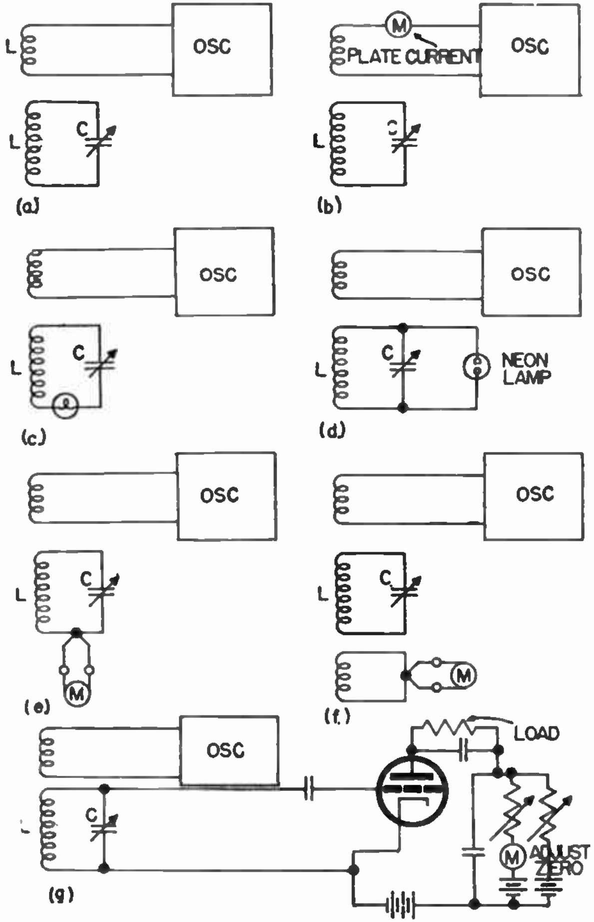


Fig. 112 Principal types of absorption wavemeter, according to method of indication of resonance. A, Basic wavemeter; B, Indication by reaction; C, Indication by flashlight bulb; D, Neon lamp indication; E. Thermal wavemeter; F, Coupled thermal wavemeter; G, Indication by vacuum tube voltmeter.

lation. Essentially the absorption wavemeter is a closed circuit (Fig. 112a) consisting of a coil L and a condenser C connected in parallel. Such a circuit has the property of resonance at one particular frequency—determined by the reactance of the coil and condenser—at which frequency the wavemeter draws power (by induction) from any circuit to which it is coupled—in order to develop a large value of circulating current. Usually the inductance is fixed and the capacitance is variable to give a range of determinable resonant frequencies. When loosely coupled to a RF oscillator whose frequency is to be determined, *some* alternating current is likely to flow in the closed circuit; after adjusting the condenser C so that the current flow is *maximum,* this condition indicates resonance and that the frequency of the radio wave under test is the same as the natural frequency of the wavemeter circuit. The scale of the variable condenser is usually calibrated directly *in terms of radio frequency* for a fixed value of inductance. However, the resonant frequency can be computed by the familiar equation:

$$F = \frac{1}{6.28\sqrt{LC}} \times 10^6$$

where F = frequency in kilocycles,
L = inductance in microhenries,
C = capacitance in micromicrofarads.

Since the operation of such a measuring circuit depends upon current induction from another circuit to give an indication of resonance, the wavemeter can only be used to determine the frequency of circuits which are actually functioning as oscillators—and there must be suitable coupling between the oscillator and wavemeter circuits, so that the condition of resonance can be indicated with certainty. There are several methods of indicating resonance, the simplest of which is based on reactionary effects in the oscillator circuit (Fig. 112b). Since a wavemeter absorbs the most energy from the oscillating circuit when both circuits are tuned to the same frequency, a pronounced increase in plate current (or decrease in grid current) in the oscillator stage is sufficient indication that the wavemeter has determined the correct frequency of oscillation. There are, however, more direct methods of indicating resonance between the two circuits. The relatively high value of circulating current in the wavemeter circuit *at resonance only* can be indicated by a small flashlight bulb in series with the circuit (Fig. 112c), *or,* the maximum voltage across the condenser C *at resonance only* can be applied to a neon lamp (Fig. 112). An indicating device of greater accuracy is the thermocouple-type milliammeter, which can either be connected in series with the wavemeter circuit (Fig. 112e) or coupled into the circuit by means of a small fixed coil near the tuning inductance L of the wavemeter (Fig. 112f). The degree of sharpness in tuning a wavemeter is largely determined by the "Q" of the circuit, and therefore the circuit resistance should be as low as possible. Since the indicating device is the chief source of resistance in the circuit, its undesirable effect can best be offset by loose transformer coupling so that any indicator resistance reflected into the wavemeter circuit is far less than the actual resistance of the indicator. Probably the best method of indicating resonance, however, is by use of a sensitive vacuum-tube voltmeter connected across the tuned circuit (Fig. 112g). An RF voltage between the grid and filament of a triode acting as a plate detector will, by suitable rectifier action, produce a direct current in the plate circuit which is a proportional indication of the amount of applied AC grid voltage. In addition, the steady negative bias applied to the grid of the tube insures that

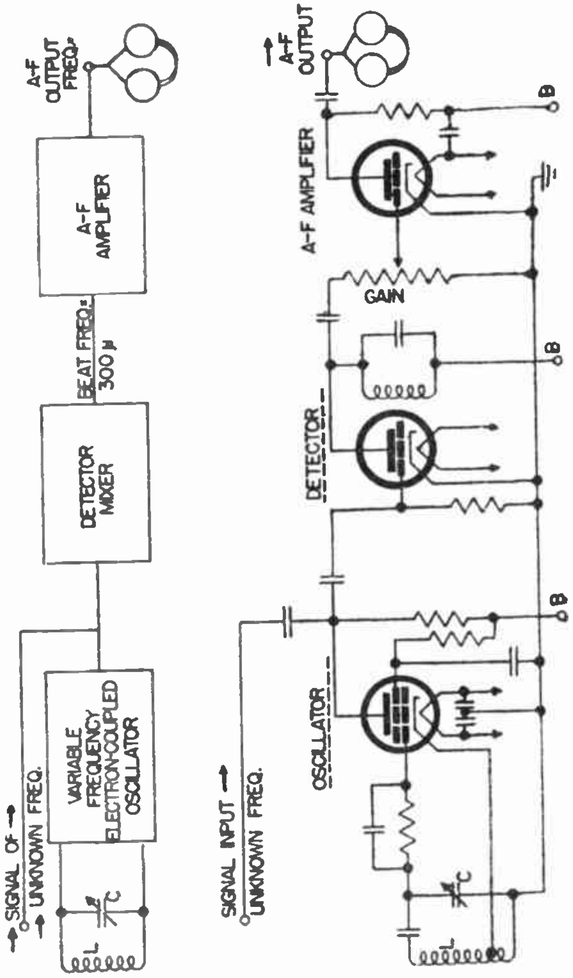


Fig. 113 Principle and typical circuit of a heterodyne frequency meter.

little or no current is drawn from the circuit operating it. Thus, damping effects are avoided in the wavemeter circuit through use of a vacuum-tube voltmeter and, consequently, the determination of the resonant condition is very sharp and accurate.

119. Heterodyne Frequency Meter.—These extremely sensitive instruments determine the frequency of an unknown RF signal by matching that signal with a locally generated signal *of identical frequency* obtained with a precision-calibrated oscillator. In operation, both signals are applied to the same detector-mixer stage, but a suitable filter passes only the difference or *beat frequency*—which invariably is in the audio range of frequencies. After amplification, this result of heterodyne action is audible and therefore can be heard with telephone receivers or headphones. The aural presence of *any* AF signal indicates that the local oscillator of the frequency meter is *not* tuned to the exact frequency of the unknown RF signal. Accordingly, the value of the tuning condenser C (in the local oscillator stage) is adjusted so that the output of the stage is identical in frequency with the unknown RF signal being measured. This condition is apparent when no audio-frequency tone is heard in the headphones. The tuning condenser C of the local oscillator is calibrated directly *in frequency* and thus the frequency of the unknown RF signal is determined by direct reference to the dial or scale, or a suitable calibration chart. A block diagram and basic circuit of a typical three-stage heterodyne meter is shown in Fig. 103. The heart of the test instrument is the variable-frequency oscillator, which must provide a wide range of radio-frequency signals with good stabiilty. The electron-coupled oscillator satisfies this requirement, and it is invariably used in heterodyne frequency. Since a self-controlled oscillator is susceptible to the effects of temperature and humidity, age, changing electrode potentials, vibration, and other factors—every precaution is taken to achieve and maintain optimum operating conditions *at all times* in order to obtain the greatest accuracy of frequency measurement. Some heterodyne frequency meters make use of *harmonics* of the fundamental frequency in order to provide a very wide range of frequencies. In such cases, the detector and AF amplifier stages are untuned and not filtered, and the equipment will check harmonics or sub-harmonics of the local oscillator frequency. Some instruments provide measurement of frequencies as high as the 20th harmonic of calibrated oscillator frequencies. Characteristics of the output circuit of almost all types of frequency meters permit the use of either high-impedance (15,000 ohms) or low-impedance (2500 ohms) headphones without modification of the circuit. The accuracy of measurements with the heterodyne frequency meter is dependent upon proper calibration *in terms of frequency* of the variable condenser C in the tuned circuit LC of the local oscillator. To provide the exceptionally high degree of accuracy required of instruments of this type, the heterodyne frequency meter is calibrated by comparison with an extremely reliable frequency source, known as a *secondary standard of frequency.*

120. Frequency Standards.—Of considerable importance in measurements of wave length and frequency are the standards by which wavemeters and frequency meters are compared and calibrated. The absolute standard of frequency—1 cycle per day—is the period of rotation of the earth as measured by astronomical observations. More practical standards for radio work are classified as either *primary* or *secondary standards.* A primary standard is an elaborate electronics system that generates a fixed frequency of very high stability over long periods of time. Operation of the system is based on oscillations produced by either a 50 kc or a 100 kc crystal maintained at constant temperature; these oscillations are then applied to a succession of multivibrator stages and associated isolating amplifiers to produce a fixed frequency of 1000 cycles, which operates a synchronous clock for purposes of frequency control. Associated with the principal circuit of the primary standard are other stages providing accurate harmonic or sub-harmonic frequencies for related measurement work.

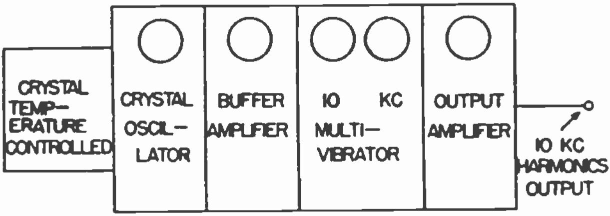


Fig. 114 Block diagram of typical secondary frequency standard.

121. Secondary Frequency Standards.—When a stable oscillator is synchronized and calibrated with a primary frequency standard and is then used as a standard in the absence or unavailability of the primary standard, the apparatus is known as *a secondary frequency standard.* In addition to the crystal-controlled oscillator, the complete circuit usually consists only of a single multivibrator stage with a suitable output amplifier (Fig. 114). Despite its simplicity, the circuit of the secondary frequency standard is similar in general function to the primary standard previously described. The oscillator operates in the frequency range between about 30 to 100 kc. and the fixed frequency of oscillations is accurately maintained by a simple temperature-controlled oven or compartment. Plate tuning of the oscillator stage is usually semi-fixed so that it cannot easily be moved or changed after proper initial adjustment. Harmonics and sub-harmonics of the oscillator frequency are provided by a multivibrator stage. For additional frequency division or multiplication, two or more multivibrator stages are employed. The accuracy of a secondary frequency standard is maintained only when periodic calibration checks are made with either a primary standard, another secondary standard which was previously compared with a primary standard, or the standard frequency transmissions of the U. S. Bureau of Standards which are broadcast regularly over station WWV on 5, 10, and 20 megacycles.

122. Frequency Monitors.—All radio transmitters used for broadcasting, communications, or other commercial purposes are required by Federal law to measure the carrier frequency of the transmitter and to make certain that any deviation is within the permissible tolerance allowed. Instruments for accomplishing this purpose are *frequency monitors*—sometimes known as frequency-deviation meters, or frequency-limit monitors. These are essentially secondary frequency standards used to provide a continuous indication of any deviation in the carrier frequency of a specific radio transmitting station. There are two similar systems of operation. When the crystal oscillator functions at the assigned carrier frequency of the station, any deviation in frequency is indicated directly by a suitable meter. When the frequency of the oscillator differs by some fixed value—usually 1000 cycles—from the carrier frequency of the radio station, any departure from this *fixed difference of 1000 cycles* is indicated either directly, or in terms of percentage deviation, by a suitable meter. The latter system (Fig. 115) is more generally used in radio broadcasting transmitters.

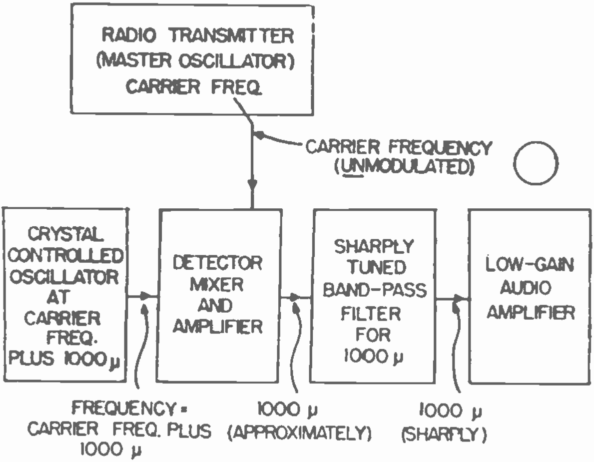


Fig. 115 Typical frequency monitor.

123. Lecher-Wire System.—Measurements of radio waves at ultra-high frequencies above 300 mc—or at wave lengths of less than 1 meter—require specialized techniques. Absorption wavemeters and heterodyne frequency meters are useful only if specifically designed for microwave operation. A simpler and far more economical method of accurate measurement is by means of a *Lecher-Wire system,* where the wave length of a signal is determined by direct measurement of the standing wave pattern on a short section of a resonant transmission line. In a typical arrangement (Fig. 116), the section of transmission line actually consists of a "folded" wire or bar—which is the Lecher Wire. The loop end is coupled to the source of frequency to be measured, and across the two opposite ends is a short circuit. In series with the shorting bar is a sensitive RF thermocouple-type meter. As the position of the shorting bar is varied, a series of sharply defined positions are identified and located—according to high-current indications of the meter. These positions represent the proper dimensions of the transmission line for resonance, and thus are exactly one-half wave length apart for the particular signal being measured. Accordingly, the wave length of the unknown signal is obtained simply by measuring the distance *in centimeters* between any two such points. When the wave length is known, the frequency of the unknown signal is determined by the equation:

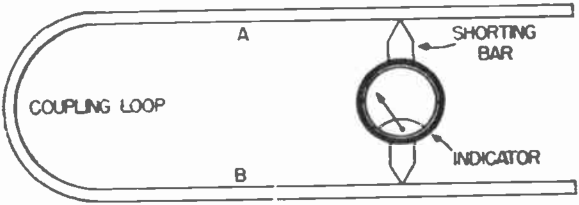


Fig. 116 Lecher wire system.

$$f = \frac{30{,}000}{\lambda}$$

where f = frequency in megacycles
λ = wave length, centimeters

FIELD-STRENGTH AND TUNING METERS

124. Highly accurate measurements of the field strength of radio waves require use of commercial field-strength equipment, which are universally accepted as standard apparatus. Less pretentious and less accurate are any of the smaller portable meters, which only indicate relative values of field strength. Many of these meters can be used for a wide variety of other, somewhat-related purposes—such as checking the adjustment and performance of an antenna, determining the radiation pattern of an antenna, measuring frequency or wave length, indicating resonance or resonant tuning, adjusting matching systems and transmission lines, checking the neutralization of an RF amplifier stage, locating standing waves on transmission lines, matching line and antenna impedances, and considerable other functions.

Some types of field strength and tuning meters designed for use at ultra-high frequencies often incorporate additional circuits and measuring functions in an effort to achieve extreme versatility.

Such combinations are possible because many of the functions are closely related—usually through frequency of operation, or a state of resonance.

125. Field Strength.—The value of the electric field of a radio wave *at a given point* is known as the field strength, and is measured in terms of *microvolts per meter.* Variations of field strength around an antenna system are shown graphically by polar diagrams, and are commonly known as the radiation pattern, field pattern, or radiation field for a particular antenna or antenna system. With *zero* taken as the center of such a chart, computed or measured values of field strength are plotted radially in a manner that indicates both magnitude and direction for a given distance from the antenna. Field strengths in the *vertical* plane are plotted on a semi-circular polar chart, and are usually known as vertical polar diagrams. The field strength of a radio wave is determined by measuring the RF voltage induced in a receiving antenna by the radio wave.

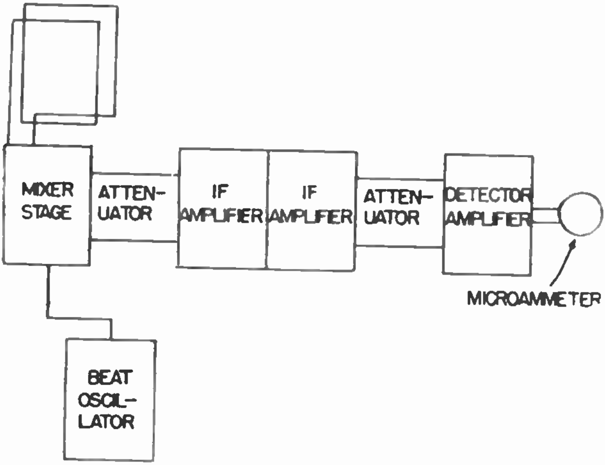


Fig. 117 High precision field-strength equipment.

126. Commercial Equipment.—When accuracy of field-strength measurements is required, large commercial types of standardized equipment are used to measure the minute voltages induced in an exposed receiving antenna by the radio waves. Essential component of this equipment (Fig. 117) is a special type of superheterodyne receiver with a gain control between two of the intermediate-frequency amplifiers, and with the first detector stage arranged to function as a vacuum-tube voltmeter when required. Precision attenuators are used throughout the equipment, with measurements of field strength by an appropriate microammeter in the plate circuit of the output tube. A standard loop antenna is used for radio reception, since it provides some degree of directivity when properly oriented with respect to a specific radio transmitting station.

127. Simple Field-Strength Meter.—Using no vacuum tubes, this instrument is fairly adequate for field-strength measurements when equipped with a sensitive DC microammeter—range 0 to 50 microamperes. Frequency of reception is determined by the tuned circuit LC (Fig. 118), and tight coupling is necessary between the antenna coil and the coil L of the tuned circuit. RF signals are rectified by either a silicon or germanium crystal diode before application to the DC meter. Although indicated values are only relative, this small meter proves itself a fairly practical instrument where accuracy is unimportant.

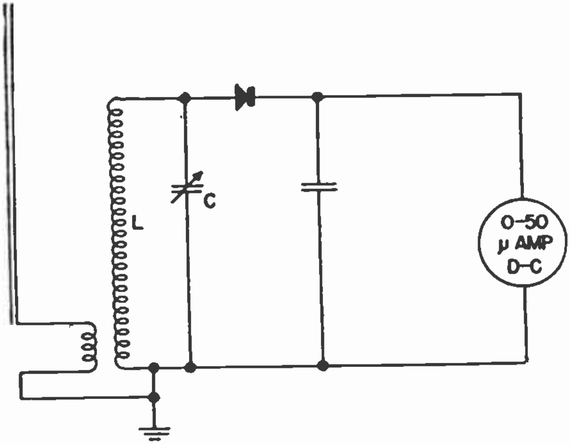


Fig. 118 Tubeless field-strength meter.

128. Diode Field-Strength Meter.—This instrument gives a direct indication of relative field strength with a fair degree of accuracy. It consists of a tuned circuit LC, a diode rectifier, and a series-connected DC microammeter—range 0 to 100 microamperes—which provides good sensitivity (Fig. 119). A short doublet antenna is tightly coupled to the coil L; and sensitivity is considerably improved when the antenna is resonant at the same frequency of the signals being received. This instrument can also be used as a resonance indicator, an absorption wavemeter, or as a neutralizing indicator. It also proves practical as a tuning meter for adjusting antenna systems where extremely high precision is not required.

129. Grid-Leak Field-Strength Meter.—Great sensitivity and a wider decibel range are provided by this instrument, surpassing any of the simpler types of field-strength meters previously described. The instrument uses a dual-triode vacuum tube for maximum power sensitivity, and measurements are indicated on a milliammeter—range 0 to 1 ma (Fig. 120). Operation of the circuit is stable and, once calibrated, it will retain good accuracy over a considerable length of time. When a doublet is used, the antenna coil should be coupled tightly to the output coil. The instrument can also be used as a resonance indicator, an absorption wavemeter, a means of checking antenna performance as well as tuning the antenna, and many other purposes.

130. The "Micromatch" Indicator.—This is essentially a utility RF tuning meter which combines a variety of important functions. It is used for matching impedances of transmission lines, checking "flat" transmission lines, measuring RF power, indicating standing-wave ratios on transmission lines, and testing RF output and interstage coupling units. Probably its chief use, however, is in the measuring and matching of transmission lines. For this work, the "Micromatch" Indicator is equipped to measure RF power flow in either direction on a transmission line. If the line is terminated in a matched load equal to the surge impedance of the line, the load will absorb all of the power carried on the transmission line; if the load is not matched to the line, however, part of the power is reflected back to the generator or transmitter. It is the reaction between the direct and the reflected power that results in a standing-wave ratio. When the instrument is inserted in the transmission line between the load and the source of RF power, the meter reading is proportional *only* to the reflected energy and is *not* influenced by the direct or transmitted wave. Precise calibration of the instrument for measuring standing-wave ratios is not necessary, since the

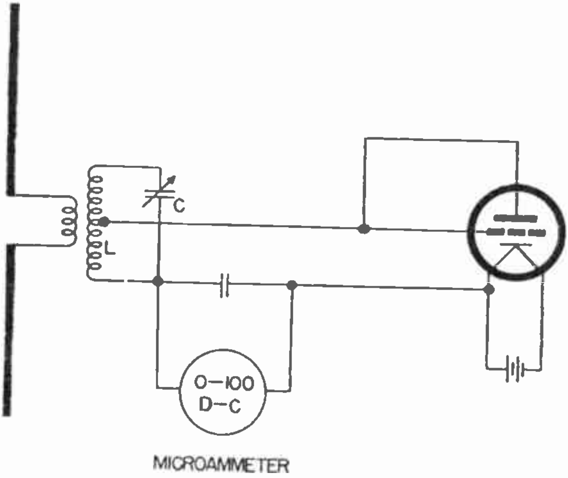


Fig. 119 Diode field-strength meter.

meter is ordinarily used to obtain so-called "minimum" indications.

131. Grid-Dip Meter.—This tuning meter—sometimes known as a megacycle meter—is a multi-purpose instrument which can be used as a variable frequency oscillator, an absorption wavemeter, or an oscillating detector. It consists essentially of a self-excited oscillator which is usually mounted into a compact unit and connected by a flexible cable to an associated power supply and a grid-current meter. Operation of the grid-dip meter is based on the principle that when an LC circuit is tuned to resonance with a self-excited oscillator, and coupled to the coil of that oscillator, the LC draws power from the oscillator. Since the oscillator is then supplying power to a load and less power is fed from the plate to the grid of the tube in order to sustain oscillation, this results in decreased grid current which is popularly known as the "grid dip." Not confined to resonance tuning, the meter is used to measure values of inductance and capacitance, to locate parasitic circuits and spurious resonances, to align receivers, to determine the resonant frequencies of transmission lines, antennas, and other tuned circuits.

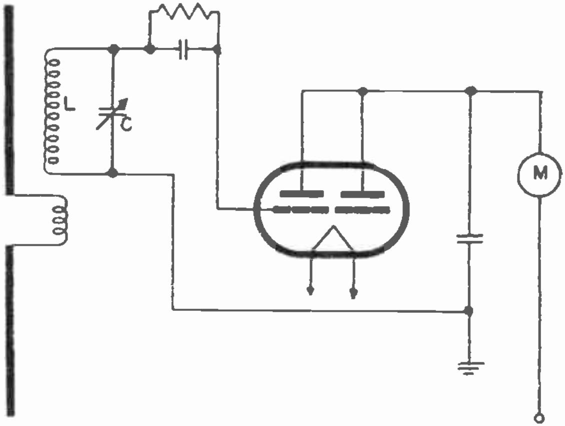


Fig. 120 Grid-leak field-strength meter.

Section 16

TESTING, MEASURING AND ALIGNING

DIRECT CURRENT MEASUREMENTS

1. Instruments.—Direct current flowing in a circuit is usually measured by means of *d'Arsonval* or permanent-magnet moving-coil meters—known as DC *ammeters, milliammeters,* or *microammeters.* These are all basically the same instrument; depending upon the magnitude of current to be measured, they are equipped with suitable shunts to divert part of the flow of current away from the sensitive low-resistance moving coil. The coil movement is delicately balanced, and very little current is required to obtain maximum rotation of the coil and thus full-scale deflection of the pointer.

Current-measuring instruments are always connected *in series* with the circuit or load under test, and the full current flows through the meter. Care must be taken *not* to overload and damage DC meters by (1) applying the wrong polarity of current, (2) connecting meters across or in parallel with the circuit, or (3) applying excessive amount of current greater than the range indicated by the scale of the meter. If the approximate value of current is unknown, first use a meter (or a scale of a multi-range meter) having a high maximum range; when the reading thus obtained is small compared to the range scale, use another meter (or another scale of the multi-range meter) having a lower and more appropriate maximum range. This procedure is always used with multi-range instruments as a precautionary measure. Accuracy of current readings is improved by using, whenever possible, the lowest range scale which permits measurement without damage to the meter. For example, a current of 2 milliamperes can be read more accurately on a scale having a range of 0 to 3 milliamperes than on a scale calibrated for 0 to 300 milliamperes. In general, DC meters are more accurate near the center of the scale than at the extremities.

There are several common sources of error in DC measuring instruments. A change in the spring tension often shifts the "zero" position of the pointer—above or below true *zero.* These meters should not be used in the vicinity of strong, external electromagnetic fields—such as those associated with PM speakers, etc.—because the permanency of the meter magnet will be impaired, thus providing a source of inaccuracy. Similarly, current instruments should not be mounted on steel or other magnetic types of panels, unless the meter has been calibrated especially for such use. Changes in the electrical resistance of the coil or springs, or the values of shunt resistance, may also influence the accuracy of instrument readings. The DC meter requiring the least amount of current for full-scale deflection is the most sensitive instrument; in general, the higher the sensitivity of a meter, the greater the accuracy of readings.

Direct current can also be measured by means of DC vacuum-tube milliammeters or microammeters, which function similarly to DC vacuum-tube voltmeters; these instruments consume negligible energy, and provide indications of extremely small currents. Some types of AC instruments—such as moving-vane or moving-iron meters, and electrodynamometers—are sometimes used to measure direct current. However, the use of such AC meters is very limited and usually impractical, because they compare unfavorably with the more efficient DC moving-coil meter.

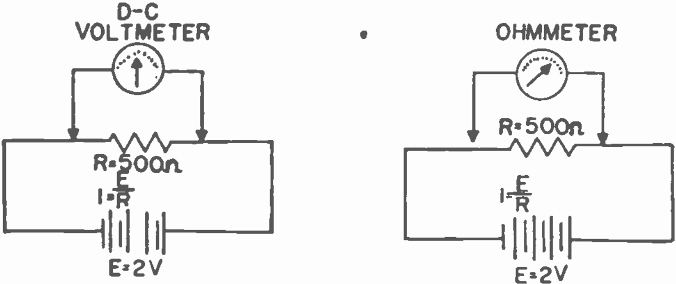


Fig. 1 Indirect method of measuring current in a DC circuit.

2. Indirect Methods.—When the value of resistance in a closed DC circuit is known, the amount of direct current flowing in the circuit can be determined by means of a DC voltmeter and application of Ohm's Law:

$$I = E/R$$

For example, in a circuit containing a 500 ohm resistor (Fig. 1a), it is only necessary to measure the DC voltage drop across the resistor—in this case: 2 volts—and apply Ohm's Law in order to determine the direct current: 0.004 amperes or 4. milliamperes. Similarly, when a known DC voltage drop exists across an unknown resistor (Fig. 1b), the amount of direct current flowing through the resistor can be determined by means of a suitable ohmmeter and application of Ohm's Law.

DC VOLTAGE MEASUREMENTS

3. Voltmeters.—The DC voltage in a circuit or the DC voltage drop across a component, is usually measured by means of d'Arsonval or permanent-magnet moving-coil DC voltmeters. Such instruments have essentially the same movements as those used in current meters, but employ a current-limiting resistor in series with the moving coil—so that a DC voltmeter is a high-resistance measuring device. These instruments are always connected *in parallel* with the circuit or component across which the voltage is to be measured. Since the internal resistance of the meter is high—due to the series resistor—very little current flows through the measuring instrument. Despite this high resistance, care must be taken *not* to overload and damage DC voltmeters by (1) applying the wrong polarity of voltage, or (2) applying amounts of voltage greater than the range indicated by the scale of the meter. If the approximate value of voltage is unknown, first use a meter (or a scale of a multi-range voltmeter) having a high maximum range; when the reading thus obtained is small compared to the range scale, use another meter (or another scale of the multi-range voltmeter) having a lower and more appropriate maximum range. The range of a voltmeter can be selected by choosing a suitable series resistor or multiplier. To increase the range of a DC voltmeter, additional resistance is connected in series with it; conversely, the range of a DC voltmeter is decreased with any decrease in the amount of resistance in series with the movement.

Accuracy of voltage readings is improved by using, whenever possible, the lowest range scale which permits measurement without damage to the meter. For example, a voltage of 4 volts can be read more accurately on a scale having a range of 0 to 10 volts than on a scale calibrated for 0 to 1000 volts. In general, DC meters are more accurate near the center of the scale than at the extremities. Sources of inaccuracies typical of moving-coil meters are common to DC voltmeters. These instruments should *not* be used in the vicinity of strong magnetic fields, since the permanency of the meter magnet may be impaired; and the instruments should not be mounted on steel or other magnetic types of panels, unless the voltmeter has been calibrated especially for such use.

Standard sensitivity of voltmeters has been 100-ohms-per-volt for some time; the need for more accurate readings in high-resistance circuits, however, brought into existence instruments with sensitivity ratings of 20,000 ohms-per-volt. DC voltmeters with higher sensitivity give more accurate readings, regardless of the nature of the circuit being measured. Some types of AC instruments—such as moving-iron or moving-vane meters, electrostatic voltmeters, and dynamometer-type voltmeters—are sometimes used to measure DC voltage. However, the use of such meters is extremely limited and usually impractical, since they do not compare favorably with the DC moving-coil voltmeter.

4. Indirect Methods.—When the value of resistance in a closed DC circuit is known, the amount of voltage across the resistor can be determined by means of a suitable DC milliammeter or microammeter and application of Ohm's Law:

$$E = IR$$

For example, in a circuit containing a 100-ohm resistor (Fig. 2a), it is only necessary to measure the current flow—in this case: 50 ma—and apply Ohm's Law in order to determine the voltage: 5 volts. Similarly, when the value of resistance in a DC circuit is unknown (Fig. 2B), the voltage drop across the resistor can be determined by means of a suitable milliammeter or microammeter, an ohmmeter, and application of Ohm's Law.

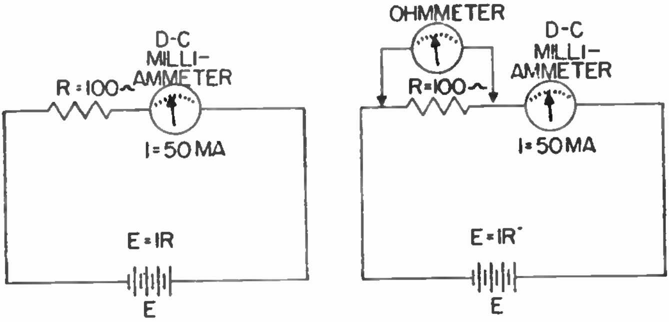


Fig. 2 Indirect methods of measuring D-C voltage.

DC POWER MEASUREMENTS

5. Wattmeters.—The electrical power *in watts* expended in a DC circuit is measured by means of dynamometer-type wattmeters. These instruments consist essentially of a fixed coil and a moveable coil which are influenced, respectively, by the *current* and by the *voltage* in the circuit being measured. Wattmeters normally have four external terminals, and are connected between the source of power and the circuit load in such a manner (Fig. 3) that the fixed coil is in series with one side of the line

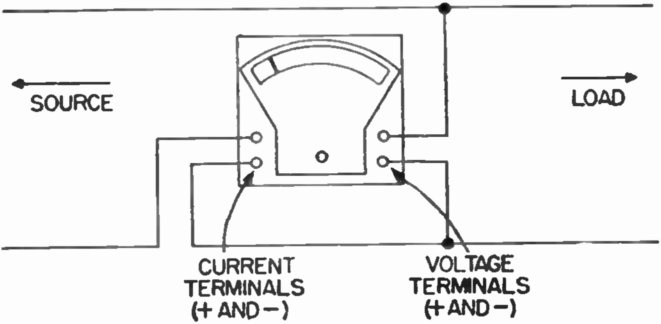


Fig. 3 Wattmeter connections.

and the moveable coil is across or in parallel with the line. Interaction between the two coils produces a single deflection indicative of the power consumed. It is important that the wattmeter be properly connected—as specifically indicated on the terminals or case—in order to prevent damage to the sensitive moving coil of the instrument.

6. Indirect Methods.—Since DC power *in watts* is the product of voltage and current, the amount of power consumed in a DC circuit can be determined by separately measuring the voltage and current—with a suitable voltmeter and ammeter or milliammeter—and multiplying the resultant quantities according to the equation:

$$P \text{ (in watts)} = E \text{ (in volts)} \times I \text{ (in amperes)}$$

The DC voltmeter is connected across or in parallel with the line or circuit, and the DC ammeter or milliammeter is connected in series with the line, as shown in Fig. 4. The product of the two readings is the power *in watts.*

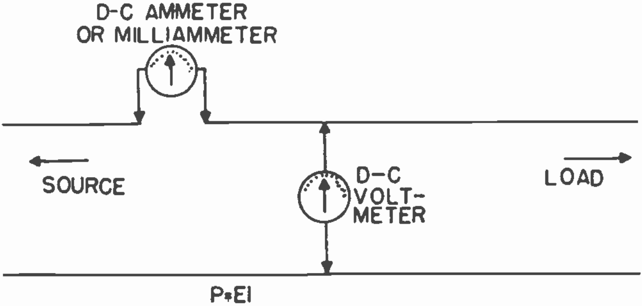


Fig. 4 Indirect method of measuring power in DC circuit.

ALTERNATING CURRENT MEASUREMENTS

7. Effect of Frequency.—AC measuring procedures are directly influenced by the *frequency range* of the current being checked or measured. Instruments and techniques used for measuring current at low (power) frequencies are different from those used at audio frequencies and at radio frequencies. Accordingly, separate procedures are required for measuring alternating currents within each of the following frequency ranges:

(a) Low (power) frequencies.
(b) Audio frequencies,
(c) Radio frequencies.

While knowledge of the exact frequency of current is not necessary, a consideration of frequency range is imperative before attempting measurements of alternating current.

8. Low-frequency Current Instruments.—Alternating current at low (power) frequencies is usually measured by means of moving-vane or moving-iron meters. These instruments have a low sensitivity rating of about 10 ma, however, and therefore represent a considerable load in the circuit being measured. For this reason, their use is restricted to filament and power-line measurements. Dynamometer-type current meters—also known as electrodynamometers—are more accurate than moving-vane meters; but they are also more expensive and require more energy to operate, and therefore are used primarily for power-line measurements. The range of both types of the above low-frequency current instruments can be extended by means of current transformers. Although seldom used at low (power) frequencies, AC rectifier-type instruments are sometimes employed for measuring small values of current. The sensitivity of a rectifier-type instrument is more than fifty times greater than that of either the dynamometer-type or the moving-vane meters. All current-measurement instruments are connected *in series* with the circuit or load under test, and the full current flows through the meter. Care must be taken *not* to overload and damage AC meters by (1) connecting them across or in parallel with the circuit, or (2) applying amounts of current greater than the range indicated by the scale of the meter.

9. Audio-frequency Current Instruments.—Alternating current at audio frequencies is usually measured by means of AC rectifier-type instruments. Most common of these devices consists of a full-wave copper-oxide rectifier unit associated with a DC moving-coil meter; some instruments use a crystal-diode rectifier unit. The small amount of capacity present in the rectifier unit tends to by-pass currents above 10,000 cycles, but the AC rectifier-type instrument is extremely sensitive for all measurements at lower (audio) frequencies. Current-measuring instruments are always connected *in series* with the circuit or load under test. The range of these instruments can be extended by means of shunts; but since the resistance of the rectifier unit varies with the amount of applied current, suitable compensation must be allowed for this variation.

The accuracy of AC rectifier-type instruments is only about 5 percent, due to the variation in resistance of the rectifier units. Care must be taken *not* to overload and damage these units by applying amounts of audio-frequency current greater than the range indicated by the scale of the meter.

10. Radio-frequency Current Instruments.—Measurements of RF current require the use of special instruments, utilizing a conversion device associated with a DC indicating meter. Chief among these are the hot-wire meter, and the thermocouple-type meter. The hot-wire meter is insensitive, slow-acting, and is used only to give approximate indications—*not* measurements—of low values of RF current. RF current is usually measured by means of thermocouple-type meters, which are available with sensitivity ratings ranging from 1 ma to 1 amp. When the thermocouple element is enclosed in a vacuum, the instrument is capable of accurately measuring alternating currents of only a few milliamperes.

Current-measuring instruments are always connected *in series* with the circuit or load under test. Care must be taken in handling thermocouple-type instruments, because of their delicate construction. Since these RF meters are easily damaged by overloading, do *not* apply amounts of RF current in excess of the range indicated on the scale of the meter.

AC VOLTAGE MEASUREMENTS

11. Effect of Frequency.—AC measuring procedures are directly influenced by the frequency range of the AC voltage being tested or measured. Instruments and techniques used for measuring voltage at low (power) frequencies are different from those used at audio frequencies and at radio frequencies. For this reason, separate procedures are required for measuring AC voltage within each of the following frequency ranges:

(a) Low (power) frequencies,
(b) Audio frequencies,
(c) Radio frequencies.

While a knowledge of the exact frequency of voltage is not necessary, a consideration of frequency range is imperative before attempting measurements of AC voltage.

12. Low-frequency Voltmeters.—AC voltage at low (power) frequencies is usually measured by means of moving-vane or moving-iron meters. Since these instruments have a low sensitivity rating of about 100-ohms-per-volt, however, they represent a considerable voltage drop in the circuit being measured. For this reason, their use is restricted to measurements of vacuum-tube filament voltages and power-line voltages. Dynamometer-type voltmeters and electrostatic voltmeters can also be used for low-frequency measurements, but these instruments are expensive and usually difficult to operate. The range of the above types of AC voltmeters can be extended by means of voltage transformers.

13. Audio-frequency Voltmeters.—AC voltage at audio frequencies is usually measured by means of rectifier-type voltmeters. These are identical to the current-operated rectifier-type instrument with the addition of a suitable series-resistor—to provide a flow of current proportional to the applied AC voltage. After full-wave rectification by either a copper-oxide unit or a crystal-diode unit, the resulting DC current operates a conventional moving-coil indicating meter. These voltmeters are always connected *in parallel* with the circuit or load being measured. The range of the instruments can be extended by means of multipliers; but since the resistance of the rectifier unit varies with the amount of current flowing through it, suitable compensation must be allowed for this variation. The indicating meter is usually provided with two scales, one for values below 50 volts and the other for values higher than 50 volts. When two or more multipliers are used with a common meter scale, the circuit of the instrument must be so arranged that the resistance facing the rectifier is constant when the source (input) of audio-frequency voltage is short-circuited.

The accuracy of AC rectifier-type voltmeters is only about 5 percent, due to the variation in resistance of the rectifier unit. Care must be taken *not* to overload and damage the rectifier unit of these instruments by applying amounts of AC voltage grater than that indicated by the scale of the meter. Audio-frequency voltage can also be measured by means of a cathode-ray oscilloscope [see paragraph 15].

14. Radio-frequency Voltmeters.—The only satisfactory instruments for measuring RF voltage are peak-reading vacuum-tube voltmeters, which can be used to measure AC voltages at all frequencies up to a hundred megacycles. Negligible power is taken from the circuit being measured, and vacuum-tube voltmeters are extremely accurate at any frequency of AC voltage. Multi-range VT voltmeters are the most practical measuring instruments. For radio servicing, the VT voltmeter should provide a continuous range from about 0.5 volt to at least 20 volts. Direct access should be provided to the grid terminal (input) of the voltmeter for all RF measurements; the more desirable instruments employ *probes*—containing a tube or crystal-rectifying device—which can be brought directly to that part of the circuit or apparatus being tested or measured.

In measuring voltages near tuned or resonant plate circuits, care must be taken to protect the input of the VT voltmeter from the high DC plate potential associated with resonant plate circuit; this is achieved by means of a DC blocking condenser, or by connecting the instrument directly across the tank coil of the plate circuit.

The vacuum-tube voltmeter is an extremely versatile test instrument; in addition to measuring voltage, the instrument is used for aligning radio receivers, measuring gain per stage, testing circuit continuity, checking circuit components, and a wide variety of other functions.

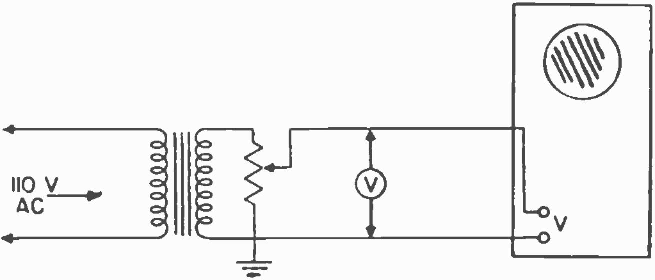


Fig. 5 Method of calibrating oscilloscope for use as AC voltmeter.

15. Oscilloscopes as AC Voltmeters.—Conventional cathode-ray oscilloscopes, after proper calibration, can be used for approximate measurements of AC voltages *over an extremely wide range of frequencies.* Depending upon the sensitivity and frequency response of individual oscilloscopes, AC voltages can be measured with equal accuracy at any frequency from about 20 cycles up to several hundred megacycles. Only one pair of electrostatic deflecting plates is employed for this purpose, and AC voltages—whether known or unknown—are applied directly to the deflecting-plate terminals without amplification.

For use as an AC voltmeter, the scope is first calibrated by applying known values of voltage to one pair of deflecting plates (Fig. 5) and noting the resultant length of the vertical (or horizontal) *line* appearing on the face of the scope. Since the scope indicates pear-to-peak values, the *line* must be calibrated either above or below—with respect to the center or *zero* point. Appropriate figures are marked on the face of the tube to facilitate comparison (Fig. 6). Calibration of the scope is independent of frequency, and AC voltages of any frequency—or even DC voltages can be used for this purpose. After calibration: unknown values of AC voltage are applied directly to the same pair of deflecting plates, and the length of the resulting *line* on the scope is compared directly with the previously graphed calibration (Fig. 7). Although not highly accurate, this method of measuring AC voltage is of considerable importance because measurements are independent of frequency.

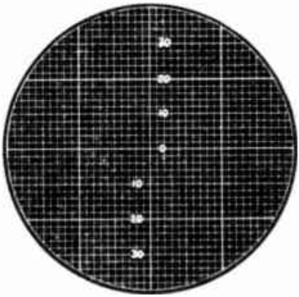


Fig. 6 Typical calibration of scope (with no applied voltage) for range: 0 to 30 volts.

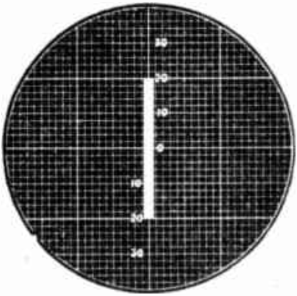


Fig. 7 Appearance of 20-volt deflection on calibrated scope used as AC voltmeter.

AC POWER MEASUREMENTS

16. Effect of Frequency.—AC power measuring procedures are directly influenced by the *frequency range* of the power being measured. Instruments and techniques for measuring power at low frequencies are different from those used at audio frequencies and at radio frequencies. Accordingly, separate procedures are required for measuring AC power within each of the following frequency ranges:

(a) Low frequencies,
(b) Audio frequencies,
(c) Radio frequencies.

While the knowledge of the exact frequency of AC power is not necessary, a consideration of frequency range is imperative before attempting any measurement of AC power.

17. Low-frequency Power Instruments.—Wattmeters are used for measuring the AC power *in watts* expended in single-phase AC (low-frequency) circuits. These dynamometer-type instruments are identical to DC wattmeters, and are used in the same manner. They are connected between the source of AC power and the circuit load (Fig. 3) but without regard to polarity markings on the terminals or case of the wattmeter. It is important, however, that the four terminals of the instrument be properly connected with respect to current and voltage markings, in order to prevent possible damage to the wattmeter.

To extend the range of a wattmeter for AC power measurements, voltage and current transformers are used across the proper input terminals. Indirect methods of measuring and calculating power (the product of voltage and current) are not applicable to alternating-current circuits, except in remote instances when the circuit load is a pure resistance. If the value of current and AC impedance are known, the AC power can be computed by the equation: I^2Z.

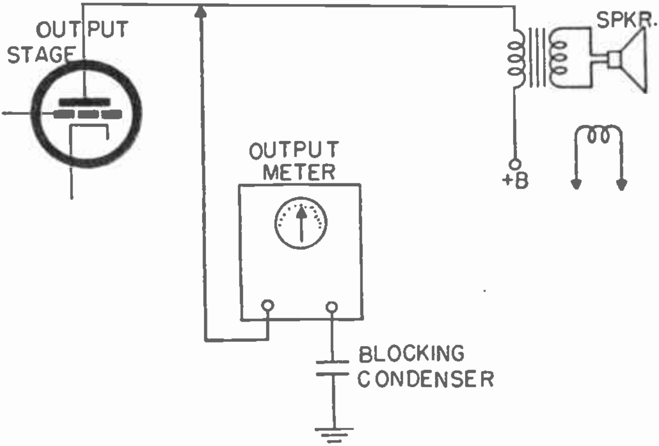


Fig. 8 Use of output meter for measuring power output of radio receiver.

18. Audio-frequency Instruments.—AC power measurements at audio frequencies fall into two distinct categories: *power output* and *power level.* The audio *power output* of radio receivers, amplifiers, and other audio-frequency equipment is measured by means of power output meters. These instruments consist of an AC rectifier-type voltmeter and a value of load resistance which matches the source of audio power being measured (Fig.

8). Relative readings are indicated on a scale which may be calibrated in watts, AC volts, or decibels. When measuring power in circuits containing a DC potential, a blocking condenser is inserted in one lead of the output meter to prevent erroneous readings.

The audio *power level* or *volume level* at any point along an audio-frequency transmission line or communication circuit is measured by means of volume level indicators or DB meters. These instruments consist of an AC rectifier-type voltmeter and a fixed value of series resistance, which is bridged across the circuit or transmission line to be measured (Fig. 9); readings are indicated on a scale which may be calibrated in watts or decibels. Highly accurate output power measurements of audio-frequency amplifying equipment requires the use of audio signal generators and more suitable meters.

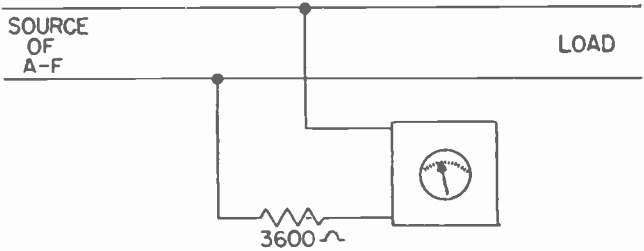


Fig. 9 Use of power level indicator in typical audio-frequency circuit.

19. Methods of Measuring RF Power.—Most accurate measurement of power at radio frequencies is by the use of a thermocouple-type ammeter in series with a noninductive resistor (of known resistance), with the amount of power determined by the equation:

$$P = I^2R$$

The ideal series resistor should be of the vacuum type, with either a 100-watt or a 250-watt rating, and the value of resistance must be known with accuracy.

20. Other Methods of RF Power Measurement.—Ordinary 6-volt or 110-volt light bulbs, connected either singly or in series-parallel to provide the necessary resistance and power rating, can be used as a "dummy" load for fairly accurate measurements of RF power. The approximate resistance of light bulbs can be computed easily from their wattage ratings at 60 cycles. This is known as the *substitution load method* of RF power measurement. Large commercial transmitting stations sometimes employ a water-cooled dummy load resistor of considerable size; and RF output power is measured—by means of a calorimeter—in terms of the amount of heat dissipated in the dummy resistor.

FREQUENCY MEASUREMENTS

21. Low-frequency Measuring Instruments.—Frequency meters used at low (power) frequencies are essentially deviation instruments. Slight variations with respect to a standard or normal frequency are indicated directly by either of two types of meters, which are connected in parallel with the power circuit being tested or measured.

The *vibrating-reed frequency meter* is essentially an electromechanical device consisting of a number of thin metal reeds, each of different length; when the applied frequency varies from the frequency standard, a different resonant vibration indicates this variance. Use of the vibrating-reed meter, however, is largely restricted to laboratories.

The *resonant-type frequency meter* consists of a parallel circuit resonant to the standard or normal frequency; and any increase or decrease in the applied frequency, with respect to the standard frequency, causes the pointer to move up or down accordingly. This is the principal type of practical direct-reading instrument for all power-frequency measurements.

22. Audio-Frequency Measuring Methods.—Audio frequencies can be measured in any of four principal ways: (1) by comparison with a calibrated audio oscillator or other available frequency standard, (2) by means of a bridge where conditions of balance are dependent upon frequency, (3) by a direct-reading frequency meter, and (4) by comparison with a known frequency using a cathode-ray oscilloscope. When available, a calibrated audio oscillator offers a good frequency standard for comparison measurements.

The most accurate method of measuring audio frequencies is by means of a bridge circuit—such as the *Wien bridge*—which can be brought into balance over a wide frequency range by the variation of resistance elements, and which requires no tuning inductance. Audio-frequency meters, employing electronic impulse-counting circuits, provide direct measurements of frequencies as high as 50 kilocycles with good accuracy.

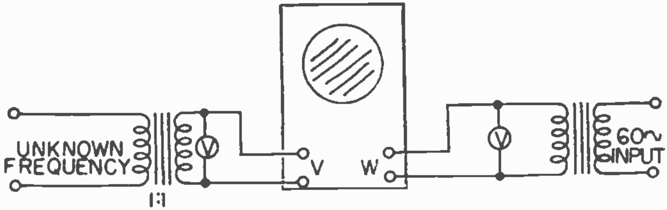


Fig. 10 Use of oscilloscope for measuring frequency.

In a typical circuit, the application of each input cycle of AC voltage causes two thermionic or gas-discharge tubes to conduct alternately, and current impulses—via a milliammeter—charge a suitable condenser: since the average DC current is proportional to the number of impulses per second, when properly calibrated the milliammeter indication is proportional to the frequency of the input voltage. Audio frequencies may also be measured *by comparison* using the cathode-ray oscilloscope.

23. Oscilloscopes as Frequency Meters.—The cathode-ray oscilloscope can be used to measure low (power) frequencies and audio frequencies, when a fixed frequency standard is available for direct comparison. When the known or standard frequency is connected to the horizontal deflecting plates, the application of an unknown frequency to the vertical deflecting plates produces images known as Lissajou patterns. By proper interpretation of these patterns, despite their usual tendency toward almost-continuous movement, the *ratio* of the unknown frequency to the standard frequency can be determined.

In a typical measuring arrangement where a 60-cycle AC power source constitutes the frequency standard (Fig. 10), the unknown frequency is compared as a *ratio* in terms of that standard frequency. For example, when the unknown frequency is 120 cycles—a ratio of 2:1—five of the most pronounced positions of the continually changing pattern resembles those shown in Figure 11. Since the two frequencies are not actually locked together, the patterns change because of the gradual shift in phase relation between the known and unknown AC voltages. However, from these patterns—and from *all* Lissajou patterns, there is a simple way of determining which input voltage has the higher frequency, and the ratio between the known and the unknown frequency. This is done by counting the "peaks" of the pattern: the number of peaks on the *top* compared with the number on the side indicates the *frequency* at the vertical plates compared with the *frequency* at the horizontal plates. Referring to Figure 11, there are two peaks vertically, and one horizontally; thus indicating a frequency ratio of 2:1. This rule applies to all Lissajou patterns; and for each pattern there are usually one or two particular positions which indicate the peaks most clearly for counting purposes. In the case of the three

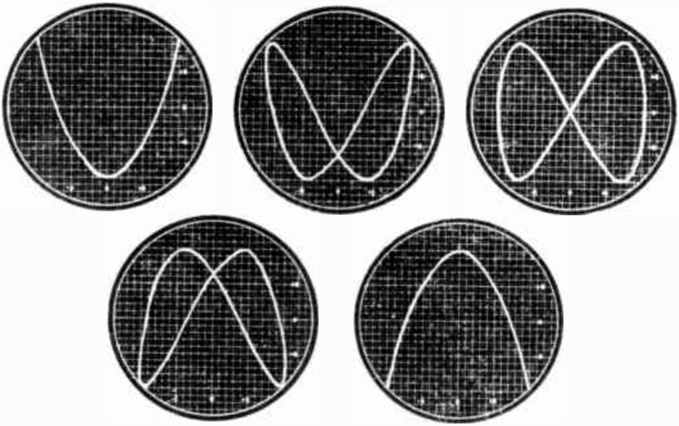


Fig. 11 Five of the most pronounced positions of the continually changing Lissajou pattern representing a frequency ratio of 2:1.

positions of the same screen pattern shown in Figure 12, the consistent presence of three vertical peaks and one horizontal peak indicates that the frequency ratio is 3:1.

The same system of peak counting is used to identify higher ratios between an unknown frequency and a known or standard

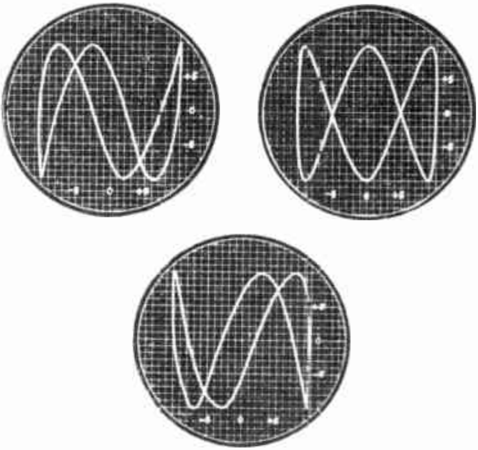


Fig. 12 Three of the most pronounced positions of the continually changing Lissajou pattern representing a frequency ratio of 3:1.

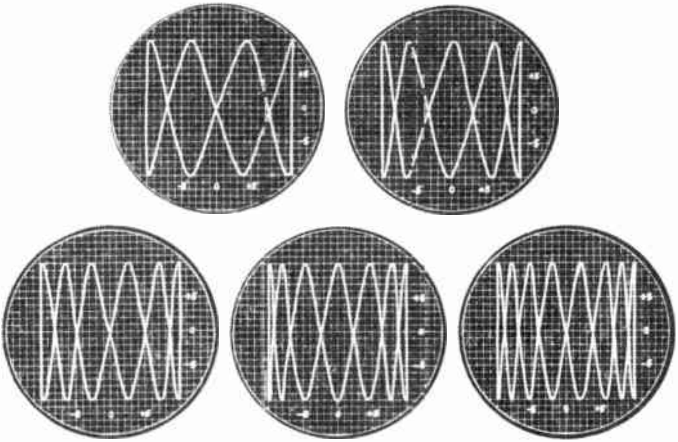


Fig. 13 Typical patterns obtained when frequency of vertical input is 4, 5, 6, 7, and 8 times the frequency of horizontal input (Patterns shown in clearest position).

frequency, as shown by the various patterns in Figure 13. Patterns appear stationary only when the two frequencies are in exact harmonic ratio to each other; for all other ratios the pattern will appear to rotate slowly in one direction or the other. For all practical purposes, a pattern having more than seven or eight peaks is difficult to enumerate with accuracy. However, by increasing the horizontal gain of the oscilloscope so that the pattern is spread beyond the limits of the screen and by counting all peaks carefully, it is possible to compare frequencies with ratios of 30:1 and higher.

24. Radio-Frequency Measuring Instruments.—The simplest method of determining the frequency of RF oscillation is by means of an absorption wavemeter (Fig. 14a) consisting of a coil and condenser in parallel, with some means of indicating exact resonance. When loosely coupled to the tank circuit of an oscillator stage or transmitter circuit, the absorption wavemeter draws a small amount of energy at the resonant frequency

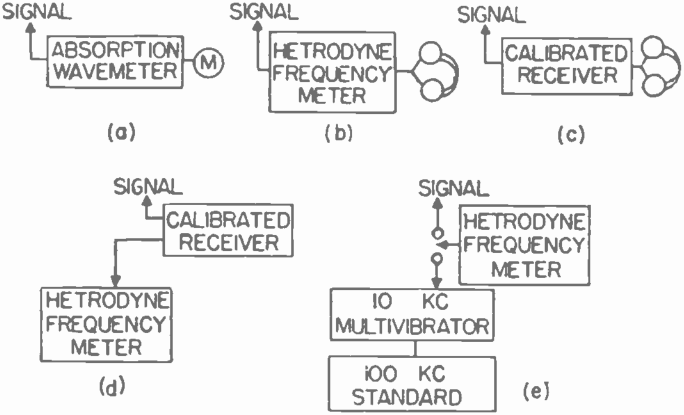


Fig. 14 Simple methods of measuring radio frequency—arranged in order of accuracy.

of the oscillator or transmitter: a flashlight bulb, milliammeter, or other device is used to indicate this resonant condition. The absorption wavemeter is extremely useful for checking the fundamental frequency of an oscillating circuit, the frequency of parasitic oscillations, and the frequency of harmonic oscillations; the instrument is also practical for determining the neutralization of an amplifier, the presence of RF energy in undesired parts of a chassis or equipment, and radiated field strength in terms of relative measurement.

More reliable instruments for measuring radio frequencies are heterodyne frequency meters (Fig. 14b), which determine the frequency of an unknown RF signal by matching it with a locally generated signal of identical frequency obtained from a calibrated, high-precision oscillator. A pair of headphones is ordinarily used as zero-beat indicator.

25. Other RF Measuring Methods.—Another elementary method of radio-frequency measurement is by means of a calibrated receiver (Fig. 14c); when the receiving equipment is well constructed and has frequency stability, extremely good accuracy can be obtained with bandspread calibration. Although the receiver can be used alone, when used in conjunction with a heterodyne frequency meter (Fig. 14d), the accuracy of measurement is improved considerably. For even greater accuracy, the heterodyne frequency meter is used as a (linear) RF interpolation oscillator in conjunction with a 100-kilocycle standard and a 10-kilocycle multivibrator frequency divider (Fig. 14e); calibration of the frequency meter is checked by means of the fixed 10-kilocycle harmonics obtained from the frequency-standard circuits.

A calibrated receiver—equipped with internal BFO stage—may be used as an interpolation oscillator in a measuring circuit (Fig. 15a), which permits alternate use with a heterodyne frequency meter for comparative and more accurate readings. Even greater accuracy of RF measurement is possible when a calibrated *audio* oscillator is used in the same way as an RF interpolation oscillator (Fig. 15b). In operation, the audio oscillator is adjusted to zero beat with the beat note obtained by combining the unknown signal frequency with the nearest harmonic of the 10-gilocycle multicibrator. Using precision apparatus, this method provides RF measurement with an accuracy better than 1 part in one million. The 100-kilocycle standard is calibrated directly with transmissions from station WWV in Washington, and the calibration is rechecked before every measurement in order to obtain optimum results.

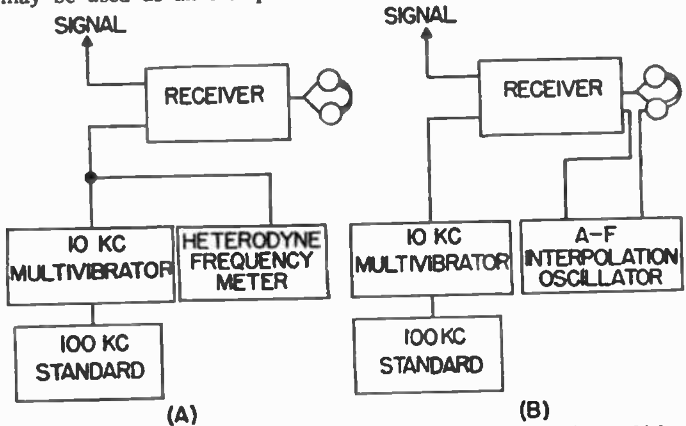


Fig. 15 Precision methods of measuring radio frequencies, which provide greatest accuracy.

26. Lecher-Wire Systems.—RF measurements at ultra-high frequencies above 300 mc—or, wavelengths of less than 1 meter

—are usually accomplished by Lecher-wire systems, which determines the actual (physical) length of such radio waves. Since the Lecher-wire system is essentially a resonance device, it must be loosely coupled to the circuit being measured in order not to affect the operation of the high-frequency oscillator or transmitting apparatus. A typical arrangement is shown in Fig. 16. Care should be taken to maintain the shorting bar at right angles to the two wires or rods of the Lecher-wire system.

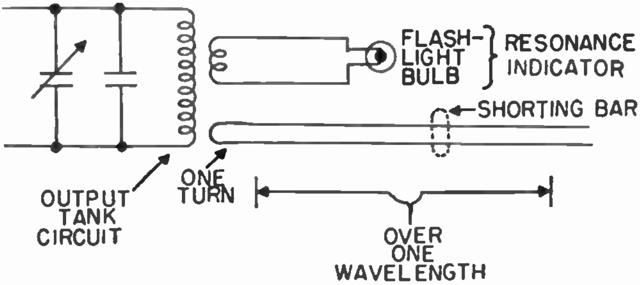


Fig. 16 Typical use of Lecher-wire system.

RESISTANCE MEASUREMENTS

27. Instruments.—Approximate measurements of resistance are obtained by means of ohmmeters, which are essentially current-indicating devices consisting of a milliammeter and a known, fixed source of energizing voltage. Since the flow of current is proportional to the value of resistance in the measuring circuit, the ohmmeter is calibrated directly in ohms. To obtain best accuracy, the fixed voltage must be set to optimum value by means of the *zero-ohms* adjustment associated with the meter. Since one end of an ohmmeter scale is severely cramped, it is necessary to use a multi-range meter for most electronic and radio work; and even then proper interpretation of the ohmmeter readings is essential to accurate measurements of resistance. When

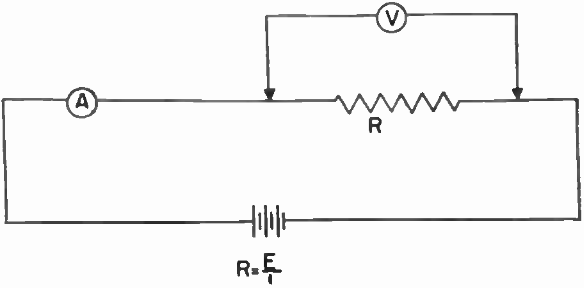


Fig. 17 Indirect method of measuring resistance with voltmeter and ammeter.

possible, make all readings near the center of the indicating scale. Never use an ohmmeter in a circuit when the power is turned on.

Extremely high values of resistance—on the order of several megohms—are usually measured with an instrument known as the *megger*. The most accurate method of measuring all values of resistance, however, is by means of a balanced bridge circuit, such as the Wheatstone bridge.

28. Indirect Methods.—In a simple DC circuit (Fig. 17), when the amount of applied voltage is measured with a voltmeter and the flow of current is measured with a suitable current meter, the resistance can be determined by application of Ohm's Law.

Another method of indirect measurement requires only the use of a voltmeter of known internal resistance (Rm = full-scale reading × ohms-per-volt). The meter is first used to determine the supply voltage. It is then connected in series with the unknown resistor and a second reading taken. The unknown resistance may then be found from the equation:

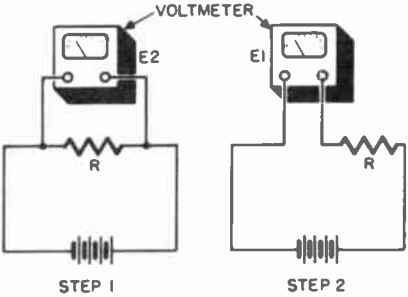


Fig. 17a.—Indirect method of measuring resistance with only a voltmeter.

$$R = Rm \frac{E_1 - E_2}{E_2}$$

where Rm is the internal resistance of the meter
R is unknown resistance
E_1 is the supply voltage
E_2 is voltage measured with meter in series

INDUCTANCE AND INDUCTIVE REACTANCE MEASUREMENTS

29. Reactance Measuring Methods.—The inductance of low-frequency coils, chokes, and similar inductive devices can be determined approximately by means of reactance measuring methods. Fairly accurate measurements are obtained with relatively simple circuits, which require only an AC source of known frequency, a voltmeter (100-ohms-per-volt), and a 1000-ohm resistor. For measuring inductances between about 0.5 henry and 5 henrys, the unknown coil L_x is connected as shown in Figure 18A; for measuring larger coils—from about 5 henries to 50 henries—the coil L_x is usually connected as shown in Fig. 18B. In both circuits: readings of the AC voltmeter are inversely proportional to the *impedance* of the coil being measured; but after proper calibration, the meter can be used for direct indications of inductive reactance. With due consideration of the DC resistance of the coil being measured, the value of inductive reactance can be calculated from the equation:

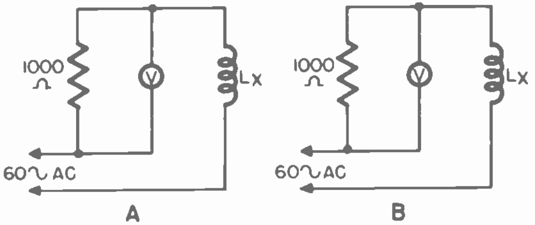


Fig. 18 Two methods of measuring the inductive reactance of coils used at power and audio frequencies.

$$X_L = \sqrt{R^2 - Z^2}$$

where all values are in *ohms*.

Then, the approximate value of inductance *in henries* can be determined from the equation:

$$L = \frac{X_L}{6.28\,f}$$

The meter can be calibrated by checking various inductances of known value against the resulting deflection of the AC voltmeter, and plotting suitable calibration curves for practical use. Indications of coil inductance obtained by reactance methods are likely to be only approximate; for more accurate measurements a suitable AC bridge should be employed.

30. Bridge Measuring Methods.—Extremely accurate measurements of the inductance of power- and audio-frequency coils, chokes, and similar inductive devices can be obtained with an AC inductance bridge—by means of which an unknown inductance is measured by comparison with a standard. Conventional AC bridge circuits are utilized for this purpose—with the condition of balance usually achieved by use of a variable inductance standard. For greatest accuracy, the ratio between unknown and known inductances should be kept as small as possible. However, good accuracy can be obtained with ratios as high as 100-to-1 when the detector or balance indicator is sufficiently sensitive. The source of energy is an audio frequency

—usually 1000 cycles—and the balance indicator is either a pair of headphones or some type of visual electronic device. Since the inductance of a coil is influenced by any flow of direct current, suitable allowance must be made for this effect in measuring choke or filter coils and transformer windings. Bridge measuring methods are not applicable to IF or RF coils which must be measured at the high frequencies at which they are normally used in RF circuits.

31. Measurements at Radio Frequencies.—The inductance of IF and RF coils is measured at the normal frequency (or frequencies) of operation according to the *resonance method*. An important requirement of this measuring procedure is an accurately calibrated variable capacitance standard having a range from about 500 to 1000 *micromicrofarads*. This condenser is connected in parallel with the unknown inductance to be measured, and the circuit combination is tuned by means of the capacitance standard.

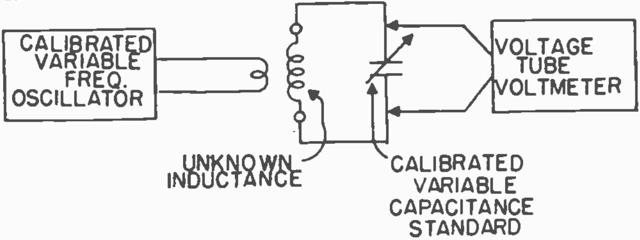


Fig. 19 Resonance method of measuring inductance at radio frequencies.

In one circuit arrangement (Fig. 19), this parallel combination is supplied RF power from a calibrated oscillator and is then tuned to resonance—the condition of resonance being indicated by means of a conventional vacuum-tube voltmeter. The oscillator *frequency* (in kilocycles) and the value of capacitance (in micromicrofarads) is noted; then the oscillator frequency is changed to the second harmonic of the original frequency, the parallel circuit is tuned to resonance, and a *second* set of measurements are noted for this second-harmonic frequency. Two sets of measurements are necessary in order to minimize errors introduced by distributed capacitance in the coil at certain frequencies. By combining both sets of measurements, the true value of inductance is determined by the following equation:

$$L = \left(\frac{1}{C_1 - C_2} \right) \left(\frac{10^{12}}{13.15\ f_2^2} \right)$$

Where L is in microhenries,

C_1 is the capacity in uuf required to tune to frequency f_1

C_2 is the capacity in uuf required to tune to frequency f_2

f_1 is the initial frequency in kilocycles

f_2 is the second-harmonic frequency in kilocycles.

Using another measuring arrangement (Fig. 20), a similar combination of standard capacitance and unknown inductance (in parallel) is coupled to a *grid-dip meter* to obtain identical results. A grid-dip meter consists, in part, of a variable oscillator and a grid-dip resonance indicator. With the parallel circuit—of known capacitance and unknown inductance—loosely coupled to the oscillator, the frequency of the oscillator is varied until a distinct dip in the grid-dip meter is observed. With this simplified measuring procedure, the value of inductance is determined by the equation:

$$L = \frac{25{,}300}{C f}$$

where L is in microhenries,
C is in micromicrofarads,
f is in megacycles.

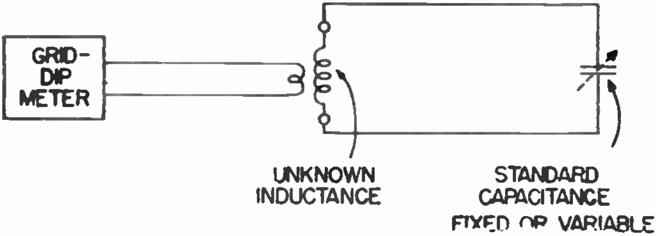


Fig. 20 Method of measuring inductance with grid-dip meter.

CAPACITANCE AND CAPACITIVE REACTANCE MEASUREMENTS

32. Reactance Measuring Methods.—The capacitance of condensers can be determined approximately by means of reactance measuring methods, using relatively simple circuits which require only an AC source of known frequency, a voltmeter (1000-ohms per-volt), and, in some cases, a 1000-ohm resistor. For measuring capacities between about 0.001 and 0.1 microfarad, the unknown condenser C_x is connected as shown in Figure 21A; for measuring capacities between about 0.1 and 10.0 microfarads, the condenser C_x is connected as shown in Figure 21B; large values

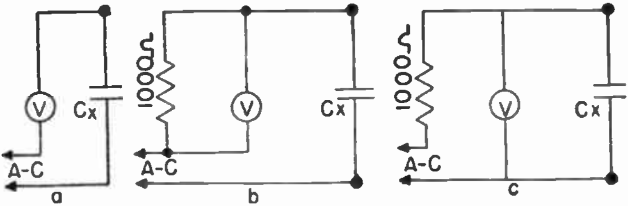


Fig. 21 Three methods of measuring capacitive reactance.

of capacitance are sometimes measured more easily by means of the circuit shown in Figure 21C.

In all of these circuits: readings of the AC voltmeter are inversely proportional to the reactance of the condenser at the frequency of measurement. Accordingly, the meter can be calibrated directly in capacitance reactance. The approximate value of capacitance *in microfarads* is determined from the equation:

$$C = \frac{1}{6.28\ f\ X_c} 10^6$$

where f is in cycles.

The meter can be calibrated by checking various capacities of known value against the resulting deflection of the AC voltmeter and plotting suitable calibration curves for practical use.

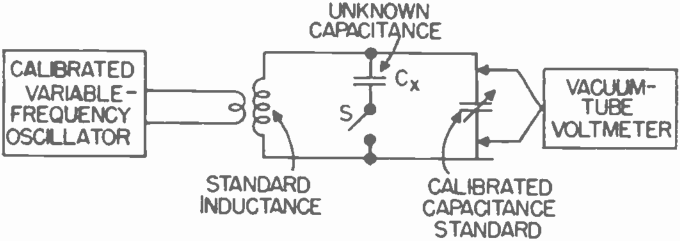


Fig. 22 Resonance method of measuring capacitance at radio frequencies.

Indications of capacitance obtained by reactance methods are likely to be only approximate; for more accurate measurements a suitable AC bridge should be employed.

33. Bridge Measuring Methods.—The most accurate measurements of capacitance can be obtained with any of the several types of AC capacity bridges—by means of which a condenser of unknown capacitance is measured by comparison with a standard. Conventional AC bridges are utilized for this purpose—with the condition of balance achieved by use of a variable capacitance standard. The source of energy is an audio frequency—usually 1000 cycles—and the balance indicator is either a pair of headphones or some type of visual electronic indicator.

For greatest accuracy in balancing such a bridge, the ratio between the unknown and known capacitance should be kept as small as possible. Often good accuracy can be obtained with ratios as high as 50-to-1, if the detector or balance indicator is sufficiently sensitive.

34. Measurements at Radio Frequencies.—Capacitance is measured at radio frequencies according to the resonance method. Required for RF measurements is an accurately calibrated variable condenser having a range usually from about 500 to 1000 *micro-microfarads,* and a fixed coil of any suitable inductance; these two components represent the capacitance and inductance standards, and are connected in parallel to form a tuned circuit. In one circuit arrangement (Fig. 22), this parallel combination is supplied RF power from a calibrated oscillator and is then tuned to resonance, the latter condition being indicated by means of a vacuum-tube voltmeter. The exact value of capacitance standard is noted carefully. Then, the unknown capacitance C_x is connected into the parallel circuit, by means of switch S, upsetting the resonant tuning. With the oscillator frequency remaining undisturbed, the capacitance standard is readjusted until the parallel circuit is again brought to resonance at the oscillator frequency. The value of the unknown condenser is then determined by the difference (in micromicrofarads) between the two settings of the capacitance standard. Using another measuring arrangement (Fig. 23), a similar combination of a capacitance standard and an inductance standard (in parallel) is coupled to a *grid-dip meter* to obtain similar results.

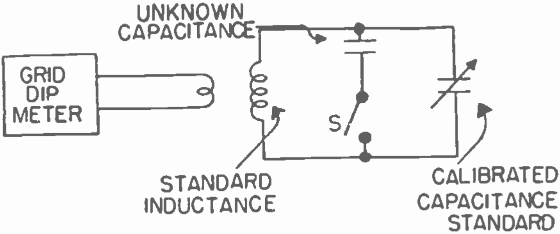


Fig. 23 Method of measuring capacitace with grid-dip meter.

A grid-dip meter consists, in part, of a variable oscillator and a grid-dip resonance indicator. With the parallel circuit—of known capacitance and fixed inductance—loosely coupled to the oscillator, the frequency of the oscillator is varied until a distinct dip in the grid-dip meter is observed. The unknown condenser C_x is then connected across the parallel circuit—by means of switch S—and the calibrated capacitance standard is readjusted and returned for resonance. The unknown capacitance is then determined by the difference (in micromicrofarads) between the two dial settings of the capacitance standard.

35. Leakage Indicators.—Possible condenser leakage can be checked either by *ohmmeters,* which give only approximate indications, or by *condenser meters and leakage testers,* which give fairly good indications of leakage and approximate measurements of reactance at low (power) frequencies. Since condenser leakage is determined by insulation resistance, ohmmeters are used extensively for initial leakage tests. Paper condensers normally have a resistance (between terminals) of over 50 megohms for each microfarad of capacitance; mica condensers should have a resistance greater than 100 megohms; power-circuit electrolytic condensers should have a resistance in excess of 500,000 ohms; other electrolytic types should have a resistance of at least 50,000 ohms.

Condenser meters and leakage testers are similar to the ohmmeter in operation, but require a source of 60-cycle AC power;

since these testing instruments give an indication of reactance, based on a known frequency and wave form, the scales are calibrated directly in microfarads. It should be noted that these are indicating, *not measuring* meters. Accurate leakage measurements must be made at the DC voltage rating of the particular condenser under test.

Q MEASUREMENTS

36. Frequency Variation Methods.—The Q (figure of merit) of tuned circuits is ordinarily measured directly by either of two *frequency-variation methods.* Since the presence of resistance in a tuned circuit causes a broadening of the resonance curve, the Q of a tuned circuit can be determined by measuring the frequency difference between the two points at which the circuit resistance equals the circuit reactance or, in other words, the two points at which the output voltage equals 70.7 percent of the peak voltage.

One circuit arrangement for determining these points requires the use of a calibrated frequency oscillator and vacuum-tube voltmeter to determine the bandwidth (Fig. 24). After first noting the frequency and RF voltage *at resonance,* the frequency of the oscillator is varied each side of resonance—until the vacuum-tube voltmeter reads 70.7 percent of its original value; the value of Q is then determined by the resonant frequency F_r and the bandwidth F_2-F_1 (where $F_2 > F_1$), as given by the equation:

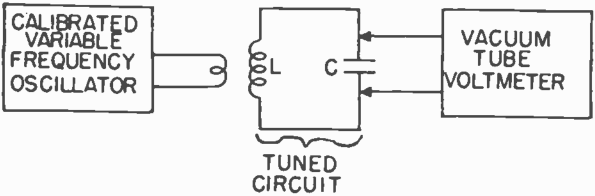


Fig. 24 Method of measuring Q with calibrated variable oscillator.

$$Q = \frac{F_R}{F_2 - F_1}$$

In another circuit arrangement (Fig. 25), the oscillator frequency is fixed and a calibrated variable capacitance is used to determine the bandwidth. First, the value of capacitance (C_R) at resonance is noted; and then the capacitance values on either side of resonance at which the V-T voltmeter reads 70.7 percent of its original value. The value of Q is then determined by the equation:

$$Q = \frac{2\,C_R}{C_2 - C_1}$$

37. Resistance Neutralization Method.—Measurement of the Q (figure of merit) of a tuned circuit is very accurate by this method, but the procedure requires considerable equipment of a specialized nature. The tuned circuit to be measured is first placed in the plate circuit of a dynatron oscillator, and the bias voltage on the grid of the dynatron is varied to a point where the tube is almost on the point of going in and out of oscillation. At such a point, the negative resistance of the dynatron is equal to the parallel impedance of the tuned circuit; and the negative resistance of the dynatron is equal to the resonant impedance of the tuned circuit. Accordingly, after determining the inductance of the coil by means of a bridge or other method, the Q of the tuned circuit can be computed by the equation:

where R_N is the negative resistance of the dynatron, *in ohms*
L is in henries.

$$Q = \frac{R_N}{6.28\ f\ L}$$

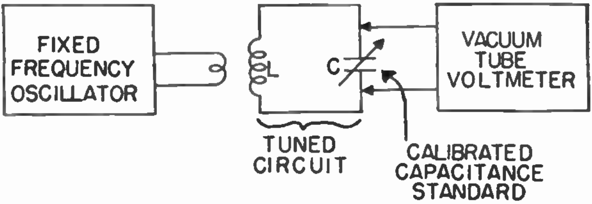


Fig. 25 Method of measuring Q with fixed oscillator and calibrated capacitance standard.

RESONANT FREQUENCY MEASUREMENTS

38. Grid-dip Meters.—The resonant frequency of a transmission line, antenna, or parallel tuned circuit can be determined by means of a *grid-dip meter,* which consists ,in part, of a self-excited oscillator and a grid-current indicating meter. In making resonant frequency measurements, the tuned circuit to be measured is coupled to the oscillator coil of the instrument. Then: as the calibrated capacitance is varied, a pronounced decrease or "dip" in grid current takes place at the resonant frequency of the tuned circuit. This "dip" indicates that RF power is being drawn from the self-excited oscillator, which occurs only at the resonant frequency of the tuned circuit. In this manner the resonant frequency is determined easily and with considerable accuracy.

AUDIO EQUIPMENT MEASUREMENTS

39. Output Power.—Accurate measurements of the output power of audio amplifying equipment require (1) a calibrated source of audio-frequency test signals connected in the input circuit, and (2) a load resistance and suitable indicating meter connected in the output circuit. There are three methods of measurement (Fig. 26) based on the type of instrument used. Output power can be determined by measuring the current flowing in the load resistance by means of a thermocouple-type meter (Fig. 26a)—by measuring the voltage drop across the load resistance with a vacuum-tube voltmeter (Fig. 26b)—or by using a power output meter with a self-contained load resistance (Fig. 26c).

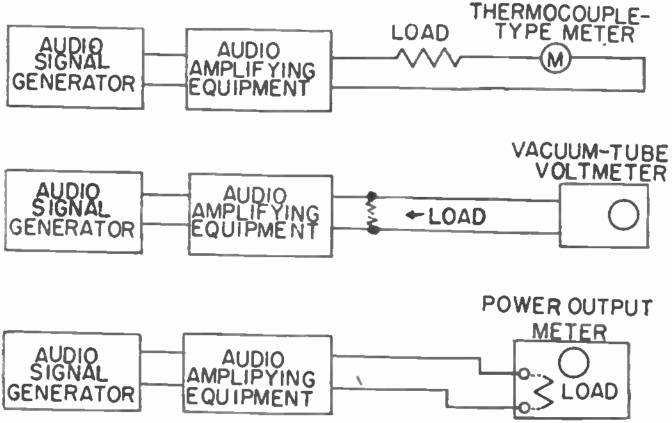


Fig. 26 Three methods of measuring output power of audio amplifying equipment. (a) Use of thermocouple-type meter, (b) Use of vacuum-tube voltmeter, (c) Use of power output meter.

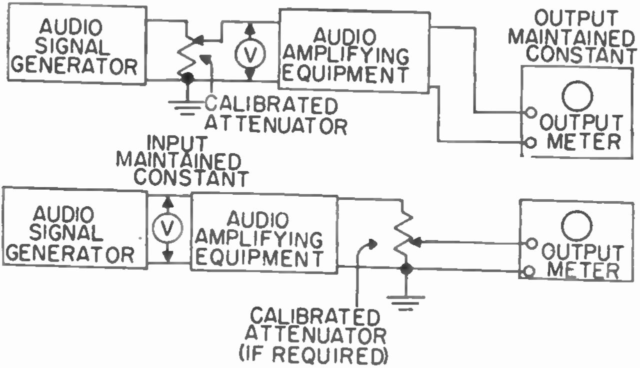


Fig. 27 Two methods of measuring amplification or gain of audio amplifying equipment. (a) Output voltage maintained constant, (b) Input voltage maintained constant.

40. Amplification or Gain.—The amount of amplification provided by audio-frequency amplifiers is an important characteristic of such equipment, and is, measured accurately by either of two basic methods. In the most popular method (Fig. 27a), a calibrated audio-frequency generator supplies any desired voltage (at any audio frequency) across the terminals of a calibrated attenuator. This precision attenuator is used to control the amount of input voltage to such values which produce a specified output voltage—as indicated by the output meter. In this way the amplification of the circuit is determined *at one or more frequencies* by measuring the input voltage necessary to maintain a constant output voltage.

In the second method of measurement (Fig. 27b), a calibrated audio-frequency generator provides a constant input voltage to the equipment being measured, and the circuit amplification *at one or more frequencies* is determined by measuring the output voltage resulting from the constant input voltage. The ratio of input voltage to output voltage is a factor in determining the gain of the amplifying equipment. Since this value of gain varies over a wide range of audio frequencies, a more practical indication of true amplification is a plot or graph of the gain for each of a wide range of audio frequencies; such a plot is known as the *frequency response* of the audio amplifying equipment.

41. Frequency Response.—Since the frequency response of audio amplifying equipment is essentially a plot of many *individual* values of gain versus frequency, acceptable frequency response curves could be plotted by either of the two basic methods used for measuring gain (Fig. 27). However, the task is considerably simplified by utilizing the circuit arrangement shown in Fig. 28a. After establishing a reference frequency (of

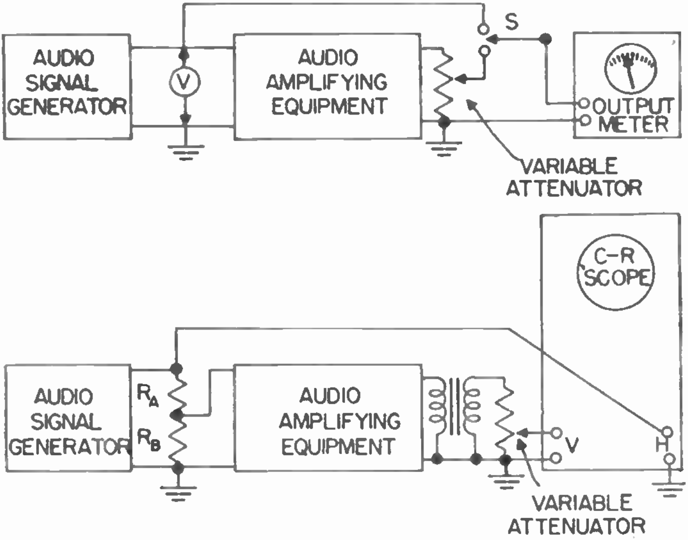


Fig. 28 Two methods of plotting frequency response curves for audio amplifying equipment (a) With output meter, (b) with oscilloscope.

either 400 or 500 cycles), the sensitivity of the output meter is adjusted to read the input voltage necessary to produce a specified output voltage; and the variable attenuator is so adjusted that when the switch is operated, input and output voltage readings coincide at the reference frequency. As the frequency of input voltage is varied, a plot of the resulting changes in output voltage—above or below the reference level—is an accurate frequency-response curve for the equipment being measured.

In some instances—such as high-gain amplifier circuits—the input audio signal is too low to be read accurately on the output meter; then it is more desirable to use the oscilloscope measuring circuit shown in Fig. 28b. In this method, the audio signal generator provides a simple voltage divider network—R_A and R_B—with a (large) voltage comparable to the output voltage; the voltage divider is so arranged that the ratio R_A/R_B corresponds to the ratio of input voltage to output voltage. Since an oscilloscope replaces the previous output meter, an additional transformer and variable attenuator are required for impedance-matching purposes. After establishing a reference frequency (of either 400 or 500 cycles), the frequency of the input voltage is varied over a wide range and the resultant changes in output voltage are recorded for plotting the frequency response curve.

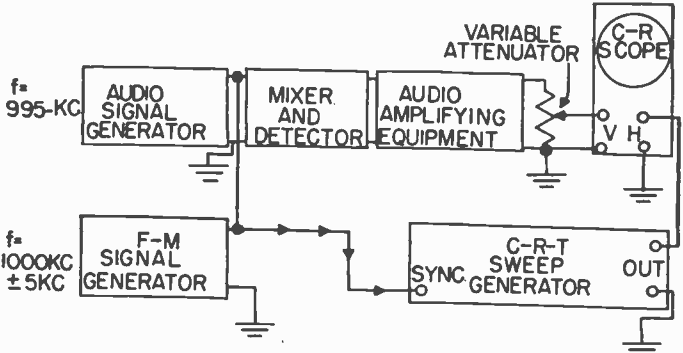


Fig. 29 Method of obtaining scope trace of frequency response curve.

In both of the above procedures, considerable laborious and tiresome plotting of data is required in order to obtain a frequency response curve. When extreme accuracy is not too great a factor, it is possible to obtain an instantaneous *visual* frequency response curve by means of a special measuring circuit (Fig 29) which provides a fairly accurate scope trace representing the complete frequency response of the audio amplifying equipment being measured. Two signal generators are used; an FM oscillator—whose frequency is swept, at a 60-cycle rate, between 1005 kc and 995 ks—is mixed with the 995 kc output of a fixed-frequency oscillator. This produces a *difference frequency*—continuously varying between 0 and 10 kc—which is rectified and used to control the vertical deflecting plates of the oscilloscope. Vertical amplitude is directly—*not* logarithmically—proportional to the output voltage, and the center frequency (5000 cycles) of the horizontal scale is one-half the maximum deviation. The resulting image on the oscilloscope is a double trace (Fig. 30), which may be in phase or out of phase, which may begin with either 0 kc or 10 kc, and which usually requires study and proper interpretation to be of practical value.

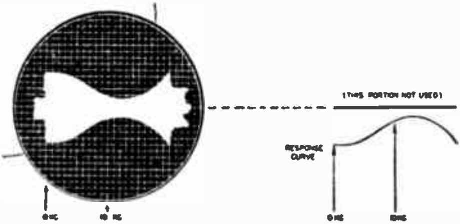


Fig. 30 Typical scope pattern of frequency response curves obtained with circuit shown in Figure 29. Interpretation of pattern (at right) shows useful portions of scope trace.

42. Phase Shift.—Any phase displacement between the input and output voltages of audio-frequency equipment is often of serious importance, since it may represent a time delay that is unequal for all frequencies being amplified. Although such distortion effects give approximate indications of phase displacement, the most practical method of actually *measuring* phase shift or phase displacement is by means of a cathode-ray oscilloscope (Fig. 28b). It is imperative that the input and output voltages be connected, respectively, to the horizontal and vertical pairs of deflecting plates. Also, the two voltages must be of the *same* frequency, and must be adjusted for *equal* magnitude. This results in a scope pattern which, when properly interpreted, indicates the presence of any phase displacement between the two voltages. If there is *no* phase difference, the trace on the scope is an oblique line indicating a *zero* phase relation. As the phase *difference* gradually increases, the oblique line becomes a flattened ellipse, which gradually broadens until the trace becomes a circle when the phase displacement is exactly 90 degrees. Then, the entire process is reversed—and the circle is compressed gradually until it becomes a straight line at 180 degrees.

Typical scope patterns indicating various degrees of phase displacement between two voltages—of equal magnitude and frequency—are shown in Fig. 31 for reference purposes. For phase measurements between 180 degrees and 360 degrees, a "reverse" arrangement providing identical scope patterns is employed.

43. Distortion.—Several kinds of distortion are encountered in audio amplifying equipment. The existence of *frequency distortion* can be determined—and often localized to a specific frequency or group of frequencies—through careful plotting of

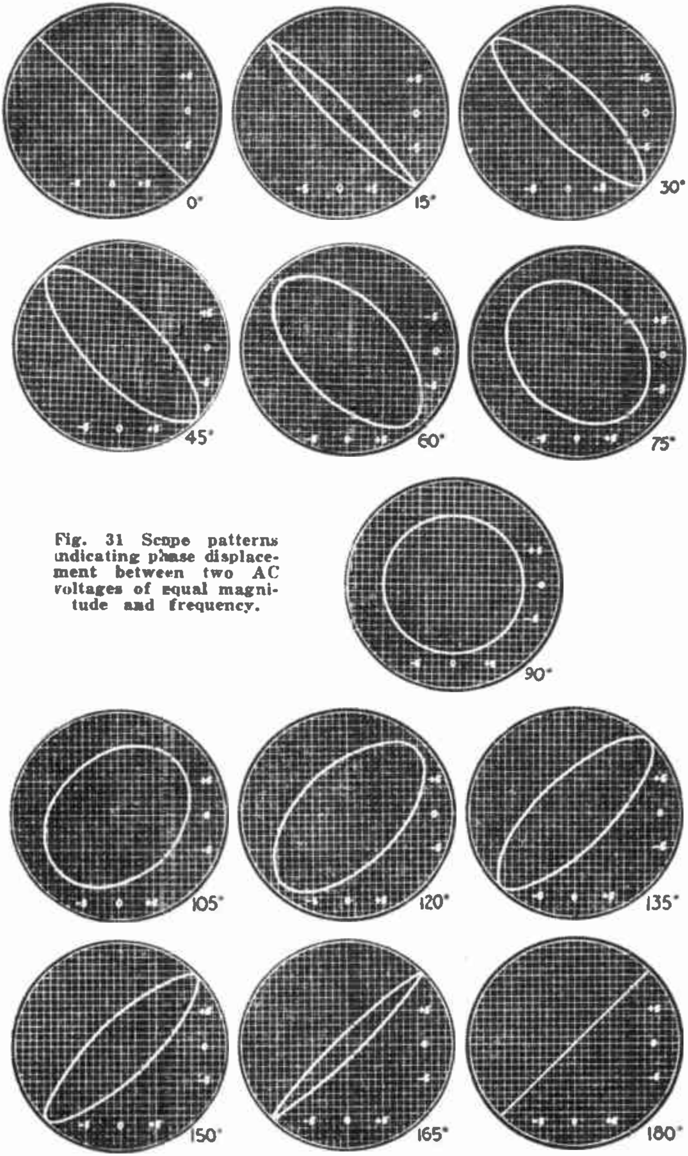


Fig. 31 Scope patterns indicating phase displacement between two AC voltages of equal magnitude and frequency.

frequency response curves (see paragraph 41). *Amplitude distortion* is measured by applying a sine-wave voltage to the amplifier input and noting the output wave shape on an oscilloscope or wave analyzer. *Phase distortion* can be detected, and usually measured, by means of oscilloscope measurements. A far more troublesome type of distortion—known as *intermodulation distortion*—is due to the nonlinearity of an amplifier or network. A suitable arrangement for checking and measuring this form of distortion (Fig. 32) employs an input test signal —obtained from a 60-cycle AC power source and from a 1000-cycle fixed-frequency signal generator. The amplitude of the 60-cycle input voltage is very high and almost overloads the amplifier under test; but the 1000-cycle voltage is maintained at a much lower amplitude. A high-pass filter removes the 60-cycle component of the amplifier *output voltage*, so that only the high-frequency signal appears on the vertical deflecting plates of the scope; a low-frequency timing wave is applied directtly to the other pair of plates. If the amplifier is entirely linear *at low frequencies*, the 1000-cycle signal appears on the scope as a rectangular trace. However, if any distortion is present—due to intermodulation by the 60-cycle signal —the scope pattern will have sloping and other nonlinear effects.

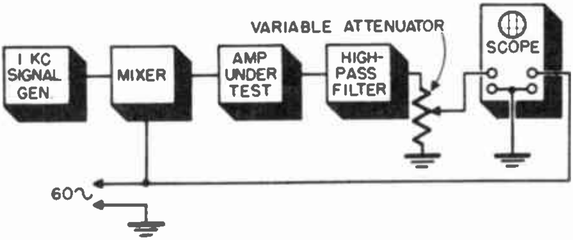


Fig. 32.—Method of checking intermodulation distortion in audio amplifying equipment.

TRANSMITTING EQUIPMENT MEASUREMENTS

44. Carrier Frequency.—The most accurate methods of measuring the carrier frequency of radio transmitters is by *comparison* with primary or secondary standards of frequency. Deviations from assigned carrier frequencies are indicated by deviation meters, or frequency monitors, and are standard equipment in all commercial radio stations.

When highly accurate measurements are not required, the frequency of radio transmisions can be determined by means of either an absorption wave-meter, a heterodyne frequency meter, an RF bridge, or a suitably calibrated radio receiver. Frequencies above 300 megacycles are usually measured with a Lecher-wire system.

45. Output Power.—Radio-frequency output power is conveniently measured by coupling a *dummy antenna circuit* to the output tank of the transmitter being measured. Such a dummy antenna consists essentially of a noninductive resistor *R* in series with an RF thermocouple-type current meter, but these essential components may be arranged in any of several different ways (Fig. 33). When the transmitter is tuned to resonance, the output power is determined by measuring the amount of current flowing in the dummy antenna circuit and then applying the following equation:

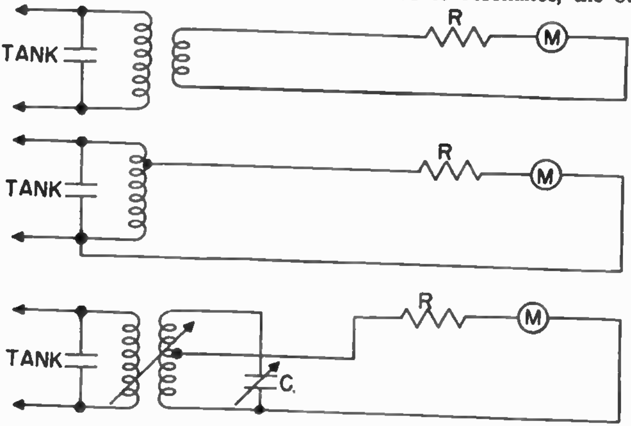


Fig. 33 Three methods of measuring output power with a dummy antenna circuit.

$$P \text{ (Watts)} = I^2 R$$

Specially constructed noninductive resistors are used in dummy antenna circuits; these range in value from about 70 ohms to 600 ohms, in order to simulate impedance values usually encountered in measurements of transmitting equipment. Light bulbs can be used in place of resistors for approximations of output power based on estimated light brilliance.

46. Plate Efficiency.—The ratio of AC output power to the DC power supplied to the final stage of a transmitter is known as the *plate efficiency* of the output stage. This plate efficiency, in percentage, is determined by separately measuring the AC output power and the DC plate voltage and plate current of the output stage, and then performing the following calculation:

$$\text{Plate efficiency (percent)} = \frac{P}{EI} \times 100$$

where P is the AC power, output *in watts*

A plate efficiency of between 65 and 75 percent represents a satisfactory plate efficiency for most practical purposes.

47. Oscilloscope as Modulation Indicator.—The cathode ray oscilloscope is widely used as an amplitude-modulation monitor as well as a measuring instrument. Since it is capable of presenting accurate *visual* indications of the modulated output of AM transmitters, the oscilloscope has become the most reliable instrument for determining *percentage of modulation*. Either of two types of modulation patterns can be provided by the oscilloscope. When coupled only to the output tank circuit, as shown in Fig. 34, the oscilloscope produces *wqve-envelope patterns* which represent the actual shape of the modulation envelope of the transmitted wave.

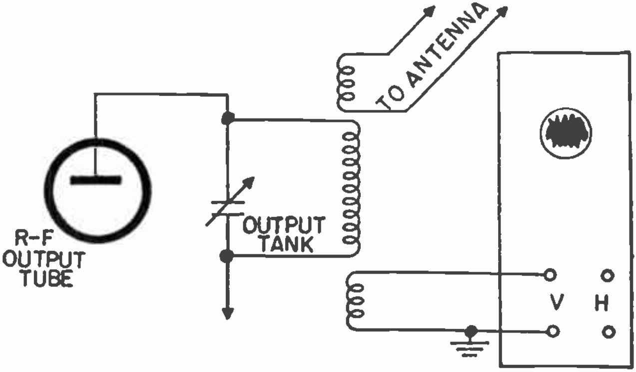


Fig. 34 Method of using oscilloscope to obtain wave-envelope patterns.

When connected as shown in Fig. 35, the oscilloscope produces visual plots of the modulation characteristic, known as *trapezoidal patterns*. Although a horizontal sweep voltage is required for obtaining wave-envelope patterns, oscilloscope connections are much simpler than those necessary for the trapezoidal patterns. Typical examples of these two types of scope patterns are shown in Fig. 36, representing several conditions of modulation.

48. Spurious Sidebands.—The transmission of spurious sidebands well beyond the normal carrier band-width can be detected by means of a superheterodyne receiver equipped with a sharply tuned crystal filter. With the receiver located some distance from the transmitter (to prevent overloading) and with the crystal filter and a beat oscillator in operation, any spurious sidebands are detected as the presence of irregular beat notes coinciding with high-percentage modulation of the transmitter is a reliable indication of spurious sidebands. A frequency bandwidth from 4 to 5 kilocycles each side of the carrier frequency should be explored. Sidebands at frequencies more than 5 kilocycles from the carrier frequency are of weak strength and unimportant.

49. Noise or Hum.—The presence of noise or hum on the transmitted carrier frequency can best be detected aurally by means of a very sensitive radio receiver located remotely from the radio station. Hum may originate with any stage or circuit of a transmitter; but it is usually most prevalent in the radio-frequency and modulator stages of the transmitter. Improper power-supply filtering is the source of most hum present on the transmitted carrier of a radio station. Random noise can be checked effectively with a cathode-ray oscilloscope.

50. F M Transmitters.—A number of special measuring and testing techniques are required for checking frequency-modulated and phase-modulated transmitters. Since either type of modulation takes place at a low level, and since subsequent tuned stages have no effect on the frequency deviation—modulation can actually be checked and measured when the RF sections of these transmitters *are not in operation.* Since the frequency deviation is identical for any frequency of audio modulation, it is the

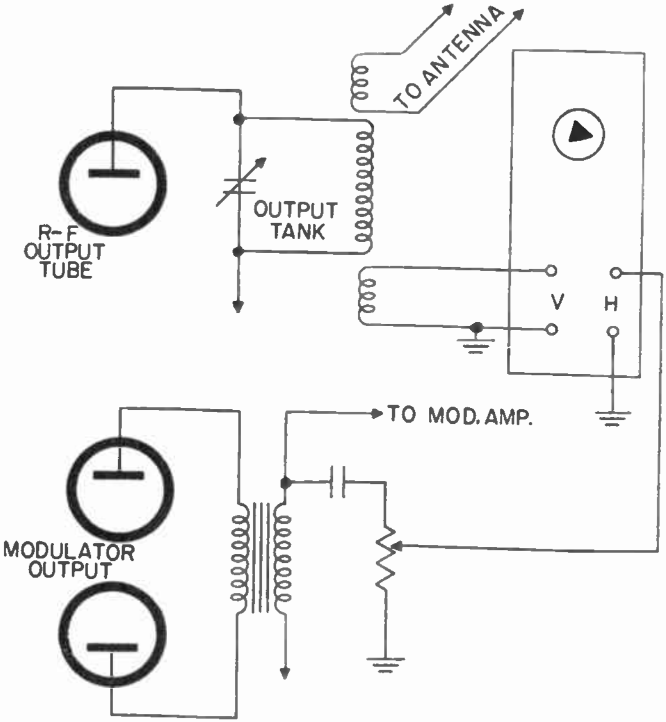
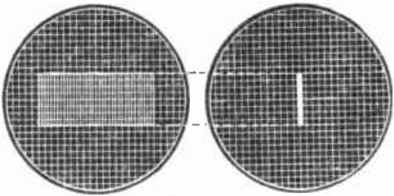


Fig. 35 Method of using oscilloscope to obtain trapezoidal patterns.

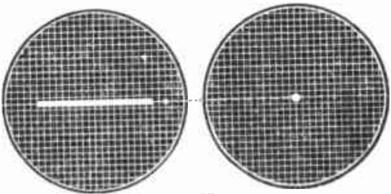
same for *zero* frequency or direct current. Thus, the application of an adjustable DC voltage to the modulator grid produces proportional changes in the oscillator frequency. By means of a suitable circuit (Fig. 37), the reactance modulator can be calibrated; and the degree of linearity can be determined by reference to this calibration. A conventional electron-ray tube — such as the type 6E5—can be put to good use as a modulation indicator, when connected as shown in Fig. 38; deflections at maximum deviation indicate so-called *100-percent* modulation. The presence of unwanted amplitude modulation in the output of an FM transmitter can be detected by close observation of the antenna current; normally there should be no change or difference in antenna current during operation of the transmitter, regardless of whether the transmitter is modulated or *un*modulated.

ANTENNA AND TRANSMISSION LINE MEASUREMENTS

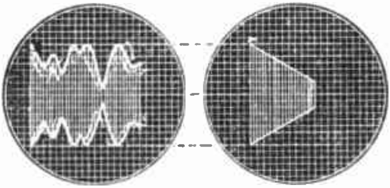
51. Field Intensity.—The relative strength of radio waves *under actual radiating conditions* is



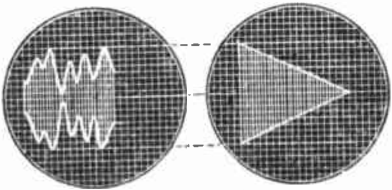
CARRIER ONLY



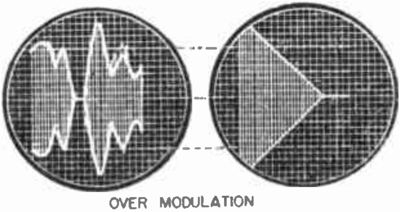
NO CARRIER



LESS THAN
100% MODULATION



100% MODULATION



OVER MODULATION

Fig. 36 Wave-envelope and trapezoidal patterns for equivalent modulation conditions.

measured by field intensity meters, which consist essentially of a receiving antenna, a tuned circuit, and an indicating device such as a rectifier-type microammeter or a vacuum-tube voltmeter. When provided with a pick-up loop or a small receiving antenna, absorption wavemeters can also be used to measure field intensity. More complex types of instruments—such as calibrated superheterodyne receivers—are used for greater accuracy. Relative values of field intensity are obtained by measuring the RF voltage induced in the receiving antenna.

Measurements are made at points more than five wavelengths distant from the radiating antenna and, if possible, at heights corresponding with the preferred angle of radiation. Field intensity is measured and expressed in terms of the universally adopted units: *volts per meter, millivolts per meter,* or *microvolts per meter.*

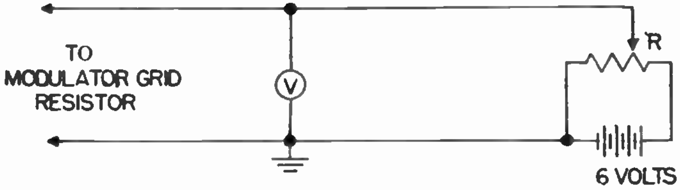


Fig. 37 Method of determining frequency deviation of a reactance-tube modulated oscillator.

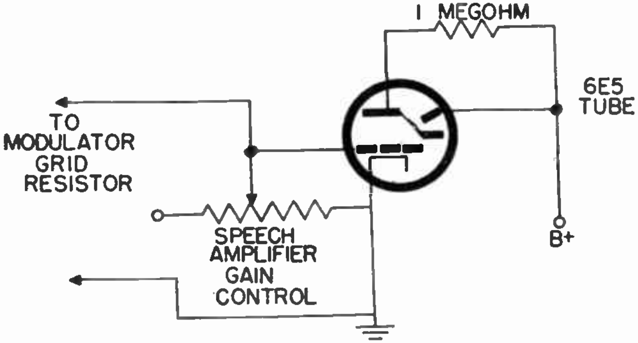


Fig. 38 Modulation-percentage indicator for frequency-modulated and phase-modulated transmitters.

52. Radiation Patterns.—Complete field-intensity patterns—indicating relative radiation by a transmitting antenna—can be measured with a field intensity meter and a small compass. The transmitting antenna is arranged to *rotate* at its site or location, and the field intensity meter is installed at a fixed site at least ten wavelengths distant. Then, for every 5 or 10 degrees of antenna rotation, the resulting values of field intensity—as observed on the meter—are noted in tabular form. This data is plotted on polar-coordinate graph paper (Fig. 39) with *zero* field strength located at the center of the graph and values of intensity plotted radially. Characteristic directional effects of many types of antennas are more clearly emphasized by such radiation or field intensity patterns.

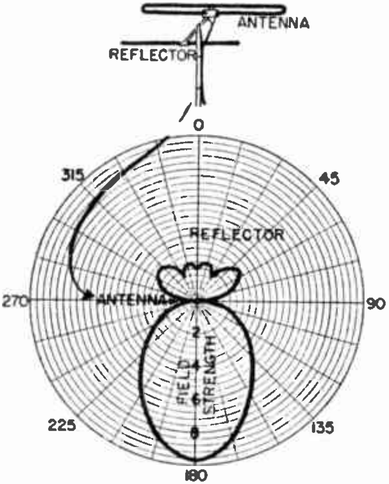


Fig. 39 Radiation pattern for high-frequency television antenna.

53. Antenna Impedance.—This important characteristic of antennas can be measured in either of two ways: by the *variation method*, or by the *substitution method*. In either case, considerable accuracy of measurement is required, because the value of antenna impedance determines the reactance of the antenna circuit as well as the coupling required to match a transmission line to the antenna.

In the variation method (Fig. 40), the antenna circuit is tuned to resonance with the switch S closed—and the value of antenna current I_o is noted. Then the switch S is opened, placing a known resistor R_s in series with the resonant circuit—and a new value of antenna current I_s is noted. The antenna impedance (in ohms) is then determined by the equation:

$$Z = R_s \left(\frac{I_s}{I_o - I_s} \right)$$

where I_o is the antenna current with resistor R_s *out* of the circuit,
and I_s is the antenna current with the known resistor R_s in series with the circuit.

In the substitution method (Fig. 41), normal current flows in the antenna circuit when the switch S is in position *A;* this current is indicated by the galvanometer. When the switch S is in position B, however, the antenna is disconnected and replaced by a calibrated variable resistor R. With the transmitter output maintained constant, the variable condenser C is adjusted until the substituted circuit is resonant at the operating frequency of the transmitter. Then the resistance R is varied until the flow of current—as indicated by the galvanometer—is of the same value as when the antenna was connected in the measuring circuit. Thus, at resonance the antenna impedance

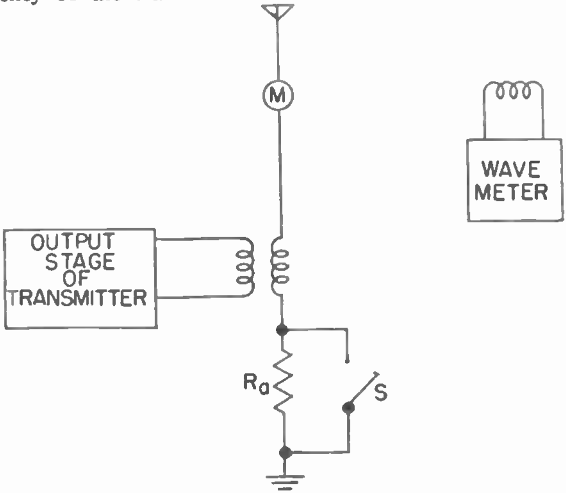


Fig. 40 Variation method of measuring antenna impedance.

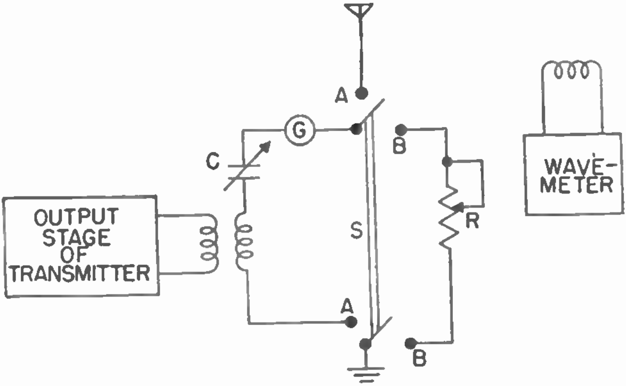


Fig. 41 Substitution method of measuring antenna impedance.

(resistance) is equal to the value of resistance R as determined directly from the calibration.

54. Resonant Frequency.—The frequency at which the antenna impedance is a resistance is known as the resonant frequency of the transmitting antenna. This fundamental frequency can be measured by means of a calibrated oscillator and some sort of meter indicating either the effect on the current in the antenna circuit or some other easily distinguishable effect. Usually the response of the antenna circuit under these conditions is measured with a sensitive thermocouple-type meter.

The resonant frequency can be determined similarly by means of the grid-dip meter and oscillator. Since every antenna can be tuned to *harmonic* resonance at a great many (harmonic) frequencies, care must be taken to measure only the fundamental resonant frequency—the magnitude of which can be estimated approximately by the physical dimensions of the antenna. Somewhat similar methods of measurement are used to determine the resonant frequency of tuned transmission lines.

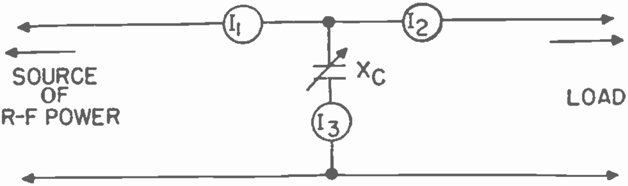


Fig. 42 Three-ammeter shunt-reactance method of measuring RF power.

55. Antenna Power.—The input power to an antenna is usually determined by measuring the flow of RF current and the amount of resistance *at the same point* in the antenna circuit, and then combining these quantities according to the equation:

$$P = I^2 R$$

Power can also be measured by means of the *three-ammeter shunt-impedance method* (Fig. 42), in which the power (in watts) flowing through the circuit is determined by the equation:

$$P = 2 X_c \sqrt{A\ (A-I_1)\ (A-I_2)\ (A-I_3)}$$

where I_1 is the current in meter 1
I_2 is the current in meter 2
I_3 is the current in meter 3

$$A = \frac{I_1 + I_2 + I_3}{2}$$

This method is also used to measure RF power in transmission lines.

56. Antenna Directivity and Gain.—The nature and degree of directivity of every major type of antenna differs in some respect, and carefully plotted radiation patterns (see paragraph 52) are the principal means of illustrating many directional characteristics.

Power gain—a related function of directional antennas—is a measure of increased radiation in any direction *with respect to the simplest type of antenna:* the half-wave dipole. Accordingly, *gain* is a power comparison; and usually it is expressed in terms of decibels. The power gain of a directional antenna can be measured with a fairly accurate field intensity meter, using an arrangement similar to that for measuring radiation patterns.

57. Standing Waves on Transmission Lines.—Current distribution along a transmission line provides an effective means of checking and testing the operation of the system. Primarily for the purpose of indicating current distribution and checking standing waves, a number of methods, meters, and special instruments are now in popular use. Rough approximations can be made with ordinary flashlight bulbs, which are connected across a few inches of the line being tested. Standing waves can also be detected with ordinary wavemeters equipped with a pick-up loop and a crystal rectifier. More accurate measurements are obtained with bridge-type standing wave indicators and many of the test instruments used for measuring resonant frequencies (see paragraph 54). Standing wave ratios are determined by taking meter readings at points of maximum and minimum current along transmission lines.

RECEIVING EQUIPMENT MEASUREMENTS

58. Sensitivity.—This important factor in the performance of a radio receiver represents an ability to respond to weak input signals. Sensitivity is defined in terms of input voltage which must be applied to a receiver in order to obtain a specified value of power output: 0.5 watts.

Sensitivity is measured by means of the arrangement shown in Fig. 43. The signal generator provides a fixed-frequency signal —modulated 30 percent at 400 cycles—which is applied to the receiver through a dummy antenna standard (Fig. 44). The minimum input voltage which produces a standard value of output power is actually a direct evaluation or measurement of sensitivity. A typical sensitivity curve of a broadcast receiver is shown in Figure 45. The limit of sensitivity is determined by (1) man-made and natural atmospheric noises, and (2) noises

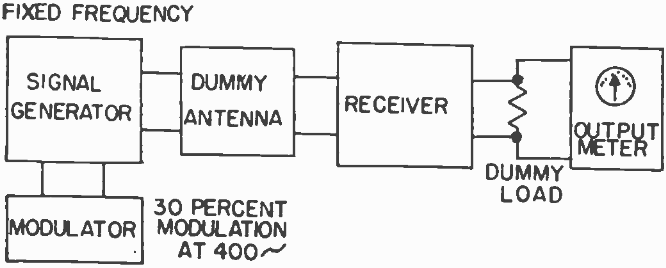


Fig. 43 Method of measuring receiver sensitivity.

developed or generated in the receiver itself. The latter category of noises is a large group, and distributed more-or-less uniformly over the entire frequency spectrum. For this reason, the signal-to-noise ratio of a receiver can be improved if the equipment is adjusted so that it responds only to a narrow band of frequencies.

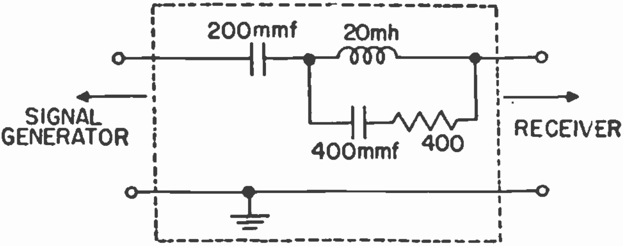


Fig. 44 Standard dummy antenna used for all tests and measurements of radio receiving equipment.

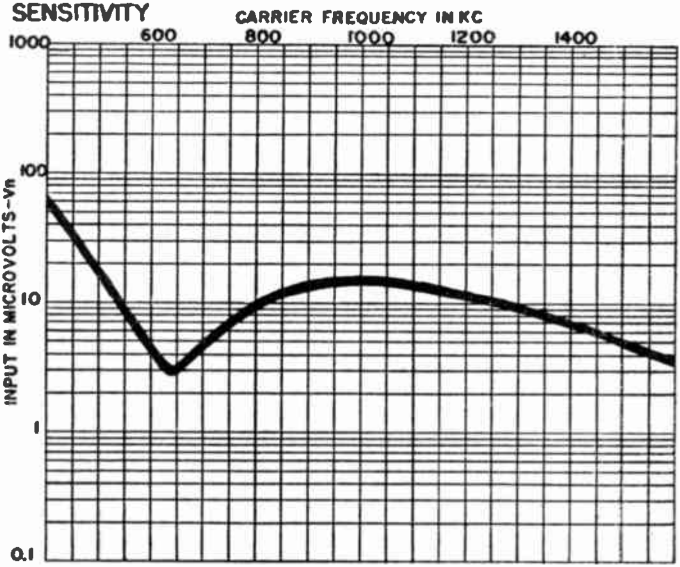


Fig. 45 Typical sensitivity curve of broadcast receiver, plotted on standard selectivity measurement graph.

59. Selectivity.—This receiver characteristic is defined as an ability to differentiate between a desired signal and other disturbances or signals occurring at slightly different or adjacent frequencies. Selectivity measurements are usually expressed in the form of a curve—similar to an inverted resonance curve—where value of input signal strength (required to maintain a constant output) are plotted against value of frequency. For radio receivers with manual volume controls or with AVC systems which can be disabled or removed, selectivity measurements are obtained by means of relatively simple circuits (Fig. 46). For receivers having operative automatic-volume-control systems, measurements of selectivity require the use of *two* signal generators, as shown in Fig. 47; one generator represents the desired signal (to which the receiver is tuned) and the second generator represents an interfering signal.

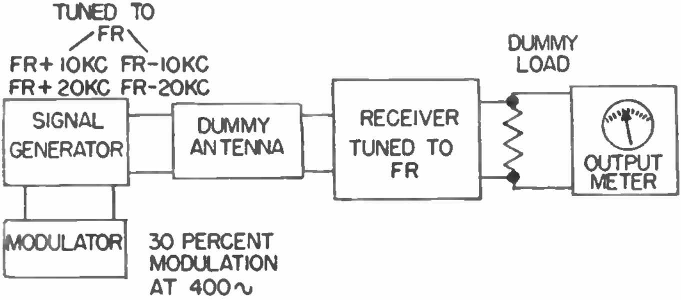


Fig. 46 Basic method of measuring receiver selectivity.

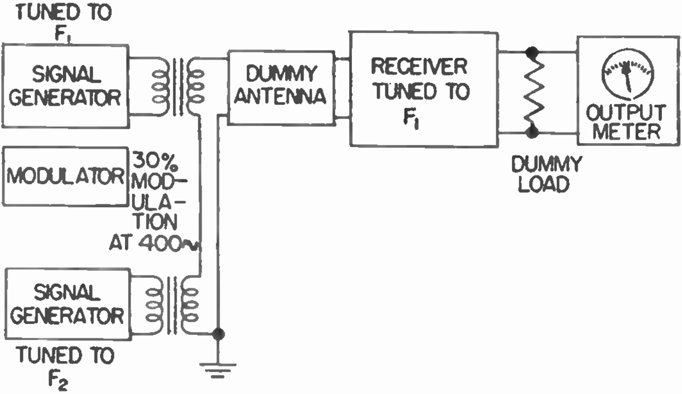


Fig. 47 Two-generator method of measuring receiver selectivity

Selectivity is measured in terms of the amplitude of the interfering signal required to produce the standard output power *and* as a function of the difference between the frequency of the interfering signal and the frequency of the desired signal. Measurements obtained by the two-generator method indicate, as well, the presence of any cross-modulation in the receiver circuit. Typical selectivity curves of a broadcast receiver are shown in Fig. 48.

Because of the close relation between the selectivity and the band-width, data on a particular receiver can be obtained by examining and measuring selectivity curves for the receiving equipment. When a selectivity curve is sharp and narrow, the receiver band-width will also be small—and useful only for CW or code reception. Audio- and voice-frequency circuits and apparatus require a band-width of nearly 10 kilocycles. For reception of frequency modulated signals, a band-width of between 40 and 50 kilocycles is desirable.

60. Stage Gain.—The amount of gain provided by any amplifier stage can be measured accurately without high precision laboratory instruments. The stage-gain of an audio-frequency voltage amplifier, or a power amplifier, can be determined with an AF signal generator, any type of input voltmeter, and a suitable power-output indicating meter (Fig. 49); if the signal generator is calibrated, the input voltmeter may not be required. Knowledge of the input voltage and the output voltage of any amplifying device permits a fairly accurate calculation of the amount of gain per stage. Similarly, the gain of an amplifier stage can be measured by means of vacuum-tube voltmeters connected across the input and the output of the amplifier stage, as shown in Fig. 50.

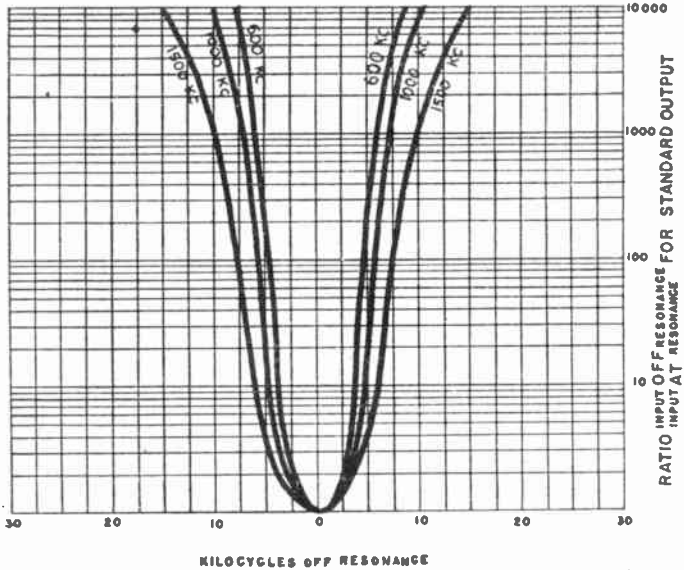


Fig. 48 Typical selectivity curves of broadcast receiver, plotted on standard selectivity measurement graph.

61. Fidelity.—This "quality" characteristic represents the ability of a radio receiver to reproduce with least distortion *all* of the modulation wave forms which were originally superimposed upon the carrier wave at the transmitter. A test of receiver fidelity shows the manner in which the audio output at a dummy load is dependent upon the modulation frequency. Fidelity is measured by first tuning the receiver and an RF signal generator to the same frequency, and then noting variations of receiver output resulting from changes or variations in the modulation frequency—*not* the carrier—of the signal generator. Tabulated results of a fidelity test are plotted in the form of a curve (Fig. 51), and approximate the shape of a radiation pattern.

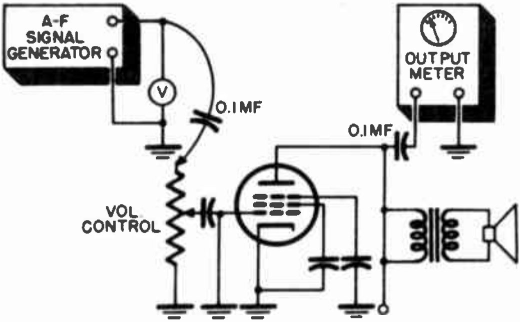


Fig. 49 Method of measuring stage-gain with signal generator and output meter.

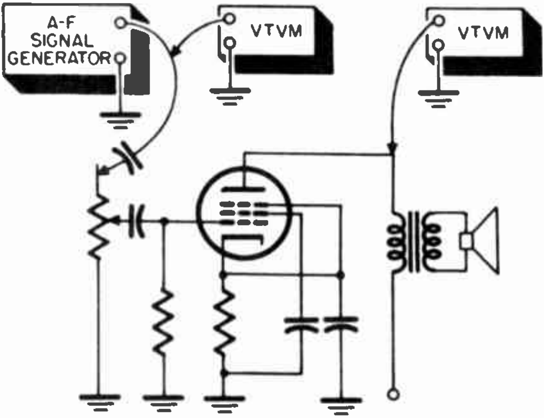


Fig. 50 Method of measuring stage-gain with vacuum-tube voltmeters.

SIGNAL TRACING

62. Instruments.—The technique of testing and checking the stage-by-stage progress of *signals* through a radio receiver, amplifier, or other communications device is known as *signal tracing.* Instruments especially designed for this important function are of two broad types: *tuned or multichannel signal tracers,* and *untuned signal tracers.* Regardless of the type of instrument, however, the practical advantages as well as the limitations of *any* kind of signal tracer must be understood in order to gain full usefulness of the test equipment. The requirements of a good signal tracer are as follows:

1. Connecting the instrument to a radio receiver should not detune, load, or otherwise influence the operation of the receiving set.

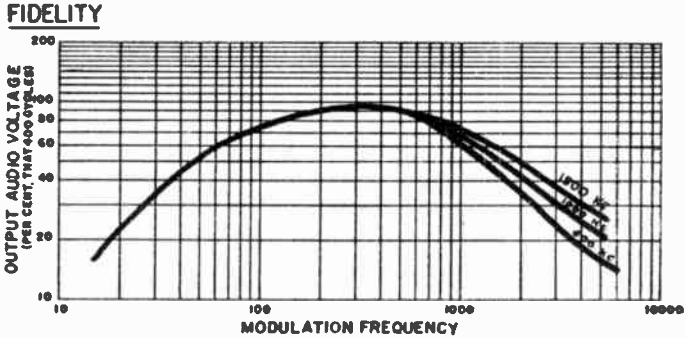


Fig. 51 Typical fidelity curve of broadcast receiver, plotted on standard fidelity measurement graph.

2. The *gain* of the signal tracer should be sufficient to permit its use with extremely weak signals.
3. The signal tracer should have a sensitive signal strength indicator.
4. The instrument should provide aural means for listening to the signal.

63. **Multichannel Signal Tracers.**—These test instruments —also known as *tuned* signal tracers—are extremely versatile in competent hands. The circuit of a typical tracer, the Rider Chanalyst, includes a special probe connected to an untuned amplifier, followed by three stages of RF amplification with a flat response over the broadcast band. A detector, with a type 6E5 tube indicates signal strength. Sufficient gain is available to observe minute signals from a test oscillator or from a station on the air. Separate circuits are provided for audio amplifier and oscillator checking, so that the signal can be "watched" at more than one point *at the same time.* Power supply operation can also be checked. A tuning eye watt meter shows power drain and a DC volt-meter monitors the plate voltage. Intermittents can be found and localized at the time they happen. Such an arrangement of multichannel observation and signal tracing is shown in Fig. 52.

64. Untuned Signal Tracers.—Signal tracers which use untuned amplifiers are now available at low cost. This type has the advantage of speed and ease of operation. Since no tuning is necessary, the same probe can be used anywhere in the receiver. But there is no multichannel feature which makes the Chanalyst so useful for finding intermittents. Tuned and untuned tracers have the common disadvantage of requiring an external signal source. On the other hand, using a signal generator for signal tracing does not eliminate the necessity for an output indicator.

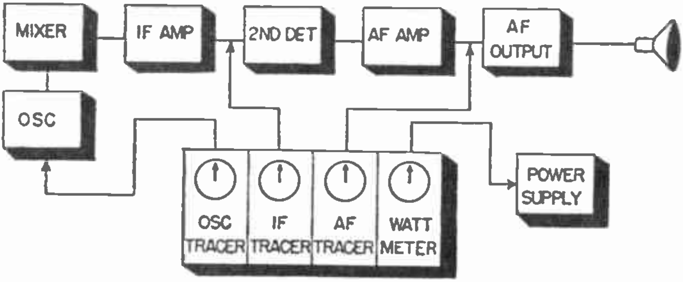


Fig. 52 Method of localizing intermittents in a superheterodyne receiver with a multichannel signal tracer.

65. Sensitivity.—An important characteristic of a signal tracer is its sensitivity. For example, the IF voltage output of a converter may vary from 150 to 1000 microvolts; sufficient tracer gain must be provided to give a good meter reading. Parts of a receiver cannot be tested in which even normal signals do not produce an indication. A tracer with a gain of 300 or better will usually produce results. When crystal or diode detectors are used, there is no gain in the detector and the tracer must be much more sensitive. With high gain, the usual care in shielding and decoupling is necessary. A high gain tracer can test antenna coils or loops. If the tracer is across the primary, no signal, *but a loud hum,* indicates an open circuit. No hum and no signal mean a short circuit. Very low hum and no signal would be observed if no stations were on the air, and the primary was in good condition. If the coil is good and the stations are transmitting, signals will be heard. At the secondary, a gain of 3 to 10 in home receivers is usual while in auto sets it may be from 10 to 50.

66. Indicators.—Choice of an indicator to be used in a tracer is important. Some use the "eye" tube, since only relative strength is to be determined. It can be located at any point in the tracer, such as directly after the detector or at the output of the amplifiers. Without the detector, it can be used to indicate relative DC potentials with no additional test equipment. A milliammeter is a less flexible indicator, since it can be used only in a vacuum tube voltmeter, requiring additional circuits to permit the same versatility as the "eye" tube. It can be used as a vacuum tube voltmeter in combination with a probe, but this limits the sensitivity.

All tracers should provide aural indicators: either a speaker, headphones or both. This is necessary in order to determine whether the signal being traced is actually a signal and not a hum or noise voltage. Also, when the complaint is distortion, the signal must be heard to determine the stage in which the distortion is originating.

67. Signal Injection Method.—A procedure of practical servicing *by signal injection*—sometimes known as "backward" signal tracing—is based on the application of appropriate AF or RF signals to strategic points of the circuit being tested.

The only equipment required for the injection method of servicing is a conventional type of signal generator. For the sake of convenience, the generator must have some means to select either an RF output or an AF output. This is possible with about 90 per cent of the service-type signal generators. It is best to use an ordinary test prod and shielded lead, with a condenser connected between the test prod and the generator output. This protects the attenuator from burnout when the prod is placed on a point of high potential. The shielded lead from the generator output prevents stray AC pickup that would be impressed on the circuits under test along with the desired signal. One difference between signal tracing and signal injection is that with the former, one starts with the front end of the receiver under test and works toward the speaker; whereas, in the latter method, one starts with the back or audio end and works toward the antenna input.

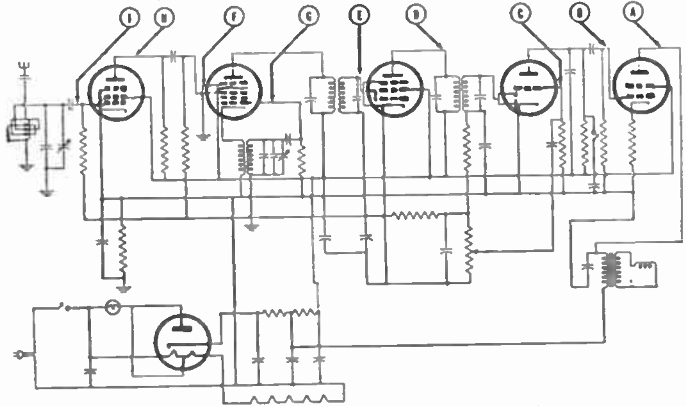


Fig. 53 Method of servicing by signal injection.

68. Servicing by Signal Injection.—The following procedure is used for quick servicing by signal injection: Turn on the receiver to be tested and allow it to warm up for a few minutes.

Adjust the signal generator for audio output and set the attenuator control at maximum. Connect the ground wire from the generator to the ground on the set and inject the signal onto the plate of the output tube (Point A on Fig. 53). This is done simply by touching the plate terminal with the test prod. If a weak audio signal (usually 400 cps) from the generator is heard in the speaker, this means that the output transformer and speaker are functioning. Next, the signal is injected on the control grid of the output tube (Point B on Fig. 53). The signal should be much louder than when it was inserted on the plate. The next step is to inject the signal on the grid of the first audio stage (Point C of Fig. 53). If this stage is functioning normally, it may be necessary to reduce the output from the generator.

If all the circuits associated with the audio end of the receiver are functioning, then the trouble must lie in the IF and RF sections. If the receiver is a superheterodyne, tune the signal generator to the prescribed IF for the set, and adjust for modulated RF output. Place the test prod on the plate of the last IF stage (Point D of Fig. 53). The signal heard in the speaker should be the same as in previous tests. Next, the prod is placed on the grid of the last IF stage (Point E of Fig. 53), and once more an increase in output should be noticed. Now proceed back through the IF stages, checking each one as for the last IF stage.

In progressing to the grids of the preceding stages, it will be noticed that the gain increases greatly. To offset this increase, the generator attenuator setting should be decreased. At the mixer: The IF signal is injected on the control grid of the mixer (Point F on Fig. 53), and if another gain in output is noticed, the mixer is amplifying. Tune the receiver to the frequency of the strongest broadcasting station in the particular locality, and if it is not heard, proceed as follows: Tune the signal generator to a frequency that is the *sum* of the frequencies of the broadcasting station and the IF of the set. For example, if the station operates on a frequency of 1000 kilocycles and the IF of the set is 455 kc, then 1000 plus 455 equals 1455—the frequency to which the signal generator should be tuned. (This is the frequency at which the oscillator in the set should operate in order to receive a station with a frequency of 1000 kc.). Turn the modulation off, and feed the signal to the oscillator grid, or to the place where the oscillator signal is normally fed to the mixer tube (point G on Fig. 53). If the station is heard, the local oscillator in the set is not functioning. If the station is not heard, the trouble is ahead of the mixer. Proceed to the RF section.

The generator should now be tuned to the frequency of the set, which, at present, happens to be 1000 kc. Proceed from plate to grid (Points H and I on Fig. 53) with the test prod, until the defective stage is found. If the set under test is an intermittent, with the injection method it is comparatively easy to locate the defective stage. Starting with the audio output stage, the signal is fed to the grid of the tube and the preceding stage is stopped from functioning by removing the tube or by shorting out the grid with a jumper. If the set does not show an intermittent, then proceed to the next stage and repeat the process until the stage that shows an intermittent is located.

ALIGNING AM SUPERHETERODYNES

69. Requirements. — Proper alignment of an AM superheterodyne requires the adjustment of every tuned circuit in the receiver according to specifications of the manufacturer. Whether or not such data is available, the following general procedure is suitable for aligning an AM superheterodyne circuit of typical complexity (Fig. 54) using a signal generator and an output meter.

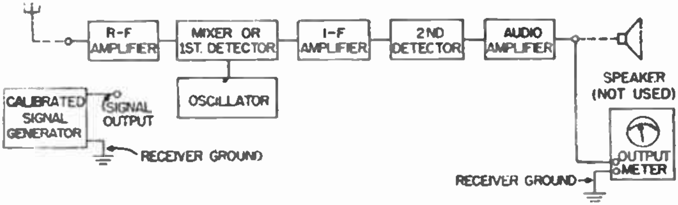


Fig. 54 Basic AM superheterodyne and test equipment for alignment with output meter.

70. Equipment.—Essential test instruments for alignment are:

1. A calibrated *signal generator* or *test oscillator* capable of producing a modulated test wave at a desired intermediate frequency or signal frequency, which is connected to appropriate points in the receiver circuit according to the alignment procedure.
2. An *AC output meter* capable of indicating relative values, which is connected across the voice coil of the speaker, or in the plate circuit of the output stage of the receiver.
3. Nonmetallic aligning tools.

71. Pre-alignment Procedure.—Before aligning a receiver, make certain that all controls are set in positions normally resulting in maximum gain. The volume control is turned to maximum; a tone control is set to minimum bass position. When present: sensitivity and selectivity controls are set to full or maximum position. The tuning dial is adjusted to the frequency required by each step of the alignment procedure. Connect the ground lead of signal generator to chassis of receiver. Allow 10 or 15 minutes for both receiver and signal generator to warm up. Determine intermediate frequency specified by manufacturer. In general, stages are aligned *in this order:* IF stages, oscillator stage, and RF stage.

72. IF Adjustments.—

1. Short circuit antenna at receiver input.

2. Short circuit oscillator tuning condenser.

3. Stop AVC action. If AVC is actuated by separate tube, remove tube from circuit.

4. Set signal generator to intermediate frequency. Connect to grid of first detector tube, and increase signal volume until

a low reading is indicated on output meter. Make certain ground lead is securely attached to chassis of receiver.

5. With test signal of lowest power, adjust secondary trimmer of IF transformer for peak deflection on output meter; adjust primary trimmer of IF transformer in same manner. Repeat this procedure for each IF transformer, proceeding backward through the circuit to the first detector stage.

73. Oscillator and RF Adjustment.—

1. Remove short circuits from antenna and from oscillator tuning condenser.
2. Connect signal from test oscillator to antenna post, and set frequency of oscillator at 1400 kc.
3. Adjust oscillator trimmer for maximum peak deflection on output meter. Then, adjust antenna trimmer for maximum peak.
4. Set frequency of test oscillator at 600 kc.
5. If receiver is equipped with low-frequency RF and oscillator trimmers, adjust each of these trimmers for maximum output response. If slotted plates are used on condensers (in place of trimmers), then bend plates for maximum peak. Since these adjustments affect the frequency setting of the entire receiver, the tuning condenser should be "rocked" back and forth *during* each adjustment period.

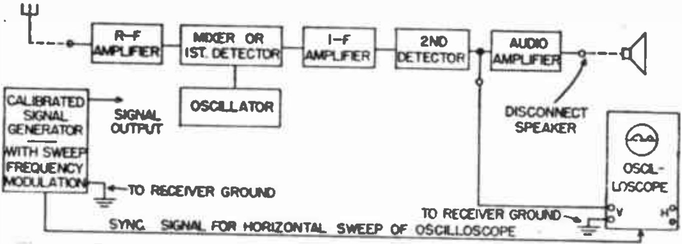


Fig. 55 Basic AM superheterodyne and test equipment for alignment with oscilloscope.

74. Visual Alignment.—The circuits of an AM superheterodyne can be aligned with considerable accuracy by means of a cathode ray oscilloscope, which reproduces a visual trace of the frequency response curve. With a suitable signal generator connected to the input and an oscilloscope connected to the output of the receiver (Fig. 55), adjustments of the tuned stages are reflected in corresponding changes in the trace or image on the oscilloscope.

75. Equipment.—Essential test instruments for visual alignment are:

1. A calibrated sweep-frequency-modulated *signal generator* or *test oscillator,* capable of producing an output frequency that can be varied rapidly from about 50 kc above to 50 kc below the indicated signal frequency. The signal generator is connected to appropriate points in the receiver circuit according to the alignment procedure.
2. A conventional *cathode ray oscilloscope* having a high im-

pedance input and means for synchronizing the horizontal sweep with the frequency sweep from the signal generator. Since it is used to replace the *envelope* of the IF signal, the exact connection of the oscilloscope will depend upon the type of receiver being aligned. With the diode detector, a suitable IF voltage is obtained across the diode load resistor (Fig. 56). For infinite-impedance detectors, the high side of the oscilloscope is connected to the cathode of the detector, and the low side to the ground. For grid leak and biased detectors, the high side of the oscilloscope is connected to the plate of the detector, and the low side to the ground (Fig. 57); if the plate load is a choke coil, or if the detector is coupled to the first audio stage by means of a transformer, insert a 20,000-ohm resistor in series with the plate, and short-circuit the choke or transformer primary in order to eliminate the reactive component of the load. The sweep voltage—between oscilloscope and signal generator—is used to synchronize operation of the oscilloscope.

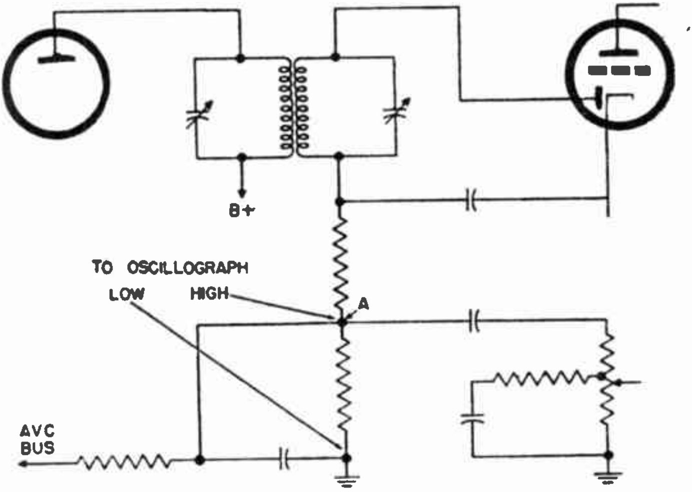


Fig. 56, Method of connecting oscilloscope to receiver with diode second detector.

3. Nonmetallic aligning tools.

76. Pre-alignment Procedure.—Before aligning the receiver, make certain that all controls are set in positions normally resulting in maximum gain, sensitivity, and selectivity. Allow 15 or 20 minutes for receiver, signal generator, and oscilloscope to warm up. Determine the intermediate frequency specified by the manufacturer of the receiver and adjust the signal generator accordingly. With the sweep-frequency-modulated output of

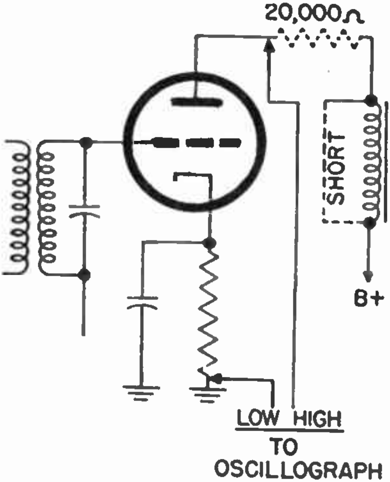


Fig. 57 Method of connecting oscilloscope to receiver with biased detector.

the signal generator to the grid of the last IF stage through a 0.001 microfarad condenser, (1) adjust the oscilloscope controls to obtain a trace of suitable intensity, properly focused, and (2) adjust the sweep and synchronizing controls to obtain *one* synchronized pattern for each complete frequency variation of the signal geenrator; this response pattern may be almost any shape at this point, such as the typical pattern shown in Fig. 58.

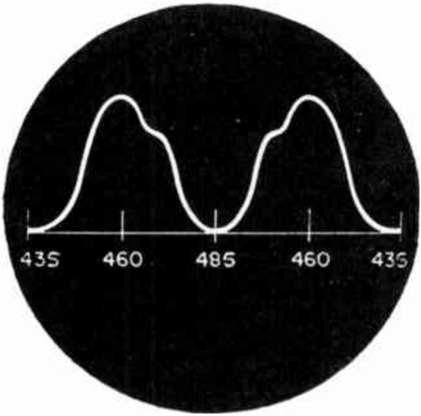


Fig. 58 Scope appearance of improperly aligned IF amplifier.

77. IF Adjustments.—

1. Short circuit antenna at receiver input.

2. With signal generator on, turn off frequency modulation. Maintain unmodulated output as low as possible to minimize effects of AVC action on the receiver circuit.

3. Set horizontal gain control of oscilloscope to minimum.

4. Set tuning dial of receiver to some position where no interfering signal is passed on to IF amplifiers.

5. Adjust IF trimmers to obtain a vertical *line* of maximum amplitude on oscilloscope.

6. Turn on frequency modulation, and adjust oscilloscope so that trace covers width of viewing screen.

7. Readjust IF trimmers for critical coupling: When curve is of maximum amplitude and symmetrical. Images will vary in shape somewhat, according to the three types of IF coupling:

a. double-tuned transformer coupling,
b. single-tuned transformer coupling,
c. single-tuned coil coupling.

Typical IF curves for various degrees—and types—of coupling are shown in Fig. 59.

8. Repeat this procedure for each IF amplifier stage of the receiver, proceeding backward through the circuit to and including the first detector or mixer stage.

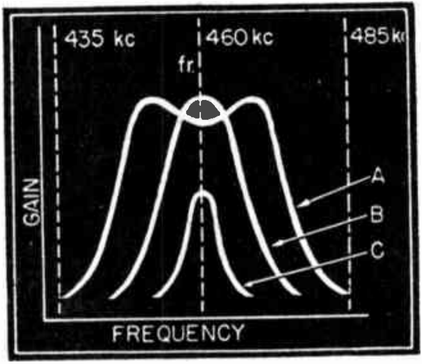


Fig. 59 Typical IF curves with various degrees and types of coupling. A Overcoupling with double-tuned transformer coupling. B Critical coupling for single-tuned coil, single-tuned transformer, and double-tuned transformer coupling. C Undercoupling with double-tuned transformer coupling.

A number of typical response patterns are shown in Fig. 60, any or all of which are likely to be encountered during the process of aligning the IF amplifier stages. Patterns 1 to 6 illustrate incorrect circuit conditions; patterns 7 to 9 are satisfactory.

78. Oscillator and RF Adjustments.—

1. Remove short circuit from antenna terminals.
2. Remove connections of signal generator.
3. Oscilloscope remains connected as for previous IF adjustments.
4. Set signal generator at 600 kc without frequency modulation. Connect to antenna terminals of receiver through a dummy antenna.
5. Set horizontal gain control of oscilloscope to minimum.
6. While tuning receiver slowly through range: 580 to 620 kc, vary low-frequency padder to obtain a trace of maximum amplitude. The dial should indicate 600 kc at this position.
7. Tune signal generator and receiver to 1400 kc. Adjust oscillator, first detector, and RF trimmers *in that order* for maximum response.
8. Repeat adjustments made at 600 kc and at 1400 kc.

ALIGNING FM SUPERHETERODYNES

79. Requirements. — Proper alignment of an FM superheterodyne requires the adjustment of every tuned circuit and the discriminator according to specifications of the manufacturer. Whether or not such data is available, the following general procedure is suitable for aligning an FM superheterodyne circuit of

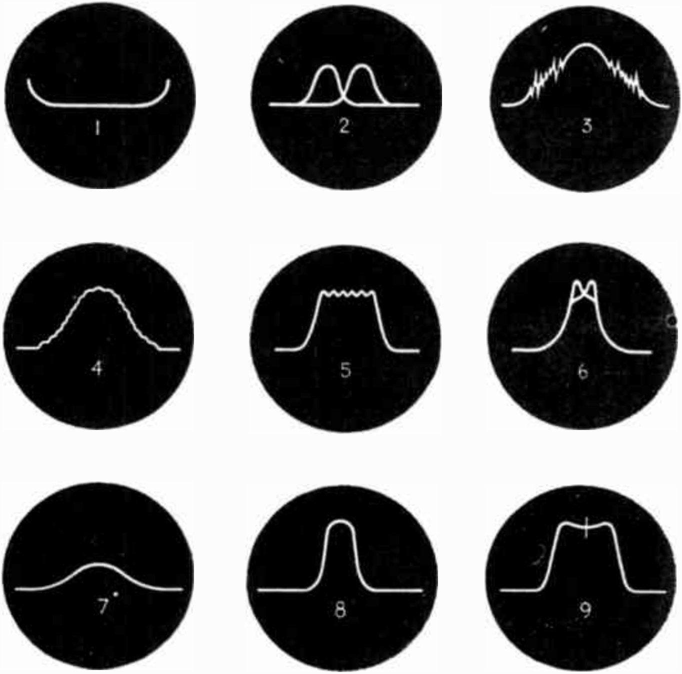


Fig. 60 Typical patterns observed on the oscillograph screen. (1) Signal approximately 20 kc off resonance of IF amplifier. (2) Signal approximately 5 kc off resonance. To correct (1) and (2), be certain signal generator frequency is right, then adjust trimmers to make curves coincide, as in (8). (3) shows presence of spurious signal from external source. (4) "singing" in IF amplifier. While (5) has good selectivity, as shown by steep sides of curve, ragged top indicates overload of oscillograph or IF amplifier. Reduce output of signal generator. (6) shows a symmetrical alignment. These two curves can be made to coincide by suitable adjustment of trimmers. (7) shows broad curve, such as is generally obtained from first step of the alignment, with only one tuned IF transformer. Increase the vertical gain of oscillograph to obtain higher curve, for greater ease in observing results of adjustments. (8) shows good curve for IF amplifier. Top of curve is fairly broad, and sides are steep. (9) shows double peak effect for higher fidelity. Curve is symmetrical, both peaks of equal amplitude, and equally spaced from frequency of resonance. Sides are fairly steep, a condition indicating good selectivity. Curve (9) characteristic of over-coupled double-tuned transformer-coupled amplifiers.

typical complexity (Fig. 61) using a signal generator and a vacuum-tube voltmeter.

80. Equipment.—Essential test instruments for alignment are:

1. An FM *signal generator* or *test oscillator* capable of producing a test wave at a desired intermediate frequency or signal frequency, which is connected to appropriate points in the receiver circuit according to the alignment procedure.
2. A vacuum-tube voltmeter.
3. Nonmetallic aligning tools.

81. Pre-alignment Procedure.—Before aligning the FM receiver, set all controls for normal operation. Connect ground leads from signal generator to receiver chassis, and from vacuum-tube voltmeter to receiver chassis. Allow 15 minutes for FM receiver and signal generator to warm up. Determine the intermediate frequency of receiver. In general, stages are aligned *in this order:* IF stages, discriminator stage, and RF stages.

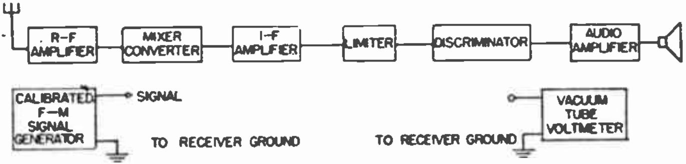


Fig. 61 Basic FM superheterodyne and test equipment for alignment with VT voltmeter.

82. IF Adjustments.—

1. Connect vacuum-tube voltmeter across the limiter grid resistor.
2. Set signal generator to intermediate frequency *without* modulation. Connect to control grid of mixer-converter through a mica condenser (between 50 and 300 micromicrofarads).
3. Adjust final IF trimmers for peak deflection on VT voltmeter. Repeat procedure for each IF trimmer, proceeding backward through the circuit.

83. Discriminator Adjustment.—

1. Without changing connections or setting of signal generator, connect the vacuum-tube voltmeter to the ungrounded cathode (output) of the discriminator stage.
2. Detune secondary of discriminator input transformer by changing secondary trimmer.
3. Adjust transformer primary trimmer for maximum voltage indication on VT voltmeter.
4. Adjust transformer secondary trimmer for *zero* voltage indication on VT voltmeter.
5. Check alignment by setting signal generator first at 50 kc above and then 50 kc below the intermediate frequency. If the two 50 kc deviation readings are qual, the discriminator is operating properly. Slight readjustment of the primary may be necessary; and, in any case, the entire alignment procedure for the discriminator should be repeated.

84. RF Adjustments.—

1. Connect the vacuum-tube voltmeter across the limiter grid resistor.
2. Set signal generator to middle of FM band. Connect to antenna terminal of receiver through a mica condenser (between 50 and 300 micromicrofarads).
3. Set tuning dial of receiver to same frequency as signal generator.
4. Adjust oscillator trimmer for peak indication on VT voltmeter.
5. Adjust mixer-converter and then RF trimmers for maximum output voltage.
6. Spot check various frequencies on FM band with modulated signal generator.

85. Aligning FM Superheterodynes Using Oscilloscope.—The circuits of an FM superheterodyne can be aligned with considerable accuracy by means of a cathode ray oscilloscope, which reproduces a visual trace of the frequency response curve. With a suitable signal generator connected to the input and an oscilloscope connected to the output of the receiver (Fig. 62), any adjustment of the tuned stages or of the discriminator are reflected in corresponding changes in the trace or image on the oscilloscope.

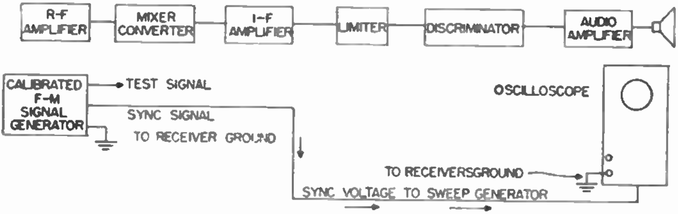


Fig. 62 Basic FM superheterodyne and test equipment for alignment with oscilloscope.

86. Equipment.—Essential test instruments for visual alignment are:

1. A calibrated frequency modulated *signal generator* or *test oscillator* capable of producing a test wave at a desired intermediate frequency or signal frequency, which is connected to appropriate points in the receiver circuit according to the alignment procedure. It must also supply the test oscilloscope with a synchronizing sweep voltage.
2. A conventional *cathode ray oscilloscope* having a high impedance input and means for synchronizing the horizontal sweep with the frequency sweep from the signal generator. This sweep synchronizing voltage is obtained by direct connect to the signal generator.
3. Nonmetallic aligning tools.

87. Pre-alignment Procedure.—Before aligning receiver, set all controls for normal operation. Connect ground leads from signal generator to receiver chassis, and from oscilloscope to receiver chassis. Allow 15 to 20 minutes for signal generator, FM receiver, and oscilloscope to warm up. Determine intermediate frequency of receiver. In general, stages are aligned *in this order;* IF stages, discriminator stage, and RF stages.

88. IF Adjustments.—

1. Connect oscilloscope across limiter grid resistor.

2. Set signal generator to intermediate frequency *without* modulation. Connect to grid of final IF stage.

3. Adjust oscilloscope controls to obtain a trace of suitable intensity, properly focused. Then, by correct synchronization with the sweep generator, a centered pattern of the frequency response should be visible at all times.

4. Adjust final IF trimmers for critical coupling (Fig. 63). Repeat this procedure for each IF trimmer, proceeding backward through the circuit.

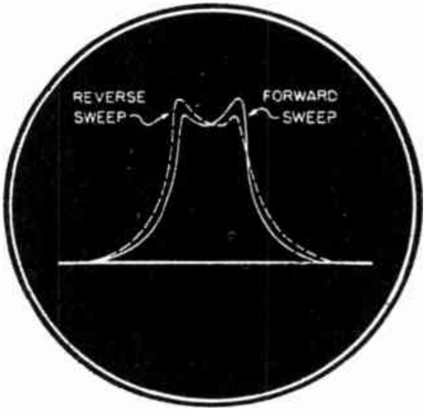


Fig. 63 Pattern obtained from a properly aligned discriminator.

89. Discriminator Adjustment—

1. Without changing connections or setting of signal generator, connect oscilloscope to output of discriminator stage.

2. Adjust transformer primary trimmer for maximum amplitude of scope pattern.

3. Adjust transformer secondary trimmer until scope pattern is correctly centered with respect to horizontal axis. Positive and negative peaks should be equal in amplitude. In general, primary trimmer controls overall amplitude and linearity of pattern, and the secondary trimmer controls distribution of pattern with respect to the horizontal or zero reference level.

90. RF Adjustments.—

1. Connect the oscilloscope across the limiter grid resistor.

2. Set signal generator to middle of FM band. Connect to antenna terminal of receiver through a mica condenser (between 50 and 300 micromicrofarads).

3. Set tuning dial to same frequency as signal generator.

4. Adjust oscillator trimmer for peak indication on oscilloscope.

5. Adjust mixer-converter and then RF trimmers for peak indication on oscilloscope.

6. Spot check tuning on various frequencies of FM band with modulated signal generator.

ALIGNING TELEVISION RECEIVERS

91. Requirements.—Proper alignment of a television receiver requires the adjustment of a great many tuned circuits—

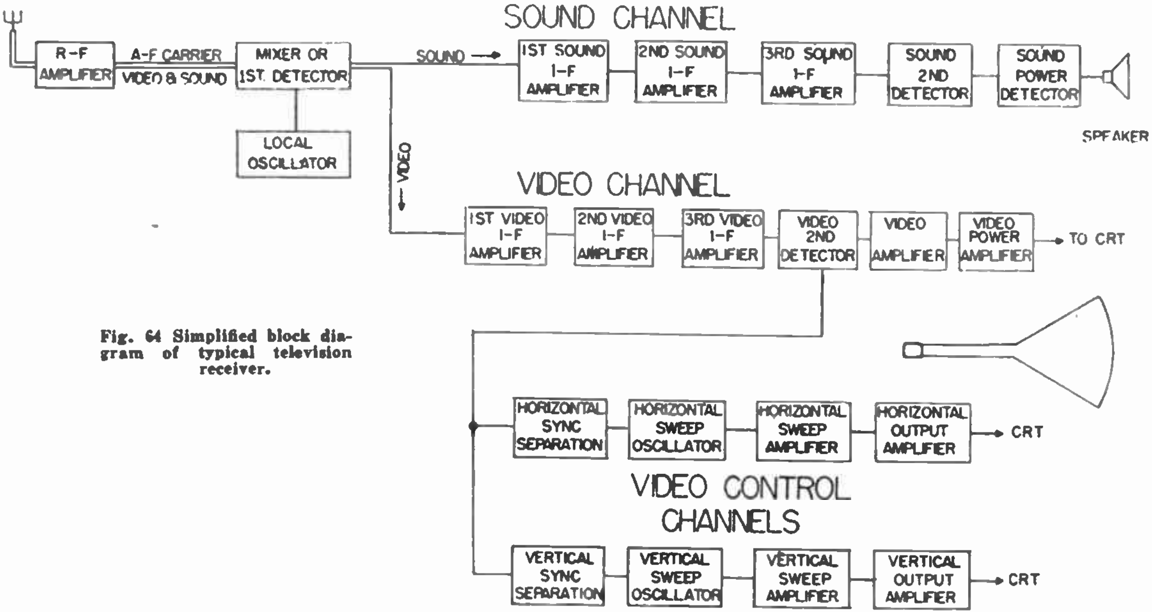


Fig. 64 Simplified block diagram of typical television receiver.

often involving as many as 25 or 30 tubes—according to the exact specifications of the manufacturer. When such data is not available, the following general procedure is suitable for aligning receivers of typcial complexity (Fig. 64), using sweep signal generator and an oscilloscope. Although consisting of a large number of tubes and stages, alignment procedures can be divided into three principal parts:

1. The sound or audio channel,
2. The video or picture channel,
3. Video control channels.

Alignment of the sound channel closely parallels the general procedure for FM superheterodynes (see Chapters 20 and 21). Alignment of the video channel introduces new techniques characteristic only to television. Alignment and adjustment of the video *control* channels—which includes all high-voltage controls associated with the oscilloscope—differ with each type of television receiver, and is of a too specialized nature to be considered in any general alignment procedure. Consequently, of principal concern is the alignment of stages associated with the video or picture channel—from antenna to the final picture tube.

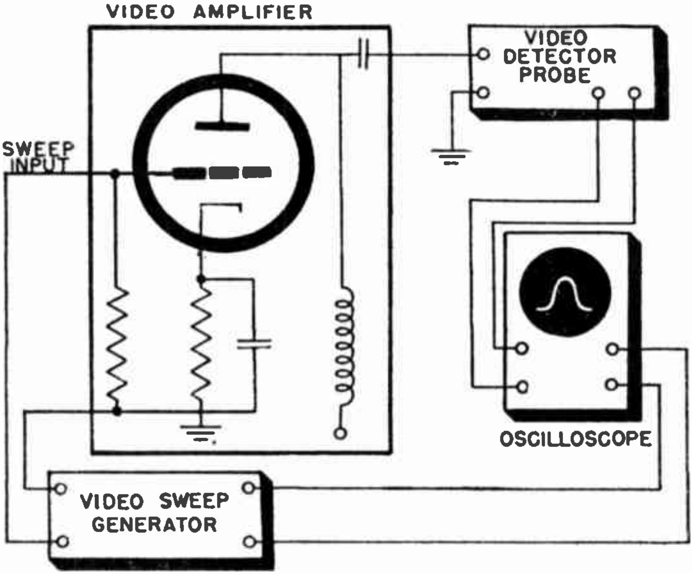


Fig. 65 Use of sweep generator and oscilloscope to align video amplifier.

92. The Video Channel.—The function of the video channel can be analyzed by referring to the receiver block diagram (Fig. 64). The incoming television carrier—6 mc in width—consists of a video or picture signal which is 4 mc in width, and an FM sound signal. After amplification, the RF carrier is converted to *two* intermediate frequencies: The sound IF and the video IF signals. The video signal (4 mc in width) is applied successively to three or four stages of IF amplification—all similar in design and having a wide-band pass to prevent distortion of the picture or video signal. After detection, the video signal (still 4 mc in width) is applied directly to one or two straight video amplifiers, and then reaches the cathode ray picture tube for visual observation. Since the band width and the selectivity of the video channel determine the quality and contrast of the final picture, the alignment must be performed with care in order to realize the maximum band width and selectivity for which the particular receiver was designed.

Fig. 65A Scope pattern obtained with sweep generator, showing location of markers.

93. Equipment.—Essential test instruments for aligning a television receiver are:

1. A sweep-frequency *signal generator* which is capable of covering the entire frequency range required by television circuits. While it is sometimes possible to perform alignment of certain stages and channels using an ordinary signal generator, the procedure consumes considerable time and is impractical. There is no substitute for the ease of alignment with a good sweep generator.

2. A conventional *cathode ray oscilloscope* having a high impedance input and means for synchronizing the horizontal sweep with the sweep generator. Although a vacuum-tube voltmeter can be substituted for the oscilloscope in aligning *some* stages of a television receiver, such a voltmeter is inadequate for IF alignment and generally lacks the *visual* accuracy of the oscilloscope. A video detector probe is used with the oscilloscope.

3. Nonmetallic aligning tools.

94. Video Amplifiers.—The detected IF picture signal is applied to one or two stages of video amplification, which must bring the signal up to a level required to modulate the grid of the cathode ray picture tube. Alignment with a sweep generator and oscilloscope provides a visual plot of the amplitude response of the video amplifier in terms of frequency or band width. Then proceed as follows:

1. Connect the output of the generator to the input terminals of the video amplifier to be tested, as shown in Fig. 65.
2. If generator is not provided with blocking condenser, a series condenser of about 0.01 microfarad must be used if connecting to a circuit in which DC voltage is present.
3. Connect the video detector probe from the output of the stage to ground, and connect the output of the detector to the vertical input and ground of the oscilloscope.
4. Adjust the attenuator of the video sweep generator until sufficient signal input is obtained to cause a pattern to appear on the oscilloscope.

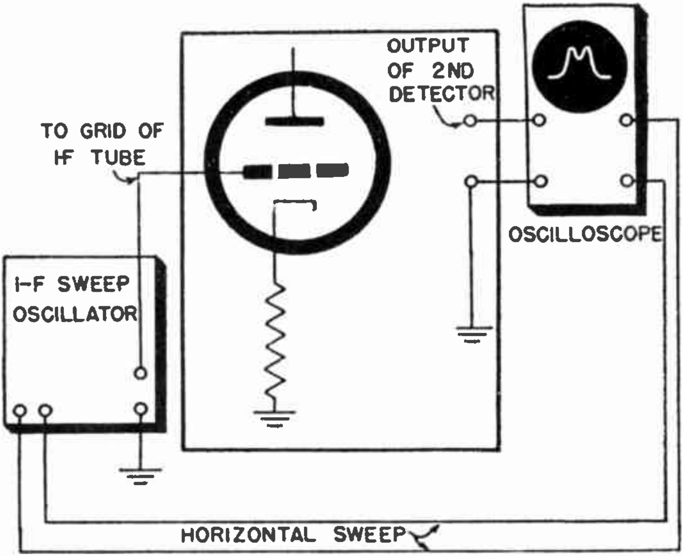


Fig. 66 Use of sweep generator and oscilloscope to align intermediate amplifiers.

95. Markers.—In order to determine whether the pattern on the oscilloscope is of proper band width, *markers* are usually provided in the sweep generator which appear as small "pips" on the pattern. These are shown in the pattern of Fig. 65A. By varying the marker frequency, the "pips" can be moved to any position on the pattern and with the calibrated dial, the frequency band width can be read directly.

96. Video IF Amplifiers.—For aligning the IF amplifier stages of the video channel, the oscilloscope is connected to the output of the second detector. With the sweep oscillator connected to the grid of the last IF tube (Fig. 66), adjustments are made on the IF coupling—between the final IF tube and the detector tube—in an effort to obtain a sufficiently wide IF response pattern on the oscilloscope (Fig. 67).

When sufficient flatness of response is obtained within the desired channel limits, and when as much selectivity as possible outside these limits is obtained, the sweep generator is connected with reduced output *in shunt* with the grid of the next-to-last IF tube and the coupling circuit adjusted between the last and the next-to-last IF tubes. The amount by which the sweep generator output voltage must be reduced, in order to obtain a given vertical deflection on the oscilloscope screen, is a direct measure of the gain of the next-to-last IF stage.

Fig. 67 A good intermediate-frequency response pattern, showing markers.

Following the same procedure the sweep generator is connected successively in shunt with the grid of each IF tube, working backward through the circuit until the mixer-converter tube is reached. The final test with the sweep generator should be with the connections in shunt with the converter-tube grid (although in operation no IF appears at this point in the circuit) in order to align the circuit immediately following the converter tube. In aligning each successive stage, note that the output was checked at the detector in all cases.

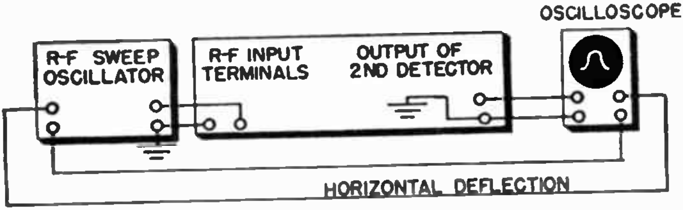


Fig. 68 Use of sweep generator and oscilloscope to align RF section of television receiver.

97. Oscillator and R-F Adjustments.—Band width characteristics of the RF stage are determined by applying three test frequencies to the antenna input, one at the picture carrier, one at the upper edge of the channel, and the other at the lower edge of the attenuated side band. If substantially equal response is obtained at the detector output from each of these three frequencies, the design of the IF circuit will usually take care of the selectivity beyond these limits—as well as the equality of response within them.

Connections for RF alignment with the sweep generator are shown in Fig. 68. Again, the overall response can be seen at a glance while adjustments are made. Oscillator performance is checked at each band switch position by using conventional meters—a microammeter for grid current, and a vacuum-tube voltmeter for measurement of output voltage. The frequency may be adjusted by heterodyne action between the output of the oscillator and a standard frequency source.

Section 17

RADIO AND ELECTRONIC DATA

FORMULAS

RESISTORS

In Parallel

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

In Series

$$R_T = R_1 + R_2 + R_3$$

CONDENSERS

In Parallel

$$TC = C_1 + C_2 + C_3$$

In Series

$$TC \text{ (two condensers)} = \frac{C_1 \times C_2}{C_1 + C_2}$$

$$TC \text{ (two or more)} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

(TC = Total Capacity)

CONDENSER CAPACITY

The Capacitance of a Parallel Plate Condenser may be determined from

$$C = 0.2235 \times \frac{KA}{d} \times (n\text{-}1) \ \mu\mu\text{fd.}$$

Where A is Area of one side of one plate in square inches
n is the total number of Plates
d is the separation between Plates in inches.
K is the Dielectric Constant

DECIBEL

The number of Decibels correcponding to a given *power* ratio is 10 times the common logarithm of the ratio, thus

$$DB = 10 \, Log_{10} \times \frac{P_2}{P_1}$$

Example: What will be the gain in Decibels for an amplifier whose Output Power rises to 5 times that at the Input?

$$DB = 10 \, Log_{10} \times \frac{10}{2} = 10 \, Log_{10} \times 5 = 10 \times .7 = 7$$

The number of Decibels corresponding to a given *Voltage or Current* ratio is 20 times the common logarithm of the ratio, thus

$$DB = 20 \, Log_{10} \times \frac{E_2}{E_1}$$

Example: What will be the gain in Decibels of an amplifier whose Output *Voltage* is 9 times that at Input?

$$DB = 20 \, Log_{10} \times 9 = 20 \times 0.954 = \text{Ans. } 19.08 \text{ DB}$$

GAIN OF AN AMPLIFIER STAGE

Where G = Gain
Mu = Amplification Factor
Rp = Plate Load
rp = A.C. Plate Resistance of Tube
G_m = Transconductance

$$G = M_u \frac{Rp}{rp + Rp} \quad \text{or} \quad G = G_m \frac{rp \times Rp}{rp + Rp} \quad \text{(see note)}$$

Note: The values for G_m, rp and Mu used in these equations are not necessarily the published values. They are the values which are measured under the circuit conditions imposed by the particular amplifier for which the calculated Gain is desired.

INDUCTANCE OF A COIL

The lumped inductance for receiving and transmitting Coils may be calculated from:

$$L = \frac{0.2 \times A^2N^2}{3A + 9B + 10C}$$

Where L is the Inductance in Microhenries

A is the Mean Diameter of the Coil in inches
B is the Length of Winding in inches
C is the Radial Depth of Winding in inches
N is the Number of Turns

Note: The quantity C may be neglected if the coil is a single-layer solenoid, as is usually the case with coils for the high frequencies.

Example: Assume that a coil having 30 turns of #30 d.s.c. wire is wound on a receiving coil having a diameter of 2 inches. Assume further, that this wire will occupy a length of ⅜ of an inch. Then

$$L = \frac{0.2 \times (2)^2 \times (30)^2}{(3 \times 2) + (9 \times .375)} = \text{Ans. } 76.8 \text{ Microhenries}$$

It is obvious that the required *Physical Dimensions* of a Coil can be determined from the above equation, if the specific *Inductance* is known.

INDUCTANCES

In Parallel

$$L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}}$$

In Series

$$L_T = L_1 + L_2 + L_3$$

LOUD SPEAKER IMPEDANCE MATCHING

Selecting the Proper Plate-to-Voice Coil (Output) Transformer may be accomplished from:

$$TR = \frac{\sqrt{Z_p}}{Z_{vc}}$$

Where Z_p is the recommended Load Resistance for the Tube or Tubes used in the Output Stage of the Amplifier (from Manufacturer's published Tube Data) and, Z_{vc} is the Voice Coil Impedance of the Speaker (from Manufacturer's published Data), TR is Turns-Ratio.

Example: What Turns-Ratio Output Transformer should be selected to match a 50L6GT to a 5 Ohm Speaker? A Load Resistance of 2000 Ohms for the

50L6GT is recommended by the Tube Manufacturer. Hence,

$$TR = \frac{\sqrt{2000}}{5} = \sqrt{400} = 20$$

A Transformer having a Turns-Ratio of 20:1 will therefore be suitable. Where such a transformer is not readily available, it is best practice to select one whose ratio is HIGHER than 20:1 rather than one of LOWER Ratio. A 24.5:1 would be satisfactory. The Transformer must, of course, have a Power Rating capable of handling the power required by the Speaker.

MULTIPLIERS FOR VOLTMETERS

Rm = Resistance of Meter
Rs = Series Resistor
E = New Voltage Range
Em = Original Voltage Range of Meter

$$Rs = Rm \left(\frac{E}{Em} \right) - 1$$

MULTIPLIERS FOR OHMMETERS

Rs = Shunt Resistor
It = Total Current
Rm = Resistance of Meter
Im = Meter Current

$$Rs = \frac{Rm}{\frac{It}{Im} - 1} \text{ and}$$

$$Im = \frac{RsIT}{Rm + Rs} \text{ and}$$

$$It = Im \frac{Rm + Rs}{Rs} \text{ and}$$

$$Rm = Rs \frac{It - Im}{Im}$$

OHM'S LAW

Where:

I = Current in Amperes
E = e.m.f. in volts
R = Resistance in Ohms

$$I = \frac{E}{R} \text{ or } E = I \times R \text{ or } R = \frac{E}{I}$$

Example: When 5 volts are applied to a tube filament having a resistance of 20 ohms, what current will flow?

$$I = \frac{E}{R} = \frac{5}{20} = \frac{1}{4} = .25 \text{ amp. (ans.)}$$

OHM'S LAW FOR ALTERNATING CURRENT

Where:

E = Voltage
X = Reactance in Ohms
X_C = Capacitive Reactance in Ohms
X_L = Inductive Reactance in Ohms
Z = Impedance in Ohms
R = Resistance in Ohms
L = Inductance in Henries
C = Capacity in Farads
F = Frequency in Cycles per Second
$2\pi = 6.28$
I = Current in Amperes

$$E = IZ \qquad I = \frac{E}{Z}$$

$$E = IX \qquad I = \frac{E}{X}$$

$$E = I\sqrt{X^2 + R^2} \qquad I = \frac{E}{\sqrt{X^2 + R^2}}$$

$$E = I\sqrt{X_L - X_C + R^2} \qquad I = \frac{E}{\sqrt{(X_L - X_C)^2 + R^2}}$$

$$Z = \frac{E}{I} \quad \text{and} \quad X = \frac{E}{I}$$

POWER IN WATTS

Where:

W = Power in Watts

$$W = E \times I \text{ or } W = I^2 \times R \text{ or } W = \frac{E^2}{R}$$

POWER OUTPUT OF AN AMPLIFIER STAGE

When eg expresses the RMS Effective Value of the A.C. (Signal) Input, the approx.,

$$\text{Power Output} = \frac{Mu^2 \times eg^2 \times Rp}{(rp + Rp)^2}$$

(when the load is non-reactive)

$$\text{Maximum Undistorted Power Output} = \frac{2Mu^2 \times eg^2}{9Rp}$$

$$\text{or } \frac{2}{9} Mu \times eg \times G_m$$

When eg is the Maximum (Peak) A.C. (Signal) Input, then the approx.,

$$\text{Maximum Undistorted Power Output} = \frac{Mu^2 \times eg^2}{9Rp}$$

Q FACTOR

The Q of a coil or condenser generally expresses a factor of Merit. The ratio of Reactance to Resistance is known as the "Q Factor" (Dissipation Factor).

Where ω is $2\pi f$:
L is Inductance in Henries
R is Resistance in Ohms
C is Capacity in Farads

For a Coil:

$$Q = \frac{\omega L}{R} \text{ (Where R and L are in Series)}$$

For a Condenser:

$$Q = \frac{1}{\omega RC} \text{ (Where R and C are in Series)}$$

For a Condenser:

$$Q = \omega RC \text{ (Where R and C are in Parallel)}$$

REACTANCE—CAPACITIVE

$$X_C = \frac{1}{2\pi FC}$$

X_C is Reactance in Ohms
F is Frequency in c.p.s.
C is Capacity in Farads

REACTANCE—INDUCTIVE

$$X_L = 2\pi FL$$

X_L is Reactance in Ohms
F is Frequency in c.p.s.
L is Inductance in Henries

WAVELENGTH VS. FREQUENCY

$$\text{Wavelength in meters} = \frac{300{,}000}{\text{frequency in kilocycles}}$$

$$\text{Wavelength in feet} = \frac{300{,}000 \times 3.28}{\text{frequency in kilocycles}}$$

$$\text{Frequency in kilocycles} = \frac{300{,}000}{\text{wavelength in meters}}$$

RESONANCE

Where F is Frequency in Kilocycles
C is Capacity in Microfarads
L is Inductance in Microhenries
π is 3.1416

$$F = \frac{10^3}{2\pi\sqrt{LC}} \quad \text{or} \quad F^2 = \frac{25330}{LC}$$

and

$$L = \frac{25330}{F^2C} \quad \text{or} \quad C = \frac{25330}{F^2L}$$

Example: To what Frequency will a .000142 mfd. Condenser (142 mmfd.), in Parallel with a 180 Microhenry Coil, tune?

$$F = \frac{10^3}{6.28\sqrt{180 \times .000142}} = 1000\ \text{KC.} = 300\ \text{Meters}$$

TRANSCONDUCTANCE

Where Mu = Amplification Factor
rp = A.C. Plate Resistance of Tube
G_m = Transconductance
and Mu and rp are *Known*, G_m can be found from:

$$G_m = \frac{Mu}{rp}$$

G_m will be in mhos. Multiply mhos by 10^6 for micromhos. From the above, it will follow, that

$$Mu = G_m \times rp$$

and

$$rp = \frac{Mu}{G_m}$$

SINE WAVE FORMULAS

(FOR VOLTAGES AND CURRENTS)

In Fig. D and in the formulas below, the following notation is used:

e—Instantaneous value of the voltage at any point.

E—Root means square value, also known as Effective value.

E_m—Maximum, or peak value; this is the highest value reached at any instant through the cycle.

E_a—Average value; the arithmetic average of all instantaneous values during the cycle.

ϕ—Angle swept through by a vector generating a Sine wave as shown in Fig. E. This is a measure of the "electrical degrees" from a reference point.

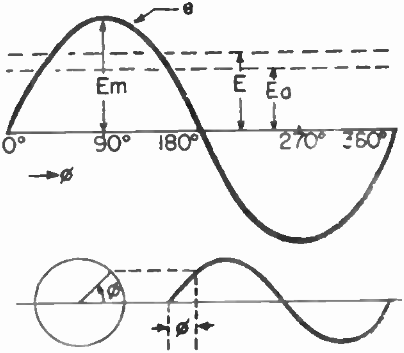


Fig. D

f—Frequency; the number of complete cycles during one second.

t—Time in seconds measured from the reference point (O).

The following formulas are given in terms of voltage, but apply equally well to current waves, in which case the symbols I and i are substituted for E and e respectively.

$$e = E_m \text{ Sin } (2\pi ft) = E_m \text{ Sin } \phi$$

$$E = \sqrt{\frac{e_1^2 + e_2^2 + e_3^2 \ldots + e_n}{n}} = .707\ E_m \equiv \frac{E_m}{\sqrt{2}}$$

$$E_a = \frac{e_1 + e_2 + e_3 \ldots + e_n}{n} = .637\ E_m$$

$$E = 1.11\ E_a$$

$$E_m = 1.414\ E = \sqrt{2}\ E$$

TRIGONOMETRIC FORMULAS

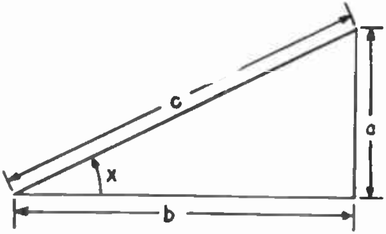


Fig. A

$$\text{Sin } x = a/c$$
$$\text{Cot } x = b/a$$

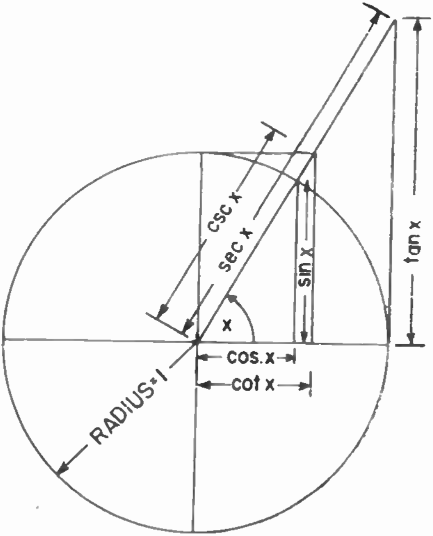


Fig. B

$$\text{Tan } x = \frac{\text{Sin } x}{\text{Cos } x}$$

$$\text{Cot } x = \frac{1}{\text{Tan } x}$$

$$\text{Tan } (x + y) = \frac{\text{Tan } x + \text{Tan } y}{1 - \text{Tan } x \text{ Tan } y}$$

$$\text{Sin } (x - y) = \text{Sin } x \text{ Cos } y - \text{Cos } x \text{ Sin } y$$

$$\text{Cos } (x - y) = \text{Cos } x \text{ Cos } y + \text{Sin } x \text{ Sin } y$$

$$\text{Tan } (x - y) = \frac{\text{Tan } x - \text{Tan } y}{1 + \text{Tan } x \text{ Tan } y}$$

$$\text{Sin}^2 x = \frac{1 - \text{Cos } 2x}{2}$$

$$\text{Cos}^2 x = \frac{1 - \text{Cos } 2x}{2}$$

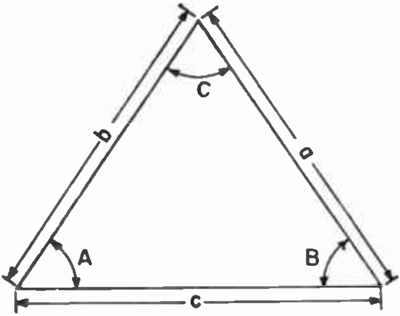


Fig. C

In any triangle, the following laws apply: (See Fig. C)

Law of Sines—

$$\frac{a}{\text{Sin } A} \qquad \frac{b}{\text{Sin } B} \qquad \frac{c}{\text{Sin } C}$$

Law of Cosines—

$$a^2 = b^2 + c^2 - 2bc \text{ Cos } A$$

Law of Tangents—

$$\frac{a + b}{a - b} = \frac{\text{Tan}\left(\frac{A + B}{2}\right)}{\text{Tan}\left(\frac{A - B}{2}\right)} = \frac{\text{Sin } A + \text{Sin } B}{\text{Sin } A - \text{Sin } B}$$

$$A + B + C = 180°$$

$$\text{Cos}^2\ x + \text{Sin}^2\ x = 1$$
$$\text{Sin}\ (-x) = -\ \text{Sin}\ x$$
$$\text{Cot}\ (-x) = -\ \text{Cot}\ x$$
$$\text{Sin}\ (90^\circ - x) = \text{Cos}\ x$$
$$\text{Cos}\ x = b/c$$
$$\text{Sec}\ x = c/b$$

$$\text{Cot}\ x = \frac{\text{Cos}\ x}{\text{Sin}\ x}$$

$$\text{Csc}\ x = \frac{1}{\text{Sin}\ x}$$

$$\text{Sec}^2\ x + \text{Tan}^2\ x = 1$$
$$\text{Cos}\ (-x) = \text{Cos}\ x$$
$$\text{Sec}\ (-x) = \text{Sec}\ x$$
$$\text{Tan}\ (90^\circ - x) = \text{Tan}\ x$$
$$\text{Tan}\ x = a/b$$
$$\text{Csc}\ x = c/a$$

$$\text{Sec}\ x = \frac{1}{\text{Cos}\ x}$$

$$\text{Csc}^2\ x + \text{Cot}^2\ x = 1$$
$$\text{Tan}\ (-x) = -\ \text{Tan}\ x$$
$$\text{Csc}\ (-x) = -\ \text{Csc}\ x$$
$$\text{Sec}\ (90^\circ - x) = \text{Sec}\ x$$

$$\text{Sin}\ (2\ x) = 2\ \text{Sin}\ x\ \text{Cos}\ x \quad \text{Cos}\ (2\ x) = 2\ \text{Cos}^2\ x - 1 = 1 - 2\ \text{Sin}^2\ x$$

$$\text{Tan}\ (2\ x) = \frac{2\ \text{Tan}\ x}{1 - \text{Tan}^2\ x}$$

$$\text{Cot}\ (2\ x) = \frac{(\text{Cot}^2\ x - 1)}{2\ \text{Cot}\ x}$$

$$\text{Sin}\ \tfrac{1}{2}\ x = \sqrt{\frac{1 - \text{Cos}\ x}{2}} = \frac{\sqrt{1 + \text{Sin}\ x}}{2} - \frac{\sqrt{1 - \text{Sin}\ x}}{2}$$

$$\text{Cos}\ \tfrac{1}{2}\ x = \sqrt{\frac{1 + \text{Cos}\ x}{2}} = \frac{\sqrt{1 + \text{Sin}\ x}}{2} + \frac{\sqrt{1 - \text{Sin}\ x}}{2}$$

$$\text{Tan}\ \tfrac{1}{2}\ x = \sqrt{\frac{1 - \text{Cos}\ x}{1 + \text{Cos}\ x}} = \frac{\text{Sin}\ x}{1 + \text{Cos}\ x} = \frac{1 - \text{Cos}\ x}{\text{Sin}\ x}$$

$$\text{Sin}\ (x + y) = \text{Sin}\ x\ \text{Cos}\ y + \text{Cos}\ x\ \text{Sin}\ y$$
$$\text{Cos}\ (x + y) = \text{Cos}\ x\ \text{Cos}\ y - \text{Sin}\ x\ \text{Sin}\ y$$

HYPERBOLIC SINES [$\sinh x = \frac{1}{2}(e^x - e^{-x})$]

x	0	1	2	3	4	5	6	7	8	9	avg diff
0.0	0.0000	0.0100	0.0200	0.0300	0.0400	0.0500	0.0600	0.0701	0.0801	0.0901	100
.1	0.1002	0.1102	0.1203	0.1304	0.1405	0.1506	0.1607	0.1708	0.1810	0.1911	101
.2	0.2013	0.2115	0.2218	0.2320	0.2423	0.2526	0.2629	0.2733	0.2837	0.2941	103
.3	0.3045	0.3150	0.3255	0.3360	0.3466	0.3572	0.3678	0.3785	0.3892	0.4000	106
.4	0.4108	0.4216	0.4325	0.4434	0.4543	0.4653	0.4764	0.4875	0.4986	0.5098	110
0.5	0.5211	0.5324	0.5438	0.5552	0.5666	0.5782	0.5897	0.6014	0.6131	0.6248	116
.6	0.6367	0.6485	0.6605	0.6725	0.6846	0.6967	0.7090	0.7213	0.7336	0.7461	122
.7	0.7586	0.7712	0.7838	0.7966	0.8094	0.8223	0.8353	0.8484	0.8615	0.8748	130
.8	0.8881	0.9015	0.9150	0.9286	0.9423	0.9561	0.9700	0.9840	0.9981	1.012	138
.9	1.027	1.041	1.055	1.070	1.085	1.099	1.114	1.129	1.145	1.160	15
1.0	1.175	1.191	1.206	1.222	1.238	1.254	1.270	1.286	1.303	1.319	16
.1	1.336	1.352	1.369	1.386	1.403	1.421	1.438	1.456	1.474	1.491	17
.2	1.509	1.528	1.546	1.564	1.583	1.602	1.621	1.640	1.659	1.679	19
.3	1.698	1.718	1.738	1.758	1.779	1.799	1.820	1.841	1.862	1.883	21
.4	1.904	1.926	1.948	1.970	1.992	2.014	2.037	2.060	2.083	2.106	22
1.5	2.129	2.153	2.177	2.201	2.225	2.250	2.274	2.299	2.324	2.350	25
.6	2.376	2.401	2.428	2.454	2.481	2.507	2.535	2.562	2.590	2.617	27
.7	2.646	2.674	2.703	2.732	2.761	2.790	2.820	2.850	2.881	2.911	30
.8	2.942	2.973	3.005	3.037	3.069	3.101	3.134	3.167	3.200	3.234	33
.9	3.268	3.303	3.337	3.372	3.408	3.443	3.479	3.516	3.552	3.589	36
2.0	3.627	3.665	3.703	3.741	3.780	3.820	3.859	3.899	3.940	3.981	39
.1	4.022	4.064	4.106	4.148	4.191	4.234	4.278	4.322	4.367	4.412	44
.2	4.457	4.503	4.549	4.596	4.643	4.691	4.739	4.788	4.837	4.887	48
.3	4.937	4.988	5.039	5.090	5.142	5.195	5.248	5.302	5.356	5.411	53
.4	5.466	5.522	5.578	5.635	5.693	5.751	5.810	5.869	5.929	5.989	58
2.5	6.050	6.112	6.174	6.237	6.300	6.365	6.429	6.495	6.561	6.627	64
.6	6.695	6.763	6.831	6.901	6.971	7.042	7.113	7.185	7.258	7.332	71
.7	7.406	7.481	7.557	7.634	7.711	7.789	7.868	7.948	8.028	8.110	79
.8	8.192	8.275	8.359	8.443	8.529	8.615	8.702	8.790	8.879	8.969	87
.9	9.060	9.151	9.244	9.337	9.431	9.527	9.623	9.720	9.819	9.918	96
3.0	10.02	10.12	10.22	10.32	10.43	10.53	10.64	10.75	10.86	10.97	11
.1	11.08	11.19	11.30	11.42	11.53	11.65	11.76	11.88	12.00	12.12	12
.2	12.25	12.37	12.49	12.62	12.75	12.88	13.01	13.14	13.27	13.40	13
.3	13.54	13.67	13.81	13.95	14.09	14.23	14.38	14.52	14.67	14.82	14
.4	14.97	15.12	15.27	15.42	15.58	15.73	15.89	16.05	16.21	16.38	16
3.5	16.54	16.71	16.88	17.05	17.22	17.39	17.57	17.74	17.92	18.10	17
.6	18.29	18.47	18.66	18.84	19.03	19.22	19.42	19.61	19.81	20.01	19
.7	20.21	20.41	20.62	20.83	21.04	21.25	21.46	21.68	21.90	22.12	21
.8	22.34	22.56	22.79	23.02	23.25	23.49	23.72	23.96	24.20	24.45	24
.9	24.69	24.94	25.19	25.44	25.70	25.96	26.22	26.48	26.75	27.02	26
4.0	27.29	27.56	27.84	28.12	28.40	28.69	28.98	29.27	29.56	29.86	29
.1	30.16	30.47	30.77	31.08	31.39	31.71	32.03	32.35	32.68	33.00	32
.2	33.34	33.67	34.01	34.35	34.70	35.05	35.40	35.75	36.11	36.48	35
.3	36.84	37.21	37.59	37.97	38.35	38.73	39.12	39.52	39.91	40.31	39
.4	40.72	41.13	41.54	41.96	42.38	42.81	43.24	43.67	44.11	44.56	43
4.5	45.00	45.46	45.91	46.37	46.84	47.31	47.79	48.27	48.75	49.24	47
.6	49.74	50.24	50.74	51.25	51.77	52.29	52.81	53.34	53.88	54.42	52
.7	54.97	55.52	56.08	56.64	57.21	57.79	58.37	58.96	59.55	60.15	58
.8	60.75	61.36	61.98	62.60	63.23	63.87	64.51	65.16	65.81	66.47	64
.9	67.14	67.82	68.50	69.19	69.88	70.58	71.29	72.01	72.73	73.46	71
5.0	74.20										

If $x > 5$, $\sinh x = \frac{1}{2}(e^x)$ and $\log_{10} \sinh x = (0.4343)x + 0.6990 - 1$, correct to four significant figures.

HYPERBOLIC COSINES [$\cosh x = \frac{1}{2}(e^x + e^{-x})$]

x	0	1	2	3	4	5	6	7	8	9	av dif
0.0	1.000	1.000	1.000	1.000	1.001	1.001	1.002	1.002	1.003	1.004	1
.1	1.005	1.006	1.007	1.008	1.010	1.011	1.013	1.014	1.016	1.018	2
.2	1.020	1.022	1.024	1.027	1.029	1.031	1.034	1.037	1.039	1.042	3
.3	1.045	1.048	1.052	1.055	1.058	1.062	1.066	1.069	1.073	1.077	4
.4	1.081	1.085	1.090	1.094	1.098	1.103	1.108	1.112	1.117	1.122	5
0.5	1.128	1.133	1.138	1.144	1.149	1.155	1.161	1.167	1.173	1.179	6
.6	1.185	1.192	1.198	1.205	1.212	1.219	1.226	1.233	1.240	1.248	7
.7	1.255	1.263	1.271	1.278	1.287	1.295	1.303	1.311	1.320	1.329	8
.8	1.337	1.346	1.355	1.365	1.374	1.384	1.393	1.403	1.413	1.423	10
.9	1.433	1.443	1.454	1.465	1.475	1.486	1.497	1.509	1.520	1.531	11
1.0	1.543	1.555	1.567	1.579	1.591	1.604	1.616	1.629	1.642	1.655	13
.1	1.669	1.682	1.696	1.709	1.723	1.737	1.752	1.766	1.781	1.796	14
.2	1.811	1.826	1.841	1.857	1.872	1.888	1.905	1.921	1.937	1.954	16
.3	1.971	1.988	2.005	2.023	2.040	2.058	2.076	2.095	2.113	2.132	18
.4	2.151	2.170	2.189	2.209	2.229	2.249	2.269	2.290	2.310	2.331	20
1.5	2.352	2.374	2.395	2.417	2.439	2.462	2.484	2.507	2.530	2.554	23
.6	2.577	2.601	2.625	2.650	2.675	2.700	2.725	2.750	2.776	2.802	25
.7	2.828	2.855	2.882	2.909	2.936	2.964	2.992	3.021	3.049	3.078	28
.8	3.107	3.137	3.167	3.197	3.228	3.259	3.290	3.321	3.353	3.385	31
.9	3.418	3.451	3.484	3.517	3.551	3.585	3.620	3.655	3.690	3.726	34
2.0	3.762	3.799	3.835	3.873	3.910	3.948	3.987	4.026	4.065	4.104	38
.1	4.144	4.185	4.226	4.267	4.309	4.351	4.393	4.436	4.480	4.524	42
.2	4.568	4.613	4.658	4.704	4.750	4.797	4.844	4.891	4.939	4.988	47
.3	5.037	5.087	5.137	5.188	5.239	5.290	5.343	5.395	5.449	5.503	52
.4	5.557	5.612	5.667	5.723	5.780	5.837	5.895	5.954	6.013	6.072	58
2.5	6.132	6.193	6.255	6.317	6.379	6.443	6.507	6.571	6.636	6.702	64
.6	6.769	6.836	6.904	6.973	7.042	7.112	7.183	7.255	7.327	7.400	70
.7	7.473	7.548	7.623	7.699	7.776	7.853	7.932	8.011	8.091	8.171	78
.8	8.253	8.335	8.418	8.502	8.587	8.673	8.759	8.847	8.935	9.024	86
.9	9.115	9.206	9.298	9.391	9.484	9.579	9.675	9.772	9.869	9.968	95
3.0	10.07	10.17	10.27	10.37	10.48	10.58	10.69	10.79	10.90	11.01	11
.1	11.12	11.23	11.35	11.46	11.57	11.69	11.81	11.92	12.04	12.16	12
.2	12.29	12.41	12.53	12.66	12.79	12.91	13.04	13.17	13.31	13.44	13
.3	13.57	13.71	13.85	13.99	14.13	14.27	14.41	14.56	14.70	14.85	14
.4	15.00	15.15	15.30	15.45	15.61	15.77	15.92	16.08	16.25	16.41	16
3.5	16.57	16.74	16.91	17.08	17.25	17.42	17.60	17.77	17.95	18.13	17
.6	18.31	18.50	18.68	18.87	19.06	19.25	19.44	19.64	19.84	20.03	19
.7	20.24	20.44	20.64	20.85	21.06	21.27	21.49	21.70	21.92	22.14	21
.8	22.36	22.59	22.81	23.04	23.27	23.51	23.74	23.98	24.22	24.47	23
.9	24.71	24.96	25.21	25.46	25.72	25.98	26.24	26.50	26.77	27.04	26
4.0	27.31	27.58	27.86	28.14	28.42	28.71	29.00	29.29	29.58	29.88	29
.1	30.18	30.48	30.79	31.10	31.41	31.72	32.04	32.37	32.69	33.02	32
.2	33.35	33.69	34.02	34.37	34.71	35.06	35.41	35.77	36.13	36.49	35
.3	36.86	37.23	37.60	37.98	38.36	38.75	39.13	39.53	39.93	40.33	39
.4	40.73	41.14	41.55	41.97	42.39	42.82	43.25	43.68	44.12	44.57	43
4.5	45.01	45.47	45.92	46.38	46.85	47.32	47.80	48.28	48.76	49.25	47
.6	49.75	50.25	50.75	51.26	51.78	52.30	52.82	53.35	53.89	54.43	52
.7	54.98	55.53	56.09	56.65	57.22	57.80	58.38	58.96	59.56	60.15	58
.8	60.76	61.37	61.99	62.61	63.24	63.87	64.52	65.16	65.82	66.48	64
.9	67.15	67.82	68.50	69.19	69.89	70.59	71.30	72.02	72.74	73.47	71
5.0	74.21										

If $x > 5$, $\cosh x = \frac{1}{2}(e^x)$, and $\log_{10}\cosh x = (0.4343)x + 0.6990 - 1$, correct to four significant figures.

HYPERBOLIC TANGENTS

$[\text{Tanh } x = (e^x - e^{-x})/(e^x + e^{-x}) = \sinh x/\cosh x]$

x	0	1	2	3	4	5	6	7	8	9	avg diff
0.0	.0000	.0100	.0200	.0300	.0400	.0500	.0599	.0699	.0798	.0898	100
.1	.0997	.1096	.1194	.1293	.1391	.1489	.1587	.1684	.1781	.1878	98
.2	.1974	.2070	.2165	.2260	.2355	.2449	.2543	.2636	.2729	.2821	94
.3	.2913	.3004	.3095	.3185	.3275	.3364	.3452	.3540	.3627	.3714	89
.4	.3800	.3885	.3969	.4053	.4136	.4219	.4301	.4382	.4462	.4542	82
0.5	.4621	.4700	.4777	.4854	.4930	.5005	.5080	.5154	.5227	.5299	75
.6	.5370	.5441	.5511	.5581	.5649	.5717	.5784	.5850	.5915	.5980	67
.7	.6044	.6107	.6169	.6231	.6291	.6352	.6411	.6469	.6527	.6584	60
.8	.6640	.6696	.6751	.6805	.6858	.6911	.6963	.7014	.7064	.7114	52
.9	.7163	.7211	.7259	.7306	.7352	.7398	.7443	.7487	.7531	.7574	45
1.0	.7616	.7658	.7699	.7739	.7779	.7818	.7857	.7895	.7932	.7969	39
.1	.8005	.8041	.8076	.8110	.8144	.8178	.8210	.8243	.8275	.8306	33
.2	.8337	.8367	.8397	.8426	.8455	.8483	.8511	.8538	.8565	.8591	28
.3	.8617	.8643	.8668	.8693	.8717	.8741	.8764	.8787	.8810	.8832	24
.4	.8854	.8875	.8896	.8917	.8937	.8957	.8977	.8996	.9015	.9033	20
1.5	.9052	.9069	.9087	.9104	.9121	.9138	.9154	.9170	.9186	.9202	17
.6	.9217	.9232	.9246	.9261	.9275	.9289	.9302	.9316	.9329	.9342	14
.7	.9354	.9367	.9379	.9391	.9402	.9414	.9425	.9436	.9447	.9458	11
.8	.9468	.9478	.9488	.9498	.9508	.9518	.9527	.9536	.9545	.9554	9
.9	.9562	.9571	.9579	.9587	.9595	.9603	.9611	.9619	.9626	.9633	8
2.0	.9640	.9647	.9654	.9661	.9668	.9674	.9680	.9687	.9693	.9699	6
.1	.9705	.9710	.9716	.9722	.9727	.9732	.9738	.9743	.9748	.9753	5
.2	.9757	.9762	.9767	.9771	.9776	.9780	.9785	.9789	.9793	.9797	4
.3	.9801	.9805	.9809	.9812	.9816	.9820	.9823	.9827	.9830	.9834	4
.4	.9837	.9840	.9843	.9846	.9849	.9852	.9855	.9858	.9861	.9863	3
2.5	.9866	.9869	.9871	.9874	.9876	.9879	.9881	.9884	.9886	.9888	2
.6	.9890	.9892	.9895	.9897	.9899	.9901	.9903	.9905	.9906	.9908	2
.7	.9910	.9912	.9914	.9915	.9917	.9919	.9920	.9922	.9923	.9925	2
.8	.9926	.9928	.9929	.9931	.9932	.9933	.9935	.9936	.9937	.9938	1
.9	.9940	.9941	.9942	.9943	.9944	.9945	.9946	.9947	.9949	.9950	1
3.0	.9951	.9959	.9967	.9973	.9978	.9982	.9985	.9988	.9990	.9992	4
4.0	.9993	.9995	.9996	.9996	.9997	.9998	.9998	.9998	.9999	.9999	1
5.0	.9999										

If x > 5, tanh x = 1.0000 to four decimal places.

MULTIPLES OF 0.4343 $[0.43429448 = \mathrm{LOG}_{10}e]$

x	0	1	2	3	4	5	6	7	8	9
0.0	0.0000	0.0434	0.0869	0.1303	0.1737	0.2171	0.2606	0.3040	0.3474	0.3909
1.0	0.4343	0.4777	0.5212	0.5646	0.6080	0.6514	0.6949	0.7383	0.7817	0.8252
2.0	0.8686	0.9120	0.9554	0.9989	1.0423	1.0857	1.1292	1.1726	1.2160	1.2595
3.0	1.3029	1.3463	1.3897	1.4332	1.4766	1.5200	1.5635	1.6069	1.6503	1.6937
4.0	1.7372	1.7806	1.8240	1.8675	1.9109	1.9543	1.9978	2.0412	2.0846	2.1280
5.0	2.1715	2.2149	2.2583	2.3018	2.3452	2.3886	2.4320	2.4755	2.5189	2.5623
6.0	2.6058	2.6492	2.6926	2.7361	2.7795	2.8229	2.8663	2.9098	2.9532	2.9966
7.0	3.0401	3.0835	3.1269	3.1703	3.2138	3.2572	3.3006	3.3441	3.3875	3.4309
8.0	3.4744	3.5178	3.5612	3.6046	3.6481	3.6915	3.7349	3.7784	3.8218	3.8652
9.0	3.9087	3.9521	3.9955	4.0389	4.0824	4.1258	4.1692	4.2127	4.2561	4.2995

MULTIPLES OF 2.3026 $[2.3025851 = 1/0.4343 = \mathrm{LOG}e10]$

x	0	1	2	3	4	5	6	7	8	9
0.0	0.0000	0.2303	0.4605	0.6908	0.9210	1.1513	1.3816	1.6118	1.8421	2.0723
1.0	2.3026	2.5328	2.7631	2.9934	3.2236	3.4539	3.6841	3.9144	4.1447	4.3749
2.0	4.6052	4.8354	5.0657	5.2959	5.5262	5.7565	5.9867	6.2170	6.4472	6.6775
3.0	6.9078	7.1380	7.3683	7.5985	7.8288	8.0590	8.2893	8.5196	8.7498	8.9801
4.0	9.2103	9.4406	9.6709	9.9011	10.131	10.362	10.592	10.822	11.052	11.283
5.0	11.513	11.743	11.973	12.204	12.434	12.664	12.894	13.125	13.355	13.585
6.0	13.816	14.046	14.276	14.506	14.737	14.967	15.197	15.427	15.658	15.888
7.0	16.118	16.348	16.579	16.809	17.039	17.269	17.500	17.730	17.960	18.190
8.0	18.421	18.651	18.881	19.111	19.342	19.572	19.802	20.032	20.263	20.493
9.0	20.723	20.954	21.184	21.414	21.644	21.875	22.105	22.335	22.565	22.796

NATURAL TRIGONOMETRIC FUNCTIONS FOR DECIMAL FRACTIONS OF A DEGREE

deg	sin	cos	tan	cot		deg	sin	cos	tan	cot	
0.0	.00000	1.0000	.00000	∞	**90.0**	**6.0**	.10453	0.9945	.10510	9.514	**84.0**
.1	.00175	1.0000	.00175	573.0	.9	.1	.10626	.9943	.10687	9.357	.9
.2	.00349	1.0000	.00349	286.5	.8	.2	.10800	.9942	.10863	9.205	.8
.3	.00524	1.0000	.00524	191.0	.7	.3	.10973	.9940	.11040	9.058	.7
.4	.00698	1.0000	.00698	143.24	.6	.4	.11147	.9938	.11217	8.915	.6
.5	.00873	1.0000	.00873	114.59	.5	.5	.11320	.9936	.11394	8.777	.5
.6	.01047	0.9999	.01047	95.49	.4	.6	.11494	.9934	.11570	8.643	.4
.7	.01222	.9999	.01222	81.85	.3	.7	.11667	.9932	.11747	8.513	.3
.8	.01396	.9999	.01396	71.62	.2	.8	.11840	.9930	.11924	8.386	.2
.9	.01571	.9999	.01571	63.66	.1	.9	.12014	.9928	.12101	8.264	.1
1.0	.01745	0.9998	.01746	57.29	**89.0**	**7.0**	.12187	0.9925	.12278	8.144	**83.0**
.1	.01920	.9998	.01920	52.08	.9	.1	.12360	.9923	.12456	8.028	.9
.2	.02094	.9998	.02095	47.74	.8	.2	.12533	.9921	.12633	7.916	.8
.3	.02269	.9997	.02269	44.07	.7	.3	.12706	.9919	.12810	7.806	.7
.4	.02443	.9997	.02444	40.92	.6	.4	.12880	.9917	.12988	7.700	.6
.5	.02618	.9997	.02619	38.19	.5	.5	.13053	.9914	.13165	7.596	.5
.6	.02792	.9996	.02793	35.80	.4	.6	.13226	.9912	.13343	7.495	.4
.7	.02967	.9996	.02968	33.69	.3	.7	.13399	.9910	.13521	7.396	.3
.8	.03141	.9995	.03143	31.82	.2	.8	.13572	.9907	.13698	7.300	.2
.9	.03316	.9995	.03317	30.14	.1	.9	.13744	.9905	.13876	7.207	.1
2.0	.03490	0.9994	.03492	28.64	**88.0**	**8.0**	.13917	0.9903	.14054	7.115	**82.0**
.1	.03664	.9993	.03667	27.27	.9	.1	.14090	.9900	.14232	7.026	.9
.2	.03839	.9993	.03842	26.03	.8	.2	.14263	.9898	.14410	6.940	.8
.3	.04013	.9992	.04016	24.90	.7	.3	.14436	.9895	.14588	6.855	.7
.4	.04188	.9991	.04191	23.86	.6	.4	.14608	.9893	.14767	6.772	.6
.5	.04362	.9990	.04366	22.90	.5	.5	.14781	.9890	.14945	6.691	.5
.6	.04536	.9990	.04541	22.02	.4	.6	.14954	.9888	.15124	6.612	.4
.7	.04711	.9989	.04716	21.20	.3	.7	.15126	.9885	.15302	6.535	.3
.8	.04885	.9988	.04891	20.45	.2	.8	.15299	.9882	.15481	6.460	.2
.9	.05059	.9987	.05066	19.74	.1	.9	.15471	.9880	.15660	6.386	.1
3.0	.05234	0.9986	.05241	19.081	**87.0**	**9.0**	.15643	0.9877	.15838	6.314	**81.0**
.1	.05408	.9985	.05416	18.464	.9	.1	.15816	.9874	.16017	6.243	.9
.2	.05582	.9984	.05591	17.886	.8	.2	.15988	.9871	.16196	6.174	.8
.3	.05756	.9983	.05766	17.343	.7	.3	.16160	.9869	.16376	6.107	.7
.4	.05931	.9982	.05941	16.832	.6	.4	.16333	.9866	.16555	6.041	.6
.5	.06105	.9981	.06116	16.350	.5	.5	.16505	.9863	.16734	5.976	.5
.6	.06279	.9980	.06291	15.895	.4	.6	.16677	.9860	.16914	5.912	.4
.7	.06453	.9979	.06467	15.464	.3	.7	.16849	.9857	.17093	5.850	.3
.8	.06627	.9978	.06642	15.056	.2	.8	.17021	.9854	.17273	5.789	.2
.9	.06802	.9977	.06817	14.669	.1	.9	.17193	.9851	.17453	5.730	.1
4.0	.06976	0.9976	.06993	14.301	**86.0**	**10.0**	.1736	0.9848	.1763	5.671	**80.0**
.1	.07150	.9974	.07168	13.951	.9	.1	.1754	.9845	.1781	5.614	.9
.2	.07324	.9973	.07344	13.617	.8	.2	.1771	.9842	.1799	5.558	.8
.3	.07498	.9972	.07519	13.300	.7	.3	.1788	.9839	.1817	5.503	.7
.4	.07672	.9971	.07695	12.996	.6	.4	.1805	.9836	.1835	5.449	.6
.5	.07846	.9969	.07870	12.706	.5	.5	.1822	.9833	.1853	5.396	.5
.6	.08020	.9968	.08046	12.429	.4	.6	.1840	.9829	.1871	5.343	.4
.7	.08194	.9966	.08221	12.163	.3	.7	.1857	.9826	.1890	5.292	.3
.8	.08368	.9965	.08397	11.909	.2	.8	.1874	.9823	.1908	5.242	.2
.9	.08542	.9963	.08573	11.664	.1	.9	.1891	.9820	.1926	5.193	.1
5.0	.08716	0.9962	.08749	11.430	**85.0**	**11.0**	.1908	0.9816	.1944	5.145	**79.0**
.1	.08889	.9960	.08925	11.205	.9	.1	.1925	.9813	.1962	5.097	.9
.2	.09063	.9959	.09101	10.988	.8	.2	.1942	.9810	.1980	5.050	.8
.3	.09237	.9957	.09277	10.780	.7	.3	.1959	.9806	.1998	5.005	.7
.4	.09411	.9956	.09453	10.579	.6	.4	.1977	.9803	.2016	4.959	.6
.5	.09585	.9954	.09629	10.385	.5	.5	.1994	.9799	.2035	4.915	.5
.6	.09758	.9952	.09805	10.199	.4	.6	.2011	.9796	.2053	4.872	.4
.7	.09932	.9951	.09981	10.019	.3	.7	.2028	.9792	.2071	4.829	.3
.8	.10106	.9949	.10158	9.845	.2	.8	.2045	.9789	.2089	4.787	.2
.9	.10279	.9947	.10334	9.677	.1	.9	.2062	.9785	.2107	4.745	.1
6.0	.10453	0.9945	.10510	9.514	**84.0**	**12.0**	.2079	0.9781	.2126	4.705	**78.0**
	cos	sin	cot	tan	deg		cos	sin	cot	tan	deg

NATURAL TRIGONOMETRIC FUNCTIONS FOR DECIMAL FRACTIONS OF A DEGREE (continued)

deg	sin	cos	tan	cot		deg	sin	cos	tan	cot	
12.0	0.2079	0.9781	0.2126	4.705	**78.0**	**18.0**	0.3090	0.9511	0.3249	3.078	**72.0**
.1	.2096	.9778	.2144	4.665	.9	.1	.3107	.9505	.3269	3.060	.9
.2	.2113	.9774	.2162	4.625	.8	.2	.3123	.9500	.3288	3.042	.8
.3	.2130	.9770	.2180	4.586	.7	.3	.3140	.9494	.3307	3.024	.7
.4	.2147	.9767	.2199	4.548	.6	.4	.3156	.9489	.3327	3.006	.6
.5	.2164	.9763	.2217	4.511	.5	.5	.3173	.9483	.3346	2.989	.5
.6	.2181	.9759	.2235	4.474	.4	.6	.3190	.9478	.3365	2.971	.4
.7	.2198	.9755	.2254	4.437	.3	.7	.3206	.9472	.3385	2.954	.3
.8	.2215	.9751	.2272	4.402	.2	.8	.3223	.9466	.3404	2.937	.2
.9	.2233	.9748	.2290	4.366	.1	.9	.3239	.9461	.3424	2.921	.1
13.0	0.2250	0.9744	0.2309	4.331	**77.0**	**19.0**	0.3256	0.9455	0.3443	2.904	**71.0**
.1	.2267	.9740	.2327	4.297	.9	.1	.3272	.9449	.3463	2.888	.9
.2	.2284	.9736	.2345	4.264	.8	.2	.3289	.9444	.3482	2.872	.8
.3	.2300	.9732	.2364	4.230	.7	.3	.3305	.9438	.3502	2.856	.7
.4	.2317	.9728	.2382	4.198	.6	.4	.3322	.9432	.3522	2.840	.6
.5	.2334	.9724	.2401	4.165	.5	.5	.3338	.9426	.3541	2.824	.5
.6	.2351	.9720	.2419	4.134	.4	.6	.3355	.9421	.3561	2.808	.4
.7	.2368	.9715	.2438	4.102	.3	.7	.3371	.9415	.3581	2.793	.3
.8	.2385	.9711	.2456	4.071	.2	.8	.3387	.9409	.3600	2.778	.2
.9	.2402	.9707	.2475	4.041	.1	.9	.3404	.9403	.3620	2.762	.1
14.0	0.2419	0.9703	0.2493	4.011	**76.0**	**20.0**	0.3420	0.9397	0.3640	2.747	**70.0**
.1	.2436	.9699	.2512	3.981	.9	.1	.3437	.9391	.3659	2.733	.9
.2	.2453	.9694	.2530	3.952	.8	.2	.3453	.9385	.3679	2.718	.8
.3	.2470	.9690	.2549	3.923	.7	.3	.3469	.9379	.3699	2.703	.7
.4	.2487	.9686	.2568	3.895	.6	.4	.3486	.9373	.3719	2.689	.6
.5	.2504	.9681	.2586	3.867	.5	.5	.3502	.9367	.3739	2.675	.5
.6	.2521	.9677	.2605	3.839	.4	.6	.3518	.9361	.3759	2.660	.4
.7	.2538	.9673	.2623	3.812	.3	.7	.3535	.9354	.3779	2.646	.3
.8	.2554	.9668	.2642	3.785	.2	.8	.3551	.9348	.3799	2.633	.2
.9	.2571	.9664	.2661	3.758	.1	.9	.3567	.9342	.3819	2.619	.1
15.0	0.2588	0.9659	0.2679	3.732	**75.0**	**21.0**	0.3584	0.9336	0.3839	2.605	**69.0**
.1	.2605	.9655	.2698	3.706	.9	.1	.3600	.9330	.3859	2.592	.9
.2	.2622	.9650	.2717	3.681	.8	.2	.3616	.9323	.3879	2.578	.8
.3	.2639	.9646	.2736	3.655	.7	.3	.3633	.9317	.3899	2.565	.7
.4	.2656	.9641	.2754	3.630	.6	.4	.3649	.9311	.3919	2.552	.6
.5	.2672	.9636	.2773	3.606	.5	.5	.3665	.9304	.3939	2.539	.5
.6	.2689	.9632	.2792	3.582	.4	.6	.3681	.9298	.3959	2.526	.4
.7	.2706	.9627	.2811	3.558	.3	.7	.3697	.9291	.3979	2.513	.3
.8	.2723	.9622	.2830	3.534	.2	.8	.3714	.9285	.4000	2.500	.2
.9	.2740	.9617	.2849	3.511	.1	.9	.3730	.9278	.4020	2.488	.1
16.0	0.2756	0.9613	0.2867	3.487	**74.0**	**22.0**	0.3746	0.9272	0.4040	2.475	**68.0**
.1	.2773	.9608	.2886	3.465	.9	.1	.3762	.9265	.4061	2.463	.9
.2	.2790	.9603	.2905	3.442	.8	.2	.3778	.9259	.4081	2.450	.8
.3	.2807	.9598	.2924	3.420	.7	.3	.3795	.9252	.4101	2.438	.7
.4	.2823	.9593	.2943	3.398	.6	.4	.3811	.9245	.4122	2.426	.6
.5	.2840	.9588	.2962	3.376	.5	.5	.3827	.9239	.4142	2.414	.5
.6	.2857	.9583	.2981	3.354	.4	.6	.3843	.9232	.4163	2.402	.4
.7	.2874	.9578	.3000	3.333	.3	.7	.3859	.9225	.4183	2.391	.3
.8	.2890	.9573	.3019	3.312	.2	.8	.3875	.9219	.4204	2.379	.2
.9	.2907	.9568	.3038	3.291	.1	.9	.3891	.9212	.4224	2.367	.1
17.0	0.2924	0.9563	0.3057	3.271	**73.0**	**23.0**	0.3907	0.9205	0.4245	2.356	**67.0**
.1	.2940	.9558	.3076	3.251	.9	.1	.3923	.9198	.4265	2.344	.9
.2	.2957	.9553	.3096	3.230	.8	.2	.3939	.9191	.4286	2.333	.8
.3	.2974	.9548	.3115	3.211	.7	.3	.3755	.9184	.4307	2.322	.7
.4	.2990	.9542	.3134	3.191	.6	.4	.3971	.9178	.4327	2.311	.6
.5	.3007	.9537	.3153	3.172	.5	.5	.3987	.9171	.4348	2.300	.5
.6	.3024	.9532	.3172	3.152	.4	.6	.4003	.9164	.4369	2.289	.4
.7	.3040	.9527	.3191	3.133	.3	.7	.4019	.9157	.4390	2.278	.3
.8	.3057	.9521	.3211	3.115	.2	.8	.4035	.9150	.4411	2.267	.2
.9	.3074	.9516	.3230	3.096	.1	.9	.4051	.9143	.4431	2.257	.1
18.0	0.3090	0.9511	0.3249	3.078	**72.0**	**24.0**	0.4067	0.9135	0.4452	2.246	**66.0**
	cos	sin	cot	tan	deg		cos	sin	cot	tan	deg

NATURAL TRIGONOMETRIC FUNCTIONS FOR DECIMAL FRACTIONS OF A DEGREE (continued)

deg	sin	cos	tan	cot	
24.0	0.4067	0.9135	0.4452	2.246	**66.0**
.1	.4083	.9128	.4473	2.236	.9
.2	.4099	.9121	.4494	2.225	.8
.3	.4115	.9114	.4515	2.215	.7
.4	.4131	.9107	.4536	2.204	.6
.5	.4147	.9100	.4557	2.194	.5
.6	.4163	.9092	.4578	2.184	.4
.7	.4179	.9085	.4599	2.174	.3
.8	.4195	.9078	.4621	2.164	.2
.9	.4210	.9070	.4642	2.154	.1
25.0	0.4226	0.9063	0.4663	2.145	**65.0**
.1	.4242	.9056	.4684	2.135	.9
.2	.4258	.9048	.4706	2.125	.8
.3	.4274	.9041	.4727	2.116	.7
.4	.4289	.9033	.4748	2.106	.6
.5	.4305	.9026	.4770	2.097	.5
.6	.4321	.9018	.4791	2.087	.4
.7	.4337	.9011	.4813	2.078	.3
.8	.4352	.9003	.4834	2.069	.2
.9	.4368	.8996	.4856	2.059	.1
26.0	0.4384	0.8988	0.4877	2.050	**64.0**
.1	.4399	.8980	.4899	2.041	.9
.2	.4415	.8973	.4921	2.032	.8
.3	.4431	.8965	.4942	2.023	.7
.4	.4446	.8957	.4964	2.014	.6
.5	.4462	.8949	.4986	2.006	.5
.6	.4478	.8942	.5008	1.997	.4
.7	.4493	.8934	.5029	1.988	.3
.8	.4509	.8926	.5051	1.980	.2
.9	.4524	.8918	.5073	1.971	.1
27.0	0.4540	0.8910	0.5095	1.963	**63.0**
.1	.4555	.8902	.5117	1.954	.9
.2	.4571	.8894	.5139	1.946	.8
.3	.4586	.8886	.5161	1.937	.7
.4	.4602	.8878	.5184	1.929	.6
.5	.4617	.8870	.5206	1.921	.5
.6	.4633	.8862	.5228	1.913	.4
.7	.4648	.8854	.5250	1.905	.3
.8	.4664	.8846	.5272	1.897	.2
.9	.4679	.8838	.5295	1.889	.1
28.0	0.4695	0.8829	0.5317	1.881	**62.0**
.1	.4710	.8821	.5340	1.873	.9
.2	.4726	.8813	.5362	1.865	.8
.3	.4741	.8805	.5384	1.857	.7
.4	.4756	.8796	.5407	1.849	.6
.5	.4772	.8788	.5430	1.842	.5
.6	.4787	.8780	.5452	1.834	.4
.7	.4802	.8771	.5475	1.827	.3
.8	.4818	.8763	.5498	1.819	.2
.9	.4833	.8755	.5520	1.811	.1
29.0	0.4848	0.8746	0.5543	1.804	**61.0**
.1	.4863	.8738	.5566	1.797	.9
.2	.4879	.8729	.5589	1.789	.8
.3	.4894	.8721	.5612	1.782	.7
.4	.4909	.8712	.5635	1.775	.6
.5	.4924	.8704	.5658	1.767	.5
.6	.4939	.8695	.5681	1.760	.4
.7	.4955	.8686	.5704	1.753	.3
.8	.4970	.8678	.5727	1.746	.2
.9	.4985	.8669	.5750	1.739	.1
30.0	0.5000	0.8660	0.5774	1.732	**60.0**
	cos	sin	cot	tan	deg

deg	sin	cos	tan	cot	
30.0	0.5000	0.8660	0.5774	1.7321	**60.0**
.1	.5015	.8652	.5797	1.7251	.9
.2	.5030	.8643	.5820	1.7182	.8
.3	.5045	.8634	.5844	1.7113	.7
.4	.5060	.8625	.5867	1.7045	.6
.5	.5075	.8616	.5890	1.6977	.5
.6	.5090	.8607	.5914	1.6909	.4
.7	.5105	.8599	.5938	1.6842	.3
.8	.5120	.8590	.5961	1.6775	.2
.9	.5135	.8581	.5985	1.6709	.1
31.0	0.5150	0.8572	0.6009	1.6643	**59.0**
.1	.5165	.8563	.6032	1.6577	.9
.2	.5180	.8554	.6056	1.6512	.8
.3	.5195	.8545	.6080	1.6447	.7
.4	.5210	.8536	.6104	1.6383	.6
.5	.5225	.8526	.6128	1.6319	.5
.6	.5240	.8617	.6152	1.6255	.4
.7	.5255	.8508	.6176	1.6191	.3
.8	.5270	.8479	.6200	1.6128	.2
.9	.5284	.8490	.6224	1.6066	.1
32.0	0.5299	0.8480	0.6249	1.6003	**58.0**
.1	.5314	.8471	.6273	1.5941	.9
.2	.5329	.8462	.6297	1.5880	.8
.3	.5344	.8453	.6322	1.5818	.7
.4	.5358	.8443	.6346	1.5757	.6
.5	.5373	.8434	.6371	1.5697	.5
.6	.5388	.8425	.6395	1.5637	.4
.7	.5402	.8415	.6420	1.5577	.3
.8	.5417	.8406	.6445	1.5517	.2
.9	.5432	.8396	.6469	1.5458	.1
33.0	0.5446	0.8387	0.6494	1.5399	**57.0**
.1	.5461	.8377	.6519	1.5340	.9
.2	.5476	.8368	.6544	1.5282	.8
.3	.5490	.8358	.6569	1.5224	.7
.4	.5505	.8348	.6594	1.5166	.6
.5	.5519	.8339	.6619	1.5108	.5
.6	.5534	.8329	.6644	1.5051	.4
.7	.5548	.8320	.6669	1.4994	.3
.8	.5563	.8310	.6694	1.4938	.2
.9	.5577	.8300	.6720	1.4882	.1
34.0	0.5592	0.8290	0.6745	1.4626	**56.0**
.1	.5606	.8281	.6771	1.4770	.9
.2	.5621	.8271	.6796	1.4715	.8
.3	.5635	.8261	.6822	1.4659	.7
.4	.5650	.8251	.6847	1.4605	.6
.5	.5664	.8241	.6873	1.4550	.5
.6	.5678	.8231	.6899	1.4496	.4
.7	.5693	.8221	.6924	1.4442	.3
.8	.5707	.8211	.6950	1.4388	.2
.9	.5721	.8202	.6976	1.4335	.1
35.0	0.5736	0.8192	0.7002	1.4281	**55.0**
.1	.5750	.8181	.7028	1.4229	.9
.2	.5764	.8171	.7054	1.4176	.8
.3	.5779	.8161	.7080	1.4124	.7
.4	.5793	.8151	.7107	1.4071	.6
.5	.5807	.8141	.7133	1.4019	.5
.6	.5821	.8131	.7159	1.3968	.4
.7	.5835	.8121	.7186	1.3916	.3
.8	.5850	.8111	.7212	1.3865	.2
.9	.5864	.8100	.7239	1.3814	.1
36.0	0.5878	0.8090	0.7265	1.3764	**54.0**
	cos	sin	cot	tan	deg

NATURAL TRIGONOMETRIC FUNCTIONS FOR DECIMAL FRACTIONS OF A DEGREE (continued)

deg	sin	cos	tan	cot		deg	sin	cos	tan	cot	
36.0	0.5878	0.8090	0.7265	1.3764	**54.0**	**40.5**	0.6494	0.7604	0.8541	1.1708	**49.5**
.1	.5892	.8080	.7292	1.3713	.9	.6	.6508	.7593	.8571	1.1667	.4
.2	.5906	.8070	.7319	1.3663	.8	.7	.6521	.7581	.8601	1.1626	.3
.3	.5920	.8059	.7346	1.3613	.7	.8	.6534	.7570	.8632	1.1585	.2
.4	.5934	.8049	.7373	1.3564	.6	.9	.6547	.7559	.8662	1.1544	.1
.5	.5948	.8039	.7400	1.3514	.5	**41.0**	0.6561	0.7547	0.8693	1.1504	**49.0**
.6	.5962	.8028	.7427	1.3465	.4	.1	.6574	.7536	.8724	1.1463	.9
.7	.5976	.8018	.7454	1.3416	.3	.2	.6587	.7524	.8754	1.1423	.8
.8	.5990	.8007	.7481	1.3367	.2	.3	.6600	.7513	.8785	1.1383	.7
.9	.6004	.7997	.7508	1.3319	.1	.4	.6613	.7501	.8816	1.1343	.6
37.0	0.6018	0.7986	0.7536	1.3270	**53.0**	.5	.6626	.7490	.8847	1.1303	.5
.1	.6032	.7976	.7563	1.3222	.9	.6	.6639	.7478	.8878	1.1263	.4
.2	.6046	.7965	.7590	1.3175	.8	.7	.6652	.7466	.8910	1.1224	.3
.3	.6060	.7955	.7618	1.3127	.7	.8	.6665	.7455	.8941	1.1184	.2
.4	.6074	.7944	.7646	1.3079	.6	.9	.6678	.7443	.8972	1.1145	.1
.5	.6088	.7934	.7673	1.3032	.5	**42.0**	0.6691	0.7431	0.9004	1.1106	**48.0**
.6	.6101	.7923	.7701	1.2985	.4	.1	.6704	.7420	.9036	1.1067	.9
.7	.6115	.7912	.7729	1.2938	.3	.2	.6717	.7408	.9067	1.1028	.8
.8	.6129	.7902	.7757	1.2892	.2	.3	.6730	.7396	.9099	1.0990	.7
.9	.6143	.7891	.7785	1.2846	.1	.4	.6743	.7385	.9131	1.0951	.6
38.0	0.6157	0.7880	0.7813	1.2799	**52.0**	.5	.6756	.7373	.9163	1.0913	.5
.1	.6170	.7869	.7841	1.2753	.9	.6	.6769	.7361	.9195	1.0875	.4
.2	.6184	.7859	.7869	1.2708	.8	.7	.6782	.7349	.9228	1.0837	.3
.3	.6198	.7848	.7898	1.2662	.7	.8	.6794	.7337	.9260	1.0799	.2
.4	.6211	.7837	.7926	1.2617	.6	.9	.6807	.7325	.9293	1.0761	.1
.5	.6225	.7826	.7954	1.2572	.5	**43.0**	0.6820	0.7314	0.9325	1.0724	**47.0**
.6	.6239	.7815	.7983	1.2527	.4	.1	.6833	.7302	.9358	1.0686	.9
.7	.6252	.7804	.8012	1.2482	.3	.2	.6845	.7290	.9391	1.0649	.8
.8	.6266	.7793	.8040	1.2437	.2	.3	.6858	.7278	.9424	1.0612	.7
.9	.6280	.7782	.8069	1.2393	.1	.4	.6871	.7266	.9457	1.0575	.6
39.0	0.6293	0.7771	0.8098	1.2349	**51.0**	.5	.6884	.7254	.9490	1.0538	.5
.1	.6307	.7760	.8127	1.2305	.9	.6	.6896	.7242	.9523	1.0501	.4
.2	.6320	.7749	.8156	1.2261	.8	.7	.6909	.7230	.9556	1.0464	.3
.3	.6334	.7738	.8185	1.2218	.7	.8	.6921	.7218	.9590	1.0428	.2
.4	.6347	.7727	.8214	1.2174	.6	.9	.6934	.7206	.9623	1.0392	.1
.5	.6361	.7716	.8243	1.2131	.5	**44.0**	0.6947	0.7193	0.9657	1.0355	**46.0**
.6	.6374	.7705	.8273	1.2088	.4	.1	.6959	.7181	.9691	1.0319	.9
.7	.6388	.7694	.8302	1.2045	.3	.2	.6972	.7169	.9725	1.0283	.8
.8	.6401	.7683	.8332	1.2002	.2	.3	.6984	.7157	.9759	1.0247	.7
.9	.6414	.7672	.8361	1.1960	.1	.4	.6997	.7145	.9793	1.0212	.6
40.0	0.6428	0.7660	0.8391	1.1918	**50.0**	.5	.7009	.7133	.9827	1.0176	.5
.1	.6441	.7649	.8421	1.1875	.9	.6	.7022	.7120	.9861	1.0141	.4
.2	.6455	.7638	.8451	1.1833	.8	.7	.7034	.7108	.9896	1.0105	.3
.3	.6468	.7627	.8481	1.1792	.7	.8	.7046	.7096	.9930	1.0070	.2
.4	.6481	.7615	.8511	1.1750	.6	.9	.7059	.7083	.9965	1.0035	.1
40.5	0.6494	0.7604	0.8541	1.1708	**49.5**	**45.0**	0.7071	0.7071	1.0000	1.0000	**45.0**
	cos	sin	cot	tan	deg		cos	sin	cot	tan	deg

LOGARITHMS OF TRIGONOMETRIC FUNCTIONS FOR DECIMAL FRACTIONS OF A DEGREE

deg	L sin	L cos	L tan	L cot	
0.0	−∞	0.0000	−∞	∞	**90.0**
.1	7.2419	0.0000	7.2419	2.7581	.9
.2	7.5429	0.0000	7.5429	2.4571	.8
.3	7.7190	0.0000	7.7190	2.2810	.7
.4	7.8439	0.0000	7.8439	2.1561	.6
.5	7.9408	0.0000	7.9409	2.0591	.5
.6	8.0200	0.0000	8.0200	1.9800	.4
.7	8.0870	0.0000	8.0870	1.9130	.3
.8	8.1450	0.0000	8.1450	1.8550	.2
.9	8.1961	9.9999	8.1962	1.8038	.1
1.0	8.2419	9.9999	8.2419	1.7581	**89.0**
.1	8.2832	9.9999	8.2833	1.7167	.9
.2	8.3210	9.9999	8.3211	1.6789	.8
.3	8.3558	9.9999	8.3559	1.6441	.7
.4	8.3880	9.9999	8.3881	1.6119	.6
.5	8.4179	9.9999	8.4181	1.5819	.5
.6	8.4459	9.9998	8.4461	1.5539	.4
.7	8.4723	9.9998	8.4725	1.5275	.3
.8	8.4971	9.9998	8.4973	1.5027	.2
.9	8.5206	9.9998	8.5208	1.4792	.1
2.0	8.5428	9.9997	8.5431	1.4569	**88.0**
.1	8.5640	9.9997	8.5643	1.4357	.9
.2	8.5842	9.9997	8.5845	1.4155	.8
.3	8.6035	9.9996	8.6038	1.3962	.7
.4	8.6220	9.9996	8.6223	1.3777	.6
.5	8.6397	9.9996	8.6401	1.3599	.5
.6	8.6567	9.9996	8.6571	1.3429	.4
.7	8.6731	9.9995	8.6736	1.3264	.3
.8	8.6889	9.9995	8.6894	1.3106	.2
.9	8.7041	9.9994	8.7046	1.2954	.1
3.0	8.7188	9.9994	8.7194	1.2806	**87.0**
.1	8.7330	9.9994	8.7337	1.2663	.9
.2	8.7468	9.9993	8.7475	1.2525	.8
.3	8.7602	9.9993	8.7609	1.2391	.7
.4	8.7731	9.9992	8.7739	1.2261	.6
.5	8.7857	9.9992	8.7865	1.2135	.5
.6	8.7979	9.9991	8.7988	1.2012	.4
.7	8.8098	9.9991	8.8107	1.1893	.3
.8	8.8213	9.9990	8.8223	1.1777	.2
.9	8.8326	9.9990	8.8336	1.1664	.1
4.0	8.8436	9.9989	8.8446	1.1554	**86.0**
.1	8.8543	9.9989	8.8554	1.1446	.9
.2	8.8647	9.9988	8.8659	1.1341	.8
.3	8.8749	9.9988	8.8762	1.1238	.7
.4	8.8849	9.9987	8.8862	1.1138	.6
.5	8.8946	9.9987	8.8960	1.1040	.5
.6	8.9042	9.9986	8.9056	1.0944	.4
.7	8.9135	9.9985	8.9150	1.0850	.3
.8	8.9226	9.9985	8.9241	1.0759	.2
.9	8.9315	9.9984	8.9331	1.0669	.1
5.0	8.9403	9.9983	8.9420	1.0580	**85.0**
.1	8.9489	9.9983	8.9506	1.0494	.9
.2	8.9573	9.9982	8.9591	1.0409	.8
.3	8.9655	9.9981	8.9674	1.0326	.7
.4	8.9736	9.9981	8.9756	1.0244	.6
.5	8.9816	9.9980	8.9836	1.0164	.5
.6	8.9894	9.9979	8.9915	1.0085	.4
.7	8.9970	9.9978	8.9992	1.0008	.3
.8	9.0046	9.9978	9.0068	0.9932	.2
.9	9.0120	9.9977	9.0143	0.9857	.1
6.0	9.0192	9.9976	9.0216	0.9784	**84.0**
	L cos	L sin	L cot	L tan	deg

deg	L sin	L cos	L tan	L cot	
6.0	9.0192	9.9976	9.0216	0.9784	**84.0**
.1	9.0264	9.9975	9.0289	0.9711	.9
.2	9.0334	9.9975	9.0360	0.9640	.8
.3	9.0403	9.9974	9.0430	0.9570	.7
.4	9.0472	9.9973	9.0499	0.9501	.6
.5	9.0539	9.9972	9.0567	0.9433	.5
.6	9.0605	9.9971	9.0633	0.9367	.4
.7	9.0670	9.9970	9.0699	0.9301	.3
.8	9.0734	9.9969	9.0764	0.9236	.2
.9	9.0797	9.9968	9.0828	0.9172	.1
7.0	9.0859	9.9968	9.0891	0.9109	**83.0**
.1	9.0920	9.9967	9.0954	0.9046	.9
.2	9.0981	9.9966	9.1015	0.8985	.8
.3	9.1040	9.9965	9.1076	0.8924	.7
.4	9.1099	9.9964	9.1135	0.8865	.6
.5	9.1157	9.9963	9.1194	0.8806	.5
.6	9.1214	9.9962	9.1252	0.8748	.4
.7	9.1271	9.9961	9.1310	0.8690	.3
.8	9.1326	9.9960	9.1367	0.8633	.2
.9	9.1381	9.9959	9.1423	0.8577	.1
8.0	9.1436	9.9958	9.1478	0.8522	**82.0**
.1	9.1489	9.9956	9.1533	0.8467	.9
.2	9.1542	9.9955	9.1587	0.8413	.8
.3	9.1594	9.9954	9.1640	0.8360	.7
.4	9.1646	9.9953	9.1693	0.8307	.6
.5	9.1697	9.9952	9.1745	0.8255	.5
.6	9.1747	9.9951	9.1797	0.8203	.4
.7	9.1797	9.9950	9.1848	0.8152	.3
.8	9.1847	9.9949	9.1898	0.8102	.2
.9	9.1895	9.9947	9.1948	0.8052	.1
9.0	9.1943	9.9946	9.1997	0.8003	**81.0**
.1	9.1991	9.9945	9.2046	0.7954	.9
.2	9.2038	9.9944	9.2094	0.7906	.8
.3	9.2085	9.9943	9.2142	0.7858	.7
.4	9.2131	9.9941	9.2189	0.7811	.6
.5	9.2176	9.9940	9.2236	0.7764	.5
.6	9.2221	9.9939	9.2282	0.7718	.4
.7	9.2266	9.9937	9.2328	0.7672	.3
.8	9.2310	9.9936	9.2374	0.7626	.2
.9	9.2353	9.9935	9.2419	0.7581	.1
10.0	9.2397	9.9934	9.2463	0.7537	**80.0**
.1	9.2439	9.9932	9.2507	0.7493	.9
.2	9.2482	9.9931	9.2551	0.7449	.8
.3	9.2524	9.9929	9.2594	0.7406	.7
.4	9.2565	9.9928	9.2637	0.7363	.6
.5	9.2606	9.9927	9.2680	0.7320	.5
.6	9.2647	9.9925	9.2722	0.7278	.4
.7	9.2687	9.9924	9.2764	0.7236	.3
.8	9.2727	9.9922	9.2805	0.7195	.2
.9	9.2767	9.9921	9.2846	0.7154	.1
11.0	9.2806	9.9919	9.2887	0.7113	**79.0**
.1	9.2845	9.9918	9.2927	0.7073	.9
.2	9.2883	9.9916	9.2967	0.7033	.8
.3	9.2921	9.9915	9.3006	0.6994	.7
.4	9.2959	9.9913	9.3046	0.6954	.6
.5	9.2997	9.9912	9.3085	0.6915	.5
.6	9.3034	9.9910	9.3123	0.6877	.4
.7	9.3070	9.9909	9.3162	0.6838	.3
.8	9.3107	9.9907	9.3200	0.6800	.2
.9	9.3143	9.9906	9.3237	0.6763	.1
12.0	9.3179	9.9904	9.3275	0.6725	**78.0**
	L cos	L sin	L cot	L tan	deg

LOGARITHMS OF TRIGONOMETRIC FUNCTIONS FOR DECIMAL FRACTIONS OF A DEGREE (continued)

deg	L sin	L cos	L tan	L cot	
12.0	9.3179	9.9904	9.3275	0.6725	**78.0**
.1	9.3214	9.9902	9.3312	0.6688	.9
.2	9.3250	9.9901	9.3349	0.6651	.8
.3	9.3284	9.9899	9.3385	0.6615	.7
.4	9.3319	9.9897	9.3422	0.6578	.6
.5	9.3353	9.9896	9.3458	0.6542	.5
.6	9.3387	9.9894	9.3493	0.6507	.4
.7	9.3421	9.9892	9.3529	0.6471	.3
.8	9.3455	9.9891	9.3564	0.6436	.2
.9	9.3488	9.9889	9.3599	0.6401	.1
13.0	9.3521	9.9887	9.3634	0.6366	**77.0**
.1	9.3554	9.9885	9.3668	0.6332	.9
.2	9.3586	9.9684	9.3702	0.6298	.8
.3	9.3618	9.9862	9.3736	0.6264	.7
.4	9.3650	9.9880	9.3770	0.6230	.6
.5	9.3682	9.9878	9.3804	0.6196	.5
.6	9.3713	9.9876	9.3837	0.6163	.4
.7	9.3745	9.9875	9.3870	0.6130	.3
.8	9.3775	9.9873	9.3903	0.6097	.2
.9	9.3806	9.9871	9.3935	0.6065	.1
14.0	9.3837	9.9869	9.3968	0.6032	**76.0**
.1	9.3867	9.9867	9.4000	0.6000	.9
.2	9.3897	9.9865	9.4032	0.5968	.8
.3	9.3927	9.9863	9.4064	0.5936	.7
.4	9.3957	9.9861	9.4095	0.5905	.6
.5	9.3986	9.9859	9.4127	0.5873	.5
.6	9.4015	9.9857	9.4158	0.5842	.4
.7	9.4044	9.9855	9.4189	0.5811	.3
.8	9.4073	9.9853	9.4220	0.5780	.2
.9	9.4102	9.9851	9.4250	0.5750	.1
15.0	9.4130	9.9849	9.4281	0.5719	**75.0**
.1	9.4158	9.9847	9.4311	0.5689	.9
.2	9.4186	9.9845	9.4341	0.5659	.8
.3	9.4214	9.9843	9.4371	0.5629	.7
.4	9.4242	9.9841	9.4400	0.5600	.6
.5	9.4269	9.9839	9.4430	0.5570	.5
.6	9.4296	9.9837	9.4459	0.5541	.4
.7	9.4323	9.9835	9.4488	0.5512	.3
.8	9.4350	9.9833	9.4517	0.5483	.2
.9	9.4377	9.9831	9.4546	0.5454	.1
16.0	9.4403	9.9828	9.4575	0.5425	**74.0**
.1	9.4430	9.9826	9.4603	0.5397	.9
.2	9.4456	9.9824	9.4632	0.5368	.8
.3	9.4482	9.9822	9.4660	0.5340	.7
.4	9.4508	9.9820	9.4688	0.5312	.6
.5	9.4533	9.9817	9.4716	0.5284	.5
.6	9.4559	9.9815	9.4744	0.5256	.4
.7	9.4584	9.9813	9.4771	0.5229	.3
.8	9.4609	9.9811	9.4799	0.5201	.2
.9	9.4634	9.9808	9.4826	0.5174	.1
17.0	9.4659	9.9806	9.4853	0.5147	**73.0**
.1	9.4684	9.9804	9.4880	0.5120	.9
.2	9.4709	9.9801	9.4907	0.5093	.8
.3	9.4733	9.9799	9.4934	0.5066	.7
.4	9.4757	9.9797	9.4961	0.5039	.6
.5	9.4781	9.9794	9.4987	0.5013	.5
.6	9.4805	9.9792	9.5014	0.4986	.4
.7	9.4829	9.9789	9.5040	0.4960	.3
.8	9.4853	9.9787	9.5066	0.4934	.2
.9	9.4876	9.9785	9.5092	0.4908	.1
18.0	9.4900	9.9782	9.5118	0.4882	**72.0**
	L cos	**L sin**	**L cot**	**L tan**	**deg**

deg	L sin	L cos	L tan	L cot	
18.0	9.4900	9.9782	9.5118	0.4882	**72.0**
.1	9.4923	9.9780	9.5143	0.4857	.9
.2	9.4946	9.9777	9.5169	0.4831	.8
.3	9.4969	9.9775	9.5195	0.4805	.7
.4	9.4992	9.9772	9.5220	0.4780	.6
.5	9.5015	9.9770	9.5245	0.4755	.5
.6	9.5037	9.9767	9.5270	0.4730	.4
.7	9.5060	9.9764	9.5295	0.4705	.3
.8	9.5082	9.9762	9.5320	0.4680	.2
.9	9.5104	9.9759	9.5345	0.4655	.1
19.0	9.5126	9.9757	9.5370	0.4630	**71.0**
.1	9.5148	9.9754	9.5394	0.4606	.9
.2	9.5170	9.9751	9.5419	0.4581	.8
.3	9.5192	9.9749	9.5443	0.4557	.7
.4	9.5213	9.9746	9.5467	0.4533	.6
.5	9.5235	9.9743	9.5491	0.4509	.5
.6	9.5256	9.9741	9.5516	0.4484	.4
.7	9.5278	9.9738	9.5539	0.4461	.3
.8	9.5299	9.9735	9.5563	0.4437	.2
.9	9.5320	9.9733	9.5587	0.4413	.1
20.0	9.5341	9.9730	9.5611	0.4389	**70.0**
.1	9.5361	9.9727	9.5634	0.4366	.9
.2	9.5382	9.9724	9.5658	0.4342	.8
.3	9.5402	9.9722	9.5681	0.4319	.7
.4	9.5423	9.9719	9.5704	0.4296	.6
.5	9.5443	9.9716	9.5727	0.4273	.5
.6	9.5463	9.9713	9.5750	0.4250	.4
.7	9.5484	9.9710	9.5773	0.4227	.3
.8	9.5504	9.9707	9.5796	0.4204	.2
.9	9.5523	9.9704	9.5819	0.4181	.1
21.0	9.5543	9.9702	9.5842	0.4158	**69.0**
.1	9.5563	9.9699	9.5864	0.4136	.9
.2	9.5583	9.9696	9.5887	0.4113	.8
.3	9.5602	9.9693	9.5909	0.4091	.7
.4	9.5621	9.9690	9.5932	0.4068	.6
.5	9.5641	9.9687	9.5954	0.4046	.5
.6	9.5660	9.9684	9.5976	0.4024	.4
.7	9.5679	9.9681	9.5998	0.4002	.3
.8	9.5698	9.9678	9.6020	0.3980	.2
.9	9.5717	9.9675	9.6042	0.3958	1
22.0	9.5736	9.9672	9.6064	0.3936	**68.0**
.1	9.5754	9.9669	9.6086	0.3914	9
.2	9.5773	9.9666	9.6108	0.3892	.8
.3	9.5792	9.9662	9.6129	0.3871	7
.4	9.5810	9.9659	9.6151	0.3849	6
.5	9.5828	9.9655	9.6172	0.3823	.5
.6	9.5847	9.9653	9.6194	0.3806	.4
.7	9.5865	9.9650	9.6215	0.3785	.3
.8	9.5883	9.9647	9.6236	0.3764	.2
.9	9.5901	9.9643	9.6257	0.3743	.1
23.0	9.5919	9.9640	9.6279	0.3721	**67.0**
.1	9.5937	9.9637	9.6300	0.3700	.9
.2	9.5954	9.9634	9.6321	0.3679	.8
.3	9.5972	9.9631	9.6341	0.3659	.7
.4	9.5990	9.9627	9.6362	0.3638	6
.5	9.6007	9.9624	9.6383	0.3617	.5
.6	9.6024	9.9621	9.6404	0.3596	.4
.7	9.6042	9.9617	9.6424	0.3576	.3
.8	9.6059	9.9614	9.6445	0.3555	.2
.9	9.6076	9.9611	9.6465	0.3535	.1
24.0	9.6093	9.9607	9.6486	0.3514	**66.0**
	L cos	**L sin**	**L cot**	**L tan**	**deg**

LOGARITHMS OF TRIGONOMETRIC FUNCTIONS FOR DECIMAL FRACTIONS OF A DEGREE (continued)

deg	L sin	L cos	L tan	L cot		deg	L sin	L cos	L tan	L cot	
24.0	9.6093	9.9607	9.6486	0.3514	**66.0**	**30.0**	9.6990	9.9375	9.7614	0.2386	**60.0**
.1	9.6110	9.9604	9.6506	0.3494	.9	.1	9.7003	9.9371	9.7632	0.2368	.9
.2	9.6127	9.9601	9.6527	0.3473	.8	.2	9.7016	9.9367	9.7649	0.2351	.8
.3	9.6144	9.9597	9.6547	0.3453	.7	.3	9.7029	9.9362	9.7667	0.2333	.7
.4	9.6161	9.9594	9.6567	0.3433	.6	.4	9.7042	9.9358	9.7684	0.2316	.6
.5	9.6177	9.9590	9.6587	0.3413	.5	.5	9.7055	9.9353	9.7701	0.2299	.5
.6	9.6194	9.9587	9.6607	0.3393	.4	.6	9.7068	9.9349	9.7719	0.2281	.4
.7	9.6210	9.9583	9.6627	0.3373	.3	.7	9.7080	9.9344	9.7736	0.2264	.3
.8	9.6227	9.9580	9.6647	0.3353	.2	.8	9.7093	9.9340	9.7753	0.2247	.2
.9	9.6243	9.9576	9.6667	0.3333	.1	.9	9.7106	9.9335	9.7771	0.2229	.1
25.0	9.6259	9.9573	9.6687	0.3313	**65.0**	**31.0**	9.7118	9.9331	9.7788	0.2212	**59.0**
.1	9.6276	9.9569	9.6706	0.3294	.9	.1	9.7131	9.9326	9.7805	0.2195	.9
.2	9.6292	9.9566	9.6726	0.3274	.8	.2	9.7144	9.9322	9.7822	0.2178	.8
.3	9.6308	9.9562	9.6746	0.3254	.7	.3	9.7156	9.9317	9.7839	0.2161	.7
.4	9.6324	9.9558	9.6765	0.3235	.6	.4	9.7168	9.9312	9.7856	0.2144	.6
.5	9.6340	9.9555	9.6785	0.3215	.5	.5	9.7181	9.9308	9.7873	0.2127	.5
.6	9.6356	9.9551	9.6804	0.3196	.4	.6	9.7193	9.9303	9.7890	0.2110	.4
.7	9.6371	9.9548	9.6824	0.3176	.3	.7	9.7205	9.9298	9.7907	0.2093	.3
.8	9.6387	9.9544	9.6843	0.3157	.2	.8	9.7218	9.9294	9.7924	0.2076	.2
.9	9.6403	9.9540	9.6863	0.3137	.1	.9	9.7230	9.9289	9.7941	0.2059	.1
26.0	9.6418	9.9537	9.6882	0.3118	**64.0**	**32.0**	9.7242	9.9284	9.7958	0.2042	**58.0**
.1	9.6434	9.9533	9.6901	0.3099	.9	.1	9.7254	9.9279	9.7975	0.2025	.9
.2	9.6449	9.9529	9.6920	0.3080	.8	.2	9.7266	9.9275	9.7992	0.2008	.8
.3	9.6465	9.9525	9.6939	0.3061	.7	.3	9.7278	9.9270	9.8008	0.1992	.7
.4	9.6480	9.9522	9.6958	0.3042	.6	.4	9.7290	9.9265	9.8025	0.1975	.6
.5	9.6495	9.9518	9.6977	0.3023	.5	.5	9.7302	9.9260	9.8042	0.1958	.5
.6	9.6510	9.9514	9.6996	0.3004	.4	.6	9.7314	9.9255	9.8059	0.1941	.4
.7	9.6526	9.9510	9.7015	0.2985	.3	.7	9.7326	9.9251	9.8075	0.1925	.3
.8	9.6541	9.9506	9.7034	0.2966	.2	.8	9.7338	9.9246	9.8092	0.1908	.2
.9	9.6556	9.9503	9.7053	0.2947	.1	.9	9.7349	9.9241	9.8109	0.1891	.1
27.0	9.6570	9.9499	9.7072	0.2928	**63.0**	**33.0**	9.7361	9.9236	9.8125	0.1875	**57.0**
.1	9.6585	9.9495	9.7090	0.2910	.9	.1	9.7373	9.9231	9.8142	0.1858	.9
.2	9.6600	9.9491	9.7109	0.2891	.8	.2	9.7384	9.9226	9.8158	0.1842	.8
.3	9.6615	9.9487	9.7128	0.2872	.7	.3	9.7396	9.9221	9.8175	0.1825	.7
.4	9.6629	9.9483	9.7146	0.2854	.6	.4	9.7407	9.9216	9.8191	0.1809	.6
.5	9.6644	9.9479	9.7165	0.2835	.5	.5	9.7419	9.9211	9.8208	0.1792	.5
.6	9.6659	9.9475	9.7183	0.2817	.4	.6	9.7430	9.9206	9.8224	0.1776	.4
.7	9.6673	9.9471	9.7202	0.2798	.3	.7	9.7442	9.9201	9.8241	0.1759	.3
.8	9.6687	9.9467	9.7220	0.2780	.2	.8	9.7453	9.9196	9.8257	0.1743	.2
.9	9.6702	9.9463	9.7238	0.2762	.1	.9	9.7464	9.9191	9.8274	0.1726	.1
28.0	9.6716	9.9459	9.7257	0.2743	**62.0**	**34.0**	9.7476	9.9186	9.8290	0.1710	**56.0**
.1	9.6730	9.9455	9.7275	0.2725	.9	.1	9.7487	9.9181	9.8306	0.1694	.9
.2	9.6744	9.9451	9.7293	0.2707	.8	.2	9.7478	9.9175	9.8323	0.1677	.8
.3	9.6759	9.9447	9.7311	0.2689	.7	.3	9.7509	9.9170	9.8339	0.1661	.7
.4	9.6773	9.9443	9.7330	0.2670	.6	.4	9.7520	9.9165	9.8355	0.1645	.6
.5	9.6787	9.9439	9.7348	0.2652	.5	.5	9.7531	9.9160	9.8371	0.1629	.5
.6	9.6801	9.9435	9.7366	0.2634	.4	.6	9.7542	9.9155	9.8388	0.1612	.4
.7	9.6814	9.9431	9.7384	0.2616	.3	.7	9.7553	9.9149	9.8404	0.1596	.3
.8	9.6828	9.9427	9.7402	0.2598	.2	.8	9.7564	9.9144	9.8420	0.1580	.2
.9	9.6842	9.9422	9.7420	0.2580	.1	.9	9.7575	9.9139	9.8436	0.1564	.1
29.0	9.6856	9.9418	9.7438	0.2562	**61.0**	**35.0**	9.7586	9.9134	9.8452	0.1548	**55.0**
.1	9.6869	9.9414	9.7455	0.2545	.9	.1	9.7597	9.9128	9.8468	0.1532	.9
.2	9.6883	9.9410	9.7473	0.2527	.8	.2	9.7607	9.9123	9.8484	0.1516	.8
.3	9.6896	9.9406	9.7491	0.2509	.7	.3	9.7618	9.9118	9.8501	0.1499	.7
.4	9.6910	9.9401	9.7509	0.2491	.6	.4	9.7629	9.9112	9.8517	0.1483	.6
.5	9.6923	9.9397	9.7526	0.2474	.5	.5	9.7640	9.9107	9.8533	0.1467	.5
.6	9.6937	9.9393	9.7544	0.2456	.4	.6	9.7650	9.9101	9.8549	0.1451	.4
.7	9.6950	9.9388	9.7562	0.2438	.3	.7	9.7661	9.9096	9.8565	0.1435	.3
.8	9.6963	9.9384	9.7579	0.2421	.2	.8	9.7671	9.9091	9.8581	0.1419	.2
.9	9.6977	9.9380	9.7597	0.2403	.1	.9	9.7682	9.9085	9.8597	0.1403	.1
30.0	9.6990	9.9375	9.7614	0.2386	**60.0**	**36.0**	9.7692	9.9080	9.8613	0.1387	**54.0**
	L cos	L sin	L cot	L tan	deg		L cos	L sin	L cot	L tan	deg

LOGARITHMS OF TRIGONOMETRIC FUNCTIONS FOR DECIMAL FRACTIONS OF A DEGREE (continued)

deg	L sin	L cos	L tan	L cot		deg	L sin	L cos	L tan	L cot	
36.0	9.7692	9.9080	9.8613	0.1387	**54.0**	**40.5**	9.8125	9.8810	9.9315	0.0685	**49.5**
.1	9.7703	9.9074	9.8629	0.1371	.9	.6	9.8134	9.8804	9.9330	0.0670	.4
.2	9.7713	9.9069	9.8644	0.1356	.8	.7	9.8143	9.8797	9.9346	0.0654	.3
.3	9.7723	9.9063	9.8660	0.1340	.7	.8	9.8152	9.8791	9.9361	0.0639	.2
.4	9.7734	9.9057	9.8676	0.1324	.6	.9	9.8161	9.8784	9.9376	0.0624	.1
.5	9.7744	9.9052	9.8692	0.1308	.5	**41.0**	9.8169	9.8778	9.9392	0.0608	**49.0**
.6	9.7754	9.9046	9.8708	0.1292	.4	.1	9.8178	9.8771	9.9407	0.0593	.9
.7	9.7764	9.9041	9.8724	0.1276	.3	.2	9.8187	9.8765	9.9422	0.0578	.8
.8	9.7774	9.9035	9.8740	0.1260	.2	.3	9.8195	9.8758	9.9438	0.0562	.7
.9	9.7785	9.9029	9.8755	0.1245	.1	.4	9.8204	9.8751	9.9453	0.0547	.6
37.0	9.7795	9.9023	9.8771	0.1229	**53.0**	.5	9.8213	9.8745	9.9468	0.0532	.5
.1	9.7805	9.9018	9.8787	0.1213	.9	.6	9.8221	9.8738	9.9483	0.0517	.4
.2	9.7815	9.9012	9.8803	0.1197	.8	.7	9.8230	9.8731	9.9499	0.0501	.3
.3	9.7825	9.9006	9.8818	0.1182	.7	.8	9.8238	9.8724	9.9514	0.0486	.2
.4	9.7835	9.9000	9.8834	0.1166	.6	.9	9.8247	9.8718	9.9529	0.0471	.1
.5	9.7844	9.8995	9.8850	0.1150	.5	**42.0**	9.8255	9.8711	9.9544	0.0456	**48.0**
.6	9.7854	9.8989	9.8865	0.1135	.4	.1	9.8264	9.8704	9.9560	0.0440	.9
.7	9.7864	9.8983	9.8881	0.1119	.3	.2	9.8272	9.8697	9.9575	0.0425	.8
.8	9.7874	9.8977	9.8897	0.1103	.2	.3	9.8280	9.8690	9.9590	0.0410	.7
.9	9.7884	9.8971	9.8912	0.1088	.1	.4	9.8289	9.8683	9.9605	0.0395	.6
38.0	9.7893	9.8965	9.8928	0.1072	**52.0**	.5	9.8297	9.8676	9.9621	0.0379	.5
.1	9.7903	9.8959	9.8944	0.1056	.9	.6	9.8305	9.8669	9.9636	0.0364	.4
.2	9.7913	9.8953	9.8959	0.1041	.8	.7	9.8313	9.8662	9.9651	0.0349	.3
.3	9.7922	9.8947	9.8975	0.1025	.7	.8	9.8322	9.8655	9.9666	0.0334	.2
.4	9.7932	9.8941	9.8990	0.1010	.6	.9	9.8330	9.8648	9.9681	0.0319	.1
.5	9.7941	9.8935	9.9006	0.0994	.5	**43.0**	9.8338	9.8641	9.9697	0.0303	**47.0**
.6	9.7951	9.8929	9.9022	0.0978	.4	.1	9.8346	9.8634	9.9712	0.0288	.9
.7	9.7960	9.8923	9.9037	0.0963	.3	.2	9.8354	9.8627	9.9727	0.0273	.8
.8	9.7970	9.8917	9.9053	0.0947	.2	.3	9.8362	9.8620	9.9742	0.0258	.7
.9	9.7979	9.8911	9.9068	0.0932	.1	.4	9.8370	9.8613	9.9757	0.0243	.6
39.0	9.7989	9.8905	9.9084	0.0916	**51.0**	.5	9.8378	9.8606	9.9772	0.0228	.5
.1	9.7998	9.8899	9.9099	0.0901	.9	.6	9.8386	9.8598	9.9788	0.0212	.4
.2	9.8007	9.8893	9.9115	0.0885	.8	.7	9.8394	9.8591	9.9803	0.0197	.3
.3	9.8017	9.8887	9.9130	0.0870	.7	.8	9.8402	9.8584	9.9818	0.0182	.2
.4	9.8026	9.8880	9.9146	0.0854	.6	.9	9.8410	9.8577	9.9833	0.0167	.1
.5	9.8035	9.8874	9.9161	0.0839	.5	**44.0**	9.8418	9.8569	9.9848	0.0152	**46.0**
.6	9.8044	9.8868	9.9176	0.0824	.4	.1	9.8426	9.8562	9.9864	0.0136	.9
.7	9.8053	9.8862	9.9192	0.0808	.3	.2	9.8433	9.8555	9.9879	0.0121	.8
.8	9.8063	9.8855	9.9207	0.0793	.2	.3	9.8441	9.8547	9.9894	0.0106	.7
.9	9.8072	9.8849	9.9223	0.0777	.1	.4	9.8449	9.8540	9.9909	0.0091	.6
40.0	9.8081	9.8843	9.9238	0.0762	**50.0**	.5	9.8457	9.8532	9.9924	0.0076	.5
.1	9.8090	9.8836	9.9254	0.0746	.9	.6	9.8464	9.8525	9.9939	0.0061	.4
.2	9.8099	9.8830	9.9269	0.0731	.8	.7	9.8472	9.8517	9.9955	0.0045	.3
.3	9.8108	9.8823	9.9284	0.0716	.7	.8	9.8480	9.8510	9.9970	0.0030	.2
.4	9.8117	9.8817	9.9300	0.0700	.6	.9	9.8487	9.8502	9.9985	0.0015	.1
40.5	9.8125	9.8810	9.9315	0.0685	**49.5**	**45.0**	9.8495	9.8495	0.0000	0.0000	**45.0**
	L cos	L sin	L cot	L tan	deg		L cos	L sin	L cot	L tan	deg

COMMON LOGARITHMS OF NUMBERS AND PROPORTIONAL PARTS

	0	1	2	3	4	5	6	7	8	9	proportional parts								
											1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

COMMON LOGARITHMS OF NUMBERS AND PROPORTIONAL PARTS (continued)

	0	1	2	3	4	5	6	7	8	9	proportional parts								
											1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8738	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	8284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

NATURAL LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	mean differences								
											1	2	3	4	5	6	7	8	9
1.0	0.0000	0100	0198	0296	0392	0488	0583	0677	0770	0862	10	19	29	38	48	57	67	76	86
1.1	0.0953	1044	1133	1222	1310	1398	1484	1570	1655	1740	9	17	26	35	44	52	61	70	78
1.2	0.1823	1906	1989	2070	2151	2231	2311	2390	2469	2546	8	16	24	32	40	48	56	64	72
1.3	0.2624	2700	2776	2852	2927	3001	3075	3148	3221	3293	7	15	22	30	37	44	52	59	67
1.4	0.3365	3436	3507	3577	3646	3716	3784	3853	3920	3988	7	14	21	28	35	41	48	55	62
1.5	0.4055	4121	4187	4253	4318	4383	4447	4511	4574	4637	6	13	19	26	32	39	45	52	58
1.6	0.4700	4762	4824	4886	4947	5008	5068	5128	5188	5247	6	12	18	24	30	36	42	48	55
1.7	0.5306	5365	5423	5481	5539	5596	5653	5710	5766	5822	6	11	17	23	29	34	40	46	51
1.8	0.5878	5933	5988	6043	6098	6152	6206	6259	6313	6366	5	11	16	22	27	32	38	43	49
1.9	0.6419	6471	6523	6575	6627	6678	6729	6780	6831	6881	5	10	15	20	26	31	36	41	46
2.0	0.6931	6981	7031	7080	7129	7178	7227	7275	7324	7372	5	10	15	20	24	29	34	39	44
2.1	0.7419	7467	7514	7561	7608	7655	7701	7747	7793	7839	5	9	14	19	23	28	33	37	42
2.2	0.7885	7930	7975	8020	8065	8109	8154	8198	8242	8286	4	9	13	18	22	27	31	36	40
2.3	0.8329	8372	8416	8459	8502	8544	8587	8629	8671	8713	4	9	13	17	21	26	30	34	38
2.4	0.8755	8796	8838	8879	8920	8961	9002	9042	9083	9123	4	8	12	16	20	24	29	33	37
2.5	0.9163	9203	9243	9282	9322	9361	9400	9439	9478	9517	4	8	12	16	20	24	27	31	35
2.6	0.9555	9594	9632	9670	9708	9746	9783	9821	9858	9895	4	8	11	15	19	23	26	30	34
2.7	0.9933	9969	1.0006	0043	0080	0116	0152	0188	0225	0260	4	7	11	15	18	22	25	29	33
2.8	1.0296	0332	0367	0403	0438	0473	0508	0543	0578	0613	4	7	11	14	18	21	25	28	32
2.9	1.0647	0682	0716	0750	0784	0818	0852	0886	0919	0953	3	7	10	14	17	20	24	27	31
3.0	1.0986	1019	1053	1086	1119	1151	1184	1217	1249	1282	3	7	10	13	16	20	23	26	30
3.1	1.1314	1346	1378	1410	1442	1474	1506	1537	1569	1600	3	6	10	13	16	19	22	25	29
3.2	1.1632	1663	1694	1725	1756	1787	1817	1848	1878	1909	3	6	9	12	15	18	22	25	28
3.3	1.1939	1969	2000	2030	2060	2090	2119	2149	2179	2208	3	6	9	12	15	18	21	24	27
3.4	1.2238	2267	2296	2326	2355	2384	2413	2442	2470	2499	3	6	9	12	15	17	20	23	26
3.5	1.2528	2556	2585	2613	2641	2669	2698	2726	2754	2782	3	6	8	11	14	17	20	23	25
3.6	1.2809	2837	2865	2892	2920	2947	2975	3002	3029	3056	3	5	8	11	14	16	19	22	25
3.7	1.3083	3110	3137	3164	3191	3218	3244	3271	3297	3324	3	5	8	11	13	16	19	21	24
3.8	1.3350	3376	3403	3429	3455	3481	3507	3533	3558	3584	3	5	8	10	13	16	18	21	23
3.9	1.3610	3635	3661	3686	3712	3737	3762	3788	3813	3838	3	5	8	10	13	15	18	20	23
4.0	1.3863	3888	3913	3938	3962	3987	4012	4036	4061	4085	2	5	7	10	12	15	17	20	22
4.1	1.4110	4134	4159	4183	4207	4231	4255	4279	4303	4327	2	5	7	10	12	14	17	19	22
4.2	1.4351	4375	4398	4422	4446	4469	4493	4516	4540	4563	2	5	7	9	12	14	16	19	21
4.3	1.4586	4609	4633	4656	4679	4702	4725	4748	4770	4793	2	5	7	9	12	14	16	18	21
4.4	1.4816	4839	4861	4884	4907	4929	4951	4974	4996	5019	2	5	7	9	11	14	16	18	20
4.5	1.5041	5063	5085	5107	5129	5151	5173	5195	5217	5239	2	4	7	9	11	13	15	18	20
4.6	1.5261	5282	5304	5326	5347	5369	5390	5412	5433	5454	2	4	6	9	11	13	15	17	19
4.7	1.5476	5497	5518	5539	5560	5581	5602	5623	5644	5665	2	4	6	8	11	13	15	17	19
4.8	1.5686	5707	5728	5748	5769	5790	5810	5831	5851	5872	2	4	6	8	10	12	14	16	19
4.9	1.5892	5913	5933	5953	5974	5994	6014	6034	6054	6074	2	4	6	8	10	12	14	16	18
5.0	1.6094	6114	6134	6154	6174	6194	6214	6233	6253	6273	2	4	6	8	10	12	14	16	18
5.1	1.6292	6312	6332	6351	6371	6390	6409	6429	6448	6467	2	4	6	8	10	12	14	16	18
5.2	1.6487	6506	6525	6544	6563	6582	6601	6620	6639	6658	2	4	6	8	10	11	13	15	17
5.3	1.6677	6696	6715	6734	6752	6771	6790	6808	6827	6845	2	4	6	7	9	11	13	15	17
5.4	1.6864	6882	6901	6919	6938	6956	6974	6993	7011	7029	2	4	5	7	9	11	13	15	17

NATURAL LOGARITHMS OF 10^{+n}

n	1	2	3	4	5	6	7	8	9
$\log_e 10^n$	2.3026	4.6052	6.9078	9.2103	11.5129	13.8155	16.1181	18.4207	20.7233

NATURAL LOGARITHMS (continued)

	0	1	2	3	4	5	6	7	8	9	mean differences								
											1	2	3	4	5	6	7	8	9
5.5	1.7047	7066	7084	7102	7120	7138	7156	7174	7192	7210	2	4	5	7	9	11	13	14	16
5.6	1.7228	7246	7263	7281	7299	7317	7334	7352	7370	7387	2	4	5	7	9	11	12	14	16
5.7	1.7405	7422	7440	7457	7475	7492	7509	7527	7544	7561	2	3	5	7	9	10	12	14	16
5.8	1.7579	7596	7613	7630	7647	7664	7681	7699	7716	7733	2	3	5	7	9	10	12	14	15
5.9	1.7750	7766	7783	7800	7817	7834	7851	7867	7884	7901	2	3	5	7	8	10	12	13	15
6.0	1.7918	7934	7951	7967	7984	8001	8017	8034	8050	8066	2	3	5	7	8	10	12	13	15
6.1	1.8083	8099	8116	8132	8148	8165	8181	8197	8213	8229	2	3	5	6	8	10	11	13	15
6.2	1.8245	8262	8278	8294	8310	8326	8342	8358	8374	8390	2	3	5	6	8	10	11	13	14
6.3	1.8405	8421	8437	8453	8469	8485	8500	8516	8532	8547	2	3	5	6	8	9	11	13	14
6.4	1.8563	8579	8594	8610	8625	8641	8656	8672	8687	8703	2	3	5	6	8	9	11	12	14
6.5	1.8718	8733	8749	8764	8779	8795	8810	8825	8840	8856	2	3	5	6	8	9	11	12	14
6.6	1.8871	8886	8901	8916	8931	8946	8961	8976	8991	9006	2	3	5	6	8	9	11	12	14
6.7	1.9021	9036	9051	9066	9081	9095	9110	9125	9140	9155	1	3	4	6	7	9	10	12	13
6.8	1.9169	9134	9199	9213	9228	9242	9257	9272	9286	9301	1	3	4	6	7	9	10	12	13
6.9	1.9315	9330	9344	9359	9373	9387	9402	9416	9430	9445	1	3	4	6	7	9	10	12	13
7.0	1.9459	9473.	9488	9502	9516	9530	9544	9559	9573	9587	1	3	4	6	7	9	10	11	13
7.1	1.9601	9615	9629	9643	9657	9671	9685	9699	9713	9727	1	3	4	6	7	8	10	11	13
7.2	1.9741	9755	9769	9782	9796	9810	9824	9838	9851	9865	1	3	4	6	7	8	10	11	12
7.3	1.9879	9892	9906	9920	9933	9947	9961	9974	9988	2.0001	1	3	4	5	7	8	10	11	12
7.4	2.0015	0028	0042	0055	0069	0082	0096	0109	0122	0134	1	3	4	5	7	8	9	11	12
7.5	2.0149	0162	0176	0189	0202	0215	0229	0242	0255	0268	1	3	4	5	7	8	9	11	12
7.6	2.0281	0295	0308	0321	0334	0347	0360	0373	0386	0399	1	3	4	5	7	8	9	10	12
7.7	2.0412	0425	0438	0451.	0464	0477	0490	0503	0516	0528	1	3	4	5	6	8	9	10	12
7.8	2.0541	0554	0567	0580	0592	0605	0618	0631	0643	0656	1	3	4	5	6	8	9	10	11
7.9	2.0669	0681	0694	0707	0719	0732	0744	0757	0769	0782	1	3	4	5	6	8	9	10	11
8.0	2.0794	0807	0819	0832	0844	0857	0869	0882	0894	0906	1	3	4	5	6	7	9	10	11
8.1	2.0919	0931	0943	0956	0968	0980	0992	1005	1017	1029	1	2	4	5	6	7	9	10	11
8.2	2.1041	1054	1066	1078	1090	1102	1114	1126	1138	1150	1	2	4	5	6	7	9	10	11
8.3	2.1163	1175	1187	1199	1211	1223	1235	1247	1258	1270	1	2	4	5	6	7	8	10	11
8.4	2.1282	1294	1306	1318	1330	1342	1353	1365	1377	1389	1	2	4	5	6	7	8	9	11
8.5	2.1401	1412	1424	1436	1448	1459	1471	1483	1494	1506	1	2	4	5	6	7	8	9	11
8.6	2.1518	1529	1541	1552	1564	1576	1587	1599	1610	1622	1	2	3	5	6	7	8	9	10
8.7	2.1633	1645	1656	1668	1679	1691	1702	1713	1725	1736	1	2	3	5	6	7	8	9	10
8.8	2.1748	1759	1770	1782	1793	1804	1815	1827	1838	1849	1	2	3	5	6	7	8	9	10
8.9	2.1861	1872	1883	1894	1905	1917	1928	1939	1950	1961	1	2	3	4	6	7	8	9	10
9.0	2.1972	1983	1994	2006	2017	2028	2039	2050	2061	2072	1	2	3	4	6	7	8	9	10
9.1	2.2083	2094	2105	2116	2127	2138	2148	2159	2170	2181	1	2	3	4	5	7	8	9	10
9.2	2.2192	2203	2214	2225	2235	2246	2257	2268	2279	2289	1	2	3	4	5	6	8	9	10
9.3	2.2300	2311	2322	2332	2343	2354	2364	2375	2386	2396	1	2	3	4	5	6	7	9	10
9.4	2.2407	2418	2428	2439	2450	2460	2471	2481	2492	2502	1	2	3	4	5	6	7	8	10
9.5	2.2513	2523	2534	2544	2555	2565	2576	2586	2597	2607	1	2	3	4	5	6	7	8	9
9.6	2.2618	2628	2638	2649	2659	2670	2680	2690	2701	2711	1	2	3	4	5	6	7	8	9
9.7	2.2721	2732	2742	2752	2762	2773	2783	2793	2803	2814	1	2	3	4	5	6	7	8	9
9.8	2.2824	2834	2844	2854	2865	2875	2885	2895	2905	2915	1	2	3	4	5	6	7	8	9
9.9	2.2925	2935	2946	2956	2966	2976	2986	2996	3006	3016	1	2	3	4	5	6	7	8	9
10.0	2.3026																		

NATURAL LOGARITHMS OF 10^{-N}

n	1	2	3	4	5	6	7	8	9
$\log_e 10^{-n}$	$\overline{3}.6974$	$\overline{5}.3948$	$\overline{7}.0922$	$\overline{10}.7897$	$\overline{12}.4871$	$\overline{14}.1845$	$\overline{17}.8819$	[illegible]	$\overline{21}.2767$

EXPONENTIALS [e^n and e^{-n}]

n	e^n	diff	n	e^n	diff	n	e^n	n	e^{-n}	diff	n	e^{-n}	n	e^{-n}
0.00	1.000	10	**0.50**	1.649	16	**1.0**	2.718*	**0.00**	1.000	−10	**0.50**	.607	**1.0**	.368*
.01	1.010	10	.51	1.665	17	.1	3.004	.01	0.990	−10	.51	.600	.1	.333
.02	1.020	10	.52	1.682	17	.2	3.320	.02	.980	−10	.52	.595	.2	.301
.03	1.030	11	.53	1.699	17	.3	3.669	.03	.970	−9	.53	.589	.3	.273
.04	1.041	10	.54	1.716	17	.4	4.055	.04	.961	−10	.54	.583	.4	.247
0.05	1.051	11	**0.55**	1.733	18	**1.5**	4.482	**0.05**	.951	−9	**0.55**	.577	**1.5**	.223
.06	1.062	11	.56	1.751	17	.6	4.953	.06	.942	−10	.56	.571	.6	.202
.07	1.073	10	.57	1.768	18	.7	5.474	.07	.932	−9	.57	.566	.7	.183
.08	1.083	11	.58	1.786	18	.8	6.050	.08	.923	−9	.58	.560	.8	.165
.09	1.094	11	.59	1.804	18	.9	6.686	.09	.914	−9	.59	.554	.9	.150
0.10	1.105	11	**0.60**	1.822	18	**2.0**	7.389	**0.10**	.905	−9	**0.60**	.549	**2.0**	.135
.11	1.116	11	.61	1.840	19	.1	8.166	.11	.896	−9	.61	.543	.1	.122
.12	1.127	12	.62	1.859	19	.2	9.025	.12	.887	−9	.62	.538	.2	.111
.13	1.139	11	.63	1.878	18	.3	9.974	.13	.878	−9	.63	.533	.3	.100
.14	1.150	12	.64	1.896	20	.4	11.02	.14	.869	−8	.64	.527	.4	.0907
0.15	1.162	12	**0.65**	1.916	19	**2.5**	12.18	**0.15**	.861	−9	**0.65**	.522	**2.5**	.0821
.16	1.174	11	.66	1.935	19	.6	13.46	.16	.852	−8	.66	.517	.6	.0743
.17	1.185	12	.67	1.954	20	.7	14.88	.17	.844	−9	.67	.512	.7	.0672
.18	1.197	12	.68	1.974	20	.8	16.44	.18	.835	−8	.68	.507	.8	.0608
.19	1.209	12	.69	1.994	20	.9	18.17	.19	.827	−8	.69	.502	.9	.0550
0.20	1.221	13	**0.70**	2.014	20	**3.0**	20.09	**0.20**	.819	−8	**0.70**	.497	**3.0**	.0498
.21	1.234	12	.71	2.034	20	.1	22.20	.21	.811	−8	.71	.492	.1	.0450
.22	1.246	13	.72	2.054	21	.2	24.53	.22	.803	−8	.72	.487	.2	.0408
.23	1.259	12	.73	2.075	21	.3	27.11	.23	.795	−8	.73	.482	.3	.0369
.24	1.271	13	.74	2.096	21	.4	29.96	.24	.787	−8	.74	.477	.4	.0334
0.25	1.284	13	**0.75**	2.117	21	**3.5**	33.12	**0.25**	.779	−8	**0.75**	.472	**3.5**	.0302
.26	1.297	13	.76	2.138	22	.6	36.60	.26	.771	−8	.76	.468	.6	.0273
.27	1.310	13	.77	2.160	21	.7	40.45	.27	.763	−7	.77	.463	.7	.0247
.28	1.323	13	.78	2.181	22	.8	44.70	.28	.756	−8	.78	.458	.8	.0224
.29	1.336	14	.79	2.203	23	.9	49.40	.29	.748	−7	.79	.454	.9	.0202
0.30	1.350	13	**0.80**	2.226	22	**4.0**	54.60	**0.30**	.741	−8	**0.80**	.449	**4.0**	.0183
.31	1.363	14	.81	2.248	22	.1	60.34	.31	.733	−7	.81	.445	.1	.0166
.32	1.377	14	.82	2.270	23	.2	66.69	.32	.726	−7	.82	.440	.2	.0150
.33	1.391	14	.83	2.293	23	.3	73.70	.33	.719	−7	.83	.436	.3	.0136
.34	1.405	14	.84	2.316	24	.4	81.45	.34	.712	−7	.84	.432	.4	.0123
0.35	1.419	14	**0.85**	2.340	23	**4.5**	90.02	**0.35**	.705	−7	**0.85**	.427	**4.5**	.0111
.36	1.433	15	.86	2.363	24			.36	.698	−7	.86	.423		
.37	1.448	14	.87	2.387	24	**5.0**	148.4	.37	.691	−7	.87	.419	**5.0**	.00674
.38	1.462	15	.88	2.411	24	**6.0**	403.4	.38	.684	−7	.88	.415	**6.0**	.00248
.39	1.477	15	.89	2.435	25	**7.0**	1097.	.39	.677	−7	.89	.411	**7.0**	.000912
0.40	1.492	15	**0.90**	2.460	24	**8.0**	2981.	**0.40**	.670	−6	**0.90**	.407	**8.0**	.000335
.41	1.507	15	.91	2.484	25	**9.0**	8103.	.41	.664	−7	.91	.403	**9.0**	.000123
.42	1.522	15	.92	2.509	26	**10.0**	22026.	.42	.657	−6	.92	.399	**10.0**	.000045
.43	1.537	16	.93	2.535	25			.43	.651	−7	.93	.395		
.44	1.553	15	.94	2.560	26	π/2	4.810	.44	.644	−6	.94	.391	π/2	.208
						2π/2	23.14						2π/2	.0432
0.45	1.568	16	**0.95**	2.586	26	3π/2	111.3	**0.45**	.638	−7	**0.95**	.387	3π/2	.00878
.46	1.584	16	.96	2.612	26	4π/2	535.5	.46	.631	−6	.96	.383	4π/2	.00187
.47	1.600	16	.97	2.638	26	5π/2	2576.	.47	.625	−6	.97	.379	5π/2	.000388
.48	1.616	16	.98	2.664	27	6π/2	12392.	.48	.619	−6	.98	.375	6π/2	.000081
.49	1.632	17	.99	2.691	27	7π/2	59610.	.49	.613	−6	.99	.372	7π/2	.000017
						8π/2	286751.						8π/2	.000003
0.50	1.649		**1.00**	2.718				0.50	0.607		**1.00**	.368		

* Note: Do not interpolate in this column.

$e = 2.71828$ $1/e = 0.367879$ $\log_{10} e = 0.4343$ $1/(0.4343) = 2.3026$

$\log_{10}(0.4343) = 9.6378 - 10$ $\log_{10}(e^n) = n(0.4343)$

RESISTANCE-COUPLED AMPLIFIERS

Resistance-coupled, audio-frequency voltage amplifiers utilize simple components and are capable of providing essentially uniform amplification over a relatively wide frequency range.

Suitable Tubes

In this section, data are given for some 80 types of tubes suitable for use in resistance-coupled circuits. These types include low- and high-mu triodes, twin triodes, triode-connected pentodes, and pentodes. The accompanying key to tube types will assist in locating the appropriate data chart.

Circuit Advantages

For most of the types shown, the data pertain to operation with cathode bias; for all of the pentodes, the data pertain to operation with series screen resistor. The use of a cathode-bias resistor where feasible and a series screen resistor where applicable offer several advantages over fixed-voltage operation.

The advantages are: (1) effects of possible tube differences are minimized; (2) operation over a wide range of palte-supply voltages without appreciable change in gain is feasible; (3) the low frequency at which the amplifier cuts off is easily changed; and (4) tendency toward motorboating is minimized.

Number of Stages

These advantages can be enhanced by the addition of suitable decoupling filters in the plate supply of each stage of a multistage amplifier. With proper filters, three or more amplifier stages can be operated from a single power-supply unit of conventional design without encountering any difficulties due to coupling through the power unit. When decoupling filters are not used, not more than two stages should be operated from a single power-supply unit.

SYMBOLS USED IN RESISTANCE-COUPLED AMPLIFIER CHARTS

C = Blocking Capacitor (μf).
C_k = Cathode Bypass Capacitor (μf).
C_{g2} = Screen Bypass Capacitor (μf).
E_{bb} = Plate-Supply Voltage (volts). Voltage at plate equals plate-supply voltage minus drop in R_p and R_k. See Note 1 below.
R_k = Cathode Resistor (ohms).
R_{g2} = Screen Resistor (megohms).
R_g = Grid Resistor (megohms) for following stage.
R_p = Plate Resistor (megohms).
V.G. = Voltage Gain.
E_o = Peak Output Voltage (volts). This voltage is obtained across R_g (for following stage) at any frequency within the flat region of the output vs frequency curve, and is for the condition where the signal level is adequate to swing the grid of the resistance-coupled amplifier tube to the point where its grid starts to draw current.

KEY TO CHARTS

Type	Chart No.
1L4	1
1S5	2
1U4	3
1U5	2
2A6	4
2B7	5
6A6	6
6AQ6	7
6AT6	7
6AU6	8
6B6-G	4
6B7	5
6B8(G)	5
6BF6	9
6C4	10
6C5(GT)	11
6C6 T	11
P	14
6C8-G	12
6F5(GT)	18
6F8-G	13
6J5(GT)	13
6J7(G, GT) T	11
P	14
6L5-G	15
6N7(GT)	6
6Q7(G, GT)	7
6R7(GT)	9
6S7(G)	16
6SC7	17
6SF5(GT)	18
6SF7	19
6SH7	8
6SJ7(GT)	20
6SL7-GT	7
6SN7-GT	13
6SQ7(GT)	4
6SR7	9
6ST7	9
6SZ7	7
6T7-G	7
6W7-G T	11
P	14
6Z7-G	21
12AT6	7
12AU6	8
12AU7	10
12AX7	25
12C8	5
12F5-GT	18
12J5-GT	13
12J7-GT T	11
P	14
12Q7-GT	7
12SC7	17
12SF5	18
12SF7	19
12SH7	8
12SJ7(GT)	20
12SL7-GT	7
12SN7-GT	13
12SQ7G(GT)	4
12SR7	9
53	6
55	22
56	23
57 T	11
P	14
75	4
76	23
79	24
85	22

T = Triode Connection
P = Pentode Connection

GENERAL CIRCUIT CONSIDERATIONS

In the discussions which follow, the frequency (f_2) is that value at which the high-frequency response begins to fall off. The frequency (f_1) is that value at which the low-frequency response drops below a satisfactory value, as discussed below. Decoupling filters are not necessary for two stages or less. A variation of 10 per cent in values of resistors and capacitors has only slight effect on performance. One-half-watt resistors are usually suitable for R_{g2}, R_g, R_p, and R_k resistors. Capacitors C and C_{g2} should have a working voltage equal to or greater than E_{bb}. Capacitor C_k may have a low working voltage in the order of 10 to 25 volts. Peak Input Voltage is equal to the Peak Output Voltage divided by the Voltage Gain.

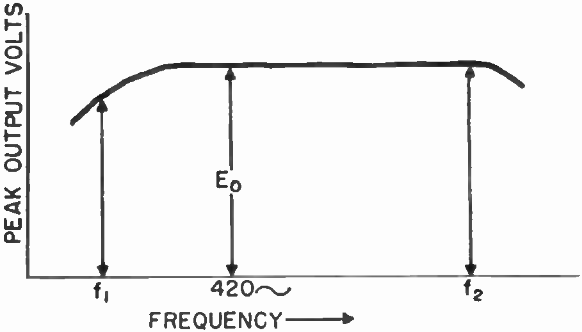


Fig. 1.

Triode (Heater-Cathode Type) Amplifier

Capacitors C and C_k have been chosen to give an output voltage equal to 0.8 E_o for a frequency (f_1) of 100 cycles. For any other value of f_1, multiply values of C and C_k by $100/f_1$. In the case

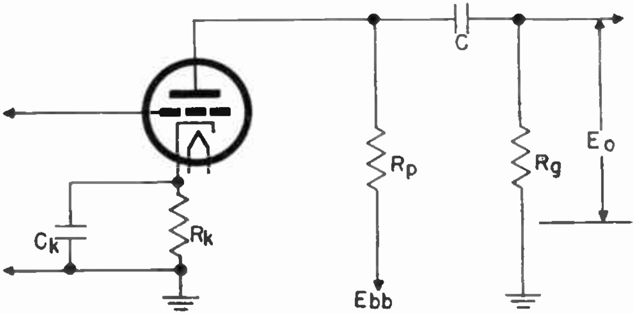


Fig. 2.

of capacitor C_k, the values shown in the charts are for an amplifier with dc heater excitation; when ac is used, depending on the character of the associated circuit, the gain, and the value of f_1, it may be necessary to increase the value of C_k to minimize hum disturbances. It may be desirable to operate the heater at a positive voltage of from 15 to 40 volts with respect to the cathode. The voltage output at f_1 of "n" like stages equals $(0.8)^n E_o$ where E_o is the peak output voltage of final stage. For an amplifier of typical construction, the value of f_2 is well above the audio-frequency range for any value of R_p.

Pentode (Filament-Type) Amplifier

Capacitors C and C_{g2} have been chosen to give an output voltage equal to 0.8 E_o for a frequency (f_1) of 100 cycles. For any other value of f_1, multiply values of C and Cg_2 by $100/f_1$. The voltage output at f_1 for "n" like stages equals $(0.8)^n E_o$ where E_o is peak output voltage of final stage. For an amplifier of typical construction, and for R_p values of 0.1, 0.25, and 0.5 megohm, approximate values of f_2 are 20000, 10000, and 5000 cps, respectively. Note: The values of input-coupling capacitor in microfarads and of grid resistor in megohms should be such that their product lies between 0.02 and 0.1. Values commonly used are 0.005 μf and 10 megohms.

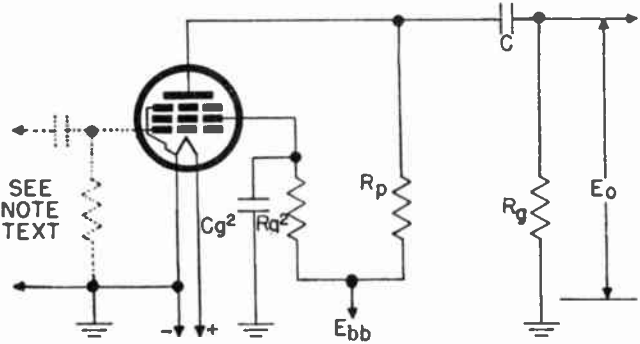


Fig. 3.

Pentode (Heater-Cathode Type) Amplifier

Capacitors C, C_k, and C_{g2} have been chosen to give an output voltage equal to 0.7 E_o for a frequency (f_1) of 100 cycles. For any other value of f_1, multiply values of C, C_k, and C_{g2} by $100/f_1$. In the case of capacitor C_k, the values shown in the charts are for an amplifier with dc heater excitation; when ac is used, depending on the character of the associated circuits, the voltage gain, and the value of f_1, it may be necessary to increase the value of C_k to minimize hum disturbances. It may be desirable to operate the heater at a positive voltage of from 15 to 40 volts with respect to the cathode. The voltage output at f_1 for "n" like stages equals

$(0.7)^n E_o$ where E_o is peak output voltage of final stage. For an amplifier of typical construction, and for R_p values of 0.1, 0.25, and 0.5 megohm, approximate values of f_2 are 20000, 10000, and 5000 cps, respectively.

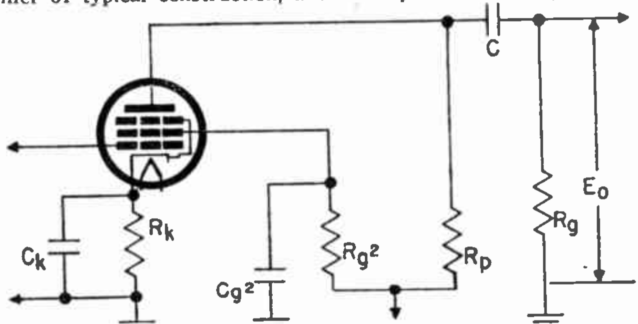


Fig. 4.

Phase Inverters

Information given for triode amplifiers, in general, applies to this case. Capacitors C have been chosen to give an output voltage equal to 0.9 E_o for a frequency (f_1) of 100 cycles. For any other value of f_1, multiply values of C by $100/f_1$. The signal input is applied to grid of triode unit A. Grid of triode unit B obtains its signal from a tap (P) on the grid resistor (R_g) in the output circuit of unit A. The tap is chosen so as to make the voltage output of unit B equal to that of Unit A. Its location is determined by the voltage gain values given in the charts. For example, if V.G. is 20 (from the charts), P is chosen so as to supply 1/20 of the voltage across R_g to the grid of unit B. For phase-inverter service, the cathode resistor may be left unbypassed unless a bypass capacitor is necessary to minimize hum; omission of the bypass capacitor assists in balancing the output stages. The value of R_k is specified on the basis that both units are operating simultaneously at the same values of plate load and plate voltage.

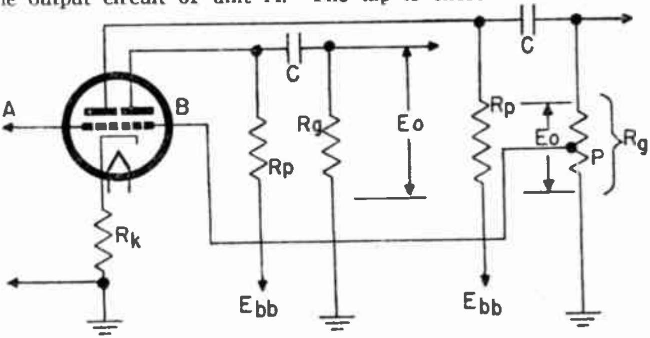


Fig. 5.

1

1L4

See Fig. 3 page 955

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
45	0.22	0.22	0.24	-	0.071	-	0.011	12	16*
		0.47	0.32	-	0.06	-	0.006	14	23
		1.0	0.39	-	0.056	-	0.0035	18	30
	0.47	0.47	0.57	-	0.049	-	0.0052	14	22
		1.0	0.64	-	0.047	-	0.0035	17	30
		2.2	0.74	-	0.044	-	0.0018	19	33
	1.0	1.0	1.1	-	0.036	-	0.0028	14	28
		2.2	1.25	-	0.035	-	0.0018	16	32
		3.3	1.45	-	0.032	-	0.0015	18	38
90	0.22	0.22	0.4	-	0.089	-	0.011	26	28
		0.47	0.46	-	0.081	-	0.0055	36	36
		1.0	0.47	-	0.08	-	0.0035	42	41
	0.47	0.47	0.84	-	0.07	-	0.0055	30	34
		1.0	0.9	-	0.069	-	0.003	38	42
		2.2	1.0	-	0.062	-	0.0018	40	50
	1.0	1.0	2.0	-	0.045	-	0.0028	30	45
		2.2	2.1	-	0.045	-	0.0018	35	55
		3.3	2.2	-	0.044	-	0.0012	40	61
135	0.22	0.22	0.5	-	0.09	-	0.011	42	34
		0.47	0.63	-	0.074	-	0.0055	54	51
		1.0	0.67	-	0.072	-	0.0035	57	60
	0.47	0.47	1.1	-	0.071	-	0.005	47	49
		1.0	1.4	-	0.06	-	0.0028	54	68
		2.2	1.5	-	0.051	-	0.0018	60	87
	1.0	1.0	2.1	-	0.059	-	0.0025	45	53
		2.2	2.4	-	0.054	-	0.0018	57	88
		3.3	2.7	-	0.049	-	0.0012	61	91

2

1S5

1U5

See Fig. 3 page 955

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
45	0.22	0.22	0.26	-	0.042	-	0.013	14	17
		0.47	0.36	-	0.035	-	0.006	17	24
		1.0	0.4	-	0.034	-	0.004	18	28
	0.47	0.47	0.82	-	0.025	-	0.0055	14	25
		1.0	1.0	-	0.023	-	0.003	17	33
		2.2	1.1	-	0.022	-	0.002	18	38
	1.0	1.0	1.9	-	0.019	-	0.003	14	31
		2.2	2.0	-	0.019	-	0.002	17	38
		3.3	2.2	-	0.018	-	0.0015	18	43
90	0.22	0.22	0.5	-	0.05	-	0.011	31	25
		0.47	0.59	-	0.05	-	0.006	37	34
		1.0	0.67	-	0.042	-	0.003	40	41
	0.47	0.47	1.2	-	0.035	-	0.005	31	37
		1.0	1.4	-	0.034	-	0.003	36	47
		2.2	1.6	-	0.031	-	0.002	40	57
	1.0	1.0	2.5	-	0.026	-	0.003	31	45
		2.2	2.9	-	0.025	-	0.002	36	58
		3.3	3.1	-	0.024	-	0.0012	38	66
135	0.22	0.22	0.66	-	0.052	-	0.011	45	31
		0.47	0.71	-	0.051	-	0.006	56	41
		1.0	0.86	-	0.039	-	0.003	60	54
	0.47	0.47	1.45	-	0.042	-	0.005	46	44
		1.0	1.8	-	0.034	-	0.003	54	62
		2.2	1.9	-	0.033	-	0.002	60	71
	1.0	1.0	3.1	-	0.03	-	0.003	45	56
		2.2	3.7	-	0.029	-	0.0015	53	76
		3.3	4.3	-	0.026	-	0.0014	56	88

* At 4 volts (RMS) output.

	Ebb	Rp	Rg	Rg2	Rk	Cg2	Ck	C	Eo	V.G.
3 **1U4** See Fig. 3 page 955	45	0.22	0.22	0.06	-	0.046	-	0.011	11	23
			0.47	0.07	-	0.045	-	0.006	15	33
			1.0	0.011	-	0.04	-	0.003	17	39
		0.47	0.47	0.34	-	0.025	-	0.005	13	34
			1.0	0.44	-	0.022	-	0.003	16	46
			2.2	0.5	-	0.022	-	0.002	18	55
		1.0	1.0	1.0	-	0.016	-	0.003	14	43
			2.2	1.0	-	0.016	-	0.002	17	51
			3.3	1.1	-	0.015	-	0.001	17	60
	90	0.22	0.22	0.3	-	0.046	-	0.01	27	37
			0.47	0.36	-	0.04	-	0.006	36	54
			1.0	0.4	-	0.038	-	0.003	39	63
		0.47	0.47	0.9	-	0.027	-	0.0045	29	61
			1.0	1.0	-	0.023	-	0.003	35	82
			2.2	1.1	-	0.022	-	0.002	38	96
		1.0	1.0	1.9	-	0.02	-	0.0025	30	77
			2.2	2.0	-	0.02	-	0.002	35	98
			3.3	2.2	-	0.018	-	0.001	37	114
	135	0.22	0.22	0.4	-	0.052	-	0.011	44	46
			0.47	0.49	-	0.037	-	0.005	55	71
			1.0	0.52	-	0.034	-	0.003	60	83
		0.47	0.47	1.1	-	0.029	-	0.0045	45	77
			1.0	1.3	-	0.023	-	0.003	53	106
			2.2	1.4	-	0.022	-	0.002	59	123
		1.0	1.0	2.3	-	0.021	-	0.0025	45	104
			2.2	2.5	-	0.019	-	0.0015	53	136
			3.3	2.9	-	0.016	-	0.001	56	163
4 **2A6** **6B6G** **6SQ7** **6SQ7GT** **12SQ7** **12SQ7GT** **75** See Fig. 2 page 954	90	0.1	0.1	-	6300	-	2.2	0.02	3	23☛
			0.25	-	6600	-	1.7	0.01	5	29■
			0.5	-	6700	-	1.7	0.006	6	31★
		0.25	0.25	-	10000	-	1.24	0.01	5	34■
			0.5	-	11000	-	1.07	0.006	7	40★
			1.0	-	11500	-	0.9	0.003	10	40
		0.5	0.5	-	16200	-	0.75	0.005	7	39
			1.0	-	16600	-	0.7	0.003	10	44
			2.0	-	17400	-	0.65	0.0015	13	48
	180	0.1	0.1	-	2600	-	3.3	0.025	16	29
			0.25	-	2900	-	2.9	0.015	22	36
			0.5	-	3000	-	2.7	0.007	23	37
		0.25	0.25	-	4300	-	2.1	0.015	21	43
			0.5	-	4800	-	1.8	0.007	28	50
			1.0	-	5300	-	1.5	0.004	33	53
		0.5	0.5	-	7000	-	1.3	0.007	25	52
			1.0	-	8000	-	1.1	0.004	33	57
			2.0	-	8800	-	0.9	0.002	38	58
	300	0.1	0.1	-	1900	-	4.0	0.03	31	31
			0.25	-	2200	-	3.5	0.015	41	39
			0.5	-	2300	-	3.0	0.007	45	42
		0.25	0.25	-	3300	-	2.7	0.015	42	48
			0.5	-	3900	-	2.0	0.007	51	53
			1.0	-	4200	-	1.8	0.004	60	56
		0.5	0.5	-	5300	-	1.6	0.007	47	58
			1.0	-	6100	-	1.3	0.004	62	60
			2.0	-	7000	-	1.2	0.002	67	63

☛ At 2 volts (RMS) output. ■ At 3 volts (RMS) output. ★ At 4 volts (RMS) output

5

2B7
6B7
6B8
6B8G
12C8

See Fig. 4 page 956

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	0.37	2000	0.07	3.0	0.02	19	24
		0.25	0.5	2200	0.07	3.0	0.01	28	33
		0.5	0.6	2000	0.06	2.8	0.006	29	37
	0.25	0.25	1.18	3500	0.04	1.9	0.008	26	43
		0.5	1.1	3500	0.04	2.1	0.007	33	55
		1.0	1.35	3500	0.04	1.9	0.003	32	65
	0.5	0.5	2.6	5000	0.04	1.5	0.004	22	63
		1.0	2.8	6000	0.04	1.55	0.003	29	85
		2.0	2.9	6200	0.04	1.5	0.003	27	100
180	0.1	0.1	0.44	1000	0.08	4.4	0.02	30	30
		0.25	0.5	1200	0.08	4.4	0.015	52	41
		0.5	0.6	1200	0.07	4.0	0.008	53	46
	0.25	0.25	1.18	1900	0.05	2.7	0.01	39	55
		0.5	1.2	2100	0.06	3.2	0.007	55	69
		1.0	1.5	2200	0.05	3.0	0.003	53	83
	0.5	0.5	2.6	3300	0.04	2.1	0.005	47	81
		1.0	2.8	3500	0.04	2.0	0.003	55	115
		2.0	3.0	3500	0.04	2.2	0.002	53	116
300	0.1	0.1	0.5	950	0.09	4.6	0.025	60	36
		0.25	0.55	1100	0.09	5.0	0.015	89	47
		0.5	0.6	900	0.08	4.8	0.009	86	54
	0.25	0.25	1.2	1500	0.06	3.2	0.015	70	64
		0.5	1.2	1600	0.06	3.5	0.008	100	79
		1.0	1.5	1800	0.08	4.0	0.004	95	100
	0.5	0.5	2.7	2400	0.05	2.5	0.006	80	96
		1.0	2.9	2500	0.05	2.3	0.003	120	150
		2.0	3.4	2800	0.05	2.8	0.0025	90	145

6

6A6#
6N7#
6N7GT#
53#

See Fig. 5 page 956

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	-	1900*	-	-	0.025	13	16
		0.25	-	2250*	-	-	0.01	19	19
		0.5	-	2500*	-	-	0.006	20	20
	0.25	0.25	-	4050*	-	-	0.01	16	20
		0.5	-	4950*	-	-	0.006	20	22
		1.0	-	5400*	-	-	0.003	24	23
	0.5	0.5	-	7000*	-	-	0.006	18	22
		1.0	-	8500*	-	-	0.003	23	23
		2.0	-	9650*	-	-	0.0015	26	23
180	0.1	0.1	-	1300*	-	-	0.03	35	19
		0.25	-	1700*	-	-	0.015	46	21
		0.5	-	1950*	-	-	0.007	50	22
	0.25	0.25	-	2950*	-	-	0.015	40	23
		0.5	-	3800*	-	-	0.007	50	24
		1.0	-	4300*	-	-	0.0035	57	24
	0.5	0.5	-	5250*	-	-	0.007	44	24
		1.0	-	6600*	-	-	0.0035	54	25
		2.0	-	7650*	-	-	0.002	61	25
300	0.1	0.1	-	1150*	-	-	0.03	60	20
		0.25	-	1500*	-	-	0.015	83	22
		0.5	-	1750*	-	-	0.007	86	23
	0.25	0.25	-	2650*	-	-	0.015	75	23
		0.5	-	3400*	-	-	0.0055	87	24
		1.0	-	4000*	-	-	0.003	100	24
	0.5	0.5	-	4850*	-	-	0.0055	76	23
		1.0	-	6100*	-	-	0.003	94	24
		2.0	-	7150*	-	-	0.0015	104	24

#The cathodes of the two units have a common terminal
***Values shown are for phase-inverter service.**

7

6AQ6
6AT6
6Q7
6Q7G
6Q7GT
6SL7GT
6SZ7
6T7G
12AT6
12Q7GT
12SL7GT
# #

See Fig. 2 page 954

Ebb	Rp	Rg	Rg2	Rk	Cg2	Ck	C	Eo	V.G.
90	0.1	0.1	-	4200	-	2.5	0.025	5.4	22◆
		0.22	-	4600	-	2.2	0.014	7.5	27◆
		0.47	-	4800	-	2.0	0.0065	9.1	30◆
	0.22	0.22	-	7000	-	1.5	0.013	7.3	30◆
		0.47	-	7800	-	1.3	0.007	10	34■
		1.0	-	8100	-	1.1	0.0035	12	37★
	0.47	0.47	-	12000	-	0.83	0.006	10	36■
		1.0	-	14000	-	0.7	0.0035	14	39★
		2.2	-	15000	-	0.6	0.002	16	41★
180	0.1	0.1	-	1900	-	3.6	0.027	19	30★
		0.22	-	2200	-	3.1	0.014	25	35
		0.47	-	2500	-	2.8	0.0065	32	37
	0.22	0.22	-	3400	-	2.2	0.014	24	38
		0.47	-	4100	-	1.7	0.0065	34	42
		1.0	-	4600	-	1.5	0.0035	38	44
	0.47	0.47	-	6600	-	1.1	0.0065	29	44
		1.0	-	8100	-	0.9	0.0035	38	46
		2.2	-	9100	-	0.8	0.002	43	47
300	0.1	0.1	-	1500	-	4.4	0.027	40	34
		0.22	-	1800	-	3.6	0.014	54	38
		0.47	-	2100	-	3.0	0.0065	63	41
	0.22	0.22	-	2600	-	2.5	0.013	51	42
		0.47	-	3200	-	1.9	0.0065	65	46
		0.1	-	3700	-	1.6	0.0035	77	48
	0.47	0.47	-	5200	-	1.2	0.006	61	48
		1.0	-	6300	-	1.0	0.0035	74	50
		2.2	-	7200	-	0.9	0.002	85	51

8

6AU6
6SH7
12AU6
12SH7

See Fig. 4 page 956

Ebb	Rp	Rg	Rg2	Rk	Cg2	Ck	C	Eo	V.G.
90	0.1	0.1	0.07	1800	0.11	9.0	0.021	25	52
		0.22	0.09	2100	0.1	8.2	0.012	32	72
		0.47	0.096	2100	0.1	8.0	0.0065	37	88
	0.22	0.22	0.25	3100	0.08	6.2	0.009	25	72
		0.47	0.26	3200	0.078	5.8	0.0055	32	99
		1.0	0.35	3700	0.085	5.1	0.003	34	125
	0.47	0.47	0.75	6300	0.042	3.4	0.0035	27	102
		1.0	0.75	6500	0.042	3.3	0.0027	32	126
		2.2	0.8	6700	0.04	3.2	0.0018	36	152
180	0.1	0.1	0.12	800	0.15	14.1	0.021	57	74
		0.22	0.15	900	0.126	14.0	0.012	82	116
		0.47	0.19	1000	0.1	12.5	0.006	81	141
	0.22	0.22	0.38	1500	0.09	9.6	0.009	59	130
		0.47	0.43	1700	0.08	8.7	0.005	67	171
		1.0	0.6	1900	0.066	8.1	0.003	71	200
	0.47	0.47	0.9	3100	0.06	5.7	0.0045	54	172
		1.0	1.0	3400	0.05	5.4	0.0028	65	232
		2.2	1.1	3600	0.04	3.6	0.0019	74	272
300	0.1	0.1	0.2	500	0.13	18.0	0.019	76	109
		0.22	0.24	600	0.11	16.4	0.011	103	145
		0.47	0.26	700	0.11	15.3	0.006	129	168
	0.22	0.22	0.42	1000	0.1	12.4	0.009	92	164
		0.47	0.5	1000	0.098	12.0	0.007	108	230
		1.0	0.55	1100	0.09	11.0	0.003	122	262
	0.47	0.47	1.0	1800	0.075	8.0	0.0045	94	248
		1.0	1.1	1900	0.065	7.6	0.0028	105	318
		2.2	1.2	2100	0.06	7.3	0.0018	122	371

◆ At 2 volts (RMS) output. ■ At 3 volts (RMS) output. ★ At 4 volts (RMS) output

The cathodes of the two units have separate terminals.

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.047	0.047	-	2200	-	2.5	0.063	14	9
		0.1	-	2800	-	2.0	0.033	18	10
		0.22	-	3200	-	1.7	0.015	20	10
	0.1	0.1	-	4100	-	1.4	0.032	13	10
		0.22	-	5400	-	1.0	0.013	20	11
		0.47	-	6400	-	0.9	0.007	24	11
	0.22	0.22	-	8500	-	0.67	0.015	18	11
		0.47	-	12000	-	0.5	0.0065	23	11
		1.0	-	14000	-	0.43	0.0035	27	11
180	0.047	0.047	-	2000	-	2.9	0.062	32	10
		0.1	-	2500	-	2.2	0.033	42	10
		0.22	-	3000	-	1.9	0.016	47	11
	0.1	0.1	-	3800	-	1.5	0.033	36	11
		0.22	-	5100	-	1.1	0.015	47	11
		0.47	-	6200	-	0.9	0.007	55	12
	0.22	0.22	-	8000	-	0.73	0.015	41	12
		0.47	-	11000	-	0.5	0.007	54	12
		1.0	-	13000	-	0.4	0.0035	69	12
300	0.047	0.047	-	1800	-	3.0	0.063	58	10
		0.1	-	2400	-	2.4	0.033	74	11
		0.22	-	2900	-	2.0	0.016	85	11
	0.1	0.1	-	3600	-	1.6	0.033	65	12
		0.22	-	5000	-	1.2	0.015	85	12
		0.47	-	6200	-	0.95	0.007	96	12
	0.22	0.22	-	7800	-	0.73	0.015	74	12
		0.47	-	11000	-	0.5	0.007	95	12
		1.0	-	13000	-	0.43	0.0035	106	12

9

6BF6

6R7

6R7GT

6SR7

6ST7

12SR7

See Fig. 2

page 954

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.047	0.047	-	1600	-	3.2	0.061	9	10■
		0.1	-	1800	-	2.5	0.033	11	11★
		0.22	-	2000	-	2.0	0.015	14	11
	0.1	0.1	-	3000	-	1.6	0.032	10	11★
		0.22	-	3800	-	1.1	0.015	15	11
		0.47	-	4500	-	1.0	0.007	18	11
	0.22	0.22	-	6800	-	0.7	0.015	14	11
		0.47	-	9500	-	0.5	0.0065	20	11
		1.0	-	11500	-	0.43	0.0035	24	11
180	0.047	0.047	-	920	-	3.9	0.062	20	11
		0.1	-	1200	-	2.9	0.037	26	12
		0.22	-	1400	-	2.5	0.016	29	12
	0.1	0.1	-	2000	-	1.9	0.032	24	12
		0.22	-	2800	-	1.4	0.016	33	12
		0.47	-	3600	-	1.1	0.007	40	12
	0.22	0.22	-	5300	-	0.8	0.015	31	12
		0.47	-	8300	-	0.56	0.007	44	12
		1.0	-	10000	-	0.48	0.0035	54	12
300	0.047	0.047	-	870	-	4.1	0.065	38	12
		0.1	-	1200	-	3.0	0.034	52	12
		0.22	-	1500	-	2.4	0.016	68	12
	0.1	0.1	-	1900	-	1.9	0.032	44	12
		0.22	-	3000	-	1.3	0.016	68	12
		0.47	-	4000	-	1.1	0.007	80	12
	0.22	0.22	-	5300	-	0.9	0.015	57	12
		0.47	-	8800	-	0.52	0.007	82	12
		1.0	-	11000	-	0.46	0.0035	92	12

10

6C4

12AU7

# #

See Fig. 2

page 954

■ At 3 volts (RMS) output. ★ At 4 volts (RMS) output.

The cathodes of the two units have separate terminals.

11

6C5

6C5GT

6C6

6J7

6J7G

6J7GT

6W7G

12J7GT

57

See Fig. 2
page 954

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.05	0.05	-	2800	-	2.0	0.05	14	9
		0.1	-	3400	-	1.62	0.025	17	9
		0.25	-	3800	-	1.3	0.01	20	10
	0.1	0.1	-	4800	-	1.12	0.025	16	10
		0.25	-	6400	-	0.84	0.01	22	11
		0.5	-	7500	-	0.66	0.005	23	12
	0.25	0.25	-	11400	-	0.52	0.01	18	12
		0.5	-	14500	-	0.4	0.006	23	12
		1.0	-	17300	-	0.33	0.004	26	13
180	0.05	0.05	-	2200	-	2.2	0.055	34	10
		0.1	-	2700	-	2.1	0.03	45	11
		0.25	-	3100	-	1.85	0.015	54	11
	0.1	0.1	-	3900	-	1.7	0.035	41	12
		0.25	-	5300	-	1.25	0.015	54	12
		0.5	-	6200	-	1.2	0.008	55	13
	0.25	0.25	-	9500	-	0.74	0.015	44	13
		0.5	-	12300	-	0.55	0.008	52	13
		1.0	-	14700	-	0.47	0.004	59	13
300	0.05	0.05	-	2100	-	3.16	0.075	57	11
		0.1	-	2600	-	2.3	0.04	70	11
		0.25	-	3100	-	2.2	0.015	83	12
	0.1	0.1	-	3800	-	1.7	0.035	65	12
		0.25	-	5300	-	1.3	0.015	84	13
		0.5	-	6000	-	1.17	0.008	88	13
	0.25	0.25	-	9600	-	0.9	0.015	73	13
		0.5	-	12300	-	0.59	0.008	85	14
		1.0	-	14000	-	0.37	0.003	97	14

12

6C8G

# #

See Fig. 2

page 954

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	-	3040	-	2.34	0.028	13	18
		0.25	-	3700	-	1.48	0.0115	17	20
		0.5	-	4520	-	1.29	0.006	19	21
	0.25	0.25	-	6770	-	0.95	0.011	15	21
		0.5	-	7870	-	0.81	0.0065	19	23
		1.0	-	8830	-	0.69	0.0035	21	23
	0.5	0.5	-	12400	-	0.51	0.006	16	22
		1.0	-	15000	-	0.43	0.0035	20	24
		2.0	-	16500	-	0.38	0.0015	25	24
180	0.1	0.1	-	2420	-	2.34	0.028	30	20
		0.25	-	3080	-	1.84	0.012	40	22
		0.5	-	3560	-	1.6	0.0065	45	23
	0.25	0.25	-	5170	-	1.25	0.012	35	24
		0.5	-	6560	-	0.95	0.007	45	25
		1.0	-	7550	-	0.85	0.0035	50	26
	0.5	0.5	-	9840	-	0.66	0.007	38	25
		1.0	-	12500	-	0.5	0.004	44	26
		2.0	-	15600	-	0.44	0.0015	51	26
300	0.1	0.1	-	2120	-	3.93	0.037	55	22
		0.25	-	2840	-	2.01	0.013	73	23
		0.5	-	3250	-	1.79	0.007	80	25
	0.25	0.25	-	4750	-	1.29	0.013	64	25
		0.5	-	6100	-	0.96	0.0065	80	26
		1.0	-	7100	-	0.77	0.004	90	27
	0.5	0.5	-	9000	-	0.67	0.007	67	27
		1.0	-	11500	-	0.48	0.004	83	27
		2.0	-	14500	-	0.37	0.002	96	28

The cathodes of the two units have separate terminals.

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.05	0.05	–	1650	–	2.80	0.06	11	11
		0.1	–	2070	–	2.66	0.029	14	12
		0.25	–	2380	–	1.95	0.012	17	13
	0.1	0.1	–	3470	–	1.85	0.035	12	13
		0.25	–	3940	–	1.29	0.012	17	13
		0.5	–	4420	–	1.0	0.007	19	13
	0.25	0.25	–	7860	–	0.73	0.0135	14	13
		0.5	–	9760	–	0.55	0.007	18	13
		1.0	–	10690	–	0.47	0.004	20	13
180	0.05	0.05	–	1190	–	3.27	0.06	24	13
		0.1	–	1490	–	2.86	0.032	30	13
		0.25	–	1740	–	2.06	0.0115	36	13
	0.1	0.1	–	2330	–	2.19	0.038	26	14
		0.25	–	2830	–	1.35	0.012	34	14
		0.5	–	3230	–	1.15	0.006	38	14
	0.25	0.25	–	5560	–	0.81	0.013	28	14
		0.5	–	7000	–	0.62	0.007	36	14
		1.0	–	8110	–	0.5	0.004	40	14
300	0.05	0.05	–	1020	–	3.56	0.06	41	13
		0.1	–	1270	–	2.96	0.034	51	14
		0.25	–	1500	–	2.15	0.012	60	14
	0.1	0.1	–	1900	–	2.31	0.035	43	14
		0.25	–	2440	–	1.42	0.0125	56	14
		0.5	–	2700	–	1.2	0.0065	64	14
	0.25	0.25	–	4590	–	0.87	0.013	46	14
		0.5	–	5770	–	0.64	0.0075	57	14
		1.0	–	6950	–	0.54	0.004	64	14

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6F8G
6J5
6J5GT
6SN7GT
12J5GT
12SN7GT
# #

See Fig. 2
page 954

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	0.37	1200	0.05	5.2	0.02	17	41
		0.25	0.44	1100	0.05	5.3	0.01	22	55
		0.5	0.44	1300	0.05	4.8	0.006	33	66
	0.25	0.25	1.1	2400	0.03	3.7	0.008	23	70
		0.5	1.18	2600	0.03	3.2	0.005	32	85
		1.0	1.4	3600	0.025	2.5	0.003	33	92
	0.5	0.5	2.18	4700	0.02	2.3	0.005	28	93
		1.0	2.6	5500	0.05	2.0	0.0025	29	120
		2.0	2.7	5500	0.02	2.0	0.0015	27	140
180	0.1	0.1	0.44	1000	0.05	6.5	0.02	42	51
		0.25	0.5	750	0.05	6.7	0.01	52	69
		0.5	0.5	800	0.05	6.7	0.006	59	83
	0.25	0.25	1.1	1200	0.04	5.2	0.008	41	93
		0.5	1.18	1600	0.04	4.3	0.005	60	118
		1.0	1.4	2000	0.04	3.8	0.0035	60	140
	0.5	0.5	2.45	2600	0.03	3.2	0.005	45	135
		1.0	2.9	3100	0.025	2.5	0.0025	56	165
		2.0	2.7	3500	0.02	2.8	0.0015	60	165
300	0.1	0.1	0.44	500	0.07	8.5	0.02	55	61
		0.25	0.5	450	0.07	8.3	0.01	81	82
		0.5	0.53	600	0.06	8.0	0.006	96	94
	0.25	0.25	1.18	1100	0.04	5.5	0.008	81	104
		0.5	1.18	1200	0.04	5.4	0.005	104	140
		1.0	1.45	1300	0.05	5.8	0.005	110	185
	0.5	0.5	2.45	1700	0.04	4.2	0.005	75	161
		1.0	2.9	2200	0.04	4.1	0.003	97	200
		2.0	2.95	2300	0.04	4.0	0.0025	100	230

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6C6
6J7
6J7G
6J7GT
6W7G
12J7GT
57

See Fig. 4
page 956

The cathodes of the two units have separate terminals.

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6L5G

See Fig. 2
page 954

Ebb	Rp	Rg	Rg2	Rk	Cg2	Ck	C	Eo	V.G.★
90	0.05	0.05	-	2120	-	2.3	0.05	14	9.3
		0.1	-	2500	-	1.86	0.03	18	10
		0.25	-	2900	-	1.65	0.014	21	11
	0.1	0.1	-	3510	-	1.36	0.03	16	11
		0.25	-	4620	-	1.08	0.015	22	12
		0.5	-	5200	-	1.0	0.0085	23	12
	0.25	0.25	-	8050	-	0.61	0.0125	18	12
		0.5	-	10300	-	0.49	0.0085	22	12
		1.0	-	12100	-	0.42	0.0055	24	12
180	0.05	0.05	-	1810	-	2.9	0.06	32	10
		0.1	-	2240	-	2.2	0.03	41	11
		0.25	-	2660	-	1.8	0.014	46	12
	0.1	0.1	-	3180	-	1.46	0.03	36	12
		0.25	-	4200	-	1.1	0.0145	46	12
		0.5	-	4790	-	1.0	0.009	50	12
	0.25	0.25	-	7100	-	0.7	0.014	38	12
		0.5	-	9290	-	0.54	0.009	46	12
		1.0	-	10950	-	0.46	0.0055	52	13
300	0.05	0.05	-	1740	-	2.91	0.06	56	11
		0.1	-	2160	-	2.18	0.032	68	12
		0.25	-	2600	-	1.82	0.015	79	12
	0.1	0.1	-	3070	-	1.64	0.032	60	12
		0.25	-	4140	-	1.1	0.014	79	13
		0.5	-	4700	-	0.81	0.0075	89	13
	0.25	0.25	-	6900	-	0.57	0.013	64	13
		0.5	-	9100	-	0.46	0.0075	80	13
		1.0	-	10750	-	0.4	0.005	88	13

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6S7
6S7G

See Fig. 4
page 956

Ebb	Rp	Rg	Rg2	Rk	Cg2	Ck	C	Eo	V.G.★
90	0.1	0.1	0.59	870	0.065	5.1	0.018	16	33
		0.25	0.65	900	0.061	5.0	0.01	21	47
		0.5	0.7	910	0.057	4.58	0.007	23	54
	0.25	0.25	1.5	1440	0.044	3.38	0.007	14	56
		0.5	1.6	1520	0.044	3.23	0.0055	18	66
		1.0	1.7	1560	0.043	3.22	0.004	19	72
	0.5	0.5	3.2	2620	0.029	2.04	0.004	12	76
		1.0	3.5	2800	0.03	1.95	0.0026	15	84
		2.0	3.7	3000	0.031	1.92	0.0024	16	94
180	0.1	0.1	0.58	530	0.073	7.2	0.017	33	47
		0.25	0.68	540	0.07	6.9	0.01	43	66
		0.5	0.71	540	0.065	6.6	0.0063	48	75
	0.25	0.25	1.6	850	0.05	4.6	0.0071	33	79
		0.5	1.8	890	0.044	4.7	0.005	40	104
		1.0	1.9	950	0.046	4.4	0.0037	44	118
	0.5	0.5	3.3	1410	0.041	3.5	0.0041	30	109
		1.0	3.6	1520	0.037	3.0	0.003	38	134
		2.0	3.8	1600	0.031	2.9	0.0024	42	147
300	0.1	0.1	0.59	430	0.007	8.5	0.0167	57	57
		0.25	0.67	440	0.071	8.0	0.01	75	78
		0.5	0.71	440	0.071	8.0	0.0066	82	89
	0.25	0.25	1.7	620	0.058	6.0	0.0071	54	98
		0.5	1.95	650	0.057	5.8	0.005	66	122
		1.0	2.1	700	0.055	5.2	0.0036	76	136
	0.5	0.5	3.6	1000	0.04	4.1	0.0037	52	136
		1.0	3.9	1080	0.041	3.9	0.0029	66	162
		2.0	4.1	1120	0.043	3.8	0.0023	73	174

★ At 4 volts (RMS) output.

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6SC7#

12SC7#

See Fig. 5 page 956

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	-	1850*	-	-	0.028	4.1	13●
		0.25	-	1960*	-	-	0.012	5.9	23■
		0.5	-	2050*	-	-	0.0065	6.9	25★
	0.25	0.25	-	3400*	-	-	0.011	6.2	26★
		0.5	-	3750*	-	-	0.006	8.6	30
		1.0	-	3900*	-	-	0.003	10	33
	0.5	0.5	-	5500*	-	-	0.005	7.4	31
		1.0	-	6300*	-	-	0.003	10	33
		2.0	-	7450*	-	-	0.0015	12	36
180	0.1	0.1	-	960*	-	-	0.031	17	25
		0.25	-	1070*	-	-	0.012	24	29
		0.5	-	1220*	-	-	0.0065	27	33
	0.25	0.25	-	1850*	-	-	0.011	21	35
		0.5	-	2150*	-	-	0.006	28	39
		1.0	-	2400*	-	-	0.003	32	41
	0.5	0.5	-	3050*	-	-	0.006	24	40
		1.0	-	3420*	-	-	0.003	32	43
		2.0	-	3890*	-	-	0.002	36	45
300	0.1	0.1	-	750*	-	-	0.033	35	29
		0.25	-	930*	-	-	0.014	50	34
		0.25	-	1040*	-	-	0.007	54	36
	0.25	0.25	-	1400*	-	-	0.012	45	39
		0.5	-	1680*	-	-	0.006	55	42
		1.0	-	1840*	-	-	0.003	64	45
	0.5	0.5	-	2330*	-	-	0.006	50	45
		1.0	-	2980*	-	-	0.003	62	48
		2.0	-	3280*	-	-	0.002	72	49

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6F5

6F5GT

6SF5

6SF5GT

12F5GT

12SF5

See Fig. 2 page 954

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	-	4400	-	2.5	0.02	4	28●
		0.25	-	4800	-	2.1	0.01	5	34■
		0.5	-	5000	-	1.8	0.005	6	35★
	0.25	0.25	-	8000	-	1.33	0.01	6	39■
		0.5	-	8800	-	1.18	0.005	7	43★
		1.0	-	9000	-	0.9	0.003	10	44
	0.5	0.5	-	12200	-	0.76	0.005	8	43
		1.0	-	13500	-	0.67	0.003	10	46
		2.0	-	14700	-	0.58	0.0015	12	48
180	0.1	0.1	-	1800	-	4.4	0.025	16	37
		0.25	-	2000	-	3.3	0.015	23	44
		0.5	-	2200	-	2.9	0.006	25	46
	0.25	0.25	-	3500	-	2.3	0.01	21	48
		0.5	-	4100	-	1.8	0.006	26	53
		1.0	-	4500	-	1.7	0.004	32	57
	0.5	0.5	-	6100	-	1.3	0.006	24	53
		1.0	-	6900	-	0.9	0.003	33	63
		2.0	-	7700	-	0.83	0.0015	37	66
300	0.1	0.1	-	1300	-	5.0	0.025	33	42
		0.25	-	1600	-	3.7	0.01	43	49
		0.5	-	1700	-	3.2	0.006	48	52
	0.25	0.25	-	2600	-	2.5	0.01	41	56
		0.5	-	3200	-	2.1	0.007	54	63
		1.0	-	3500	-	2.0	0.004	63	67
	0.5	0.5	-	4500	-	1.5	0.006	50	65
		1.0	-	5400	-	1.2	0.004	62	70
		2.0	-	6100	-	0.93	0.002	70	70

●At 2 volts (RMS) output. ■ At 3 volts (RMS) output. ★ At 4 volts (RMS) output.

The cathodes of the two units have a common terminal.

*Values are for phase-inverter service.

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6SF7

12SF7

See Fig. 4
page 956

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	0.26	1500	0.11	4.8	0.02	21	21
		0.22	0.3	1600	0.1	4.4	0.012	26	29
		0.47	0.35	1900	0.09	4.2	0.006	28	37
	0.22	0.22	0.64	2400	0.09	3.4	0.009	21	33
		0.47	0.7	2500	0.09	3.2	0.0055	26	40
		1.0	0.84	2600	0.084	3.0	0.0035	29	52
	0.47	0.47	1.5	4200	0.06	2.1	0.0045	21	50
		1.0	1.6	4400	0.06	1.9	0.003	26	59
		2.2	1.7	4800	0.058	1.6	0.002	29	64
180	0.1	0.1	0.33	1000	0.13	6.7	0.02	32	33
		0.22	0.5	1200	0.12	5.8	0.011	37	45
		0.47	0.6	1300	0.11	5.5	0.006	43	52
	0.22	0.22	0.76	1700	0.11	4.5	0.0095	37	47
		0.47	0.9	1700	0.1	4.5	0.0055	44	68
		1.0	1.0	1800	0.1	4.2	0.003	47	82
	0.47	0.47	1.8	3300	0.09	2.9	0.0045	38	70
		1.0	2.0	3800	0.08	2.4	0.003	50	85
		2.2	2.1	4000	0.07	2.3	0.002	57	98
300	0.1	0.1	0.32	750	0.19	8.0	0.021	62	39
		0.22	0.36	850	0.18	7.7	0.012	80	46
		0.47	0.37	900	0.18	7.7	0.006	93	57
	0.22	0.22	0.8	1150	0.13	6	0.01	63	62
		0.47	0.94	1300	0.12	5.7	0.0055	78	88
		1.0	0.98	1500	0.11	5.0	0.0035	99	97
	0.47	0.47	1.7	2300	0.1	3.5	0.0045	71	82
		1.0	1.9	2500	0.1	3.5	0.003	89	109
		2.2	2.0	2800	0.09	3.1	0.002	105	125

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6SJ7

6SJ7GT
12SJ7
12SJ7GT

See Fig. 4
page 956

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	0.29	820	0.09	8.8	0.02	18	41
		0.25	0.29	880	0.085	7.4	0.016	23	68
		0.5	0.31	1000	0.075	6.6	0.007	28	70
	0.25	0.25	0.69	1680	0.06	5.0	0.012	16	75
		0.5	0.92	1700	0.045	4.5	0.005	18	93
		1.0	0.82	1800	0.04	4.0	0.003	22	104
	0.5	0.5	1.5	3600	0.045	2.4	0.003	18	91
		1.0	1.7	3800	0.03	2.4	0.002	22	119
		2.0	1.9	4050	0.028	2.35	0.0015	24	139
180	0.1	0.1	0.29	760	0.10	9.1	0.019	49	55
		0.25	0.31	800	0.09	8.0	0.015	60	82
		0.5	0.37	860	0.09	7.8	0.007	62	91
	0.25	0.25	0.83	1050	0.06	6.8	0.001	38	109
		0.5	0.94	1060	0.06	6.6	0.004	47	131
		1.0	0.94	1100	0.07	6.1	0.003	54	161
	0.5	0.5	1.85	2000	0.05	4.0	0.003	37	151
		1.0	2.2	2180	0.04	3.8	0.002	44	192
		2.0	2.4	2410	0.035	3.6	0.0015	54	208
300	0.1	0.1	0.35	500	0.10	11.6	0.019	72	67
		0.25	0.37	530	0.09	10.9	0.016	96	98
		0.5	0.47	590	0.09	9.9	0.007	101	104
	0.25	0.25	0.89	850	0.07	8.5	0.011	79	139
		0.5	1.10	860	0.06	7.4	0.004	88	167
		1.0	1.18	910	0.06	6.9	0.003	98	185
	0.5	0.5	2.0	1300	0.06	6.0	0.004	64	206
		1.0	2.2	1410	0.05	5.8	0.002	79	238
		2.0	2.5	1530	0.04	5.2	0.0015	89	263

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6Z7G#

See Fig. 5 page 956

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	-	1480*	-	2.65	0.025	8	21★
		0.25	-	1760*	-	2.02	0.0115	11	25
		0.5	-	1930*	-	1.7	0.0065	14	26
	0.25	0.25	-	3000*	-	1.36	0.01	12	28
		0.5	-	3390*	-	1.1	0.006	15	30
		1.0	-	3670*	-	0.8	0.0035	18	33
	0.5	0.5	-	5300*	-	0.65	0.0055	14	31
		1.0	-	6050*	-	0.61	0.003	18	33
		2.0	-	6700*	-	0.45	0.0015	20	35
180	0.1	0.1	-	930*	-	3.4	0.028	18	26
		0.25	-	1100*	-	2.6	0.0115	28	31
		0.5	-	1210*	-	2.32	0.007	33	32
	0.25	0.25	-	1820*	-	1.7	0.012	28	35
		0.5	-	2110*	-	1.38	0.007	34	38
		1.0	-	2400*	-	1.1	0.0035	41	39
	0.5	0.5	-	3240*	-	0.9	0.006	32	39
		1.0	-	3890*	-	0.703	0.0035	38	40
		2.0	-	4360*	-	0.553	0.002	44	41
300	0.1	0.1	-	670*	-	3.81	0.028	38	31
		0.25	-	950*	-	2.63	0.012	52	34
		0.5	-	1050*	-	2.34	0.007	60	36
	0.25	0.25	-	1430*	-	1.87	0.012	50	38
		0.5	-	1680*	-	1.46	0.006	59	40
		1.0	-	1930*	-	1.19	0.0035	66	43
	0.5	0.5	-	2540*	-	0.97	0.006	55	42
		1.0	-	3110*	-	0.72	0.0035	70	44
		2.0	-	3560*	-	0.56	0.002	75	45

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See Fig. 2 page 954

90	0.05	0.05	-	3800	-	1.4	0.06	16	4.5
		0.1	-	4600	-	1.1	0.03	19	4.9
		0.25	-	5400	-	0.86	0.015	23	5.1
	0.1	0.1	-	6620	-	0.7	0.04	17	5.1
		0.25	-	9000	-	0.55	0.015	22	5.4
		0.5	-	10300	-	0.5	0.007	25	5.5
	0.25	0.25	-	15100	-	0.31	0.015	18	5.3
		0.5	-	20500	-	0.25	0.007	23	5.5
		1.0	-	24400	-	0.2	0.004	26	5.6
180	0.05	0.05	-	3200	-	1.8	0.06	33	4.9
		0.1	-	4100	-	1.6	0.045	44	5.2
		0.25	-	5000	-	1.2	0.02	49	5.3
	0.1	0.1	-	6200	-	0.9	0.04	37	5.3
		0.25	-	8700	-	0.7	0.015	47	5.5
		0.5	-	10000	-	0.57	0.008	50	5.5
	0.25	0.25	-	14500	-	0.43	0.015	40	5.6
		0.5	-	20000	-	0.29	0.008	48	5.7
		0.1	-	24000	-	0.24	0.004	53	5.7
300	0.05	0.05	-	3200	-	1.9	0.08	50	5.2
		0.1	-	4100	-	1.5	0.045	74	5.5
		0.25	-	5100	-	1.2	0.015	85	5.6
	0.1	0.1	-	5900	-	0.8	0.03	64	5.5
		0.25	-	8300	-	0.54	0.015	82	5.7
		0.5	-	9600	-	0.43	0.006	88	5.8
	0.25	0.25	-	14300	-	0.3	0.01	71	5.7
		0.5	-	19400	-	0.22	0.006	84	5.7
		1.0	-	23600	-	0.2	0.003	94	5.8

★ At 4 volts (RMS) output. *Values are for phase-inverter service.
The cathodes of the two units have a common terminal.

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See Fig. 2
page 954

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.05	0.05	-	2500	-	2.0	0.06	16	7.0
		0.1	-	3200	-	1.6	0.03	21	7.7
		0.25	-	3800	-	1.25	0.015	23	8.1
	0.1	0.1	-	4500	-	1.05	0.03	19	8.1
		0.25	-	6500	-	0.82	0.015	23	8.9
		0.5	-	7500	-	0.68	0.007	25	9.3
	0.25	0.25	-	11100	-	0.48	0.015	21	9.4
		0.5	-	15100	-	0.36	0.007	24	9.7
		1.0	-	18300	-	0.32	0.0035	28	9.8
180	0.05	0.05	-	2400	-	2.5	0.06	36	7.7
		0.1	-	3000	-	1.9	0.035	48	8.2
		0.25	-	3700	-	1.65	0.015	55	9.0
	0.1	0.1	-	4500	-	1.45	0.035	46	9.3
		0.25	-	6500	-	0.97	0.015	55	9.5
		0.5	-	7600	-	0.8	0.008	57	9.8
	0.25	0.25	-	10700	-	0.6	0.015	49	9.7
		0.5	-	14700	-	0.45	0.007	59	10
		1.0	-	17700	-	0.4	0.0045	64	10
300	0.05	0.05	-	2400	-	2.8	0.08	65	8.3
		0.1	-	3100	-	2.2	0.045	80	8.9
		0.25	-	3800	-	1.8	0.02	95	9.4
	0.1	0.1	-	4500	-	1.6	0.04	74	9.5
		0.25	-	6400	-	1.2	0.02	95	10
		0.5	-	7500	-	0.98	0.009	104	10
	0.25	0.25	-	11100	-	0.69	0.02	82	10
		0.5	-	15200	-	0.5	0.009	96	10
		1.0	-	18300	-	0.4	0.005	108	10

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See Fig. 5
page 956

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	-	2050*	-	-	0.04	5.8	23■
		0.25	-	2200*	-	-	0.015	8.4	29★
		0.5	-	2350*	-	-	0.009	9.5	29
	0.25	0.25	-	4000*	-	-	0.015	7.1	31★
		0.5	-	4250*	-	-	0.006	9.7	33
		1.0	-	4650*	-	-	0.004	12	35
	0.5	0.5	-	6150*	-	-	0.006	8.8	34
		1.0	-	6850*	-	-	0.004	12	38
		2.0	-	7500*	-	-	0.002	15	40
180	0.1	0.1	-	1050*	-	-	0.04	21	27
		0.25	-	1250*	-	-	0.02	27	31
		0.5	-	1350*	-	-	0.009	31	34
	0.25	0.25	-	2050*	-	-	0.02	26	37
		0.5	-	2450*	-	-	0.01	34	41
		1.0	-	2750*	-	-	0.005	40	42
	0.5	0.5	-	3450*	-	-	0.009	30	42
		1.0	-	4100*	-	-	0.0035	39	44
		2.0	-	4650*	-	-	0.002	44	45
300	0.1	0.1	-	800*	-	-	0.025	40	29
		0.25	-	1000*	-	-	0.01	57	34
		0.5	-	1100*	-	-	0.006	60	36
	0.25	0.25	-	1650*	-	-	0.01	56	39
		0.5	-	2050*	-	-	0.0055	66	42
		1.0	-	2350*	-	-	0.003	77	43
	0.5	0.5	-	2850*	-	-	0.0055	61	44
		1.0	-	3600*	-	-	0.003	75	46
		2.0	-	4450*	-	-	0.0015	82	46

■ At 3 volts (RMS) output. ★ At 4 volts (RMS) output.

*Values are for phase-inverter service.

The cathodes of the two units have a common terminal.

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# #

See Fig. 2 page 954

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	-	4400	-	2.7	0.023	5	29➤
		0.22	-	4700	-	2.4	0.013	6	35➤
		0.47	-	4800	-	2.3	0.007	8	41➤
	0.22	0.22	-	7000	-	1.6	0.001	6	39➤
		0.47	-	7400	-	1.4	0.006	9	45■
		1.0	-	7600	-	1.3	0.003	11	48★
	0.47	0.47	-	12000	-	0.9	0.006	9	48■
		1.0	-	13000	-	0.8	0.003	11	52★
		2.2	-	14000	-	0.7	0.002	13	55★
180	0.1	0.1	-	1800	-	4.0	0.025	18	40
		0.22	-	2000	-	3.5	0.013	25	47
		0.47	-	2200	-	3.1	0.006	32	52
	0.22	0.22	-	3000	-	2.4	0.012	24	53
		0.47	-	3500	-	2.1	0.006	34	59
		1.0	-	3900	-	1.8	0.003	39	63
	0.47	0.47	-	5800	-	1.3	0.006	30	62
		1.0	-	6700	-	1.1	0.003	39	66
		2.2	-	7400	-	1.0	0.002	45	68
300	0.1	0.1	-	1300	-	4.6	0.027	43	45
		0.22	-	1500	-	4.0	0.013	57	52
		0.47	-	1700	-	3.6	0.006	66	57
	0.22	0.22	-	2200	-	3.0	0.013	54	59
		0.47	-	2800	-	2.3	0.006	69	65
		1.0	-	3100	-	2.1	0.003	79	68
	0.47	0.47	-	4300	-	1.6	0.006	62	69
		1.0	-	5200	-	1.3	0.003	77	73
		2.2	-	5900	-	1.1	0.002	92	75

➤ At 2 volts (RMS) output. ■ At 3 volts (RMS) output. ★ At 4 volts (RMS) output

The cathodes of the two units have separate terminals.

DECIBEL CONVERSION TABLES

The tables on the following pages may be used to convert decibles to power voltage and current ratios and vice versa. To find values outside the range of the tables. the following procedure should be followed:

TABLE I: DECIBELS TO VOLTAGE AND POWER RATIOS

Number of decibels positive (+) : Subtract +20 decibels successively from the given number of decibels until the remainder falls within the range of Table I. *To find the voltage ratio,* multiply the corresponding value from the right-hand voltage-ratio column by 10 for each time you subtracted 20 db. *To find the power ratio,* multiply the corresponding value from the right-hand power-ratio column by 100 for each time you subtracted 20 db.

Example—*Given:* 49.2 db
49.2 db — 20 db — 20 db = 9.2 db
Voltage Ratio: 9.2 db →
2.884 × 10 × 10 = 288.4
Power Ratio: 9.2 db →
8.318 × 100 × 100 = 83180

Number of decibels negative (—): Add +20 decibels successively to the given number of decibels until the sum falls within the range of Table I. *For the voltage ratio,* divide the value from the left-hand voltage-ratio column by 10 for each time you added 20 db. *For the power ratio,* divide the value from the left-hand power-ratio column by 100 for each time you added 20 db.

Example—*Given:* —49.2 db
—49.2 db + 20 db + 20 db = —9.2 db
Voltage ratio: —9.2 db →
.3467 × 1/10 × 1/10 = .003467
Power ratio: —9.2 db →
.1202 × 1/100 × 1/100 = .00001202

TABLE II: VOLTAGE RATIOS TO DECIBELS

For ratios smaller than those in table—Multiply the given ratio by 10 successively until the product can be found in the table. From the number of decibels thus found, subtract +20 decibels for each time you multiplied by 10.

Example—*Given:* Voltage ratio = .0131
.0131 × 10 = .131 × 10 = 1.31
From Table II, 1.31 →
2.345 db — 20 db — 20 db = —37.655 db

For ratios greater than those in table—Divide the given ratio by 10 successively until the remainder can be found in the table. To the number of decibels thus found, add +20 db for each time you divided by 10.

Example—*Given:* Voltage ratio = 712
712 × 1/10 = 71.2 × 1/10 = 7.12
From Table II, 7.12 →
17.050 db + 20 db + 20 db = 57.050 db

TABLE I

GIVEN: Decibels TO FIND: Power and {Voltage / Current} Ratios

TO ACCOUNT FOR THE SIGN OF THE DECIBEL

For positive (+) values of the decibel—Both voltage and power ratios are greater than unity. Use the two right-hand columns.
For negative (—) values of the decibel—Both voltage and power ratios are less than unity. Use the two left-hand columns.

← *−db+* →

Voltage Ratio	*Power Ratio*	*db*	*Voltage Ratio*	*Power Ratio*
1.0000	1.0000	0	1.000	1.000
.9886	.9772	.1	1.012	1.023
.9772	.9550	.2	1.023	1.047
.9661	.9333	.3	1.035	1.072
.9550	.9120	.4	1.047	1.096
.9441	.8913	.5	1.059	1.122
.9333	.8710	.6	1.072	1.148
.9226	.8511	.7	1.084	1.175
.9120	.8318	.8	1.096	1.202
.9016	.8128	.9	1.109	1.230
.8913	.7943	1.0	1.122	1.259
.8810	.7762	1.1	1.135	1.288
.8710	.7586	1.2	1.148	1.318
.8610	.7413	1.3	1.161	1.349
.8511	.7244	1.4	1.175	1.380
.8414	.7079	1.5	1.189	1.413
.8318	.6918	1.6	1.202	1.445
.8222	.6761	1.7	1.216	1.479
.8128	.6607	1.8	1.230	1.514
.8035	.6457	1.9	1.245	1.549
.7943	.6310	2.0	1.259	1.585
.7852	.6166	2.1	1.274	1.622
.7762	.6026	2.2	1.288	1.660
.7674	.5888	2.3	1.303	1.698
.7586	.5754	2.4	1.318	1.738
.7499	.5623	2.5	1.334	1.778
.7413	.5495	2.6	1.349	1.820
.7328	.5370	2.7	1.365	1.862
.7244	.5248	2.8	1.380	1.905
.7161	.5129	2.9	1.396	1.950
.7079	.5012	3.0	1.413	1.995
.6998	.4898	3.1	1.429	2.042
.6918	.4786	3.2	1.445	2.089
.6839	.4677	3.3	1.462	2.138
.6761	.4571	3.4	1.479	2.188
.6683	.4467	3.5	1.496	2.239
.6607	.4365	3.6	1.514	2.291
.6531	.4266	3.7	1.531	2.344
.6457	.4169	3.8	1.549	2.399
.6383	.4074	3.9	1.567	2.455
.6310	.3981	4.0	1.585	2.512
.6237	.3890	4.1	1.603	2.570
.6166	.3802	4.2	1.622	2.630
.6095	.3715	4.3	1.641	2.692
.6026	.3631	4.4	1.660	2.754
.5957	.3548	4.5	1.679	2.818
.5888	.3467	4.6	1.698	2.884
.5821	.3388	4.7	1.718	2.951
.5754	.3311	4.8	1.738	3.020
.5689	.3236	4.9	1.758	3.090

← *−db+* →

Voltage Ratio	*Power Ratio*	*db*	*Voltage Ratio*	*Power Ratio*
.5623	.3162	5.0	1.778	3.162
.5559	.3090	5.1	1.799	3.236
.5495	.3020	5.2	1.820	3.311
.5433	.2951	5.3	1.841	3.388
.5370	.2884	5.4	1.862	3.467
.5309	.2818	5.5	1.884	3.548
.5248	.2754	5.6	1.905	3.631
.5188	.2692	5.7	1.928	3.715
.5129	.2630	5.8	1.950	3.802
.5070	.2570	5.9	1.972	3.890
.5012	.2512	6.0	1.995	3.981
.4955	.2455	6.1	2.018	4.074
.4898	.2399	6.2	2.042	4.169
.4842	.2344	6.3	2.065	4.266
.4786	.2291	6.4	2.089	4.365
.4732	.2239	6.5	2.113	4.467
.4677	.2188	6.6	2.138	4.571
.4624	.2138	6.7	2.163	4.677
.4571	.2089	6.8	2.188	4.786
.4519	.2042	6.9	2.213	4.898
.4467	.1995	7.0	2.239	5.012
.4416	.1950	7.1	2.265	5.129
.4365	.1905	7.2	2.291	5.248
.4315	.1862	7.3	2.317	5.370
.4266	.1820	7.4	2.344	5.495
.4217	.1778	7.5	2.371	5.623
.4169	.1738	7.6	2.399	5.754
.4121	.1698	7.7	2.427	5.888
.4074	.1660	7.8	2.455	6.026
.4027	.1622	7.9	2.483	6.166
.3981	.1585	8.0	2.512	6.310
.3936	.1549	8.1	2.541	6.457
.3890	.1514	8.2	2.570	6.607
.3846	.1479	8.3	2.600	6.761
.3802	.1445	8.4	2.630	6.918
.3758	.1413	8.5	2.661	7.079
.3715	.1380	8.6	2.692	7.244
.3673	.1349	8.7	2.723	7.413
.3631	.1318	8.8	2.754	7.586
.3589	.1288	8.9	2.786	7.762
.3548	.1259	9.0	2.818	7.943
.3508	.1230	9.1	2.851	8.128
.3467	.1202	9.2	2.884	8.318
.3428	.1175	9.3	2.917	8.511
.3388	.1148	9.4	2.951	8.710
.3350	.1122	9.5	2.985	8.913
.3311	.1096	9.6	3.020	9.120
.3273	.1072	9.7	3.055	9.333
.3236	.1047	9.8	3.090	9.550
.3199	.1023	9.9	3.126	9.772

TABLE I (continued)

← −db+ →

Voltage Ratio	Power Ratio	db	Voltage Ratio	Power Ratio
.3162	.1000	10.0	3.162	10.000
.3126	.09772	10.1	3.199	10.23
.3090	.09550	10.2	3.236	10.47
.3055	.09333	10.3	3.273	10.72
.3020	.09120	10.4	3.311	10.96
.2985	.08913	10.5	3.350	11.22
.2951	.08710	10.6	3.388	11.48
.2917	.08511	10.7	3.428	11.75
.2884	.08318	10.8	3.467	12.02
.2851	.08128	10.9	3.508	12.30
.2818	.07943	11.0	3.548	12.59
.2786	.07762	11.1	3.589	12.88
.2754	.07586	11.2	3.631	13.18
.2723	.07413	11.3	3.673	13.49
.2692	.07244	11.4	3.715	13.80
.2661	.07079	11.5	3.758	14.13
.2630	.06918	11.6	3.802	14.45
.2600	.06761	11.7	3.846	14.79
.2570	.06607	11.8	3.890	15.14
.2541	.06457	11.9	3.936	15.49
.2512	.06310	12.0	3.981	15.85
.2483	.06166	12.1	4.027	16.22
.2455	.06026	12.2	4.074	16.60
.2427	.05888	12.3	4.121	16.98
.2399	.05754	12.4	4.169	17.38
.2371	.05623	12.5	4.217	17.78
.2344	.05495	12.6	4.266	18.20
.2317	.05370	12.7	4.315	18.62
.2291	.05248	12.8	4.365	19.05
.2265	.05129	12.9	4.416	19.50
.2239	.05012	13.0	4.467	19.95
.2213	.04898	13.1	4.519	20.42
.2188	.04786	13.2	4.571	20.89
.2163	.04677	13.3	4.624	21.38
.2138	.04571	13.4	4.677	21.88
.2113	.04467	13.5	4.732	22.39
.2089	.04365	13.6	4.786	22.91
.2065	.04266	13.7	4.842	23.44
.2042	.04169	13.8	4.898	23.99
.2018	.04074	13.9	4.955	24.55
.1995	.03981	14.0	5.012	25.12
.1972	.03890	14.1	5.070	25.70
.1950	.03802	14.2	5.129	26.30
.1928	.03715	14.3	5.188	26.92
.1905	.03631	14.4	5.248	27.54
.1884	.03548	14.5	5.309	28.18
.1862	.03467	14.6	5.370	28.84
.1841	.03388	14.7	5.433	29.51
.1820	.03311	14.8	5.495	30.20
.1799	.03236	14.9	5.559	30.90
.1778	.03162	15.0	5.623	31.62
.1758	.03090	15.1	5.689	32.36
.1738	.03020	15.2	5.754	33.11
.1718	.02951	15.3	5.821	33.88
.1698	.02884	15.4	5.888	34.67
.1679	.02818	15.5	5.957	35.48
.1660	.02754	15.6	6.026	36.31
.1641	.02692	15.7	6.095	37.15
.1622	.02630	15.8	6.166	38.02
.1603	.02570	15.9	6.237	38.90

← −db+ →

Voltage Ratio	Power Ratio	db	Voltage Ratio	Power Ratio
.1585	.02512	16.0	6.310	39.81
.1567	.02455	16.1	6.383	40.74
.1549	.02399	16.2	6.457	41.69
.1531	.02344	16.3	6.531	42.66
.1514	.02291	16.4	6.607	43.65
.1496	.02239	16.5	6.683	44.67
.1479	.02188	16.6	6.761	45.71
.1462	.02138	16.7	6.839	46.77
.1445	.02089	16.8	6.918	47.86
.1429	.02042	16.9	6.998	48.98
.1413	.01995	17.0	7.079	50.12
.1396	.01950	17.1	7.161	51.29
.1380	.01905	17.2	7.244	52.48
.1365	.01862	17.3	7.328	53.70
.1349	.01820	17.4	7.413	54.95
.1334	.01778	17.5	7.499	56.23
.1318	.01738	17.6	7.586	57.54
.1303	.01698	17.7	7.674	58.88
.1288	.01660	17.8	7.762	60.26
.1274	.01622	17.9	7.852	61.66
.1259	.01585	18.0	7.943	63.10
.1245	.01549	18.1	8.035	64.57
.1230	.01514	18.2	8.128	66.07
.1216	.01479	18.3	8.222	67.61
.1202	.01445	18.4	8.318	69.18
.1189	.01413	18.5	8.414	70.79
.1175	.01380	18.6	8.511	72.44
.1161	.01349	18.7	8.610	74.13
.1148	.01318	18.8	8.710	75.86
.1135	.01288	18.9	8.811	77.62
.1122	.01259	19.0	8.913	79.43
.1109	.01230	19.1	9.016	81.28
.1096	.01202	19.2	9.120	83.18
.1084	.01175	19.3	9.226	85.11
.1072	.01148	19.4	9.333	87.10
.1059	.01122	19.5	9.441	89.13
.1047	.01096	19.6	9.550	91.20
.1035	.01072	19.7	9.661	93.33
.1023	.01047	19.8	9.772	95.50
.1012	.01023	19.9	9.886	97.72
.1000	.01000	20.0	10.000	100.00

← −db+ →

Voltage Ratio	Power Ratio	db	Voltage Ratio	Power Ratio
3.162×10^{-1}	10^{-1}	10	3.162	10
10^{-1}	10^{-2}	20	10	10^{2}
3.162×10^{-2}	10^{-3}	30	3.162×10	10^{3}
10^{-2}	10^{-4}	40	10^{2}	10^{4}
3.162×10^{-3}	10^{-5}	50	3.162×10^{2}	10^{5}
10^{-3}	10^{-6}	60	10^{3}	10^{6}
3.162×10^{-4}	10^{-7}	70	3.162×10^{3}	10^{7}
10^{-4}	10^{-8}	80	10^{4}	10^{8}
3.162×10^{-5}	10^{-9}	90	3.162×10^{4}	10^{9}
10^{-5}	10^{-10}	100	10^{5}	10^{10}

TABLE II

GIVEN: }Current{ / }Voltage{ Ratios **TO FIND: Decibels**

POWER RATIOS

To find the number of decibels corresponding to a given power ratio—Assume the given power ratio to be a voltage ratio and find the corresponding number of decibels from the table. The desired result is exactly one-half of the number of decibels thus found.

Voltage Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.0
1.0	**.000**	**.086**	**.172**	**.257**	**.341**	**.424**	**.506**	**.588**	**.668**	**.74**
1.1	.828	.906	.984	1.062	1.138	1.214	1.289	1.364	1.438	1.51
1.2	1.584	1.656	1.727	1.798	1.868	1.938	2.007	2.076	2.144	2.21
1.3	2.279	2.345	2.411	2.477	2.542	2.607	2.671	2.734	2.798	2.86
1.4	2.923	2.984	3.046	3.107	3.167	3.227	3.287	3.346	3.405	3.46
1.5	3.522	3.580	3.637	3.694	3.750	3.807	3.862	3.918	3.973	4.02
1.6	4.082	4.137	4.190	4.244	4.297	4.350	4.402	4.454	4.506	4.55
1.7	4.609	4.660	4.711	4.761	4.811	4.861	4.910	4.959	5.008	5.05
1.8	5.105	5.154	5.201	5.249	5.296	5.343	5.390	5.437	5.483	5.52
1.9	5.575	5.621	5.666	5.711	5.756	5.801	5.845	5.889	5.933	5.97
2.0	**6.021**	**6.064**	**6.107**	**6.150**	**6.193**	**6.235**	**6.277**	**6.319**	**6.361**	**6.40**
2.1	6.444	6.486	6.527	6.568	6.608	6.649	6.689	6.729	6.769	6.80
2.2	6.848	6.888	6.927	6.966	7.008	7.044	7.082	7.121	7.159	7.19
2.3	7.235	7.272	7.310	7.347	7.384	7.421	7.458	7.495	7.532	7.56
2.4	7.604	7.640	7.676	7.712	7.748	7.783	7.819	7.854	7.889	7.92
2.5	7.959	7.993	8.028	8.062	8.097	8.131	8.165	8.199	8.232	8.26
2.6	8.299	8.333	8.366	8.399	8.432	8.465	8.498	8.530	8.563	8.59
2.7	8.627	8.659	8.691	8.723	8.755	8.787	8.818	8.850	8.881	8.91
2.8	8.943	8.974	9.005	9.036	9.066	9.097	9.127	9.158	9.188	9.21
2.9	9.248	9.278	9.308	9.337	9.367	9.396	9.426	9.455	9.484	9.51
3.0	**9.542**	**9.571**	**9.600**	**9.629**	**9.657**	**9.686**	**9.714**	**9.743**	**9.771**	**9.79**
3.1	9.827	9.855	9.883	9.911	9.939	9.966	9.994	10.021	10.049	10.07
3.2	10.103	10.130	10.157	10.184	10.211	10.238	10.264	10.291	10.317	10.34
3.3	10.370	10.397	10.423	10.449	10.475	10.501	10.527	10.553	10.578	10.60
3.4	10.630	10.655	10.681	10.706	10.731	10.756	10.782	10.807	10.832	10.85
3.5	10.881	10.906	10.931	10.955	10.980	11.005	11.029	11.053	11.078	11.10
3.6	11.126	11.150	11.174	11.198	11.222	11.246	11.270	11.293	11.317	11.34
3.7	11.364	11.387	11.411	11.434	11.457	11.481	11.504	11.527	11.550	11.57
3.8	11.596	11.618	11.641	11.664	11.687	11.709	11.732	11.754	11.777	11.79
3.9	11.821	11.844	11.866	11.888	11.910	11.932	11.954	11.976	11.998	12.01
4.0	**12.041**	**12.063**	**12.085**	**12.106**	**12.128**	**12.149**	**12.171**	**12.192**	**12.213**	**12.23**
4.1	12.256	12.277	12.298	12.319	12.340	12.361	12.382	12.403	12.424	12.44
4.2	12.465	12.486	12.506	12.527	12.547	12.568	12.588	12.609	12.629	12.64
4.3	12.669	12.690	12.710	12.730	12.750	12.770	12.790	12.810	12.829	12.84
4.4	12.869	12.889	12.908	12.928	12.948	12.967	12.987	13.006	13.026	13.04
4.5	13.064	13.084	13.103	13.122	13.141	13.160	13.179	13.198	13.217	13.23
4.6	13.255	13.274	13.293	13.312	13.330	13.349	13.368	13.386	13.405	13.42
4.7	13.442	13.460	13.479	13.497	13.516	13.534	13.552	13.570	13.589	13.60
4.8	13.625	13.643	13.661	13.679	13.697	13.715	13.733	13.751	13.768	13.78
4.9	13.804	13.822	13.839	13.857	13.875	13.892	13.910	13.927	13.945	13.96
5.0	**13.979**	**13.997**	**14.014**	**14.031**	**14.049**	**14.066**	**14.083**	**14.100**	**14.117**	**14.134**
5.1	14.151	14.168	14.185	14.202	14.219	14.236	14.253	14.270	14.287	14.30
5.2	14.320	14.337	14.353	14.370	14.387	14.403	14.420	14.436	14.453	14.46
5.3	14.486	14.502	14.518	14.535	14.551	14.567	14.583	14.599	14.616	14.63
5.4	14.648	14.664	14.680	14.696	14.712	14.728	14.744	14.760	14.776	14.791
5.5	14.807	14.823	14.839	14.855	14.870	14.886	14.902	14.917	14.933	14.948
5.6	14.964	14.979	14.995	15.010	15.026	15.041	15.056	15.072	15.087	15.102
5.7	15.117	15.133	15.148	15.163	15.178	15.193	15.208	15.224	15.239	15.254
5.8	15.269	15.284	15.298	15.313	15.328	15.343	15.358	15.373	15.388	15.402
5.9	15.417	15.432	15.446	15.461	15.476	15.490	15.505	15.519	15.534	15.549

TABLE II (continued)

ltage atio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	**15.563**	**15.577**	**15.592**	**15.606**	**15.621**	**15.635**	**15.649**	**15.664**	**15.678**	**15.692**
.1	15.707	15.721	15.735	15.749	15.763	15.778	15.792	15.806	15.820	15.834
.2	15.848	15.862	15.876	15.890	15.904	15.918	15.931	15.945	15.959	15.973
.3	15.987	16.001	16.014	16.028	16.042	16.055	16.069	16.083	16.096	16.110
.4	16.124	16.137	16.151	16.164	16.178	16.191	16.205	16.218	16.232	16.245
6.5	16.258	16.272	16.285	16.298	16.312	16.325	16.338	16.351	16.365	16.378
6.6	16.391	16.404	16.417	16.430	16.443	16.456	16.469	16.483	16.496	16.509
6.7	16.521	16.534	16.547	16.560	16.573	16.586	16.599	16.612	16.625	16.637
6.8	16.650	16.663	16.676	16.688	16.701	16.714	16.726	16.739	16.752	16.764
6.9	16.777	16.790	16.802	16.815	16.827	16.840	16.852	16.865	16.877	16.890
7.0	**16.902**	**16.914**	**16.927**	**16.939**	**16.951**	**16.964**	**16.976**	**16.988**	**17.001**	**17.013**
7.1	17.025	17.037	17.050	17.062	17.074	17.086	17.098	17.110	17.122	17.135
7.2	17.147	17.159	17.171	17.183	17.195	17.207	17.219	17.231	17.243	17.255
7.3	17.266	17.278	17.290	17.302	17.314	17.326	17.338	17.349	17.361	17.373
7.4	17.385	17.396	17.408	17.420	17.431	17.443	17.455	17.466	17.478	17.490
7.5	17.501	17.513	17.524	17.536	17.547	17.559	17.570	17.582	17.593	17.605
7.6	17.616	17.628	17.639	17.650	17.662	17.673	17.685	17.696	17.707	17.719
7.7	17.730	17.741	17.752	17.764	17.775	17.786	17.797	17.808	17.820	17.831
7.8	17.842	17.853	17.864	17.875	17.886	17.897	17.908	17.919	17.931	17.942
7.9	17.953	17.964	17.975	17.985	17.996	18.007	18.018	18.029	18.040	18.051
8.0	**18.062**	**18.073**	**18.083**	**18.094**	**18.105**	**18.116**	**18.127**	**18.137**	**18.148**	**18.159**
8.1	18.170	18.180	18.191	18.202	18.212	18.223	18.234	18.244	18.255	18.266
8.2	18.276	18.287	18.297	18.308	18.319	18.329	18.340	18.350	18.361	18.371
8.3	18.382	18.392	18.402	18.413	18.423	18.434	18.444	18.455	18.465	18.475
8.4	18.486	18.496	18.506	18.517	18.527	18.537	18.547	18.558	18.568	18.578
8.5	18.588	18.599	18.609	18.619	18.629	18.639	18.649	18.660	18.670	18.680
8.6	18.690	18.700	18.710	18.720	18.730	18.740	18.750	18.760	18.770	18.780
8.7	18.790	18.800	18.810	18.820	18.830	18.840	18.850	18.860	18.870	18.880
8.8	18.890	18.900	18.909	18.919	18.929	18.939	18.949	18.958	18.968	18.978
8.9	18.988	18.998	19.007	19.017	19.027	19.036	19.046	19.056	19.066	19.075
9.9	**19.085**	**19.094**	**19.104**	**19.114**	**19.123**	**19.133**	**19.143**	**19.152**	**19.162**	**19.171**
9.1	19.181	19.190	19.200	19.209	19.219	19.228	19.238	19.247	19.257	19.266
9.2	19.276	19.285	19.295	19.304	19.313	19.323	19.332	19.342	19.351	19.360
9.3	19.370	19.379	19.388	19.398	19.407	19.416	19.426	19.435	19.444	19.453
9.4	19.463	19.472	19.481	19.490	19.499	19.509	19.518	19.527	19.536	19.545
9.5	19.554	19.564	19.573	19.582	19.591	19.600	19.609	19.618	19.627	19.636
9.6	19.645	19.654	19.664	19.673	19.682	19.691	19.700	19.709	19.718	19.726
9.7	19.735	19.744	19.753	19.762	19.771	19.780	19.789	19.798	19.807	19.816
9.8	19.825	19.833	19.842	19.851	19.860	19.869	19.878	19.886	19.895	19.904
9.9	19.913	19.921	19.930	19.939	19.948	19.956	19.965	19.974	19.983	19.991

oltage Ratio	0	1	2	3	4	5	6	7	8	9
10	**20.000**	**20.828**	**21.584**	**22.279**	**22.923**	**23.522**	**24.082**	**24.609**	**25.105**	**25.575**
20	26.021	26.444	26.848	27.235	27.604	27.959	28.299	28.627	28.943	29.248
30	29.542	29.827	30.103	30.370	30.630	30.881	31.126	31.364	31.596	31.821
40	32.041	32.256	32.465	32.669	32.869	33.064	33.255	33.442	33.625	33.804
50	33.979	34.151	34.320	34.486	34.648	34.807	34.964	35.117	35.269	35.417
60	35.563	35.707	35.848	35.987	36.124	36.258	36.391	36.521	36.650	36.777
70	36.902	37.025	37.147	37.266	37.385	37.501	37.616	37.730	37.842	37.953
80	38.062	38.170	38.276	38.382	38.486	38.588	38.690	38.790	38.890	38.988
90	39.085	39.181	39.276	39.370	39.463	39.554	39.645	39.735	39.825	39.913
100	**40.000**	—	—	—	—	—	—	—	—	—

CONVERSION FACTORS

to convert	into	multiply by	conversely multiply by
Acres	Square feet	4.356×10^{4}	2.296×10^{-5}
Acres	Square meters	4,047	2.471×10^{-4}
Ampere-hours	Coulomb	3,600	2.778×10^{-4}
Amperes per sq cm	Amperes per sq inch	6.452	0.1550
Ampere turns	Gilberts	1.257	0.7958
Ampere turns per cm	Ampere turns per inch	2.540	0.3937
Atmospheres	Mm of mercury @ 0° C	760	1.316×10^{-3}
Atmospheres	Feet of water @ 4° C	33.90	2.950×10^{-2}
Atmospheres	Inches mercury @ 0° C	29.92	3.342×10^{-2}
Atmospheres	Kg per sq meter	1.033×10^{4}	9.678×10^{-5}
Atmospheres	Pounds per sq inch	14.70	6.804×10^{-2}
Btu	Foot-pounds	778.3	1.285×10^{-3}
Btu	Joules	1,054.8	9.480×10^{-4}
Btu	Kilogram-calories	0.2520	3.969
Btu	Horsepower-hours	3.929×10^{-4}	2,545
Bushels	Cubic feet	1.2445	0.8036
Centigrade	Fahrenheit	(C° × 9/5) + 32	(F° − 32) × 5/9
Circular mils	Square centimeters	5.067×10^{-6}	1.973×10^{5}
Circular mils	Square mils	0.7854	1.273
Cubic feet	Cords	7.8125×10^{-3}	128
Cubic feet	Gallons (liq US)	7.481	0.1337
Cubic feet	Liters	28.32	3.531×10^{-2}
Cubic inches	Cubic centimeters	16.39	6.102×10^{-2}
Cubic inches	Cubic feet	5.787×10^{-4}	1,728
Cubic inches	Cubic meters	1.639×10^{-6}	6.102×10^{4}
Cubic inches	Gallons (liq US)	4.329×10^{-3}	231
Cubic meters	Cubic feet	35.31	2.832×10^{-2}
Cubic meters	Cubic yards	1.308	0.7646
Degrees (angle)	Radians	1.745×10^{-2}	57.30
Dynes	Pounds	2.248×10^{-6}	4.448×10^{5}
Ergs	Foot-pounds	7.367×10^{-8}	1.356×10^{7}
Fathoms	Feet	6	0.16666
Feet	Centimeters	30.48	3.281×10^{-2}
Feet of water @ 4° C	Inches of mercury @ 0° C	0.8826	1.133
Feet of water @ 4° C	Kg per sq meter	304.8	3.281×10^{-3}
Feet of water @ 4° C	Pounds per sq foot	62.43	1.602×10^{-2}
Foot-pounds	Horsepower-hours	5.050×10^{-7}	1.98×10^{6}
Foot-pounds	Kilogram-meters	0.1383	7.233
Foot-pounds	Kilowatt-hours	3.766×10^{-7}	2.655×10^{6}
Gallons	Cubic meters	3.785×10^{-3}	264.2
Gallons (liq US)	Gallons (liq Br Imp)	0.8327	1.201
Gauss	Lines per sq inch	6.452	0.1550
Grams	Dynes	980.7	1.020×10^{-3}
Grams	Grains	15.43	6.481×10^{-2}
Grams	Ounces (avoirdupois)	3.527×10^{-2}	28.35
Grams	Poundals	7.093×10^{-2}	14.10
Grams per cm	Pounds per inch	5.600×10^{-3}	178.6
Grams per cu cm	Pounds per cu inch	3.613×10^{-2}	27.68
Grams per sq cm	Pounds per sq foot	2.0481	0.4883
Hectares	Acres	2.471	0.4047
Horsepower (boiler)	Btu per hour	3.347×10^{4}	2.986×10^{-5}
Horsepower (metric) (542.5 ft-lb per sec)	Btu per minute	41.83	2.390×10^{-2}
Horsepower (metric) (542.5 ft-lb per sec)	Foot-lb per minute	3.255×10^{4}	3.072×10^{-5}

CONVERSION FACTORS (continued)

to convert	into	multiply by	conversely multiply by
Horsepower (metric) (542.5 ft-lb per sec)	Kg-calories per minute	10.54	9.485×10^{-2}
Horsepower (550 ft-lb per sec)	Btu per minute	42.41	2.357×10^{-2}
Horsepower (550 ft-lb per sec)	Foot-lb per minute	3.3×10^{4}	3.030×10^{-5}
Horsepower (metric) (542.5 ft-lb per sec)	Horsepower (550 ft-lb per sec)	0.9863	1.014
Horsepower (550 ft-lb per sec)	Kg-calories per minute	10.69	9.355×10^{-2}
Inches	Centimeters	2.540	0.3937
Inches	Feet	8.333×10^{-2}	12
Inches	Miles	1.578×10^{-5}	6.336×10^{4}
Inches	Mils	1,000	0.001
Inches	Yards	2.778×10^{-2}	36
Inches of mercury @ 0° C	lbs per sq inch	0.4912	2.036
Inches of water @ 4° C	Kg per sq meter	25.40	3.937×10^{-2}
Inches of water	Ounces per sq inch	0.5781	1.729
Inches of water	Pounds per sq foot	5.204	0.1922
Joules.	Foot-pounds	0.7376	1.356
Joules	Ergs	10^{7}	10^{-7}
Kilogram-calories	Kilogram-meters	426.9	2.343×10^{-3}
Kilogram-calories	Kilojoules	4.186	0.2389
Kilograms	Tons, long (avdp 2240 lb)	9.842×10^{-4}	1,016
Kilograms	Tons, short (avdp 2000 lb)	1.102×10^{-3}	907.2
Kilograms	Pounds (avoirdupois)	2.205	0.4536
Kg per sq meter	Pounds per sq foot	0.2048	4.882
Kilometers	Feet	3,281	3.048×10^{-4}
Kilowatt-hours	Btu	3,413	2.930×10^{-4}
Kilowatt-hours	Foot-pounds	2.655×10^{6}	3.766×10^{-7}
Kilowatt-hours	Joules	3.6×10^{6}	2.778×10^{-7}
Kilowatt-hours	Kilogram-calories	860	1.163×10^{-3}
Kilowatt-hours	Kilogram-meters	3.671×10^{5}	2.724×10^{-6}
Kilowatt-hours	Pounds carbon oxydized	0.235	4.26
Kilowatt-hours	Pounds water evaporated from and at 212° F	3.53	0.283
Kilowatt-hours	Pounds water raised from 62° to 212° F	22.75	4.395×10^{-2}
Liters	Bushels (dry US)	2.838×10^{-2}	35.24
Liters	Cubic centimeters	1,000	0.001
Liters	Cubic meters	0.001	1,000
Liters	Cubic inches	61.02	1.639×10^{-2}
Liters	Gallons (liq US)	0.2642	3.785
Liters	Pints (liq US)	2.113	0.4732
$\log_e N$ or $l_n N$	$\log_{10} N$	0.4343	2.303
Lumens per sq foot	Foot-candles	1	1
Lux	Foot-candles	0.0929	10.764
Meters	Yards	1.094	0.9144
Meters per min	Knots (nautical mi per hour)	3.238×10^{-2}	30.88
Meters per min	Feet per minute	3.281	0.3048
Meters per min	Kilometers per hour	0.06	16.67
Microhms per cm cube	Microhms per inch cube	0.3937	2.540
Microhms per cm cube	Ohms per mil foot	6.015	0.1662
Miles (nautical)	Feet	6,080.27	1.645×10^{-4}

CONVERSION FACTORS (continued)

to convert	**into**	**multiply by**	**conversely multiply by**
Miles (nautical)	Kilometers	1.853	0.5396
Miles (statute)	Kilometers	1.609	0.6214
Miles (statute)	Miles (nautical)	0.8684	1.1516
Miles (statute)	Feet	5,280	1.894×10^{-4}
Miles per hour	Kilometers per minute	2.682×10^{-2}	37.28
Miles per hour	Feet per minute	88	1.136×10^{-2}
Miles per hour	Knots (nautical mi per hour)	0.8684	1.1516
Miles per hour	Kilometers per hour	1.609	0.6214
Pounds of water (dist)	Cubic feet	1.603×10^{-2}	62.38
Pounds of water (dist)	Gallons	0.1198	8.347
Pounds per cu foot	Kg per cu meter	16.02	6.243×10^{-2}
Pounds per cu inch	Pounds per cu foot	1,728	5.787×10^{-4}
Pounds per sq foot	Pounds per sq inch	6.944×10^{-3}	144
Pounds per sq inch	Kg per sq meter	703.1	1.422×10^{-3}
Poundals	Dynes	1.383×10^{4}	7.233×10^{-5}
Poundals	Pounds (avoirdupois)	3.108×10^{-2}	32.17
Sq inches	Circular mils	1.273×10^{6}	7.854×10^{-7}
Sq inches	Sq centimeters	6.452	0.1550
Sq feet	Sq meters	9.290×10^{-2}	10.76
Sq miles	Sq yards	3.098×10^{6}	3.228×10^{-7}
Sq miles	Acres	640	1.562×10^{-3}
Sq miles	Sq kilometers	2.590	0.3861
Sq millimeters	Circular mils	1,973	5.067×10^{-4}
Tons, short (avoir 2000 lb)	Tonnes (1000 kg)	0.9072	1.102
Tons, long (avoir 2240 lb)	Tonnes (1000 kg)	1.016	0.9842
Tons, long (avoir 2240 lb)	Tons, short (avoir 2000 lb)	1.120	0.8929
Tons (US shipping)	Cubic feet	40	0.025
Watts	Btu per minute	5.689×10^{-2}	17.58
Watts	Ergs per second	10^{7}	10^{-7}
Watts	Foot-lb per minute	44.26	2.260×10^{-2}
Watts	Horsepower (550 ft-lb per sec)	1.341×10^{-3}	745.7
Watts	Horsepower (metric) (542.5 ft-lb per sec)	1.360×10^{-3}	735.5
Watts	Kg-calories per minute	1.433×10^{-2}	69.77

MATHEMATICAL CONSTANTS

$\pi = 3.1416$

$1/\pi = 0.3183$

$\pi^2 = 9.8696$

$1/\pi^2 = 0.1013$

$\pi^3 = 31.0063$

$1/\pi^3 = 0.0323$

$\sqrt{\pi} = 1.7725$

$1/\sqrt{\pi} = 0.5642$

$\sqrt{\pi/2} = 1.2533$

$2\pi = 6.2832$

$\dfrac{1}{\log_{10}\varepsilon} = 2.3026$

$1/2\pi = 0.1592$

$(1/2\pi)^2 = 0.0253$

$(2\pi)^2 = 39.4784$

$\log_{10}\pi = 0.4971$

$\log_{10}(\pi/2) = 0.1961$

$\log_{10}\pi^2 = 0.9943$

$\log_{10}\sqrt{\pi} = 0.2486$

$\varepsilon = 2.7183$

$1/\varepsilon = 0.3679$

$\varepsilon^2 = 7.3890$

$\sqrt{\varepsilon} = 1.6487$

$\log_{10}\varepsilon = 0.4343$

$\sqrt{2} = 1.4142$

$\sqrt{3} = 1.7321$

$1/\sqrt{2} = 0.7071$

$1/\sqrt{3} = 0.5773$

SYMBOLS AND ABBREVIATIONS

Admittance	Y, y
Alternating-current (adjective)	a-c
Alternating current (noun)	a.c.
Ampere (amperes)	a.
Amplitude modulation	a.m.
Angular velocity ($2\pi f$)	ω
Antenna	ant.
Audio-frequency (adjective)	a-f
Audio frequency (noun)	a.f.
Automatic volume control	a.v.c.
Automatic volume expansion	a.v.e.
Capacitance	C
Capacitive reactance	X_C
Centimeter	cm.
Conductance	G,g
Conductivity	γ
Continuous waves	c.w.
Current	I,i
Cycles per second	c.p.s.
Decibel	db.
Difference of potential	E,e
Dielectric constant	K
Dielectric flux	ψ
Direct-current (adjective)	d-c
Direct current (noun)	d.c.
Double cotton covered	d.c.c.
Double pole, double throw	d.p.d.t.
Double pole, single throw	d.p.s.t.
Double silk covered	d.s.c.
Electric field intensity	E

Electromotive force	e.m.f.
Energy	W
Frequency	f.
Frequency modulation	f.m.
Ground	gnd.
Henry	h.
High-frequency (adjective)	h-f
High frequency (noun)	h.f.
Impedance	Z,z
Inductance	L
Inductive reactance	X_L
Intermediate-frequency (adjective)	i-f
Intermediate frequency (noun)	i.f.
Interrupted continuous waves	i.c.w.
Kilocycles (per second)	kc.
Kilovolt	kv.
Kilovolt ampere	kva
Kilowatt	kw.
Low-frequency (adjective)	l-f
Low frequency (noun)	l.f.
Magnetic intensity	H
Magnetic flux	Φ
Magnetic flux density	B
Magnetomotive force	m.m.f.,F.
Medium frequency	m.f.
Megacycles (per second)	Mc.
Megohm	MΩ
Meter	m.
Microampere	μa.
Microfarad (mfd)	μfd.
Microhenry	μh.
Micromicrofarad (mmfd)	μμfd.
Microvolt	μv.
Microvolt per meter	μv/m.
Microwatt	μw.
Milliampere	ma.
Millihenry	mh.
Millivolt	mv.
Millivolt per meter	mv/m.
Milliwatt	mw.
Modulated continuous waves	m.c.w.
Mutual inductance	M
Number of conductors or turns	N
Ohm	Ω
Period	T
Permeability	μ
Phase displacement	θ
Power	P,p
Power factor	p.f.
Quantity of electricity	Q,q

Radio-frequency (adjective)	r-f
Radio-frequency (noun)	r.f.
Reactance	X,x
Reactance, Capacitive	X_c
Reactance, Inductive	X_L
Reluctivity	ν
Resistance	R,r
Resistivity	ρ
Revolutions per minute	r.p.m.
Root mean square	r.m.s.
Self-inductance	L
Short wave	s.w.
Single cotton covered	s.c.c.
Single cotton enamel	s.c.e.
Single pole, double throw	s.p.d.t.
Single pole, single throw	s.p.s.t
Single silk covered	s.s.c.
Speed of rotation	n
Susceptance	b
Tuned radio frequency	t.r.f.
Ultra high frequency	u.h.f.
Vacuum tube voltmeter	v.t.v.m.
Very-high frequency	v.h.f.
Volt (volts)	v.
Voltage	E,e
Volt-Ohm-Milliammeter	v.o.m.
Watt (watts)	w
Work	W

VACUUM TUBE LETTER SYMBOLS

Amplification factor	μ
Cathode current	I_c
Emission current	I_s
Filament current	I_f
Filament terminal voltage	E_f
Grid bias voltage	E_c
Grid capacity	C_g
Grid conductance	g_g
Grid current	I_g, i_g
Grid potential	E_g, e_g
Grid resistance	r_g
Grid to cathode capacity	C_{gk}
Grid to plate capacity	C_{gp}
Mutual conductance	g_m
Plate capacity	C_p
Plate conductance	g_p
Plate current	I_p, i_p
Plate potential	E_p, e_p
Plate resistance	r_p
Plate supply voltage	E_b
Plate to cathode capacity	C_{pk}

GREEK ALAPHABET

commonly used to designate

ALPHA	Α	α		Angles, coefficients, attenuation constant, absorption factor, area
BETA	Β	β		Angles, coefficients, phase constant
GAMMA	Γ	γ		Complex propagation constant (cap), specific gravity, angles, electrical conductivity, propagation constant
DELTA	Δ	δ		Increment or decrement (cap or small), determinant (cap), permittivity (cap), density, angles
EPSILON	Ε	ε		Dielectric constant, permittivity, base of natural lagarithms, electric intensity
ZETA	Ζ	ζ		Coordinates, coefficients
ETA	Η	η		Intrinsic impedance, efficiency, surface charge density, hysteresis, coordinates
THETA	Θ	ϑ	θ	Angular phase displacement, time constant, reluctance, angles
IOTA	Ι	ι		Unit vector
KAPPA	Κ	κ		Susceptibility, coupling coefficient
LAMBDA	Λ	λ		Permeance (cap), wavelength, attenuation constant
MU	Μ	μ		Permeability, amplification factor, prefix micro
NU	Ν	ν		Reluctivity, frequency
XI	Ξ	ξ		Coordinates
OMICRON	Ο	ο		
PI	Π	π		3.1416
RHO	Ρ	ρ		Resistivity, volume charge density, coordinates
SIGMA	Σ	σ	ς	Summation (cap), surface charge density, complex propagation constant, electrical conductivity, leakage coefficient
TAU	Τ	τ		Time constant, volume resistivity, time-phase displacement, transmission factor, density
UPSILON	ϒ	υ		
PHI	Φ	ϕ	φ	Scalar potential (cap), magnetic flux, angles
CHI	Χ	χ		Electric susceptibility, angles
PSI	Ψ	ψ		Dielectric flux, phase difference, coordinates, angles
OMEGA	Ω	ω		Resistance in ohms (caps), solid angle (cap), angular velocity

INSULATING MATERIALS

material	electrical properties*								physical properties	
	dielectric constant			power factor			dielectric strength kv/mm†	resistivity ohms—cm 25° C	thermal expansion per ° C	softening point
	60~	10^6~	10^8~	60~	10^6~	10^8~				
Aniline Formaldehyde Resin	3.6	3.5	3.4	.003	.007	.004	16–25	$>10^{13}$	5.4×10^{-5}	260° F
Casein		6.2			.052		16–28	Poor	5×10^{-5}	200° F
Cellulose Acetate (plastic)	4.4	3.9	3.4	.007	.039	.039	10–14	10^{10}	$6–15 \times 10^{-5}$	100–190° F
Cellulose Acetobutyrate	3.6	3.2	3.0	.004	.017	.019	10–16	10^{10}	$11–17 \times 10^{-5}$	110–180° F
Ebonite	3.0	2.8	2.8	.008	.006	.004	18	2×10^{15}	7×10^{-5}	140° F
Ethyl Cellulose	4.0	3.4	3.2	.005	.028	.024	16–28	10^{15}	3.4×10^{-4}	120° F
Glass, Corning 707	4.0	4.0	4.0	.0006	.0008	.0012		1.5×10^{11} at 250° C	31×10^{-7}	1400° F
Glass, Corning 774	5.6	5.2	5.0	.0136	.0048	.008		1.4×10^{8} at 250° C	33×10^{-7}	1500° F
Glass, Corning 790	3.9	3.9	3.9	.0006	.0006	.0006		5.2×10^{8} at 250° C	8×10^{-7}	2600° F
Glass, Corning 7052	5.2	5.1	5.1	.008	.0024	.0036		1×10^{9} at 250° C	47×10^{-7}	1300° F
Halowax	3.8	3.7	3.4	.002	.0014	.105		$10^{13}–10^{14}$		190° F
Isolantite		6.0			.0018					
Melamine Formaldehyde Resin	7.5	4.5	4.5	.08	.08	.03	18		3.5×10^{-5}	260° F
Methyl Methacrylate—a Lucite HM119	3.3	2.6	2.6	.066	.015	.007	16	10^{15}	$11–14 \times 10^{-5}$	160° F
b Plexiglas	3.5	2.6	2.6	.064	.015	.007	16	10^{15}	8×10^{-5}	160° F
Mica	5.45	5.4	5.4	.005	.0003	.0003		5×10^{13}		
Mycalex 364	7.1	7.0	7.0	.0064	.0021	.0022	14		$8–9 \times 10^{-6}$	660° F
Nylon FM–1	3.6	3.6	3.6	.018	.020	.018	12	10^{13}	5.7×10^{-5}	160° F
Paraffin Oil	2.2	2.2	2.2	.0001	.0001	.0004	15		7.1×10^{-4}	liquid
Petroleum Wax (Paraffin Wax)	2.25	2.25	2.25	.0002	.0002	.0002	8–12	10^{16}		M.P. 132° F
Phenol Formaldehyde Resins										
a general purpose	5.5	4.5	4.0	.018	.014	.014	14	10^{11}	$3–4 \times 10^{-5}$	275° F
b. mineral filled	4.6	4.4	4.3	.024	.006	.012	20			212° F
c. cast	8.0	8.0	8.0	.05	.05	.08	10		$7.5–15 \times 10^{-5}$	140° F
Phenol Furfural Resins	7.0	5.0	4.0	.20	.04	.05				
Polyethylene	2.25	2.25	2.25	.0003	.0003	.0003	40	$>10^{15}$	Varies	220° F
Polyisobutylene MW 100,000	2.20	2.22	2.22	.0003	.0003	.0004		10^{15}		>0° F
Polystyrene MW 80,000	2.55	2.53	2.52	.0002	.0002	.0003	20–30	10^{17}	7×10^{-5}	175° F
Polyvinyl Carbazole	2.95	2.95	2.95	.0017	.0005	.0006	31–40		$4.5–5.5 \times 10^{-5}$	300° F
Polyvinyl Chlor-Acetate	3.2	2.9	2.8	.009	.014	.009				180° F
Polyvinyl Chloride	3.2	2.9	2.9	.012	.016	.008				180° F
Polyvinylidine Chloride-Saran	4.5	3.0	2.8	.03	.046	.014	15	10^{13}	1.58×10^{-4}	175° F
Quartz (fused)	3.9	3.8	3.8	.0009	.0002	.0002	60		5.7×10^{-7}	3000° F
Shellac	3.9	3.5	3.1	.006	.031	.030		10^{16}		
Styraloy 22	2.4	2.4	2.4	.0010	.0012	.0043	30	10^{16}	1.8×10^{-4}	150° F
Styramic	2.9	2.75	2.73	.003	.0002	.0002			7×10^{-5}	175° F
Styramic HT	2.64	2.64	2.62	.0002	.0002	.0002				250° F
Urea Formaldehyde Resins	6.6	5.6	5.0	.032	.028	.05	15	10^{13}	2.6×10^{-5}	260° F
Wood—African Mahogany (dry)	2.4	2.1	2.1	.01	.03	.04				
Balsa (dry)	1.4	1.4	1.3	.048	.012	.013				

* Values given are average for the materials listed.

†To convert Kilovolts per millimeter to volts per mil, multiply by 25.4

REACTANCE-RESONANCE CHARTS

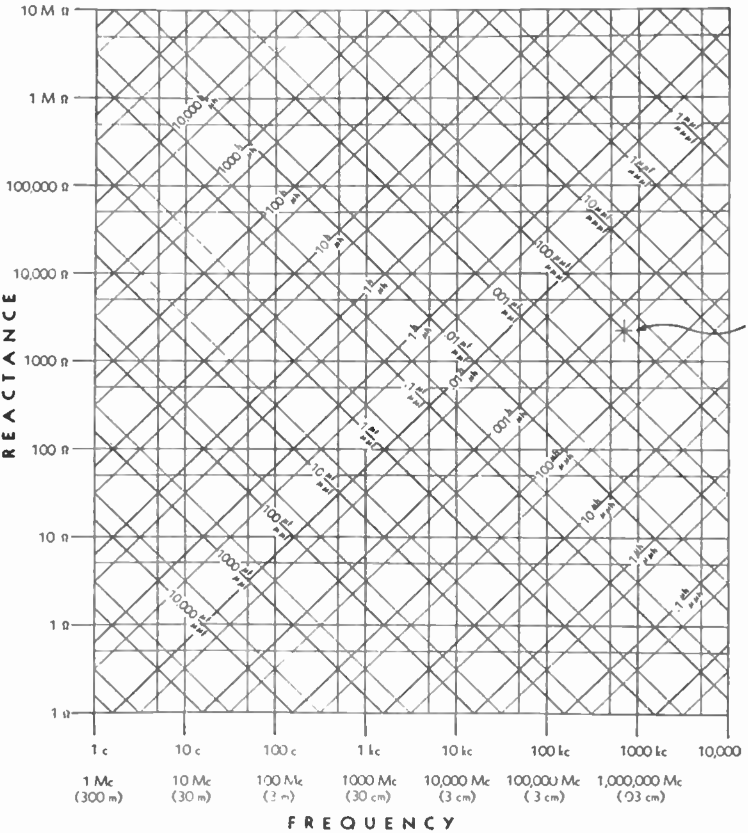


Chart 1.

The charts on this and the following page may be used to find: (1) The reactance of a given inductance at a given frequency. (2) The reactance of a given capacitance at a given frequency. (3) The resonant frequency of a given inductance and capacitance.

In order to facilitate the determination of magnitude of the quantities involved to two or three significant figures the chart is divided into two parts. Chart 1 is the complete chart to be used for rough calculations. Chart 2, which is a single decade of Chart 1 enlarged approximately 7 times, is to be used where the significant two or three figures are to be determined.

To find reactance:

Enter the charts vertically from the bottom (frequency) and along the lines slanting upward to the left (capacitance) or to the right (inductance). Corresponding scales (upper or lower) must be used throughout. Project horizontally to the left from the intersection and read reactance.

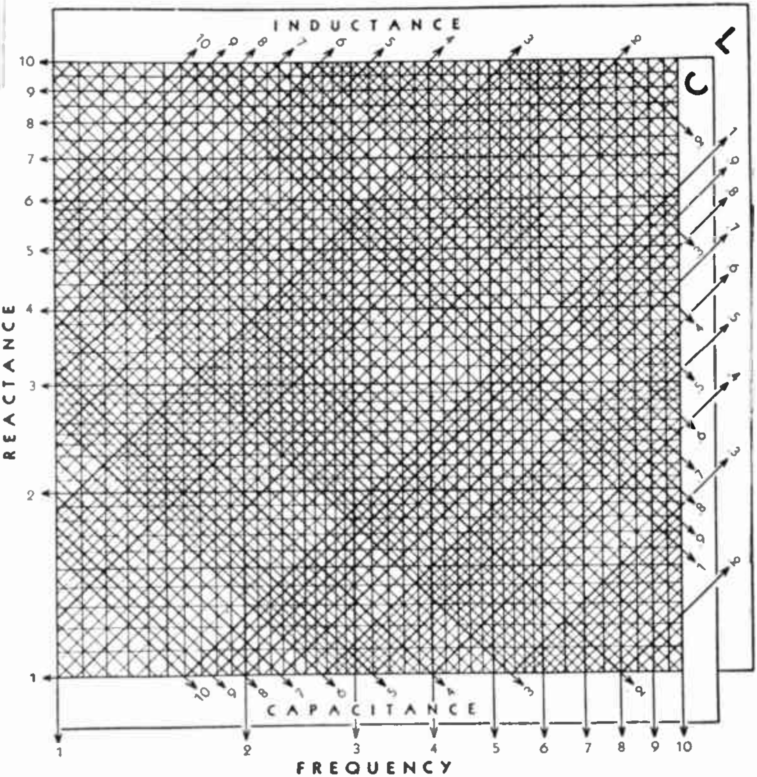


Chart 2.

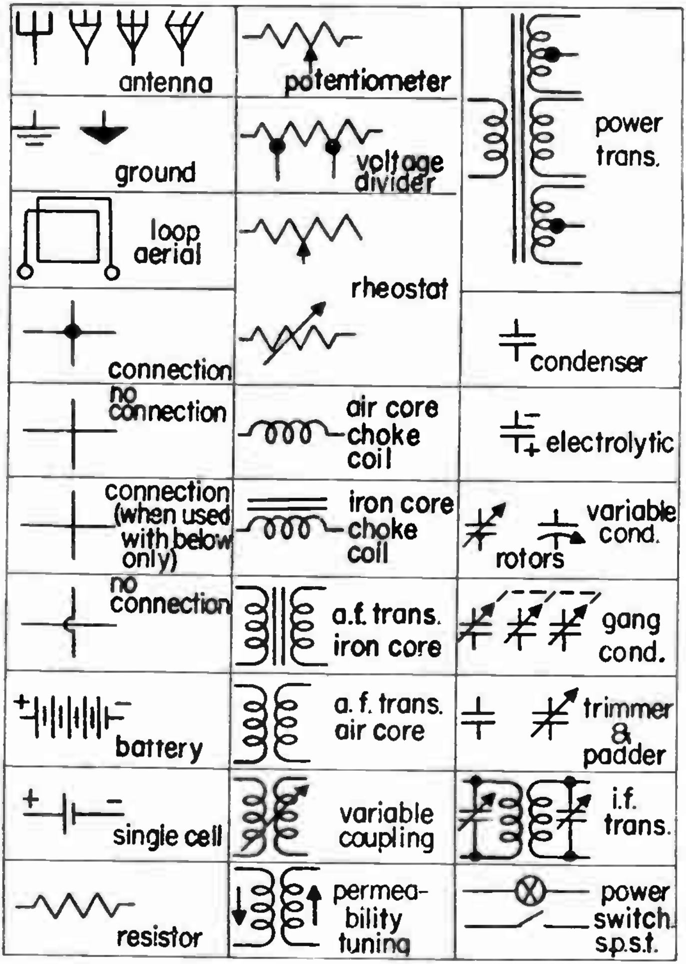
To find resonant frequency:

Enter the slanting lines for the given inductance and capacitance. Project downward from their intersection and read resonant frequency from the bottom scale. Corresponding scales (upper or lewore) must be used throughout.

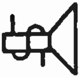
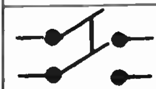
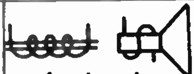
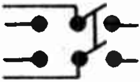
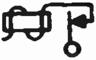
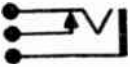
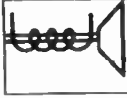
Example: The sample point indicated (Chart 1) corresponds to a frequency of about 700 kc and an inductance of 500μh, or a capacitance of 100$\mu\mu$f, giving in either casce a reactance of about 2,000 ohms. The resonant frequency of a circuit containing these values of inductance and capacitance is, of course, 700 kc approximately. The reactance corresponding to 500μh or 100$\mu\mu$f is 2,230 ohms at 712 kc, their resonant frequency.

Chart 2 is used to obtain additional precision if reading but does not place the decimal point which must be located from a preliminary entry on Chart 1. Since the chart necessarily requires two logarithmic decades for inductance and capacitance for every single decade of frequency and reactance unless the correct decade for L and C is chosen, the calculated values of reactance and frequency will be in error by a factor of 3.16.

SCHEMATIC SYMBOLS



SCHEMATIC SYMBOLS (continued)

	switch s.p.d.t.		loudsp'kr. p.m. dynamic		crystal detector
	switch d.p.s.t.		electrodynamic		crystal
	switch d.p.d.t.		phono. pick-up		lightn'g arrester
	switch rotary		filament		fuse
	buzzer		cathode		pilot light
	key		cold cathode		twisted pair
	jack		grid		coaxial cable
	plug		plate		shielded wire
	mirophone		3 element vacuum tube		Faraday shield
	head-phones				terminals
	head-phone single		octal base aligning key		meter
	loud-speaker magnetic		neon tube		motor

THE INTERNATIONAL MORSE CODE

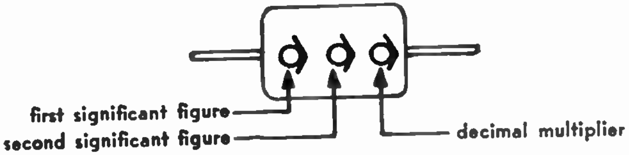
A	• —
B	— • • •
C	— • — •
D	— • •
E	•
F	• • — •
G	— — •
H	• • • •
I	• •
J	• — — —
K	— • —
L	• — • •
M	— —
N	— •
O	— — —
P	• — — •
Q	— — • —
R	• — •
S	• • •
T	—
U	• • —
V	• • • —
W	• — —
X	— • • —
Y	— • — —
Z	— — • •

1	• — — — —
2	• • — — —
3	• • • — —
4	• • • • —
5	• • • • •
6	— • • • •
7	— — • • •
8	— — — • •
9	— — — — •
0	— — — — —

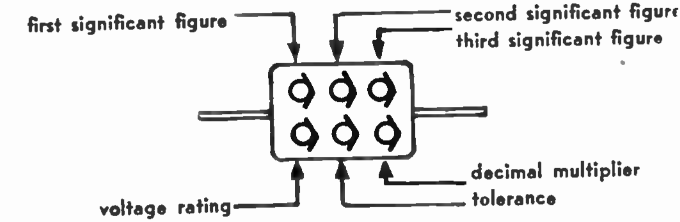
Period	• — • — • —
Comma	— — • • — —
Question mark	• • — — • •
Error	• • • • • • • •
Double Dash	— • • • —
Wait	• — • • •
End of message	• — • — •
Invitation to transmit	— • —
End of work	• • • — • —

CAPACITOR COLOR CODE

Color	Significant Figure	Decimal Multiplier	Tolerance	Voltage Rating
Black	0	1		
Brown	1	10	1%	100 volts
Red	2	100	2%	200 volts
Orange	3	1,000	3%	300 volts
Yellow	4	10,000	4%	400 volts
Green	5	100,000	5%	500 volts
Blue	6	1,000,000	6%	600 volts
Violet	7	10,000,000	7%	700 volts
Gray	8	100,000,000	8%	800 volts
White	9	1,000,000,000	9%	900 volts
Gold		0.1	5%	1000 volts
Silver		0.01	10%	2000 volts
No Color			20%	500 volts



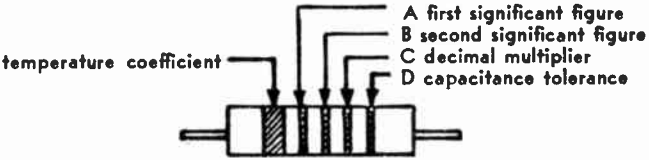
RMA 3-dot **500-volt, ± 20% tolerance only**



RMA 6-dot

CERAMIC CAPACITOR COLOR CODE

Color	Significant Figure	Multiplier	Tolerance For Capacitance of More Than 10 μμf	Tolerance For Capacitance of 10 μμf or Less	Temperature Coefficient Parts/Million/°C
Black	0	1	±20	±2.0μμf	0
Brown	1	10	± 1	±0.1μμf	—30
Red	2	100	± 2		—80
Orange	3	1,000		μμf	—150
Yellow	4				—220
Green	5		± 5	±0.5μμf	—330
Blue	6				—470
Violet	7				—750
Gray	8	0.01		±0.25μμf	+ 30
White	9	0.1	±10	±1.0μμf	—330 ±500

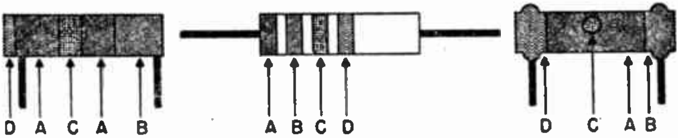


Wide Band	Narrow Bands or Dots A	B	C	D	Description
Black	Black	Red	Black	Black	2.0μμf ± 2μμf, zero temp. coeff.
Blue	Red	Red	Black	Green	22μμf ± 5%, —470 ppm/°C. temp. coeff.
Violet	Gray	Red	Brown	Silver	820μμf ± 10%, —750 ppm/°C. temp. coeff.

RESISTOR COLOR CODE

Color	Significant Figure	Decimal Multiplier	Tolerance
Black	0	1	
Brown	1	10	
Red	2	100	
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	
Blue	6	1,000,000	
Violet	7	10,000,000	
Gray	8	100,000,000	
White	9	1,000,000,000	
Gold		0.1	± 5
Silver		0.01	±10
No color			±20

The exterior body color of insulated axial-lead composition resistors is usually tan, but other colors, except black, are used. Non-insulated axial-lead composition resistors have a black body color. Radial-lead composition resistors may have a body color representing the first significant figure of the resistance value.



Axial Leads	Radial Leads	Color
Band A	Body A	Indicates first significant figure of resistance value in ohms.
Band B	End B	Indicates second significant figure.
Band C	Band C or dot	Indicates decimal multiplier.
Band D	Band D	Indicates tolerance in percent about nominal resistance value. No color is 20% tolerance.

RESISTOR VALUES

Preferred values of resistance (ohms) ±20% D = no col	±10% D = silver	±5% D = gold	Resistance designation A	B	C
			Green	Black	Black
		51	Green	Brown	Black
	56	56	Green	Blue	Black
		62	Blue	Red	Black
68	68	68	Blue	Gray	Black
		75	Violet	Green	Black
	82	82	Gray	Red	Black
		91	White	Brown	Black
100	100	100	Brown	Black	Brown
		110	Brown	Brown	Brown
	120	120	Brown	Red	Brown
		130	Brown	Orange	Brown
150	150	150	Brown	Green	Brown
		160	Brown	Blue	Brown
	180	180	Brown	Gray	Brown
		200	Red	Black	Brown
220	220	220	Red	Red	Brown
		240	Red	Yellow	Brown
			Red	Green	Brown
	270	270	Red	Violet	Brown
		300	Orange	Black	Brown
330	330	330	Orange	Orange	Brown
			Orange	Green	Brown
		360	Orange	Blue	Brown
	390	390	Orange	White	Brown
			Yellow	Black	Brown
		430	Yellow	Orange	Brown
			Yellow	Green	Brown
470	470	470	Yellow	Violet	Brown
			Green	Black	Brown
		510	Green	Brown	Brown
	560	560	Green	Blue	Brown
			Blue	Black	Brown
		620	Blue	Red	Brown
680	680	680	Blue	Gray	Brown
		750	Violet	Green	Brown
	820	820	Gray	Red	Brown
		910	White	Brown	Brown

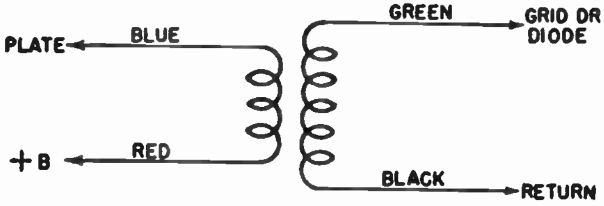
Preferred values of resistance (ohms) ±20% D = no col	±10% D = silver	±5% D = gold	Resistance designation A	B	C
1,000	1,000	1,000	Brown	Black	Red
		1,100	Brown	Brown	Red
	1,200	1,200	Brown	Red	Red
		1,300	Brown	Orange	Red
1,500	1,500	1,500	Brown	Green	Red
		1,600	Brown	Blue	Red
	1,800	1,800	Brown	Gray	Red
		2,000	Red	Black	Red
2,200	2,200	2,200	Red	Red	Red
		2,400	Red	Yellow	Red
			Red	Green	Red
	2,700	2,700	Red	Violet	Red
		3,000	Orange	Black	Red
3,300	3,300	3,300	Orange	Orange	Red
			Orange	Green	Red
		3,600	Orange	Blue	Red
	3,900	3,900	Orange	White	Red
			Yellow	Black	Red
		4,300	Yellow	Orange	Red
4,700	4,700	4,700	Yellow	Violet	Red
			Green	Black	Red
		5,100	Green	Brown	Red
	5,600	5,600	Green	Blue	Red
		6,200	Blue	Red	Red
6,800	6,800	6,800	Blue	Gray	Red
		7,500	Violet	Green	Red
	8,200	8,200	Gray	Red	Red
		9,100	White	Brown	Red
10,000	10,000	10,000	Brown	Black	Orange
		11,000	Brown	Brown	Orange
	12,000	12,000	Brown	Red	Orange
		13,000	Brown	Orange	Orange
15,000	15,000	15,000	Brown	Green	Orange
		16,000	Brown	Blue	Orange
	18,000	18,000	Brown	Gray	Orange
		20,000	Red	Black	Orange
22,000	22,000	22,000	Red	Red	Orange
		24,000	Red	Yellow	Orange

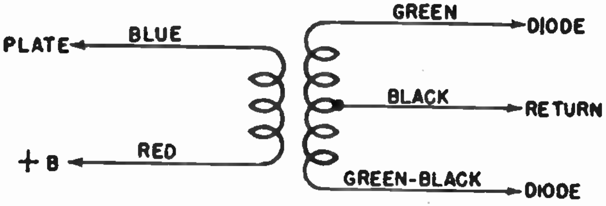
RESISTOR VALUES

Preferred values of resistance (ohms)			Resistance designation		
±20% D = no col	±10% D = silver	±5% D = gold	A	B	C
			Red	Green	Orange
	27,000	27,000	Red	Violet	Orange
		30,000	Orange	Black	Orange
33,000	33,000	33,000	Orange	Orange	Orange
		36,000	Orange	Blue	Orange
	39,000	39,000	Orange	White	Orange
			Yellow	Black	Orange
		43,000	Yellow	Orange	Orange
47,000	47,000	47,000	Yellow	Violet	Orange
			Green	Black	Orange
		51,000	Green	Brown	Orange
	56,000	56,000	Green	Blue	Orange
			Blue	Black	Orange
		62,000	Blue	Red	Orange
68,000	68,000	68,000	Blue	Gray	Orange
		75,000	Violet	Green	Orange
	82,000	82,000	Gray	Red	Orange
		91,000	White	Brown	Orange
100,000	100,000	100,000	Brown	Black	Yellow
		110,000	Brown	Brown	Yellow
	120,000	120,000	Brown	Red	Yellow
		130,000	Brown	Orange	Yellow
150,000	150,000	150,000	Brown	Green	Yellow
		160,000	Brown	Blue	Yellow
	180,000	180,000	Brown	Gray	Yellow
		200,000	Red	Black	Yellow
220,000	220.000	220,000	Red	Red	Yellow
		240,000	Red	Yellow	Yellow
			Red	Green	Yellow
	270,000	270,000	Red	Violet	Yellow
		300,000	Orange	Black	Yellow
330,000	330,000	330,000	Orange	Orange	Yellow
		360,000	Orange	Blue	Yellow
	390,000	390,000	Orange	White	Yellow
			Yellow	Black	Yellow
		430,000	Yellow	Orange	Yellow
470,000	470,000	470,000	Yellow	Violet	Yellow
			Green	Black	Yellow

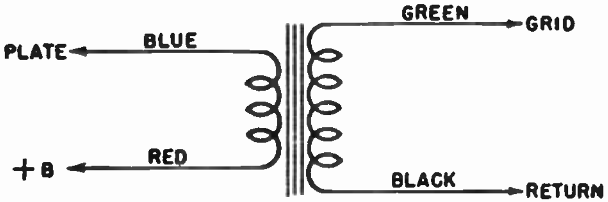
Preferred values of resistance (ohms)			Resistance designation		
±20% D = no col	±10% D = silver	±5% D = gold	A	B	C
		510,000	Green	Brown	Yellow
	560,000	560,000	Green	Blue	Yellow
			Blue	Black	Yellow
		620,000	Blue	Red	Yellow
680,000	680,000	680,000	Blue	Gray	Yellow
		750,000	Violet	Green	Yellow
	820,000	820,000	Gray	Red	Yellow
		910,000	White	Brown	Yellow
1.0 Meg	1.0 Meg	1.0 Meg	Brown	Black	Green
		1.1 Meg	Brown	Brown	Green
	1.2 Meg	1.2 Meg	Brown	Red	Green
		1.3 Meg	Brown	Orange	Green
1.5 Meg	1.5 Meg	1.5 Meg	Brown	Green	Green
		1.6 Meg	Brown	Blue	Green
	1.8 Meg	1.8 Meg	Brown	Gray	Green
		2.0 Meg	Red	Black	Green
2.2 Meg	2.2 Meg	2.2 Meg	Red	Red	Green
		2.4 Meg	Red	Yellow	Green
	2.7 Meg	2.7 Meg	Red	Violet	Green
		3.0 Meg	Orange	Black	Green
3.3 Meg	3.3 Meg	3.3 Meg	Orange	Orange	Green
		3.6 Meg	Orange	Blue	Green
	3.9 Meg	3.9 Meg	Orange	White	Green
			Yellow	Black	Green
		4.3 Meg	Yellow	Orange	Green
4.7 Meg	4.7 Meg	4.7 Meg	Yellow	Violet	Green
			Green	Black	Green
		5.1 Meg	Green	Brown	Green
	5.6 Meg	5.6 Meg	Green	Blue	Green
			Blue	Black	Green
		6.2 Meg	Blue	Red	Green
6.8 Meg	6.8 Meg	6.8 Meg	Blue	Gray	Green
			Violet	Black	Green
		7.5 Meg	Violet	Green	Green
			Gray	Black	Green
	8.2 Meg	8.2 Meg	Gray	Red	Green
			White	Black	Green
		9.1 Meg	White	Brown	Green
10 Meg	10 Meg	10 Meg	Brown	Black	Blue

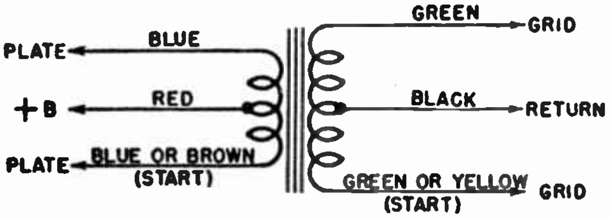
INTERMEDIATE FREQUENCY TRANSFORMER COLOR CODE



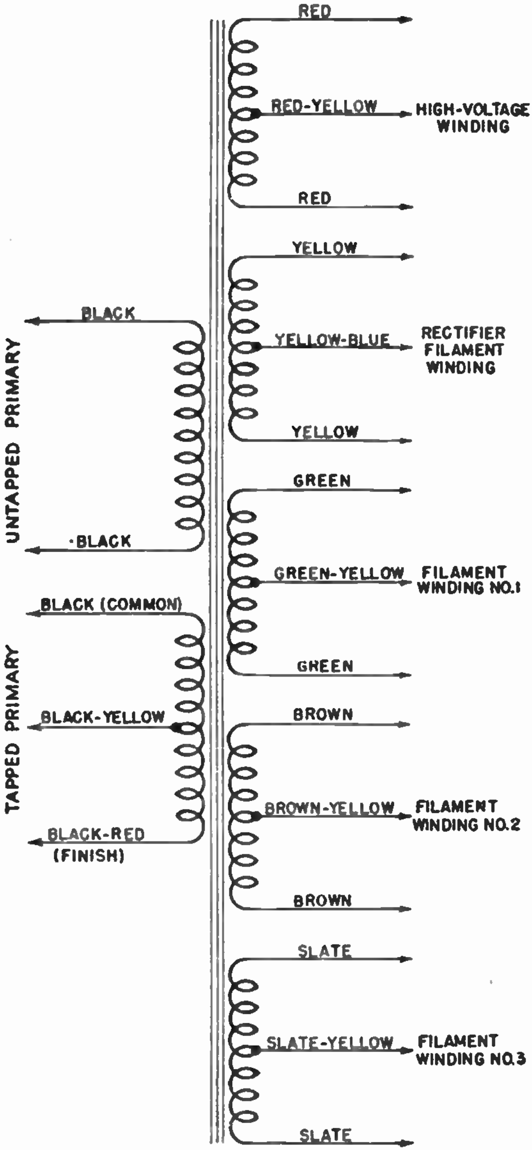


AUDIO TRANSFORMER COLOR CODE

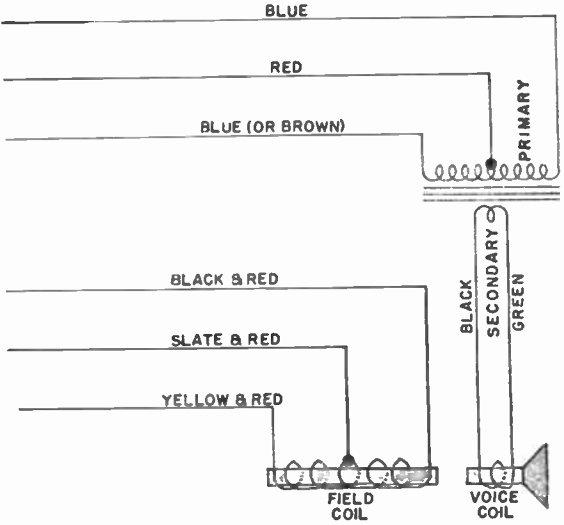


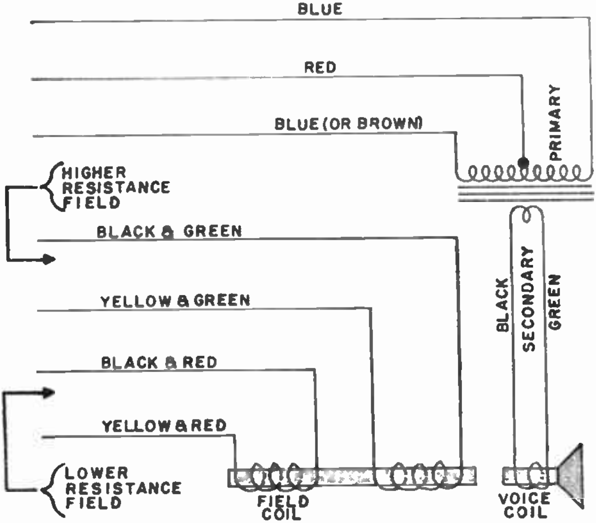


POWER TRANSFORMER COLOR CODE

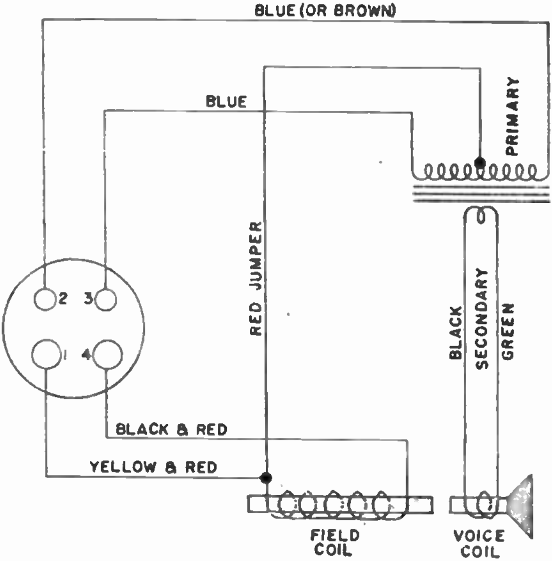


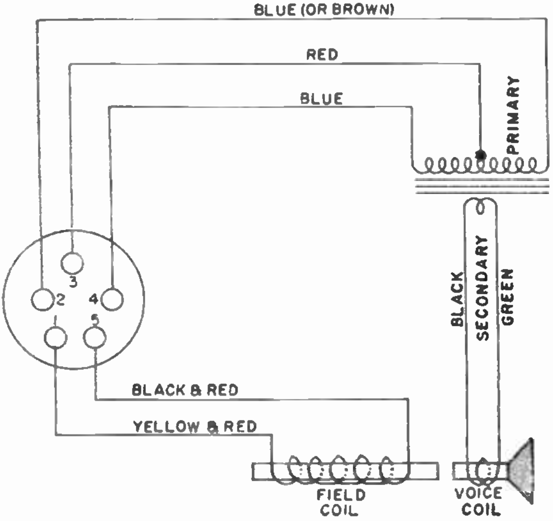
SPEAKER LEAD COLOR CODE





SPEAKER LEAD AND PLUG COLOR CODE





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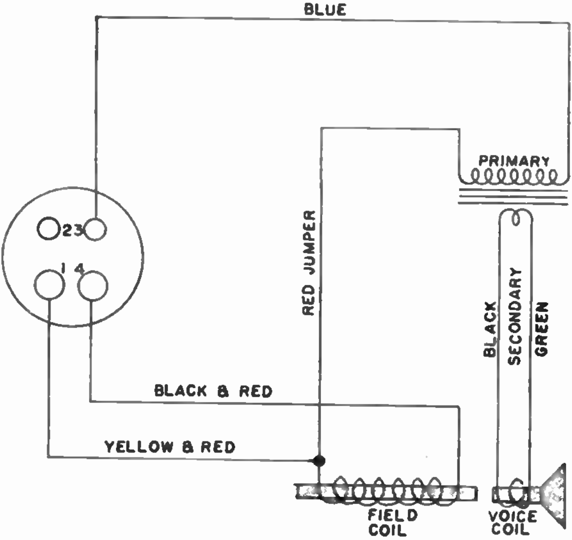
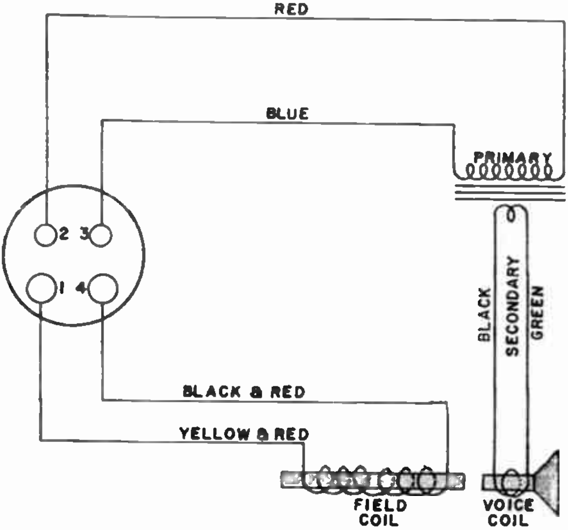
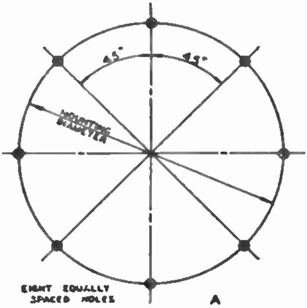


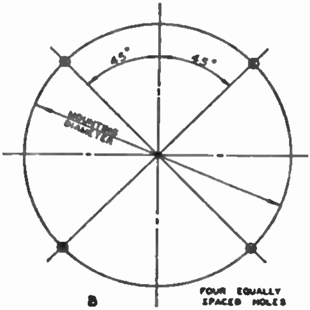


SPEAKER MOUNTING DIMENSIONS

Nominal Speaker Size	Hole Arrangement	Mounting Diameter	Minimum Hole Diameter
3-1/2"	B	3-15/16"	3/16"
4"	B	4-11/16"	.200"
5"	A	4-11/16"	.200"
5-3/4"	A	5-3/8"	.200"
6-1/2"	A	6-1/8"	.200"
8"	A	7-5/8"	7/32"
10"	B	9-5/8"	7/32"
12"	B	11-9/16"	1/4"
15"	A	14-9/16"	17/64"

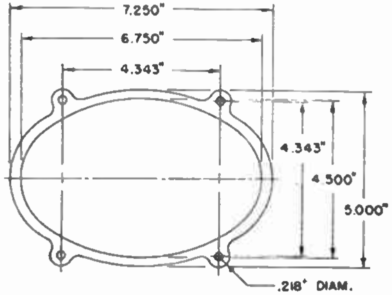


A

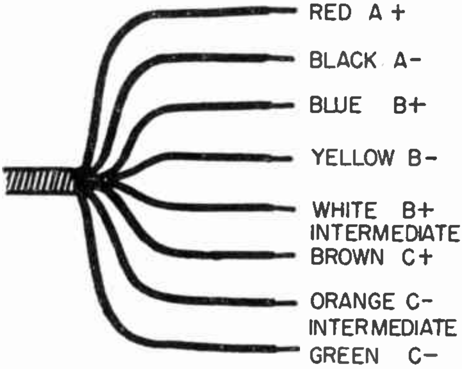


B

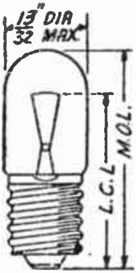
OVAL SPEAKER



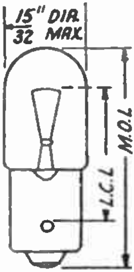
BATTERY CABLE COLOR CODE



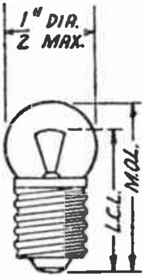
PILOT LAMPS



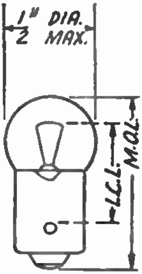
T3¼



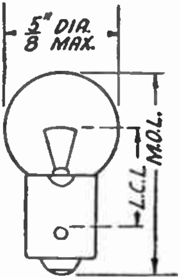
T3¼



G3½



G3½



G4½

PILOT LAMP DATA

Type No.	Volts	Amps.	Approx. Candle Power	Bulb	Base	Bead Color	Light Center Length	Max. Overall Length	Type No.
40	6-8	0.15	0.5	T-3-1/4	Min. Screw	Brown	29/32"	1-1/8"	40
40-A	6-8	0.15	0.5	T-3-1/4	Min. Bayonet	Brown	23/32"	1-1/8"	40-A
41	2.5	0.5	0.5	T-3-1/4	Min. Screw	White	29/32"	1-1/8"	41
42	3.2	†	—	T-3-1/4	Min. Screw	Green	29/32"	1-1/8"	42
43	2.5	0.5	0.5	T-3-1/4	Min. Bayonet	White	23/32"	1-1/8"	43
44	6-8	0.25	0.8	T-3-1/4	Min. Bayonet	Blue	23/32"	1-1/8"	44
45	3.2	0.5	0.75	T-3-1/4	Min. Bayonet	*	23/32"	1-1/8"	45
46	6-8	0.25	0.8	T-3-1/4	Min. Screw	Blue	29/32"	1-1/8"	46
47	SAME CHARACTERISTICS AS 40A, WITH WHICH IT IS INTERCHANGEABLE								47
48	2.0	0.06	0.03	T-3-1/4	Min. Screw	Pink	29/32"	1-1/8"	48
49	2.0	0.06	0.03	T-3-1/4	Min. Bayonet	Pink	23/32"	1-1/8"	49
49-A	2.1	0.12	0.07	T-3-1/4	Min. Bayonet	White	23/32"	1-1/8"	49-A
50	6-8	0.2	1.0	G-3-1/2	Min. Screw	White	23/32"	15/16"	50
51	6-8	0.2	1.0	G-3-1/2	Min. Bayonet	White	1/2"	15/16"	51
55	6-8	0.4	1.5	G-4-1/2	Min. Bayonet	White	1/2"	1-1/16"	55
292	2.9	0.17	0.3	T-3-1/4	Min. Screw	White	29/32"	1-1/8"	292
292-A	2.9	0.17	0.3	T-3-1/4	Min. Bayonet	White	23/32"	1-1/8"	292-A
1455	18.0	0.25	—	G-5	Min. Screw	Brown	—	—	1455
1455-A	18.0	0.25	—	G-5	Min. Bayonet	Brown	—	—	1455-A

† 0.35 in G.E. and Sylvania; 0.5 in National Union Raytheon and Tung-Sol.

* In G.E. and Sylvania, White; In National Union Raytheon and Tung-Sol, Green.

MACHINE SCREWS

Screw Size and Threads	Outside Diameter	Clearance Drill		Tap Drill	
		Number	Diameter	Number	Diameter
2-56	.086	42	.093	48	.076
3-48	.099	37	.104	44	.086
4-40	.112	31	.120	40	.098
5-40	.125	29	.136	36	.106
6-32	.138	27	.144	33	.113
8-32	.164	18	.169	28	.140
10-32	.190	9	.196	20	.161
12-24	.216	1	.228	15	.180
1/4-20	.250		17/64	6	.204

NUMBERED DRILL SIZES

No. of Drill	Diam. in Inches	No. of Drill	Diam. in Inches
1	0.2280	25	0.1495
2	0.2210	26	0.1470
3	0.2130	27	0.1440
4	0.2090	28	0.1405
5	0.2055	29	0.1360
6	0.2040	30	0.1285
7	0.2010	31	0.1200
8	0.1990	32	0.1160
9	0.1960	33	0.1130
10	0.1935	34	0.1110
11	0.1910	35	0.1100
12	0.1890	36	0.1065
13	0.1850	37	0.1040
14	0.1820	38	0.1015
15	0.1800	39	0.0995
16	0.1770	40	0.0980
17	0.1730	41	0.0960
18	0.1695	42	0.0935
19	0.1660	43	0.0890
20	0.1610	44	0.0860
21	0.1590	45	0.0820
22	0.1570	46	0.0810
23	0.1540	47	0.0785
24	0.1520	48	0.0760

LETTERED DRILL SIZES

Drill	Size	Diam. in.	Drill	Size	Diam. in.
A	15/64	0.234	N	.....	0.302
B	.....	0.238	O	5/16	0.316
C	.....	0.242	P	21/64	0.323
D	.....	0.246	Q	.....	0.332
E	1/4	0.250	R	11/32	0.339
F	.....	0.257	S	.....	0.348
G	.....	0.261	T	23/64	0.358
H	17/64	0.266	U	.....	0.368
I	.....	0.272	V	3/8	0.377
J	.....	0.277	W	25/64	0.386
K	9/32	0.281	X	.....	0.397
L	.....	0.290	Y	13/32	0.404
M	19/64	0.295	Z	.....	0.413

STANDARD STRANDED COPPER WIRE

American Wire Gauge

Circular mils	Size AWG	Number of wires	Individual wire diam inches	Cable diam inches	Area square inches	Weight lbs per 1000 ft.	*Maximum resistance ohms per 1000 ft. at 20° C.
211,600	4/0	19	.1055	.528	0.1662	653.3	0.05093
167,800	3/0	19	.0940	.470	0.1318	518.1	0.06422
133,100	2/0	19	.0837	.419	0.1045	410.9	0.08097
105,500	1/0	19	.0745	.373	0.08286	325.7	0.1022
83,690	1	19	.0664	.332	0.06573	258.4	0.1288
66,370	2	7	.0974	.292	0.05213	204.9	0.1624
52,640	3	7	.0867	.260	0.04134	162.5	0.2048
41,740	4	7	.0772	.232	0.03278	128.9	0.2582
33,100	5	7	.0688	.206	0.02600	102.2	0.3256
26,250	6	7	.0612	.184	0.02062	81.05	0.4105
20,820	7	7	.0545	.164	0.01635	64.28	0.5176
16,510	8	7	.0486	.146	0.01297	50.98	0.6528
13,090	9	7	.0432	.130	0.01028	40.42	0.8233
10,380	10	7	.0385	.116	0.008152	32.05	1.038
6,350	12	7	.0305	.0915	0.005129	20.16	1.650
4,107	14	7	.0242	.0726	0.003226	12.68	2.624
2,583	16	7	.0192	.0576	0.002029	7.975	4.172
1,624	18	7	.0152	.0456	0.001275	5.014	6.636
1,022	20	7	.0121	.0363	0.008027	3.155	10.54

WIRE TABLE
STANDARD ANNEALED COPPER
American Wire Gauge (B&S)

Gauge no.	Diameter, mils	Cross section		Ohms per 1000 ft at 20° C (68° F)	Lb per 1000 ft	Ft per lb	Ft per ohm at 20° C (68° F)
		circular mils	square inches				
0000	460.0	211,600	0.1662	0.04901	640.5	1.561	20,400
000	409.6	167,800	0.1318	0.06180	507.9	1.968	16,180
00	364.8	133,100	0.1045	0.07793	402.8	2.482	12,830
0	324.9	105,500	0.08289	0.09827	319.5	3.130	10,180
1	289.3	83,690	0.06573	0.1239	253.3	3.947	8,070
2	257.6	66,370	0.05213	0.1563	200.9	4.977	6,400
3	229.4	52,640	0.04134	0.1970	159.3	6.276	5,075
4	204.3	41,740	0.03278	0.2485	126.4	7.914	4,025
5	181.9	33,100	0.02600	0.3133	100.2	9.980	3,192
6	162.0	26,250	0.02062	0.3951	79.46	12.58	2,531
7	144.3	20,820	0.01635	0.4982	63.02	15.87	2,007
8	128.5	16,510	0.01297	0.6282	49.98	20.01	1,592
9	114.4	13,090	0.01028	0.7921	39.63	25.23	1,262
10	101.9	10,380	0.008155	0.9989	31.43	31.82	1,001
11	90.74	8,234	0.006467	1.260	24.92	40.12	794
12	80.81	6,530	0.005129	1.588	19.77	50.59	629.6
13	71.96	5,178	0.004067	2.003	15.68	63.80	499.3
14	64.08	4,107	0.003225	2.525	12.43	80.44	396.0
15	57.07	3,257	0.002558	3.184	9.858	101.4	314.0
16	50.82	2,583	0.002028	4.016	7.818	127.9	249.0
17	45.26	2,048	0.001609	5.064	6.200	161.3	197.5
18	40.30	1,624	0.001276	6.385	4.917	203.4	156.6
19	35.89	1,288	0.001012	8.051	3.899	256.5	124.2
20	31.96	1,022	0.0008023	10.15	3.092	323.4	98.50
21	28.46	810.1	0.0006363	12.80	2.452	407.8	78.11
22	25.35	642.4	0.0005046	16.14	1.945	514.2	61.95
23	22.57	509.5	0.0004002	20.36	1.542	648.4	49.13
24	20.10	404.0	0.0003173	25.67	1.223	817.7	38.96
25	17.90	320.4	0.0002517	32.37	0.9699	1,031.0	30.90
26	15.94	254.1	0.0001996	40.81	0.7692	1,300	24.50
27	14.20	201.5	0.0001583	51.47	0.6100	1,639	19.43
28	12.64	159.8	0.0001255	64.90	0.4837	2,067	15.41
29	11.26	126.7	0.00009953	81.83	0.3836	2,607	12.22
30	10.03	100.5	0.00007894	103.2	0.3042	3,287	9.691
31	8.928	79.70	0.00006260	130.1	0.2413	4,145	7.685
32	7.950	63.21	0.00004964	164.1	0.1913	5,227	6.095
33	7.080	50.13	0.00003937	206.9	0.1517	6,591	4.833
34	6.305	39.75	0.00003122	260.9	0.1203	8,310	3.833
35	5.615	31.52	0.00002476	329.0	0.09542	10,480	3.040
36	5.000	25.00	0.00001964	414.8	0.07568	13,210	2.411
37	4.453	19.83	0.00001557	523.1	0.06001	16,660	1.912
38	3.965	15.72	0.00001235	659.6	0.04759	21,010	1.516
39	3.531	12.47	0.000009793	831.8	0.03774	26,500	1.202
40	3.145	9.888	0.000007766	1,049.0	0.02993	33,410	0.9534

WIRE TABLE—SOLID COPPERWELD

Size AWG	Diam inch	Cross section area circular mils	Cross section area square inch	Weight Pounds per 1000 feet	Weight Feet per pound	Resistance ohms/1000 ft at 68° F. 40%	Resistance ohms/1000 ft at 68° F. 30%	Breaking load, pounds 40% conduct	Breaking load, pounds 30% conduct	Attenuation—db per mile* 40% cond dry	Attenuation—db per mile* 40% cond wet	Attenuation—db per mile* 30% cond dry	Attenuation—db per mile* 30% cond wet	Characteristic impedance* 40%	Characteristic impedance* 30%
4	.2043	41,740	.03278	115.8	8.63	0.6337	0.8447	3,541	3,934	—	—	—	—	—	—
5	.1819	33,100	.02600	91.86	10.89	0.7990	1.065	2,938	3,250	—	—	—	—	—	—
6	.1620	26,250	.02062	72.85	13.73	1.008	1.343	2,433	2,680	.078	.086	.103	.109	650	686
7	.1443	20,820	.01635	57.77	17.31	1.270	1.694	2,011	2,207	.093	.100	.122	.127	685	732
8	.1285	16,510	.01297	45.81	21.83	1.602	2.136	1,660	1,815	.111	.118	.144	.149	727	787
9	.1144	13.090	.01028	36.33	27.52	2.020	2.693	1,368	1,491	.132	.138	.169	.174	776	852
10	.1019	10,380	.008155	28.81	34.70	2.547	3.396	1,130	1,231	.156	.161	.196	.200	834	920
11	.0907	8,234	.006467	22.85	43.76	3.212	4.28	896	975	.183	.188	.228	.233	910	1,013
12	.0808	6,530	.005129	18.12	55.19	4.05	5.40	711	770	.216	.220	.262	.266	1,000	1,120
13	.0720	5,178	.004067	14.37	69.59	5.11	6.81	490	530						
14	.0641	4,107	.003225	11.40	87.75	6.44	8.59	400	440						
15	.0571	3,257	.002558	9.038	110.6	8.12	10.83	300	330						
16	.0508	2,583	.002028	7.167	139.5	10.24	13.65	250	270						
17	.0453	2,048	.001609	5.684	175.9	12.91	17.22	185	205						
18	.0403	1,624	.001276	4.507	221.9	16.28	21.71	153	170						
19	.0359	1,288	.001012	3.575	279.8	20.53	27.37	122	135						
20	.0320	1,022	.0008023	2.835	352.8	25.89	34.52	100	110						
21	.0285	810.1	.0006363	2.248	444.8	32.65	43.52	73.2	81.1						
22	.0253	642.5	.0005046	1.783	560.9	41.17	54.88	58.0	64.3						
23	.0226	509.5	.0004002	1.414	707.3	51.92	69.21	46.0	51.0						
24	.0201	404.0	.0003173	1.121	891.9	65.46	87.27	36.5	40.4						
25	.0179	320.4	.0002517	0.889	1.125	82.55	110.0	28.9	31.1						
26	.0159	254.1	.0001996	0.705	1,418	104.1	138.8	23.0	25.4						
27	.0142	201.5	.0001583	0.559	1,788	131.3	175.0	18.2	20.1						
28	.0126	159.8	.0001255	0.443	2,255	165.5	220.6	14.4	15.9						
29	.0113	126.7	.0000995	0.352	2,843	208.7	278.2	11.4	12.6						
30	.0100	100.5	.0000789	0.279	3,586	263.2	350.8	9.08	10.0						
31	.0089	79.70	.0000626	0.221	4,521	331.9	452.4	7.20	7.95						
32	.0080	63.21	.0000496	0.175	5,701	418.5	557.8	5.71	6.30						
33	.0071	50.13	.0000394	0.139	7,189	527.7	703.4	4.53	5.00						
34	.0063	39.75	.0000312	0.110	9,065	665.4	887.0	3.59	3.97						
35	.0056	31.52	.0000248	0.087	11,430	839.0	1,119	2.85	3.14						
36	.0050	25.00	.0000196	0.069	14,410	1,058	1,410	2.26	2.49						
37	.0045	19.83	.0000156	0.055	18,180	1,334	1,778	1.79	1.98						
38	.0040	15.72	.0000123	0.044	22,920	1,682	2,243	1.42	1.57						
39	.0035	12.47	.00000979	0.035	28,900	2,121	2,828	1.13	1.24						
40	.0031	9.89	.00000777	0.027	36,440	2,675	3,566	0.893	0.986						

RG TYPE COAXIAL CABLES

AN NUMBER	IMPEDANCE	DIELECTRIC	O. D. OF ARMOR	JACKET DIA.	JACKET MAT'L	SHIELDS 1ST	SHIELDS 2ND	O. D. OF DIELECTRIC	INNER CONDUCTOR MATL	V. P. %	CAP. IN MMFD.	MAX. OPER. VOLTS	ATTENUATION IN DB/100 FT. 100	300	1000	3000	USE
RG-5U	52.5	P		.332	BLACK V	C	C	.185	16	65.9	28.5	3000	2.6	4.7	9.5	18	MICROWAVE/SS
RG-5A/U	50	P		.328	GREY V	S	S	.181	16S	65.9	28.5	3000	2.4	4.4	8.8	17	MICROWAVE/SS
RG-6 U	76	P		.332	GREY V	S	C	.185	21CW	65.9	20	2700	2.8	5.3	11	21	VIDEO/SS
RG-7U	90-105	P		.370	BLACK V	C		.250	19	65.9	12.5	1000	2.0	3.8	7.8		LC/AS/MS
RG-8U	52	P		.405	BLACK V	C		.285	7/21	65.9	29.5	4000	2.1	4.2	9.0	18	GP/MS
RG-9U	51	P		.420	GREY V	S	C	.280	7/21S	65.9	30	4000	2.0	4.0	8.5	17	LL/MS
RG-9A/U	51	P		.420	GREY V	S	S	.280	7/21S	65.9	30	4000	2.3	4.2	8.6	18	LL/MS/SP
RG-10U	52	P	.475	.405	GREY V	C		.285	7/21	65.9	29.5	4000	2.1	4.2	9.0	18	GP/MS/A
RG-11U	75	P		.405	BLACK V	C		.285	7/26T	65.9	20.5	4000	2.1	3.8	7.8	16	GP/FLEX/MS
RG-12U	75	P	.475	.405	GREY V	C		.285	7/26T	65.9	20.5	4000	2.1	3.8	7.8	16	GP/FLEX/MS/A
RG-13U	74	P		.420	BLACK V	C	C	.280	7/26T	65.9	20.5	4000	2.1	3.8	7.8	16	I. F. CABLE
RG-14U	52	P		.545	GREY V	C	C	.370	10	65.9	29.5	5500	1.4	2.8	6.3	13	GP/PTC/MS
RG-15U	76	P		.545	BLACK V	C	C	.370	15CW	65.9	20	5000	1.5	2.9	6.5	15	VIDEO/MS
RG-16U	52	P		.630	VINYL	C		.460	.125CT	65.9	29.5	6000					PTC
RG-17U	52	P		.870	GREY V	C		.680	.188	65.9	29.5	11000	.85	1.8	4.2	10	GP/LS
RG-18U	52	P	.945	.870	GREY V	C		.680	.188	65.9	29.5	11000	.85	1.8	4.2	10	GP/LS/A
RG-19U	52	P		1.120	GREY V	C		.910	.250	65.9	29.5	14000	.69	1.5	3.5	7.7	GP/VERY/LS
RG-20U	52	P	1.195	1.120	GREY V	C		.910	.250	65.9	29.5	14000	.69	1.5	3.5	7.7	GP/VERY/LS/A
RG-21U	53	P		.332	GREY V	S	S	.185	16N	65.9	29	2700	14	25	46	82	AC
RG-22U	95	P		.405	BLACK V	T		.285	TWO7/.0152C	65.9	16	1000	3.6	7.0			TC/SS
RG-22A/U	95	P		.420	GREY V	T	T	.285	TWC7/.0152C	65.9	16	1000	4.0	7.0			BTC
RG-23U	125	P		.650x945	VINYL	C	C	.380	TWO7/21C		12	3000	1.7	3.5			
RG-25A/U	48	E		.505	S. R.	T	T	.288	19/.0117 T		50	8000					PC/MS
RG-26A/U	48	E		.505	S. R.	T		.288	19/.0117 T		50	8000					PC/MS/A
RG-27U	48	D	.675		VINYL	T		.455	19/.0185 T		50	15000					PC/LS/A
RG-28U	48	D		.805	S. R.	T	ST	.455	19/.0185 T		50	15000					PC/LS

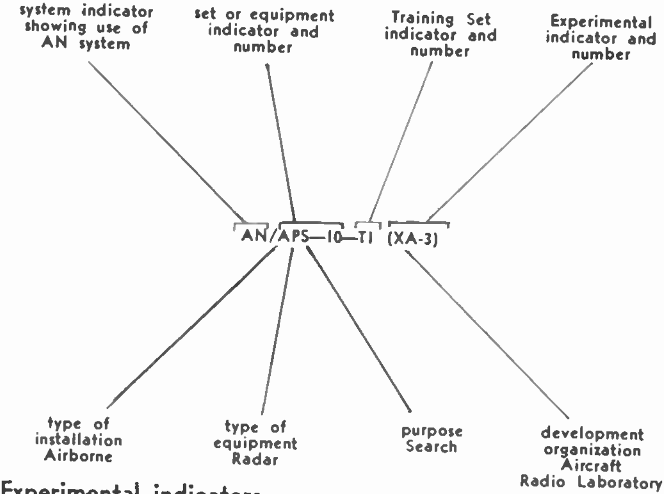
RG-29U	53.5	P		.184	POLY	T		.116	20	65.9	28.5	1900	4.2	7.9	16	32	GP/SS
RG-34U	71	P		.625	BLACK V	C		.455	7/21	65.9	21.5	5200	1.8	3.5			GP/FLEX/MS
RG-35U	71	P	.945	.870	GREY V	C		.680	9	65.9	21.5	10000	.70	1.8	4.2	9.2	VIDEO/LS
RG-38U	52.5	C•		.312	POLY	T	T	.196	17T		38	1000					HIGH LOSS/FLEX
RG-39U	72.5	C•		.312	POLY	T	T	.196	22T CW		28	1000					VIDEO/HIGH LOSS
RG-40U	72.5	C•		.420	S. R.	T	T	.196	22T CW		28	1000					VIDEO/HIGH LOSS
RG-41U	67.5	C•		.425	NEOPRENE	T		.250	16/30 .C		27	3000					
RG-42U	78	P		.342	GREY V	S	S	.196	21N	65.9	20	2700	17	29	54	95	AC
RG-54A/U	58	P		.250	POLY	T		.178	7/.0152	65.9	26.5	3000	3.1	5.7			FLEX/SS
RG-55U	53.5	P		.206	POLY	T	T	.116	20	65.9	28.5	1900	4.2	7.9	16	32	FLEX/SS
RG-57U	95	P		.625	BLACK V	T		.472	TWC 7/21	65.9	17	3000	3.0	5.9			TC/LS
RG-58U	53.5	P		.195	BLACK V	T		.116	20	65.9	28.5	1900	4.2	7.9	16	32	GP/SS
RG-58A/U	50	P		.195	BLACK V	T		.116	19/.0068	65.9	29	1900	5.3	9.6	22	45	HIGH FLEX/SS
RG-59U	73	P		.242	BLACK V	C		.146	22 CW	65.9	21	2300	3.8	7.0	14	29	GP/VIDEO/SS
RG-62U	93	P		.242	BLACK V	C		.146SSD	22 CW	84	13.5	750	3.1	5.5	10	18	LC/AS/SS
RG-63U	125	P		.405	BLACK V	C		.285SSD	22 CW	84	10	1000	2.0	3.6	7.0	12	LC/AS/MS
RG-64A/U	48	E		.475	S. R.	T	T	.288	19/.0117T		50	8000					PC/MS
RG-65U	950	P		.405	VINYL	C		.285	.32FFH × .128		44	1000					HI-IMP./VIDEO
RG-71U	93	P		.250	POLY	T	[illegible]	.146SSD	22 CW	84	13.5	750	3.1	5.5	10	18	LC/AS/SS
RG-74U	52	P	.615	.545	GREY V	C	C	.370	10	65.9	20.5	5500	1.4	2.8	6.2	13	GP/PTC/MS/A
RG-79U	125	P	.475	.405	BLACK V	C		.285SSD	22 CW	84	10	1000	2.0	3.6	7.0	12	
RG-83U	35	P		.405	BLACK V	C		.240	10	65.9	44	2000	3.0	4.5		25	
RG-87U	50	P		.425	FSI	S	S	.280TD	7/20S	69.5	29.5	4000	2.0	3.8	7.6	15	
RG-89U	125	P		.332	BLACK V	C		.285SSD	22 CW	84	10	1000	2.0	3.6	7.0	12	
RG-108U	76	P		.230	BLACK V	T		.073EAC	TWO-7/28								
RG-111U	95	P	.490	.420	GREY V	T	I	.285	TWO7/.0152	65.9	16	1000	4.0	7.0			

CHART ABBREVIATIONS

A	ARMORED
AC	ATTENUATING CABLE WITH SMALL TEMPERATURE COEFFICIENT OF ATTENUATION
AN	ARMY-NAVY
AS	AIR SPACED
BTC	BALANCED TWIN COAX
C	COPPER
C•	SYNTHETIC RUBBER
CAP	CAPACITY
CW	COPPERWELD
D	RUBBER LAYERS (SYN AND COND)
DB	DECIBELS
E	RUBBER LAYERS (COND., SYN AND RED)
FFH	FORMEX F HELIX
FSI	FIBERGLASS SILICONE IMPREGNATED
GP	GENERAL PURPOSE
IF	INTERMEDIATE FREQUENCY
IMP	IMPEDANCE
LC	LOW CAPACITY
LL	LOW LEVEL CIRCUIT CABLE
LS	LARGE SIZE
MMFD	MICRO-MICRO FARADS
MS	MEDIUM SIZE
N	NICHROME
O. D.	OUTSIDE DIAMETER
P	POLYETHYLENE
PC	PULSE CABLE
PTC	POWER TRANSMISSION CABLE
S	SILVERED COPPER
SP	SPECIAL
SS	SMALL
SSD	SEMI-SOLID DIELECTRIC
S. R.	SYNTHETIC RUBBER
ST	GALVANIZED STEEL
STC	SPECIAL TWIST CABLE
T	TINNED COPPER
TC	TWIN CONDUCTOR
TD	TEFLON DIELECTRIC
V	VINYL

RG TYPE COAXIAL CABLES

In the Joint Army-Navy nomenclature system the name of an equipment is followed by a type number. A sample type number is shown below. The first two letters indicate that the Joint Army-Navy or A N system is used. The letters following the bar indicate the type of installation, equipment and purpose as shown in the chart which follows the example. The meanings of the balance of the numbers and letters is indicated on the example.



Experimental indicators

Below are listed the development organizations and the indicators assigned to them.

XA	Aircraft Radio Laboratory, Wright Field, Dayton, Ohio
XB	Naval Research Laboratory, Anacostia Station, Belleville, D. C.
XC	Coles Signal Laboratory, Red Bank, New Jersey
XE	Evans Signal Laboratory, Belmar, New Jersey
XG	USN Electronic Laboratory, San Diego, California
XM	Squier Signal Laboratory, Fort Monmouth, New Jersey
XN	Navy Department, Washington, D. C.
XU	USN Underwater Sound Laboratory, Fort Trumbull, New London, Connecticut
XW	Watson Laboratories, Red Bank, New Jersey

JAN NOMENCLATURE SYSTEM

Set or equipment indicator letters

type of installation	type of equipment	purpose
A Airborne	A Invisible light, heat radiation	A Auxiliary assemblies (not complete operating sets)
B Underwater mobile, submarine	B Pigeon	B Bombing
C Air transportable (inactivated, do not use)	C Carrier (wire)	C Communications
D Pilotless carrier		D Direction finder
F Ground, fixed	F Photographic	
G Ground, general ground use (includes two or more ground installations)	G Telegraph or teletype (wire)	G Gun directing
		H Recording (photographic, meteorological, and sound)
	I Interphone and public address	
K Amphibious	K Telemetering	
		L Searchlight control
M Ground, mobile in a vehicle which has no function other than transporting the equipment	M Meteorological	M Maintenance and test assemblies
	N Sound in air	N Navigational aids
P Ground, pack, or portable	P Radar	P Reproducing (photographic and sound)
	Q Underwater sound	Q Special, or combination of types
	R Radio	R Receiving
S Shipboard	S Special types, magnetic, etc., or combinations of types	S Search
T Ground, transportable	T Telephone (wire)	T Transmitting
U General utility (includes two or more general classes)		
V Ground, vehicular, installed in vehicle designed for other functions, i. e., tanks	V Visual and visible light	
W Underwater, fixed		W Remote control
	X Facsimile or television	X Identification and recognition

Table of component indicators

indicator	family name
AB	Supports, Antenna
AM	Amplifiers
AS	Antenna Assemblies
AT	Antennas
BA	Battery, primary type
BB	Battery, secondary type
BZ	Signal Devices, Audible
C	Control Articles
CA	Commutator Assemblies, Sonar
CB	Capacitor Bank
CG	Cables and Trans. Line, R.F.
CK	Crystal Kits
CM	Comparators
CN	Compensators
CP	Computers
CR	Crystals
CU	Coupling Devices
CV	Converters (electronic)
CW	Covers
CX	Cords
CY	Cases
DA	Antenna, Dummy
DT	Detecting Heads
DY	Dynamotors
E	Hoist Assembly
F	Filters
FN	Furniture
FR	Frequency Measuring Devices
G	Generators
GO	Goniometers
GP	Ground Rods
H	Head, Hand, and Chest Sets
HC	Crystal Holder
HD	Air Conditioning Apparatus
ID	Indicating Devices
IL	Insulators
IM	Intensity Measuring Devices
IP	Indicators, Cathode-Ray Tube
J	Junction Devices
KY	Keying Devices
LC	Tools, Line Construction
LS	Loudspeakers
M	Microphones
MD	Modulators
ME	Meters, Portable
MK	Maintenance Kits or Equipments
ML	Meteorological Devices
MT	Mountings
MX	Miscellaneous
O	Oscillators
OA	Operating Assemblies
OS	Oscilloscope, Test
PD	Prime Drivers
PF	Fittings, Pole
PH	Photographic Articles
PP	Power Supplies
PT	Plotting Equipments
PU	Power Equipments
R	Radio and Radar Receivers
RD	Recorders and Reproducers
RE	Relay Assemblies
RF	Radio Frequency Component
RG	Cables and Trans. Lines, Bulk R.F.
RL	Reel Assemblies
RP	Rope and Twine
RR	Reflectors
RT	Receiver and Transmitter
S	Shelters
SA	Switching Devices
SB	Switchboards
SG	Generators, Signal
SM	Simulators
SN	Synchronizers
ST	Straps
T	Radio and Radar Transmitters
TA	Telephone Apparatus
TD	Timing Devices
TF	Transformers
TG	Positioning Devices
TH	Telegraph Apparatus
TK	Tool Kits or Equipments
TL	Tools
TN	Tuning Units
TS	Test Equipment
TT	Teletype and Facsimile Apparatus
TV	Tester, Tube
U	Connectors, Audio and Power
UG	Connectors, R.F.
V	Vehicles
VS	Signaling Equipment, Visual
WD	Cables, Two-Conductor
WF	Cables, Four-Conductor
WM	Cables, Multiple-Conductor
WS	Cables, Single-Conductor
WT	Cables, Three-Conductor
ZM	Impedance Measuring Devices

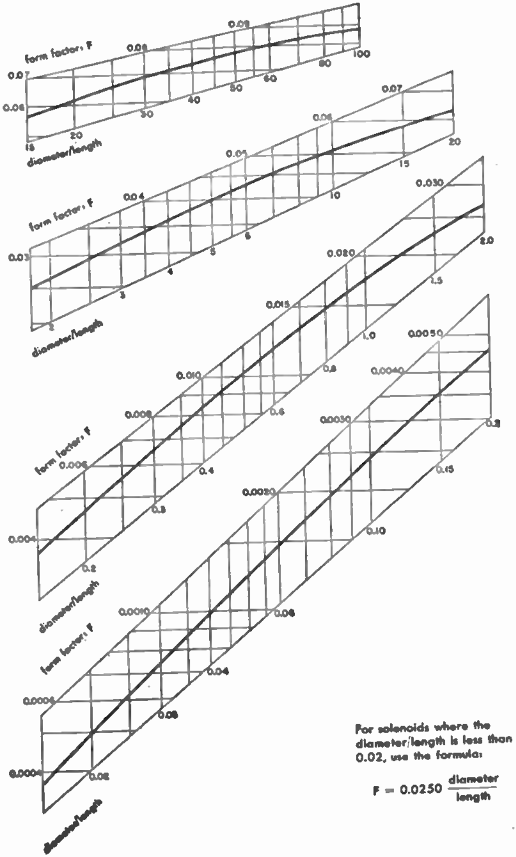
SINGLE-LAYER SOLONOIDS

The chart below may be used to closely approximate the inductance of a single-layer solonoid. First find the form factor (F) from the chart by dividing the diameter of the coil by its length and locating the result on one of the lines below the curves. The form factor (F) will be found along the line above the curve. The inductance may then be determined from the formula:

$L = Fn^2d$ where L = inductance in microhenries, F = form factor, n = number of turns, d = diameter of coil center to center of conductors.

The number of turns required for a coil of given inductance and dimensions may be determined from the formula:

$$n = \frac{L}{Fd}$$



For solenoids where the diameter/length is less than 0.02, use the formula:

$$F = 0.0250 \frac{\text{diameter}}{\text{length}}$$

Section 18

RECEIVING AND TRANSMITTING TUBE CHARTS AND PIN INDEX

GENERAL NOTES PERTAINING TO THIS SECTION

1. All tubes appearing in charts on even numbered pages have bases shown above chart.
2. All tubes appearing in charts on odd numbered pages have bases shown below chart—exception is rectifier tubes in vertical charts with all bases shown at top of page.
3. All tube base diagrams are bottom views, showing standard socket connections for that tube. Terminal designations are as follows:

KEY TO PIN INDEX

TERMINAL DESIGNATIONS

A = Anode
B = Beam
BP = Bayonet Pin
BS = Base sleeve
D = Deflecting Plate
F = Filament
G = Grid
H = Heater
IC = Internal Connection
IS = Internal Shield
K = Cathode
NC = No Connection

P = Plate (Anode)
P_1 = Starter-Anode
P_{BF} = Beam-Forming Plates
RC = Ray-Control Electrode
Ref = Reflector or repeller
S = Shell
TA = Target
• = Gas-Type Tube
U = Unit

4. Receiving Tube Charts include values for use under typical operating conditions.
5. Transmitting tubes are usually given tw osets of ratings by their manufacturers. In these charts "Intermittent Commercial and Amateur Service" (icas) ratings are given when available.
6. Numerical notations used in the charts have the following meanings:—

NUMERICAL NOTATIONS

1 Cathode resistor in Ohms
2 Values for two tubes in push-pull
3 With screen connected to plate
4 Value at maximum signal
5 Plate-to-plate value
6 Value for one plate
7 Value for triode number 1
8 Value for triode number 2
9 Peak AF volts grid-to-grid
10 Applied through a 20,000 ohm resistor
11 The values shown are for each section
12 Current to plate number 1
13 With grid number 2 and grid number 3 connected to the plate
14 With grid number 2 connected to the plate
15 With grid number 1 connected to grid number 2
16 Value of oscillator grid leak in ohms
17 Value of screen resistor in ohms
18 Plate current with no signal applied
19 Zero signal current for both sections
20 Applied through suitable resistor
21. Filament can also be operated from 1.4 volts supply
22 Designed to operate with a 6.3 volt pilot lamp connected between pins 6 and 7
23 The values shown are for both sections, in push-pull operation
24 Grid number 2 connected to the plate and grid number 3 connected to the cathode
25 Triode Section
26 Pentode Section
27 The values shown are for each unit—in push-pull operation
28 Filament designed for intermittent operation only
29. Choke input
30 Condenser input
31 Filament tapped to provide voltage source for pilot lamp
32 No panel lamp
33 With panel lamp
34 Value when one-half of filament is used
35 Two tubes with choke input
36 Transconductance in micro-mhos
37 Values given in micro-microfarads
38 From anode number 2 to deflecting plates
39 Maximum values given are in milliwatts per square centimeter
40 Values given are in d-c volts per inch
41 Values given are in millimeters per d-c volt
42 Values given are in d-c volts per inch
43 Maximum design center values

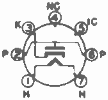
VT NUMBERS IDENTIFICATION LIST

VT NUMBERS	RMA NUMBERS
VT—4B	211
VT—4C	211 SPECIAL
VT—17	860
VT—19	861
VT—22	204A
VT—24	864
VT—25	10
VT—25A	10 SPECIAL
VT—26	22
VT—27	30
VT—28	24, 24A
VT—29	27
VT—30	01-A
VT—31	31
VT—33	33
VT—34	207
VT—35	35/51
VT—36	36
VT—37	37
VT—38	38
VT—39	869
VT—39A	869B
VT—40	40
VT—41	851
VT—42	872
VT—42A	872A SPEC. FIL
VT—43	845W
VT—44	32
VT—45	45
VT—46	866
VT—46A	866A
VT—47	47
VT—48	41
VT—49	39/44
VT—50	50
VT—51	841
VT—52	45 SPECIAL
VT—54	34
VT—55	865
VT—56	56
VT—57	57
VT—58	58
VT—60	850
VT—62	801, 801A
VT—63	46
VT—64	800
VT—65	6C5
VT—65A	6C5G
VT—66	6F6
VT—66A	6F6G
VT—67	30 SPECIAL
VT—68	6B7
VT—69	6D6
VT—70	6F7
VT—72	842
VT—73	843
VT—74	5Z4
VT—75	75
VT—76	76
VT—77	77
VT—78	78
VT—80	80
VT—83	83
VT—84	84/6Z4
VT—86	6K7
VT—86A	6K7G
VT—868	6K7GT
VT—87	6L7
VT—87A	6L7G
VT—88	6R7
VT—88A	6R7G
VT—888	6R7GT
VT—89	89
VT—90	6H6
VT—90A	6H6GT
VT—91	6J7
VT—91A	6J7GT
VT—92	6Q7
VT—93	6B8
VT—93A	6B8G
VT—94	6J5
VT—94A	6J5G
VT—94B	6J5 SPEC. SELEC.
VT—94C	6J5G SPEC. SEL.
VT—94D	6J5GT/G
VT—95	2A3
VT—96	6N7
VT—96B	6N7 SPEC. SEL.
VT—97	5W4
VT—98	6U5/6G5
VT—99	6F8G
VT—100	807
VT—100A	807 MODIFIED
VT—101	837
VT—103	6SQ7
VT—104	12SQ7
VT—105	6SC7
VT—106	803
VT—107	6V6
VT—107A	6V6GT
VT—107B	6V6G
VT—108	450TH
VT—109	2051
VT—111	5BP4/1802P4
VT—112	6AC7/1852
VT—114	5T4
VT—115	6L6
VT—115A	6L6G
VT—116	6SJ7
VT—116A	6SJ7GT
VT—1168	6SJ7Y
VT—117	6SK7
VT—117A	6SK7GT
VT—118	832
VT—119	2X2/879
VT—120	954

VT NUMBERS	RMA NUMBERS
VT—121	955
VT—122	530
VT—124	1A5GT
VT—125	1C5GT
VT—126	6X5
VT—126A	6X5G
VT—126B	6X5GT
VT—128	1630 (A-5588)
VT—129	304TL
VT—130	250TL
VT—131	12SK7
VT—132	12K8 SPECIAL
VT—133	12SR7
VT—134	12A6
VT—135	12J5GT
VT—135A	12J5
VT—136	1625
VT—137	1626
VT—138	1629
VT—139	VR150-30
VT—141	531
VT—143	805
VT—144	813
VT—145	5Z3
VT—146	1N5GT
VT—147	1A7GT
VT—148	1D8GT
VT—149	3A8GT
VT—150	6SA7
VT—150A	6SA7GT
VT—151	6A8G
VT—151B	6A8GT
VT—152	6K6GT
VT—152A	6K6G
VT—153	12C8 SPECIAL
VT—154	814
VT—161	12SA7
VT—162	12SJ7
VT—163	6C8G
VT—164	1619
VT—165	1624
VT—166	371A
VT—167	6K8
VT—168A	6Y6G
VT—169	12C8
VT—170	1E5-GP
VT—171	1R5
VT—171A	1R5 LOK. EQUIV.
VT—172	1S5
VT—173	1T4
VT—174	3S4
VT—175	1613
VT—176	6AB7/1853
VT—177	1LH4
VT—178	1LC6
VT—179	1LN5
VT—181	7Z4
VT—182	3B7/1291
VT—183	1R4/1294
VT—184	VR90-30
VT—185	3D6/1299
VT—187	575A
VT—188	7E6
VT—189	7F7
VT—190	7H7
VT—191	316A
VT—192	7A4.
VT—193	7C7
VT—194	7J7
VT—195	1005
VT—196	6W5G
VT—197A	6Y3GT/G
VT—198A	6G6G
VT—199	6SS7
VT—200	VR105-30
VT—201	25L6
VT—201C	25L6GT
VT—202	9002
VT—203	9003
VT—204	HK24G
VT—205	6ST7
VT—206A	5V4G
VT—207	12AH7GT
VT—208	7B8
VT—209	12SG7
VT—210	1S4
VT—211	6SG7
VT—212	958
VT—213A	6L5G
VT—214	12H6
VT—215	6E5
VT—216	816
VT—217	811
VT—218	100TH
VT—220	250TH
VT—221	3Q5GT
VT—222	884
VT—223	1H5GT
VT—224	2C34-RK34
VT—225	307A
VT—226	3EP1/1806P1
VT—227	7184
VT—228	8012
VT—229	6SL7GT
VT—230	350A
VT—231	6SN7GT
VT—232	E-1148
VT—233	6SR7
VT—236	836
VT—237	957
VT—238	956
VT—239	1LE3
VT—240	710A
VT—241	7E5/1201
VT—243	7C4/1203A
VT—244	5U4G
VT—245	2050
VT—246	918
VT—247	6AG7
VT—249	1006
VT—255	705A
VT—260	VR75-30
VT—264	3Q4
VT—268	12SC7
VT—269	717A
VT—287	815
VT—288	12SH7
VT—289	12SL7GT

RECEIVING TUBES

00A
01A



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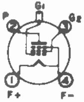

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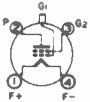

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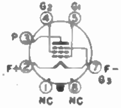

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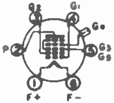

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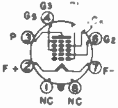

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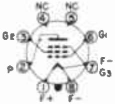

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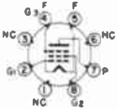


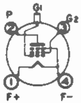
1AC5
1AD5

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
COA	Triode Detector	5. 0	0. 25	3. 2	2. 0	8. 50	Grid-Leak Detector	45	--	--	--	1. 5	30000	666	20	--	--
C1A	Triode Detector Amp	5. 0	0. 25	--	--	--	Class A Amplifier	135	-9. 0	--	--	3. 0	10000	800	8. 0	--	--
1A3	H. F. Diode	1. 4	0. 15	--	--	--	Detector-F. M. Disc		Max AC Voltage per Plate - 117 Max. Output current - 0. 5 MA								
1A4P	Variable Mu Pentode	2. 0	0. 06	5	11	. 007	R. F. Amplifier	180	-3. 0	67. 5	0. 8	2. 3	1000000	750	750	--	--
1A4T	Variable Mu Tetrode	2. 0	0. 06	5	11	. 007	R. F. Amplifier	180	-3. 0	67. 5	0. 7	2. 3	960000	750	720	--	--
1A5GT	Pentode Power Amp	1. 4	0. 05	--	--	--	Class A_1 Amplifier	90	-4. 5	90	0. 8	4. 0	300000	850	240	25000	115
1A6	Pentagrid Converter	2. 0	0. 06	--	--	--	Converter	180	-3. 0	67. 5	2. 4	1. 3	500000	Anode Grid(No. 2)180 Max Volts			
1A7GT	Pentagrid Converter	1. 4	0. 05	--	--	--	Converter	90	0	45	0. 6	0. 55	600000	Anode Grid Volts 90			
1AB5	Pentode R. F. Amp	1. 2	0. 05	2. 8	4. 2	0. 25	R. F. Amplifier	90	0	90	0. 8	3. 5	275000	1100	--	--	--
								150	-1. 5	150	2. 0	6. 8	125000	1350	--	--	--
1AC5	Power Pentode	1. 25	0. 04	--	--	--	Class A_1 Amplifier	67. 5	-4. 5	67. 5	0. 4	2. 0	0. 15Meg	750	--	25000	50 MW
1AD5	Sharp Cutoff Pentode	1. 25	0. 04	1. 8	2. 8	0. 010	Class A_1 Amplifier	67. 5	0	67. 5	0. 75	1. 85	0. 7Meg	735	--	--	--

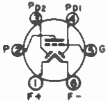
1B4P/951	Pentode RF Amp	2.0	0.06	5	11	.007	R. F. Amplifier	180	-3.0	67.5	0.6	1.7	1500000	650	1000	--	--
								90	-3.0	67.5	0.7	1.6	1000000	600	550	--	--
1B5, 255	Duplex-Diode Triode	2.0	0.06	1.6	1.9	3.6	Triode Class A	135	-3.0	--	--	0.8	35000	575	20	--	--
1B7GT	Heptode	1.4	0.1	--	--	--	Converter	90	0	45	1.3	1.5	350000	Grid No. 1 Resistor 200,000 ohms			
1B8GT	Diode Triode Pentode	1.4	0.1	--	--	--	Triode Amp.	90	0	--	--	0.15	240000	275	--	--	--
							Pentode Amp.	90	-6.0	90	1.4	6.3	--	1150	--	14000	210
1C4	Super Cont RF Amp Pentode	2.0	0.12	--	--	--	Amplifier	180	0	67.5	0.9	2.5	1000000	1000	1000	--	--
1C5GT	Pentode Power Amp.	1.4	0.1	--	--	--	Class-A₁ Amp.	90	-7.5	90	1.6	7.5	115000	1550	165	8000	240
1C6	Pentagrid Converter	2.0	0.12	10	10	--	Converter	180	-3.0	67.5	2.0	1.5	750000	Anode Grid(No. 2) 135 Max. volts			
1C7G	Heptode	2.0	0.06	10	14	0.26	Converter	180	-3.0	67.5	2.0	1.5	750000	Anode Grid(No. 2) 135 Max. volts			
1C8	Heptode	1.25	0.04	6.5	4.0	0.25	Converter	30	0	30	0.75	0.32	300000	100	--	--	--
1D4GT	Power Amp Pentode	2.0	0.24	--	--	--	Class A Amp.	180	-6.0	180	2.3	9.5	137000	2400	330	15000	0.750
1D5GP	Variable Mu Pentode	2.0	0.06	5	11	.007	R. F. Amplifier	180	-3.0	67.5	0.8	2.3	1000000	750	750	--	--
1D5GT	Variable Mu Tetrode	2.0	0.06	--	--	--	R. F. Amplifier	180	-3.0	67.5	0.7	2.2	600000	650	--	--	--
1D7G	Pentagrid Converter	2.0	0.06	10.5	9.0	0.25	Converter	180	-3.0	67.5	2.4	1.3	500000	Anode Grid(No. 2) 180 Max volts			

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



1B4P/951
1C4



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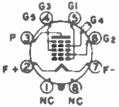
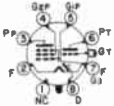


1B7GT
1C7G
1D7G



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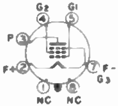

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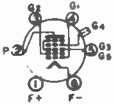

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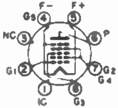

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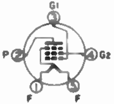

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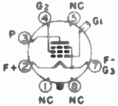

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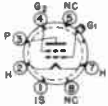
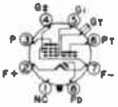


1D5GT

RECEIVING TUBES



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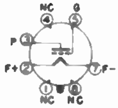

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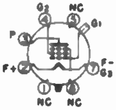

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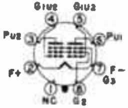

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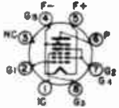

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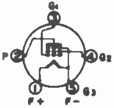

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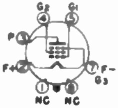

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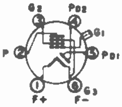

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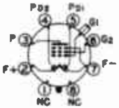


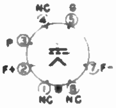
1F7G

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
1D8GT	Diode Triode Pentode	1.4	0.1	--	--	--	Triode Amp	90	0	--	--	1.1	43500	575	25	--	--
							Pentode Amp	90	-9.0	90	1.0	5.0	200000	925	--	--	--
1E4G	Triode Amplifier	1.4	0.05	2.4	6	2.40	Class A Amp	90	0	--	--	4.5	11000	1325	14.5	--	--
								90	-3.0	--	--	1.5	17000	825	14	--	--
1E5GP	Pentode Amplifier	2.0	0.06	5	11	.007	RF Amplifier	180	-3.0	67.5	0.6	1.7	1500000	650	1000	--	--
								90	-3.0	67.5	0.7	1.6	1000000	600	550	--	--
1E7G	Double Pent. Power Amp	2.0	0.24	--	--	--	Class A Amp	135	-7.5	135	2.0(1)	6.5(1)	220000	1600	350	24000	0.65
1E8	Pentagrid Converter	1.25	0.04	--	--	--	Converter Service	67.5		67.5	1.5	1.0	0.4 Meg	--	--	--	--
1F4	Pentode Power Amp	2.0	0.12	--	--	--	Class A Amp	135	-4.5	135	2.6	8.0	200000	1700	340	16000	0.34
1F5G	Pentode Power Amp	2.0	0.12	--	--	--	Class A Amp	135	-4.5	135	2.6	8.0	200000	1700	340	16000	0.34
1F6	Duplex Diode Pentode	2.0	0.06	4	9	.007	RF Amplifier	180	-1.5	67.5	0.6	2.0	1000000	650	650	--	--
							AF Amplifier	135	-1.0	135	Plate 0.25 Megohm; Screen, 1.0 Megohm Amp = 48						
1F7G	Duplex Diode Pentode	2.0	0.06	3.8	9.5	0.01	Detector Amplifier	180	-1.5	67.5	0.6	2.0	1000000	650	650	--	--
								135	-1.0	135	Plate 0.25 Megohm; Screen, 1.0 Megohm Amp = 48						

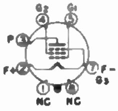
1G4GT	Triode Amplifier	1.4	0.05	2.2	3.4	2.80	Class A Amplifier	90	-6.0	--	--	2.3	10700	825	8.8	--	--
1G5G	Pentode Power Amp	2.0	0.12	--	--	--	Class A Amplifier	135	-13.5	135	2.5	8.7	160000	1550	250	9000	0.55
1G6GT	Twin Triode	1.4	0.1	--	--	--	Class A Amplifier	90	0	--	--	1.0	45000	675	30	--	--
							Class B Amplifier	90	0	--	--	1/7	34 volts input per grid			12000	675
1H4G	Triode Amplifier	2.0	0.06	--	--	--	Detector-Amplifier	180	-13.5	--	--	3.1	10300	900	9.3	--	--
1H5GT	Diode High mu Triode	1.4	0.05	1.1	6	1.00	Class A Amplifier	90	0	--	--	0.14	240000	275	65	--	--
1H6G	Duplex-Diode Triode	2.0	0.06	1.6	1.9	3.6	Detector-Amplifier	135	-3.0	--	--	0.8	35000	575	20	--	--
1J5G	Pentode Power Amp	2.0	0.12	--	--	--	Class A Amplifier	135	-16.5	135	2.0	7.0	--	950	100	13500	0.45
1J6G	Twin Triode	2.0	0.24	--	--	--	Class B Amplifier	135	0	--	--	--	Load Plate to Plate			10000	2.1
1L4	Sharp Cut-off Pentode	1.4	0.05	3.6	7.5	.008	Class A Amplifier	90	0	90	2.0	4.5	350000	1025	--	--	--
1LA4	Pentode Power Amp	1.4	0.05	--	--	--	Class A Amplifier	90	-4.5	90	0.8	4.0	300000	850	240	25000	115
1LA6	Pentagrid Converter	1.4	0.05	--	--	--	Converter	90	0	45	0.6	0.55	Anode Grid Volts 90				
1LB4	Pentode Power Amp	1.4	0.05	--	--	--	Class A Amplifier	90	-9	90	1.0	5.0	200000	925	--	12000	200
1LB6	Heptode Converter	1.4	0.05	--	--	--	Converter	90	0	67.5	2.2	0.4	Grid No. 4 - 67.5V., No. 5 - 0V.				
1LC5	Remote Cut-off Pentode	1.4	0.05	3.2	7	.007	R. F. Amplifier	90	0	45	0.2	1.15	1500000	775	--	--	--

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



1G4GT
1H4G



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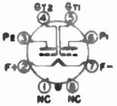
1J5G



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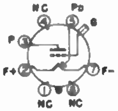
1J6G



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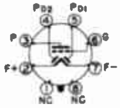

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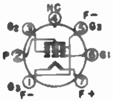

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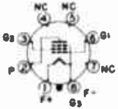
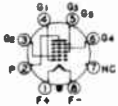
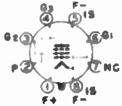


1LA4
1LB4



1LA6

1LB6



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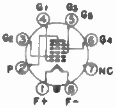
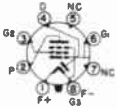
RECEIVING TUBES



11C6



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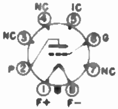

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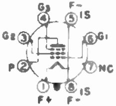
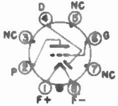


1LG5
1LN5



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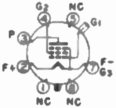
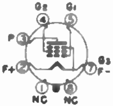


1N5GT
1P5GT

1N6G



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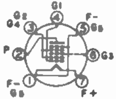


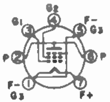
1R4

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm^{36} Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
1LC6	Pentagrid Converter	1.4	0.05	--	--	--	Converter	90	0	35^{80}	0.7	0.75	Anode Grid Volts 45				
1LD5	Diode Pentode	1.4	0.05	3.2	6	0.18	Class A Amplifier	90	0	45	0.1	0.6	950000	600	--	--	--
1LE3	Triode Amplifier	1.4	0.05	1.7	3	1.70	Class A Amplifier	90	0	--	--	4.5	11200	1300	14.5	--	--
								90	-3	--	--	1.3	19000	760		--	--
1LG5	Pentode RF Amplifier	1.4	0.05	--	--	--	Class A Amplifier	90	0	45	0.4	1.7	1000000	800	--	--	--
1LH4	Diode High Mu Triode	1.4	0.05	1.1	6	1.00	Class A Amplifier	90	0	--	--	0.15	240000	275	65	--	--
1LN5	Remote Cutoff Pentode	1.4	0.05	3.4	8	.007	Class A Amplifier	90	0	90	0.3	1.2	1500000	750	--	--	--
1N5GT	Remote Cutoff Pentode	1.4	0.05	3	10	.007	Class A Amplifier	90	0	90	0.3	1.2	1500000	750	1160	--	--
1N6G	Diode Power Pentode	1.4	0.05	--	--	--	Class A Amplifier	90	-4.5	90	0.6	3.1	300000	800	--	25000	100
1P5GT	Pentode	1.4	0.05	3	10	.007	R. F. Amplifier	90	0	90	0.7	2.3	800000	800	640	--	--
1Q5GT	Tetrode Power Amp	1.4	0.1	--	--	--	Class A Amplifier	85	-5.0	85	1.2	7.2	70000	1950	--	9000	250
								90	-4.5	90	1.6	9.5	75000	2100	--	8000	270
1R5	Pentagrid Converter	1.4	0.05	--	--	--	Converter	90	0	67.5	3.0	1.7	500000	300	Grid No. 1 100000 Ohms		

1S4	Pentagrid Power Amp	1. 4	0. 1	--	--	--	Class A Amplifier	90	-7. 0	67. 5	1. 4	7. 4	100000	1575	--	8000	0. 270
1S5	Diode Pentode	1. 4	0. 05	--	--	--	Class A Amplifier	67. 5	0	67. 5	0. 4	1. 6	600000	625	--	--	--
							R-Coupled Amp	90	0	90	Screen Resistor 3 Meg; Grid 10 Meg.					1 Meg.	0. 050
1SA6GT	Medium Cutoff Pentode	1. 4	0. 05	5. 2	8. 6	0. 01	R. F. Amplifier	90	0	67. 5	0. 68	2. 45	800000	970	--	--	--
1SB6GT	Diode Pentode	1. 4	0. 05	3. 2	3	0. 25	Class A Amplifier	90	0	67. 5	0. 38	1. 45	700000	665	--	--	--
							R. C. Amplifier	90	0	90	Screen Resistor 5 Meg. Grid 10 Meg.					1 Meg.	
1T4	Variable Mu Pentode	1. 4	0. 05	3. 6	7. 5	0. 01	Class A Amplifier	90	0	67. 5	1. 4	3. 5	500000	900	--	--	--
1T5GT	Beam Power Amp	1. 4	0. 05	4. 8	8	0. 50	Class A Amplifier	90	-6. 0	90	1. 4	6. 5		1150	--	14000	170
1T6	Diode Pentode	1. 25	0. 04	--	--	--	Class A_1 Amplifier	67. 5	0	67. 5	0. 4	1. 6	0. 4 Meg	600	--	--	--
1U4	Sharp Cutoff Pentode	1. 4	0. 05	3. 6	7. 5	0. 01	Class A Amplifier	90	0	90	0. 5	1. 6	1500000	900	--	--	--
1U5	Diode Pentode	1. 4	0. 05	--	--	--	Class A Amplifier	67. 5	0	67. 5	0. 4	1. 6	600000	625	--	--	--
1V5	Audio Pentode	1. 25	0. 04	--	--	--	Class A_1 Amplifier	67. 5	-4. 5	67. 5	0. 4	2. 0	150000	750	--	25000	0. 05
1W5	Sharp Cutoff Pentode	1. 25	0. 04	2. 3	3. 5	0. 01	Class A_1 Amplifier	67. 5	0	67. 5	0. 75	1. 85	700000	735	--	--	--

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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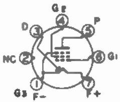

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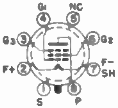

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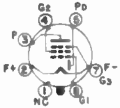

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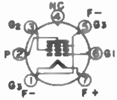
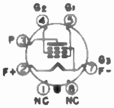


1T4
1U4



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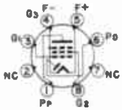

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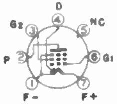

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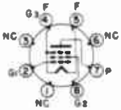
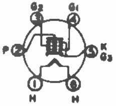


1V5
1W5

RECEIVING TUBES

2A3



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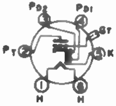

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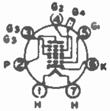

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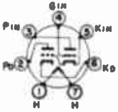

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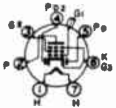

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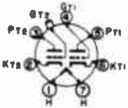

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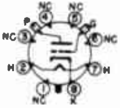

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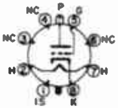

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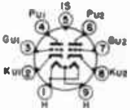


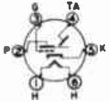
2C51

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[34] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
2A3	Triode Power Amp	2.5	2.5	7.5	5.5	16.5	Class A Amp	250	-45	--	--	60	800	5250	4.2	2500	3.5
2A5	Pentode Power Amp	2.5	1.75	--	--	--	Class A Amp	250	-16.5	250	6.5	34.0	100000	2200	220	7000	3.0
2A6	Duplex-Diode Triode	2.5	0.8	1.7	3.8	1.7	Class A Amp	250	-1.35	--	--	0.4	91000	1100	100	--	--
2A7	Pentagrid Converter	2.5	0.8	--	--	--	Converter	250	-3.0	100	2.2	3.5	360000	Anode Grid(No. 2)200 Volts Max			
2B6	Direct Coupled Amp	2.5	2.25	--	--	--	Amplifier	250	-24.0	--	--	40.0	5150	3500	18.0	5000	4.0
2B7	Duplex-Diode Pentode	2.5	0.8	3.5	9.5	.007	Pentode Amp	250	-3.0	125	2.3	9.0	650000	1125	730	--	--
2C21/1642	Twin Triode Amp	6.3	0.6	--	--	--	Class A Amp	250	-16.5	--	--	8.3	7600	1375	10.4	--	--
2C22	Triode	6.3	0.3	2.2	0.7	3.60	Class A Amp	300	-10.5	--	--	11	6600	3000	20	--	--
2C35	Special Hi-Mu Triode	6.3	0.3	5.2	2.3	0.62	ShuntVoltage Regulator	8000	-200	--	--	5.0	525000	950	500	--	--
2C51	Twin Triode	6.3	0.3	2.2	1.0	1.3	Class A_1 Amp	150	-2	--	--	8.2[6]	--	5500	35	--	--

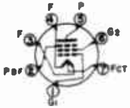
2E5	Electron-Ray Tube	2.5	0.3	--	--	--	Indicator Tube	250	0	--	--	0.25	Target Current 4 MA				--
2E30	Beam Power Tetrode	6.0	0.7	10	4.5	0.5	Class A_1 Single	250	450^1	250	7.4	44	63000	3700	--	4500	4.5
							Class A_1 Amp^2	250	225^1	250	14.8	88	--	--	--	9000^6	9
							Class AB_1 Amp^2	250	-25	250	13.5	80	--	--	--	8000^6	12.5
							Class AB_2 Amp^2	250	-30	250	20	120	--	--	--	3800^6	17
2E31	R. F. Pentode	1.25	0.05	--	--	--	Class A_1 Amp	22.5	0	22.5	0.3	0.4	--	500	--	--	--
2E32	R. F. Pentode	1.25	0.05	--	--	--	Class A Amp	22.5	0	22.5	0.3	0.4	350000	500	--	--	--
2E35	Audio Pentode	1.25	0.03	--	--	--	Class A_1 Amp	22.5	0	22.5	0.07	0.27	--	385	--	--	.0012
2E36	Audio Pentode	1.25	0.03	--	--	--	Class A_1 Amp	22.5	0	22.5	0.07	0.27	220000	385	--	150000	0.0012
								45	-1.25	45	0.11	0.45	250000	500	--	100000	0.006
2E41	Diode Pentode	1.25	0.03	--	--	--	Detector Amp	22.5	0	22.5	0.12	0.35	--	--	--	--	--
2E42	Diode Pentode	1.25	0.03	--	--	--	Detector Amp	22.5	0	22.5	0.12	0.35	250000	375	--	1 Meg	--
2G5	Electron-Ray Tube	2.5	0.8	--	--	--	Indicator Tube	250	Cutoff Grid Bias -22 V.			0.24	Target Current 4 MA				
								100	Cutoff Grid Bias -8 V.			0.19	Target Current 1 MA				

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



2E5
2G5



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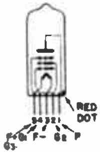

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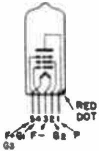
2E32



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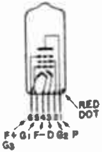
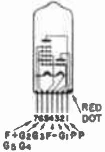
2E36

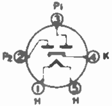


2E41
2E42

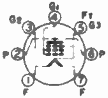
RECEIVING TUBES



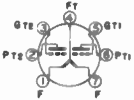
2G21
2G22



2S/4S



3A4



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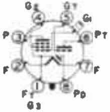

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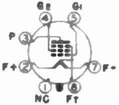
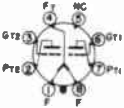


3B5GT



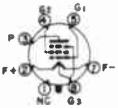
3B7

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
2G21	Triode Heptode	1.25	0.05	--	--	--	Converter	22.5	--	22.5	0.2	0.3	--	75	--	--	--
2G22	Converter	1.25	0.05	--	--	--	Converter	22.5	0	22.5	0.3	0.2	500000	60	--	--	--
2S/4S	Duodiode	2.5	1.35	--	--	--	Detector	At 50 D. C. Volts per Plate, Cathode MA. =80									
3A4	Power Amp Pentode	1.4	0.2	4.8	4.2	0.34	Class A_1 Amp	135	-7.5	90	2.6	14.9	90000	1900	--	8000	0.6
		2.8	0.1					150	-8.4	90	2.2	14.1	100000				0.7
3A5	H. F. Twin Triode	1.4	0.22	0.9	1.0	3.20	Class A Amp	90	-2.5	--	--	3.7	8300	1800	15	--	--
		2.8	0.11														
3A8GT	Diode Triode Pentode	1.4	0.1	2.6	1.2	2.0	Class A Triode	90	0	--	--	0.15	240000	275	65	--	--
		2.8	0.05	3.0	10.0	0.012	Class A Pentode	90	0	90	0.3	1.2	600000	750	--	--	--
3B5GT	Beam Power Amp	1.4	0.1	--	--	--	Class A Amp	67.5	-7.0	67.5	0.6	8.0	100000	1650	--	5000	0.2
		2.8	0.05								0.5	6.7		1500			0.18
3B7	U. H. F. Twin Triode	2.8[H]	0.11	1.4	2.6	2.6	Class A Amp	90	0	--	--	5.2	11350	1850	21	--	--

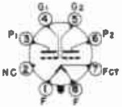
3C5GT	Power Output Pentode	1.4	0.1	--	--	--	Class A Amp	90	-9.0	90	1.4	6.0	--	1550	--	8000	0.24
		2.8	0.05											1450		10000	0.26
3C6	Twin Triode	1.4	0.1	--	--	--	Class A Amp	90	0	--	--	4.5	11200	1300	14.5	--	--
		2.8	0.05														
3C33	Twin-Triode Power Amp	12.6	1.125	8.5	4	5	Control Amp	600	-160	--	--	--	--	--	11	3000	--
3D6	U. H. F. Tetrode	2.8[21]	0.11	7.5	6.5	0.30	Class A Amp	135	-6	90	0.7	5.7	--	2200	--	13000	500
3E6	R. F. Pentode	1.4	0.10	5.5	7.5	0.007	Class A Amp	90	0	90	1.3	3.8	300000	2100	--	--	--
		2.8	0.05														
3LE4	Power Amp Pentode	2.8	0.05	--	--	--	Class A Amp	90	-9.0	90	1.8	9.0	110000	1600	--	6000	0.30
3LF4	Power Amp Tetrode	1.4	0.1	--	--	--	Class A Amp	90	-4.5	90	1.3	9.5	75000	2200	--	8000	0.27
		2.8	0.05								1.0	8.0	80000	2000	--	7000	0.23
3Q4	Power Amp Pentode	1.4	0.1	Parallel Filaments			Class A Amp	90	-4.5	90	2.1	9.5	100000	2150	--	10000	0.27
		2.8	0.05	Series Filaments							1.7	7.7	120000	2000			0.24
3Q5GT	Beam Power Amp	1.4	0.1	Parallel Filaments			Class A Amp	90	-4.5	90	1.3	9.5	--	2100	--	8000	0.27
		2.8	0.05	Series Filaments							1.0	7.5	--	1800	--		0.25

BOTTOM VIEWS SHOWN

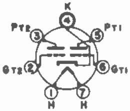
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



3C5GT
3Q5GT



3C6



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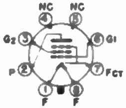
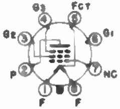


3D6
3L F4



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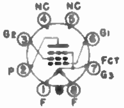
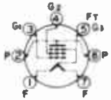
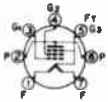


3LE4

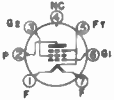


3Q4

RECEIVING TUBES



3S4



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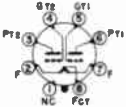
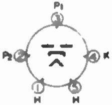
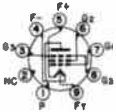


4A6G



4S



5A6

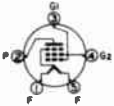
6A3

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[10] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
3S4	Power Amp Pentode	1.4	0.1	Parallel Filaments			Class A Amp	90	-7.0	67.5	1.4	7.4	100000	1575	--	8000	0.27
		2.8	0.05	Series Filaments							1.1	6.1		1425			0.235
3V4	Power Amp Pentode	1.4	0.01	Parallel Filaments			Class A Amp	90	-4.5	90	2.1	9.5	100000	2150	--	10000	0.27
		2.8	0.05	Series Filaments			Class A Amp	90	-4.5	90	1.7	7.7	120000	2000	--	10000	0.24
4A6G	Twin Triode Amp	4.0	0.06	--	--	--	Class A Amp	90	-1.5	--	--	2.2	13300	1500	20	--	--
		2.0	0.12	--	--	--	Class B Amp	90	0	--	--	4.6	--	--	--	8000	1.0
4S	Duplex Diode	2.5	1.35	--	--	--	Detector	The two Diode Plates each rated approx. 40 ma with 50 volts D. C. on the plates									
5A6	Beam Pentode	2.5	.46	8.5	6	0.15	Class B Amp	150	-15	150	7	40	--	--	6.8	--	2.8
6A3	Triode Power Amp	6.3	1.0	7.0	5.0	16.0	Class A Amp	250	-45	--	--	60	800	5250	4.2	2500	3.5
							Class AB$_1$ Amp[2]	300	-62	Fixed Bias		80	--	--	--	3000[6]	15
								300	850[1]	Self Bias		80	--	--	--	5000[5]	10

6A4	Pentode Power Amp	6. 3	0. 3	--	--	--	Class A Amp	180	-12. 0	180	3. 9	22	60000	2500	150	8000	1. 5
6A5G	Triode Power Amp	6. 3	1. 0	--	--	--	Class A Amp	250	-45. 0	--	--	60	800	--	4. 2	2500	3. 75
							P. P. Class AB^{2}	325	-68. 0	--	--	80	--	5250	--	3000^{5}	15. 0
							P. P. Class AB^{3}	325	850^{1}	--	--	80	--	--	--	5000^{5}	10. 0
6A6	Twin Triode Amp	6. 3	0. 8	--	--	--	Class B Amp P. P.	250	0	--	--	Power Output is for one Tube at				8000	8. 0
								300	0	--	--	stated Load Plate-to-Plate				10000	10. 0
6A7	Pentagrid Converter	6. 3	0. 3	8. 5	9. 0	0. 3	Converter	250	-3. 0	100	2. 2	3. 5	360000	Anode Grid(No. 2)200 Volts Max			
6A8	Pentagrid Converter	6. 3	0. 3	--	--	--	Osc. Mixer	250	-3. 0	100	3. 2	3. 3	Anode Grid(No. 2)250V max thru 20000 ohms				
6AB5	Electron-Ray Tube	6. 3	0. 15	--	--	--	Indicator Tube	180	Cutoff Grid Bias= -12 V.			0. 5	Target Current 2 MA				
6AB6G	Direct Coupled Amp	6. 3	0. 5	--	--	--	Class A Amp	250	0	Input		5. 0	40000	1800	72	8000	3. 5
								250	0	Output		34					
6AB4	R. F. Amp Triode	6. 3	0. 15	2. 2	0. 50	1. 5	Frequency Converter Class A, Amp	100	-1	--	--	3. 7	--	4000	54	--	--
								180	-1	--	--	11	--	6600	62	--	--
								250	-2	--	--	10	--	5500	55	--	--

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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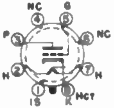
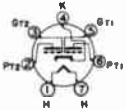


6A5G



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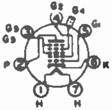

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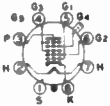

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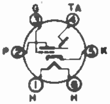

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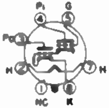
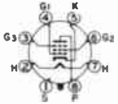


6AB6G

6AB4



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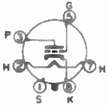
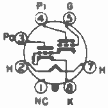


6AC5G
6AD5G
6AE5G



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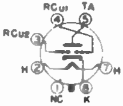

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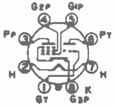

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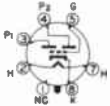


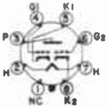
6AE6GT

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[38] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
6AB7	TV Amp Pentode	6.3	0.45	8	5	0.015	Class A Amp	300	-3.0	200	3.2	12.5	700000	5000	3500	--	--
6AC5G	High Mu Power Amp Triode	6.3	0.4	--	--	--	P. P. Class B[2]	250	0	--	--	5.0	36700	3400	125	10000[3]	8.0
							Dyn.-Coupled	250	--	--	--	32				7000	3.7
6AC6G	Direct Coupled Amp	6.3	1.1	--	--	--	Class A Amp	180	0	Input		7.0	--	3000	54	4000	3.8
								180	0	Output		45					
6AC7	TV Amp Pentode	6.3	0.45	11	5	0.015	Class A Amp	300	160[1]	150	2.5	10	1000000	9000	6750	--	--
6AD5G	High Mu Triode	6.3	0.3	4.1	3.9	3.3	Class A Amp	250	-2.0	--	--	0.9	--	1500	100	--	--
6AD6G	Electron Ray Tube	6.3	0.15	--	--	--	Indicator	100	--	0 for 90°; -23 for 135°; 45 for 0°; Target Current 1.5 MA							
6AD7G	Triode-Pentode	6.3	0.85	--	--	--	Triode Amp	250	-25.0	--	--	4.0	19000	325	6.0	--	--
							Pentode Amp	250	-16.5	250	6.5	34	80000	2500	--	7000	3.2
6AE5G	Triode Amp	6.3	0.3	--	--	--	Class A Amp	95	-15.0	--	--	7.0	3500	1200	4.2	--	--
6AE6GT	Twin Plate Triode With Single Grid	6.3	0.15	Remote Cutoff			Class A Amp	250	-1.5	--	--	6.5	25000	1000	25	--	--
				Sharp Cutoff			Class A Amp	250	-1.5	--	--	4.5	35000	950	33	--	--

6AE7GT	Twin-Input Triode	6. 3	0. 5	--	--	--	Driver Amp	250	-13. 5	--	--	5. 0	9300	1500	14	--	--
6AF5G	Triode	6. 3	0. 3	--	--	--	Class A Amp	180	-18. 0	--	--	7. 0	--	1500	7. 4	--	--
6AF6G	Electron-Ray Tube Twin Indicator Tube	6. 3	0. 15	--	--	--	Indicator Tube	135	--	Ray Control Volt. =81 for 0° Shadow Angle. Target Current 1. 5 MA							
								100		Ray Control Volt. =60 for 0° Shadow Angle. Target Current 0. 9 MA							
6AF7G	Twin Electron Ray	6. 3	0. 3	--	--	--	Indicator Tube										
6AG5	Sharp Cutoff Pentode	6. 3	0. 3	--	--	--	Class A Amp	250	200[1]	150	2. 0	7. 0	800000	5000	--	--	--
								100	100[1]	100	1. 6	5. 5	300000	4750	--	--	--
6AG6G	Power Amp Pentode	6. 3	1. 25	--	--	--	Class A Amp	250	-6. 0	250	6. 0	32	--	10000	--	8500	3. 75
6AG7	Sharp Cutoff Pentode	6. 3	0. 65	13	7. 5	0. 06	Class A_1 Amp	300	-3. 0	150	7/9	30/30. 5	130000	11000	--	10000	3. 0
6AH5G	Beam Power Amp	6. 3	0. 9	--	--	--	Class A Amp	350	-18	250	--	--	33000	5200	--	4200	10. 8
6AH6	Sharp Cutoff Pentode	6. 3	0. 45	10	2	0. 03	Pentode Amp	300	160[1]	150	2. 5	10	500000	9000	--	--	--
							Triode Amp[7]	150	160[1]	--	--	12. 5	3600	11000	40	--	--
6AH7GT	Twin Triode	6. 3	0. 3	--	--	--	Converter and Amp	250	-90	--	--	12[6]	6600	2400	16	--	--

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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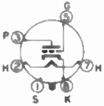

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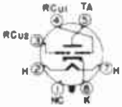

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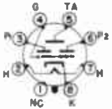

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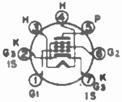

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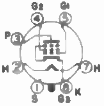

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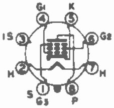

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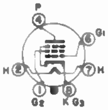

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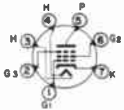

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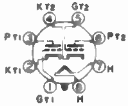
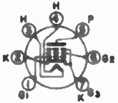


6AH7GT

RECEIVING TUBES



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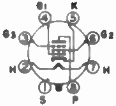

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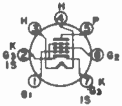

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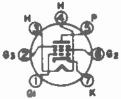

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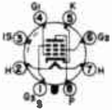

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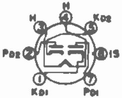

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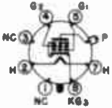

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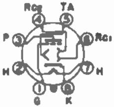


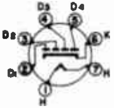
6AL7GT

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm Micro-mhos	Amp. Factor	Load Resistance Ohms	Output Watts
		Volts	Amps.	In	Out	Plate Grid											
6AJ5	Sharp Cutoff Pentode	6.3	0.175	--	--	--	R. F. Amp	28	200[1]	28	1.2	3.0	90000	2750	250	--	--
							Class AB Amp[2]	180	-7.5	75	--	--	--	--	--	28000[6]	1.0
6AJ7	Sharp Cutoff Pentode	6.3	0.45	--	--	--	Class A Amp	300	160[1]	300	2.5	10	1000000	9000	--	--	--
6AK5	Sharp Cutoff Pentode	6.3	0.175	4.3	2.1	0.03	R. F. Amp	180	200[1]	120	2.4	7.7	690000	5100	3500	--	--
								150	330[1]	140	2.2	7.0	420000	4300	1800	--	--
								120	200[1]	120	2.5	7.5	340000	5000	1700	--	--
6AK6	Power Amp Pentode	6.3	0.15	3.6	4.2	0.12	Class A Amp	180	-9.0	180	2.5	15.0	200000	2300	--	10000	1.1
6AK7	Pentode Power Amp	6.3	0.65	13	7.5	0.06	Class A Amp	300	-3	150	7	30	130000	11000	--	10000	3.0
6AL5	U. H. F. Twin Diode	6.3	0.3	--	--	--	Detector	--	Max R. M. S. Voltage 150. Max. D. C. Output Current 10 MA[6]								
6AL6G	Beam Power Amp	6.3	0.9	--	--	--	Class A Amp	250	-14.0	250	5.0	72	22500	6000	--	2500	6.5
6AL7GT	Electron-Ray Tube	6.3	0.15	--	--	--	Indicator	Outer Edge of any of the three Illuminated Areas Displaced 1/16 in. min.									
								Outward with +5v. to its elect. Similar inward disp. with -5v. no pattern with -6v. Grid									
6AN5	Power Amp Pentode	6.3	0.5	9.0	4.8	0.05	Class A_1 Amp	120	-6	120	12	35	12500	8000	--	--	--

6AN6	Twin Diode	6.3	0.2	--	--	--	Detector	R. M. S. voltage per plate=75 v.; D. C. output=35MA with 25000 ohms and 8 mmfd. load; peak current per plate = 10 MA.; peak inverse voltage = 210									
6AQ5	Beam Power Tetrode	6.3	0.45	7.6	6.0	0.35	Class A_1 Amp	180	-8.5	180	4.0	30	58000	3700	--	5500	2.0
								250	-12.5	250	7.0	47	52000	4100	--	5000	4.5
6AQ6	Duo Diode Hi-Mu Triode	6.3	0.15	1.7	1.5	1.80	Class A Triode	250	-3.0	--	--	1.0	58000	1200	70	--	--
								100	-1.0	--	--	0.8	61000	1150	70	--	--
6AQ7GT	Duplex Diode Triode	6.3	0.3	2.3	1.5	2.8	Class A Amp	250	-2.0	--	--	2.3	44000	1600	70	--	--
6AR5	Pentode Power Amp	6.3	0.4	--	--	--	Class A_1 Amp	250	-18	250	5.5	33	68000	2300	--	7600	3.4
								250	-16.5	250	5.5	35	65000	2400	--	7000	3.2
6AR6	Beam Power Amp	6.3	1.2	11	7	0.55	Class A Amp	250	-22.5	250	5	77	21000	5400	95	--	--
6AR7GT	Diode Triode	6.3	0.3	1.4	1	2	Class A Amp	250	-2	--	--	1.3	66500	1050	70	--	--
6AS5	Beam Pentode	6.3	0.8	12	6.2	0.6	Class A_1 Amp	150	-8.5	110	2/6.5	35/36	--	5600	--	4500	2.2
6AS6	Sharp Cutoff Pentode	6.3	0.175	4.0	3.0	0.02	Class A Amp	120	-2	120	3.5	5.5	--	3500	--	--	--
6AS7G	Low-Mu Twin Triode	6.3	2.5	--	--	--	D. C. Amp	135	250^{1}	--	--	125	280	7500	2.1	--	--
							Class A_1 Amp P. P.	250	2500^{1}	--	--	100/106	280	225^{8}	--	6000^{8}	13

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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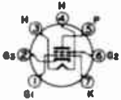

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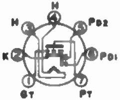

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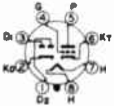

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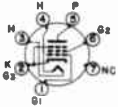

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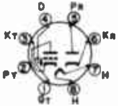
6AR6



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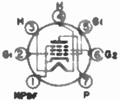

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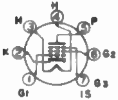

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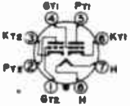

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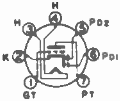
RECEIVING TUBES



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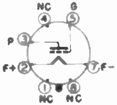
6AV6

6AU6



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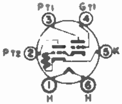

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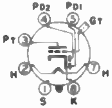

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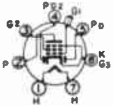

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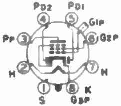

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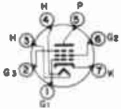


6BA6

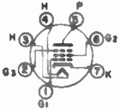
Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm^{36} Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
6AT6	Duplex Diode Triode	6. 3	0. 3	2. 3	1. 1	2. 10	Class A Amp	250	-3	--	--	1. 0	58000	1200	70	--	--
6AU6	Sharp Cutoff Pentode	6. 3	0. 3	5. 5	5. 0	. 0035	Class A Amp	250	-1	150	4. 3	10. 8	2000000	5200	--	--	--
6AV6	DuoDiode Hi-Mu Triode	6. 3	0. 3	--	--	--	Class A_1 Amp	250	-2	--	--	1. 2	62500	1600	100	--	--
6B4G	Triode Power Amp	6. 3	1. 0	--	--	--	Power Amp	250	-45	--	--	60	800	5250	4. 2	2500	3. 5
								300	-62	Fixed Bias		80	--	--	--	3000^{5}	15
								300	850^{1}	Self Bias		80	--	--	--	5000^{5}	10
6B5	Direct-Coupled Power Amp	6. 3	0. 8	--	--	--	Class A Amp	300	0	--	6^{12}	45	241000	2400	58	7000	4. 0
							Push - Pull Amp^{2}	400	-13. 0	--	4. 5^{12}	40	--	--	--	10000^{5}	20
6B6G	Duplex-Diode Hi-Mu Triode	6. 3	0. 3	1. 7	3. 8	1. 7	Detector Amp	250	-1. 35	--	--	0. 4	91000	1100	100	--	--
6B7	Duplex-Diode Pentode	6. 3	0. 3	3. 5	9. 5	. 007	Pentode R. F. Amp	250	-3. 0	125	2. 3	9. 0	650000	1125	730	--	--
6B8	Duplex-Diode Pentode	6. 3	0. 3	6	9	0. 005	Class A Amp	250	-3. 0	125	2. 3	9. 0	650000	1125	730	--	--
6BA6	Remote Cutoff Pentode	6. 3	0. 3	5. 5	5. 0	. 0035	Class A Amp	250	68^{1}	100	4. 2	11	1500000	4400	--	--	--

6BA7	Pentagrid Converter	6. 3	0. 3	9. 5	8. 3	--	Converter	250	-1	100	10	3. 8	1000000	3. 5	--	--	--
6BD6	Remote Cutoff Pentode	6. 3	0. 3	--	--	--	Class A Amp	100	-1	100	5	13	120000	2350	--	--	--
								250	-3	100	3. 5	9	700000	2000	--	--	--
6BE6	Pentagrid Converter	6. 3	0. 3	--			Converter	250	-1. 5	100	7. 8	3. 0	1000000	475	--	--	--
6BF6	Duplex Diode Triode	6. 3	0. 3	1. 8	1. 1	2. 0	Class A_1 Amp	250	-9	--	--	9. 5	8500	1900	16	10000	--
6BG6	Beam Power Amp	6. 3	0. 9	11	6. 5	0. 5	Deflection Amp	400	-50	350	6. 0	70	--	6000	--	--	--
6BH6	Sharp Cutoff Pentode	6. 3	0. 15	5. 4	4. 4	0. 0035	Class A_1 Amp	250	-1	150	2. 9	7. 4	1400000	4600	--	--	--
6BJ6	Remote Cutoff Pentode	6. 3	0. 15	4. 5	5. 0	0. 0035	Class A_1 Amp	250	-1	100	3. 3	9. 2	1300000	3800	--	--	--
6C4	Triode Amp	6. 3	0. 15	1. 8	1. 3	1. 60	Class A_1 Amp	250	-8. 5	--	--	10. 5	7700	2200	17	--	--
6C5	Triode	6. 3	0. 3	3	11	2	Class A Amp	250	-8. 0	--	--	8. 0	10000	2000	20	--	--
							Bias Detector	250	-17. 0	--	Plate Current Adjusted to 0. 2 MA. with no signal						
6C6	Sharp Cutoff Pentode	6. 3	0. 3	5	6. 5	.007	R. F. Amp	250	-3. 0	100	0. 5	2. 0	1500000	1225	1500	--	--
6C7	Duplex-Diode Triode	6. 3	0. 3	--	--	--	Class A Amp	250	-9. 0	--	--	4. 5	--	20	1250	--	--

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

6BA7



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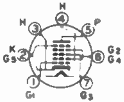

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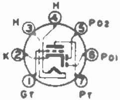

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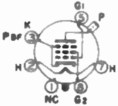

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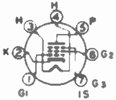

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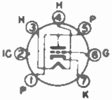
6BJ6



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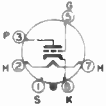

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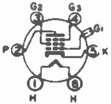

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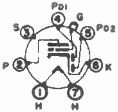
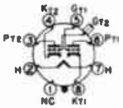


6C7

RECEIVING TUBES



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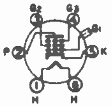

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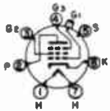

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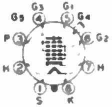
6E7



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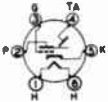

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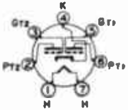

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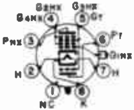

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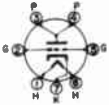


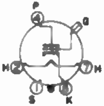
6F4

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[10] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
6C8G	Twin Triode	6.3	0.3	--	--	--	Amp 1 Section	250	-4.5	--	--	3.1	26000	1450	38	--	--
6D6	Variable Mu Pentode	6.3	0.3	4.7	6.5	.007	R. F. Amp	250	-3.0	100	2.0	8.2	800000	1600	1280	--	--
6D7	Sharp Cutoff Pentode	6.3	0.3	5.2	6.8	.01	Class A Amp	250	-3.0	100	0.5	2.0	--	1600	1280	--	--
6D8G	Pentagrid Converter	6.3	0.15	--	--	--	Converter	250	-3.0	100	Cathode Current 13.0MA; Anode Grid(No. 2) Volts=250[10]						
6E5	Electron-Ray Tube	6.3	0.3	--	--	--	Indicator Tube	250	0	--	--	0.25	Target Current 4 MA.				--
6E6	Twin Triode Amp	6.3	0.6	--	--	--	Class A Amp	250	-27.5	Per Plate - 18.0			3500	1700	6.0	14000	1.6
6E7	Variable Mu Pentode	6.3	0.3	--	--	--	R. F. Amp	250	-3.0	100	2.0	6.2	800000	1600	1280	--	--
6E8G	Triode-Hexode Converter	6.3	0.3	--	--	--	Converter	250	-2.0	--	Triode Plate 150 Volts						
6F4	Acorn Triode	6.3	0.225	2.0	0.6	1.90	Class A Amp	80	150[1]	--	--	13.0	2900	5800	17	--	--

6F5	High Mu Triode	6.3	0.3	5.5	4	2.3	Class A Amp	250	-1.3	--	--	0.2	66000	1500	100	--	--
6F6	Pentode Power Amp	6.3	0.7	6.5	13	0.2	Class A_1 Pentode	250	-16.5	250	6.5	36⁴	80000	2500	200	7000	3.2
								315	-22.0	315	8.0	42	75000	2650	200	7000	5.0
							Triode Amp³	250	-20.0	--	--	34⁴	2600	2600	6.8	4000	0.85
							Class AB_2 Amp²	375	340¹	250	18⁴	77⁴	Power output for 2 tubes			10000⁵	19.0
							Class AB_1 Amp⁶	350	-38.0	--	--	22.5	At stated load P-to-P			6000⁵	18.0
							Class AB_2 Amp⁶⁻³	350	730¹	--	--	50/61	--	--	--	10000⁵	9
								350	-38	--	--	48/92	--	--	--	6000⁵	13
6F7	Triode Pentode	6.3	0.3	--	--	--	Triode Unit Amp	100	-3.0	--	--	3.5	16000	500	8	--	--
							Pentode Unit Amp	250	-3.0	100	1.5	6.5	850000	1100	900	--	--
6F8G	Twin Triode	6.3	0.6	--	--	--	Amplifier	250	-8.0	--	--	9⁴	7700	2600	20	--	--

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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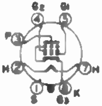

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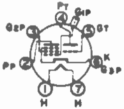

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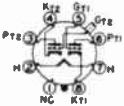
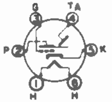


6F8G

RECEIVING TUBES



6G5
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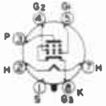
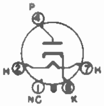


6G6G



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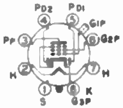
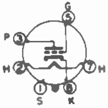


6H8G

6J4



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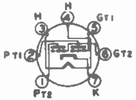


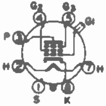
6J6

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm^{38} Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
6G5	Electron-Ray Tube	6 3	0. 3	--	--	--	Indicator Tube	250	Cutoff Bias = -22 v.			0. 24	Target Current 4 MA.				
								100	Cutoff grid bias=-8V.			0. 19	Target Current 1 MA.				
6G6G	Pentode Power Amp	6. 3	0. 15	--	--	--	Class A Amp	180	-9. 0	180	2. 5	15	175000	2300	400	10000	1. 1
							Class A Amp^{3}	180	-12. 0	--	--	--	4750	2000	9. 5	12000	0. 25
6H4GT	Diode Rectifier	6. 3	0. 15	--	--	--	Detector	100	--	--	--	4. 0	--	--	--	--	--
6H5	Electron-Ray Tube	6. 3	0. 3	--	--	--	Indicator Tube	250	Cutoff grid bias = -22 V.			0. 24	Target Current 4 MA. circular pattern				
								100	Cutoff grid bias = -8V			0. 19	Target Current 1 MA.				
6H8G	DuoDiode Hi-Mu Pentode	6. 3	0. 3	--	--	--	Class A Amp	250	-2. 0	100	--	8. 5	650000	2400	--	--	--
6J4	U. H. F. Grounded Grid R. F. Amp	6. 3	0. 4	5. 5	0. 24	4. 0	Grounded Grid	150	200^{1}	--	--	15. 0	4500	12000	55	--	--
							Class A$_{1}$ Amp	100	100^{1}	--	--	10. 0	5000	11000	55	--	--
6J5	Triode	6. 3	0. 3	3. 4	3. 6	3. 4	Class A Amp	250	-8. 0	--	--	9	7700	2600	20	--	--
6J6	Twin Triode	6. 3	0. 45	2. 2	0. 4	1. 6	Class A$_{1}$ Amp Mixer Osc	100	50^{1}	--	--	8. 5	7100	5300	38	--	--

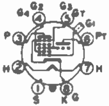
6J7	Sharp Cutoff Pentode	6. 3	0. 3	7	12	0. 005	R. F. Amp	250	-3. 0	100	0. 5	2. 0	1. 5 meg	1225	1500	--	--
							Bias Detector	250	-4. 3	100	Cathode current 0. 43 Ma.			--	--	0. 5 Meg.	--
6J8G	Triode Heptode	6. 3	0. 3	--	--	--	Converter	250	-3. 0	100	2. 8	1. 2	Anode Grid(No. 2)250 V. Max.^{10} 5 MA.				
6K4	Triode	6. 3	0. 15	2. 4	0. 8	2. 4	Class A_1 Amp	200	680^{1}	--	--	11. 5	4650	3450	16	--	--
6K5GT	High-Mu Triode	6. 3	0. 3	2. 4	3. 6	2. 0	Class A Amp	250	-3. 0	--	--	1. 1	50000	1400	70	--	--
6K6GT	Pentode Power Amp	6. 3	0. 4	--	--	--	Class A Amp	250	-18. 0	250	5. 5	32. 0	68000	2200	150	7600	3. 4
6K7	Variable Mu Pentode	6. 3	0. 3	7	12	0. 005	R. F. Amp	250	-3. 0	125	2. 6	10. 5	600000	1650	990	--	--
							Mixer	250	-10. 0	100	--	--	--	Oscillator Peak Volts = 7. 0			
6K8	Triode-Hexode	6. 3	0. 3	--	--	--	Converter	250	-3. 0	100	6	2. 5	Triode Plate(No. 2) 100 V. 3. 8 MA.				

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



6J7
6K7



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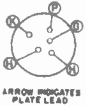

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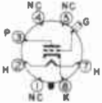

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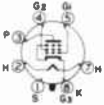

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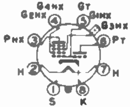
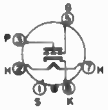
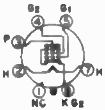


6K8

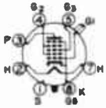
RECEIVING TUBES



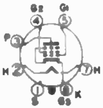
6L5G



6L6



6L7



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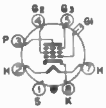
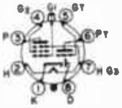


6M7G



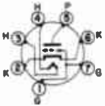
6M8GT

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[34] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
6L5G	Triode Amp	6.3	0.15	2.8	5.0	2.6	Class A Amp	250	-9.0	--	--	8.0	--	1900	17	--	--
6L6	Beam Power Amp	6.3	0.9	10	12	0.4	Single Tube	250	170[1]	250	5.4/7.2	75/78	--	--	--	2500	6.5
							Class A_1	300	220[1]	200	3.0/4.6	51/54.5	--	--	--	4500	6.5
							Single Tube	250	-14.0	250	5/7.3	72/79	22500	6000	--	2500	6.5
							Class A_1	350	-18.0	250	2.5/7.0	54/66	33000	5200	--	4200	10.8
							P. P. Class A_1[2]	270	125[1]	270	11/17	134/145	--	--	--	5000[8]	18.5
							P. P. Class A_1[2]	250	-16.0	250	10/16	120/140	24500	5500	--	5000[8]	14.5
								270	-17.5	270	11/17	134/155	23500	5700	--	5000[8]	17.5
							P. P. Class AB_1[2]	360	250[1]	270	5/17	88/100	Power Output For 2 Tubes Load Plate-to-Plate			9000[8]	24.5
							P. P. Class AB_1[2]	360	-22.5	270	5/15	88/132				6600[8]	26.5
							P. P. Class AB_2[2]	360	-18.0	225	3.5/11	78/142				6000[8]	31.0
								360	-22.5	270	5/16	88/205				3800[8]	47.0
6L7	Pentagrid Mixer Amp	6.3	0.3	--	--	--	R. F. Amp	250	-3.0	100	5.5	5.3	800000	1100	--	--	--
							Mixer	250	-6.0	150	8.3	3.3	Over 1 meg. Osc.-Grid(No. 3) Volt. = -15				
6M6G	Power Amp Pentode	6.3	1.2	--	--	--	Class A Amp	250	-6.0	250	4.0	36	--	9500	--	7000	4.4
6M7G	Pentode Amp	6.3	0.3	--	--	--	R. F. Amp.	250	-2.5	125	2.6	10.5	900000	3400	--	--	--
6M8GT	Diode Triode Pentode	6.3	0.6	--	--	--	Triode Amp	100	--	--	--	0.5	91000	1100	--	--	--
							Pentode Amp	100	-3.0	100	--	8.5	200000	1900	--	--	--

6N4	U. H. F. Triode Amp	6. 3	0. 2	3. 0	1. 6	1. 10	Class A Amp	180	-3. 5	--	--	12. 0	--	6000	32	--	--
6N5	Electron-Ray Tube	6. 3	0. 15	--	--	--	Indicator Tube	180	Cutoff Grid Bias=-12 V.			0. 5	Target Current 2 MA.				--
6N6G	Direct-Coupled Amp	6. 3	0. 8	--	--	--	Power Amp	300	0	--	6^{12}	45	241000	2400	58	7000	4. 0
								400	-13. 0	--	4.5^{12}	40	--	--	--	10000^{8}	20
6N7	Twin Triode	6. 3	0. 8	--	--	--	Class B Amp	300	0	--	--	35/70	--	--	--	8000	10. 0
6P5GT	Triode Amp	6. 3	0. 3	3. 4	5. 5	2. 6	Class A Amp	250	-13. 5	--	--	5. 0	9500	1450	13. 8	--	--
6P7G	Triode-Pentode	6. 3	0. 3	--	--	--	Class A Amp	100	-3. 0	--	--	3. 5	16000	500	8	--	--
								250	-3. 0	100	1. 5	6. 5	850000	1100	900	--	--
6P8G	Triode Hexode Converter	6. 3	0. 8	--	--	--	Converter	250	-2. 0	75	1. 4	1. 5	Triode Plate 100 V. 2. 2 MA				
6Q6G	Diode-Triode	6. 3	0. 15	--	--	--	Class A Amp	250	-3. 0	--	--	1. 2	--	1050	65	--	--
6Q7	Duplex-Diode Triode	6. 3	0. 3	5	3. 8	1. 4	Triode Amp	250	-3. 0	--	--	1. 1	58000	1200	70	--	--
6R6G	Pentode Amp	6. 3	0. 3	4. 5	11	0. 007	Class A Amp	250	-3. 0	100	1. 7	7. 0	--	1450	1160	--	--
6R7	Duplex-Diode Triode	6. 3	0. 3	4. 8	3. 8	2. 4	Triode Amp	250	-9. 0	--	--	9. 5	8500	1900	16	10000	0. 28
6S5	Electron-Ray Tube	6. 3	0. 3	--	--	--	Visual Indicator	Target	-8. 0	Vane grid Target current 0 MA. values for 0° angle							
								250	0	135	Target current 2 MA values for 300° angle						

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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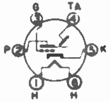
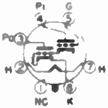
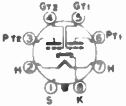


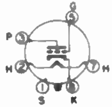
6N5
6S5



6N6G



6N7



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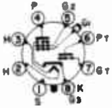
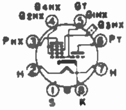
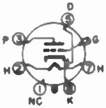


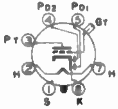
6P7G



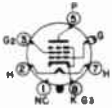
6P8G



6Q6G

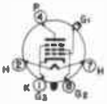


6Q7
6R7

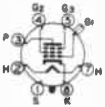


6R6G

RECEIVING TUBES



6S6GT



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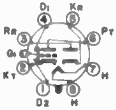

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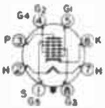
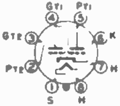


6SA7Y
6SB7Y



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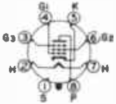
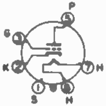


6SD7GT
6SE7GT



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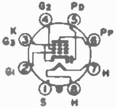


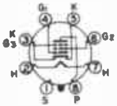
6SF7

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
6S6GT	Remote Cutoff Pentode	6.3	0.45	--	--	--	R. F. Amp	250	-2.0	100	3.0	13	350000	4000	--	--	--
6S7	Remote Cutoff Pentode	6.3	0.15	6.5	10.5	0.005	Class A Amp	250	-3.0	100	2.0	8.5	1000000	1750	--	--	--
6S8GT	Triple Diode Triode	6.3	0.3	1.2	5	2	Class A Amp	250	-2.0	--	--	0.9	91000	1100	100	--	--
6SA7	Pentagrid Converter	6.3	0.3	--	--	--	Converter	250	0	100	8.0	3.4	800000	Grid No. 1 resistor 20000 ohms			
6SB7Y	Pentagrid Converter	6.3	0.3	9.6	9.2	--	Converter	100	-1	100	10.2	3.6	500000	900	--	--	--
							Converter	250	-1	100	10	3.8	1000000	950	--	--	--
							Oscillator	250	22000[16]	12000[17]	12.6/12.5	6.8/6.5	--	--	--	--	--
6SC7	Twin-Triode	6.3	0.3	--	--	--	Class A Amp	250	-2.0	--	--	2.0	53000	1325	70	--	--
6SD7GT	Medium Cutoff Pentode	6.3	0.3	9	7.5	.0035	R. F. Amp	250	-2.0	100	1.9	6.0	1000000	3600	--	--	--
6SE7GT	Sharp Cutoff Pentode	6.3	0.3	8	7.5	.005	R. F. Amp	250	-1.5	100	1.5	4.5	1100000	3400	3750	--	--
6SF5	High-Mu Triode	6.3	0.3	4	3.6	2.4	Class A Amp	250	-2.0	--	--	0.9	66000	1500	100	--	--
6SF7	Diode Var. Mu Pentode	6.3	0.3	5.5	6	0.004	Class A Amp	250	-1.0	100	3.3	12.4	700000	2050	--	--	--

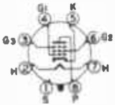
6SG7	Semivariable Mu Pentode	6.3	0.3	8.5	7	0.003	H. F. Amp	250	-2.5	150	3.4	9.2	over1 meg	4000	--	--	--
6SH7	Sharp Cutoff Pentode	6.3	0.3	8.5	7	0.003	Class A Amp	250	-1.0	150	4.1	10.8	900000	4900	--	--	--
6SH7L	Pentode R. F. Amp	6.3	0.3	--	--	--	Class A Amp	100	-1.0	100	2.1	5.3	350000	4000	--	--	--
								250	-1.0	150	4.1	10.8	900000	4900	--	--	--
6SJ7	Sharp Cutoff Pentode	6.3	0.3	6	7	0.005	Class A Amp	250	-3.0	100	0.8	3	1500000	1650	2500	--	--
6SK7	Variable Mu Pentode	6.3	0.3	6	7	0.003	Class A Amp	250	-3.0	100	2.4	9.2	800000	2000	1600	--	--
6SL7GT	Twin Triode	6.3	0.3	--	--	--	Class A Amp	250	-2.0	--	--	2.3*	44000	1600	70	--	--
6SN7GT	Twin Triode	6.3	0.6	--	--	--	Class A Amp	250	-8.0	--	--	9.0*	7700	2600	20	--	--
6SQ7	Duplex-Diode Triode	6.3	0.3	3.2	3.0	1.6	Class A Amp	250	-2.0	--	--	0.8	91000	1100	100	--	--
6SR7	Duplex-Diode Triode	6.3	0.3	3.6	2.8	2.40	Class A Amp	250	-9.0	--	--	9.5	8500	1900	16	--	--
6SS7	Variable Mu Pentode	6.3	0.15	5.5	7.0	0.004	Class A Amp	250	-3.0	100	2.0	9.0	1000000	1850	--	--	--
6ST7	Duplex-Diode Triode	6.3	0.15	2.8	3	1.50	Class A Amp	250	-9.0	--	--	9.5	8500	1900	16	--	--
6SU7GTY	Twin Triode	6.3	0.3	--	--	--	Class A Amp	250	-2.0	--	--	2.3	44000	1600	70	--	--
6SV7	Diode R. F. Pentode	6.3	0.3	6.5	6	0.004	Class A Amp	250	-1	150	2.8	7.5	600000	3400	--	--	--
6SZ7	Duplex-Diode Triode	6.3	0.15	2.6	2.8	1.10	Class A Amp	250	-3	--	--	1.0	58000	1200	70	--	--
6T5	Electron-Ray Tube	6.3	0.3	--	--	--	Indicator Tube	250	Cutoff grid bias=-12 V.			0.24	Target Current 4 MA.				
6T6GM	Amplifier	6.3	0.45	--	--	--	Class A Amp	250	-1.0	100	2.0	10	1000000	5500	--	--	--

BOTTOM VIEWS SHOWN

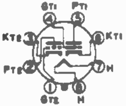
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



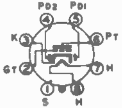
6SG7
6SH7
6SH7L



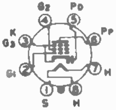
6SJ7
6SK7
6SS7



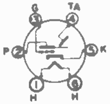
6SL7GT
6SN7GT
6SU7GT



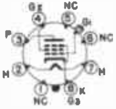
6SQ7
6SR7
6ST7
6SZ7



6SV7

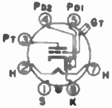


6T5

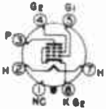


6T6GM

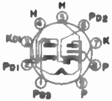
RECEIVING TUBES



6T7
6V7G



6U6GT
6V6
6W6GT
6Y6G



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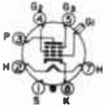

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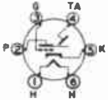
6W7G



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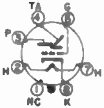


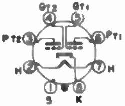
6X6G

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[36] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
6T7	Duplex-Diode Triode	6.3	0.15	1.8	3.1	1.70	Class A Amp	250	-3.0	--	--	1.2	62000	1050	65	--	--
6T8	Triple-Diode Triode	6.3	0.3	1.5	1.1	2.4	Class A$_1$ Amp	250	-3	--	--	1.0	5800	1200	70	--	--
								100	-1	--	--	0.8	5400	1300	70	--	--
6U5	Electron-Ray Tube	6.3	0.3	--	--	--	Indicator Tube	250	Cutoff grid bias=-22 V.			0.24	Target Current 4 MA.				
								100	Cutoff grid bias= -8 V.			0.19	Target Current 1 MA.				
6U6GT	Beam Power Amp	6.3	0.75	--	--	--	Class A Amp	200	-14.0	135	3.0	56	20000	6200	--	3000	5.5
6U7G	Variable Mu Pentode	6.3	0.3	5	9	.007	Class A Amp	250	-3.0	100	2.0	8.2	800000	1600	1280	--	--
6V6	Beam Power Amp	6.3	0.45	2.0	7.5	0.7	Class A$_1$ Amp	250	-12.5	250	4.5/7.0	45/47	52000	4100	218	5000	4.5
							Class AB$_1$ Amp[2]	250	-15.0	250	5/13	70/79	60000	3750	--	10000[5]	10.0
								285	-19.0	285	4/13.5	70/92	65000	3600	--	8000[5]	14.0
6V7G	Duplex-Diode Triode	6.3	0.3	2	3.5	1.7	Detector - Amp	250	-20.0	--	--	8.0	7500	1100	8.3	20000	0.35
6W6GT	Beam Power Amp	6.3	1.25	--	--	--	Class A Amp	135	-9.5	135	12.0	61.0	--	9000	215	2000	3.3
6W7G	Pentode Det. Amp	6.3	0.15	5	8.5	.007	Class A Amp	250	-3.0	100	2.0	0.5	1500000	1225	1850	--	--
6X6G	Electron-Ray Tube	6.3	0.3	--	--	--	Indicator Tube	250	0 V. for 300° 2MA. -8 V. for 0°, 0MA. Vane Grid 125 Volts								--
6Y6G	Beam Power Amp	6.3	1.25	15	8	0.7	Class A Amp	135	-13.5	135	3.0	60.0	9300	7000	--	2000	3.6

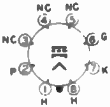
6Y7G	Twin Triode Amp	6. 3	0. 3	--	--	--	Class B Amp	250	0	--	--	10. 6[16]	power output is for 1tube			14000	8. 0
6Z7G	Twin Triode Amp	6. 3	0. 3	--	--	--	Class B Amp	180	0	--	--	6. 4	--	--	--	12000	4. 2
								135	0	--	--	6. 0	--	--	--	9000	2. 5
7A4	Triode Amp	7. 0	0. 32	3. 4	3	4	Class A Amp	250	-8. 0	--	--	9. 0	7700	2600	20	--	--
7A5	Beam Power Amp	7. 0	0. 75	13	7. 2	0. 44	Class A$_1$ Amp	125	-9. 0	125	3. 2/8	37.5/40	17000	6100	--	2700	1. 9
7A7	Remote Cutoff Pentode	7. 0	0. 32	6	7	. 005	Class A Amp	250	-3. 0	100	2. 0	8. 6	800000	2000	1600	--	--
7A8	Multigrid Converter	7. 0	0. 16	7. 5	9. 0	0. 15	Converter	250	-3. 0	100	3. 1	3. 0	50000	Anode grid 250 volts Max.[10]			
7AB7	Sharp Cutoff Pentode	6. 3	0. 15	3. 5	4. 0	0. 06	Class A Amp	250	-2	100	0. 6	1. 75	800000	1200	--	--	--
7AD7	Pentode	6. 3	0. 6	11. 5	7. 5	0. 03	Class A$_1$ Amp	300	68[1]	150	7. 0	28. 0	300000	9500	--	--	--
7AF7	Twin Triode	6. 3	0. 3	2. 2	1. 6	2. 3	Class A Amp	250	-10	--	--	9. 0	7600	2100	16	--	--
7AG7	Sharp Cutoff Pentode	7. 0	0. 16	7. 0	6. 0	0. 005	Class A$_1$ Amp	250	250[1]	250	2. 0	6. 0	750000	4200	--	--	--
7AH7	Pentode Amp	6. 3	0. 15	7. 0	6. 5	0. 005	Class A$_1$ Amp	250	250[1]	250	1. 9	6. 8	1000000	3300	--	--	--
7B4	High-Mu Triode	7. 0	0. 32	3. 6	3. 4	1. 6	Class A Amp	250	-2. 0	--	--	0. 9	66000	1500	100	--	--
7B5	Pentode Power Amp	7. 0	0. 43	3. 2	3. 2	1. 6	Class A$_1$ Amp	250	-18. 0	250	5.5/10	32/33	68000	2300	--	7600	3. 4

BOTTOM VIEWS SHOWN

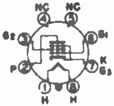
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



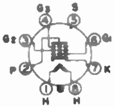
6Y7G
6Z7G



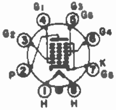
7A4
7B4



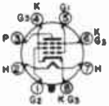
7A5



7A7
7AD7
7AG7
7AH7



7A8



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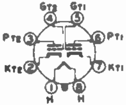

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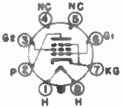

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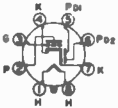
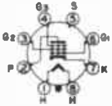


7B6
7C6
7E6



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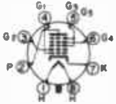

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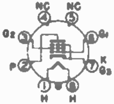

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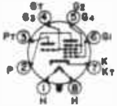

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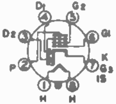

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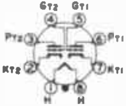


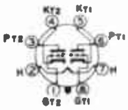
7F7

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[36] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
7B6	Duo-Diode Triode	7.0	0.32	3.0	2.4	1.6	Class A Amp	250	-2.0	--	--	1.0	91000	1100	100	--	--
7B7	Remote Cutoff Pentode	7.0	0.16	5	7	.005	Class A Amp	250	-3.0	100	2.0	8.5	700000	1700	1200	--	--
7B8	Pentagrid Converter	7.0	0.32	10.0	9.0	0.2	Converter	250	-3.0	100	2.7	3.5	360000	Anode-Grid 250 Volts Max.[10]			
7C5	Tetrode Power Amp	7.0	0.48	9.5	9.0	0.4	Class A_1 Amp	250	-12.5	250	4.5/7	45/47	52000	4100	--	5000	4.5
7C6	Duo-Diode Triode	7.0	0.16	2.4	3	1.4	Class A Amp	250	-1.0	--	--	1.3	100000	1000	100	--	--
7C7	Pentode Amp	7.0	0.16	5.5	6.5	.007	Class A Amp	250	-3.0	100	0.5	2.0	2 meg	1300	--	--	--
7D7	Triode Hexode Converter	7.0	0.48	--	--	--	Converter	250	-3.0	Triode Plate (No. 3) 150 volts 3.5 MA.							
7E5	U. H. F. Triode	6.3	0.15	3.6	2.8	1.50	Class A Amp	180	-3	--	--	5.5	12000	--	36	--	--
7E6	Duo-Diode Triode	7.0	0.32	--	--	--	Class A Amp	250	-9.0	--	--	9.5	8500	1900	16	--	--
7E7	Duo-Diode Pentode	7.0	0.32	4.6	4.6	.005	Class A Amp	250	-3.0	100	1.6	7.5	700000	1300	--	--	--
7F7	Twin Triode	7.0	0.32	--	--	--	Class A Amp[11]	250	-2.0	--	--	2.3	44000	1600	70	--	--

7F8	Twin Triode	6.3	0.30	2.8	1.4	1.2	R. F. Amp	250	-2.5	--	--	10.0	10400	5000	--	--	--
								180	-1.0	--	--	12.0	8500	7000	--	--	--
7G7	Sharp Cutoff Pentode	7.0	0.48	9	7	.007	Class A Amp	250	-2.0	100	2.0	6.0	800000	4500	--	--	--
7G8	Dual Tetrode	6.3	0.30	3.4	2.6	0.15	R. F. Amp[11]	250	-2.5	100	0.8	4.5	225000	2100	--	--	--
7H7	Semi Var. Mu Pentode	7.0	0.32	8	7	.007	R. F. Amp	250	-2.5	150	2.5	9.0	1000000	3500	--	--	--
7J7	Triode Heptode Converter	7.0	0.32	--	--	--	Converter	250	-3.0	100	2.9	1.3	Triode Plate 250 Volts Max.[16]				
7K7	Duo Diode Hi-Mu Triode	7.0	0.32	--	--	--	Class A Amp	250	-2.0	--	--	2.3	44000	1600	70	--	--
7L7	Sharp Cutoff Pentode	7.0	0.32	8	6.5	.01	Class A Amp	250	-1.5	100	1.5	4.5	100000	3100	Cathode resistor 250 ohms		
7N7	Twin Triode	7.0	0.6	3.4[7]	2.0[7]	3.0[7]	Class A Amp[11]	250	-8.0	--	--	9.0	7700	2600	20	--	--
				2.9[8]	2.4[8]	3.0[8]											
7Q7	Pentagrid Converter	7.0	0.32	--	--	--	Converter	250	0	100	8.0	3.4	800000	Grid No.1 resistor 20000 ohms			
7R7	Duo-Diode Pentode	7.0	0.32	5.6	5.3	.004	Class A Amp	250	-1.0	100	1.7	5.7	1000000	3200	--	--	--

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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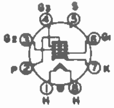
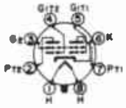


7G7
7H7
7L7



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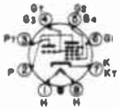

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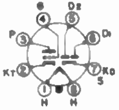

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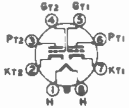

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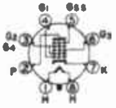

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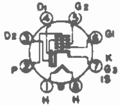
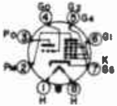


7R7

RECEIVING TUBES



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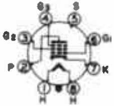

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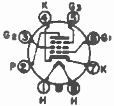
7V7



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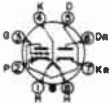


7X7

9C26

10

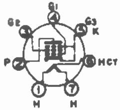
Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma	Plate Ma	Plate Resistance Ohms	Gm[34] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
7S7	Triode Hexode Converter	7.0	0.32	--	--	--	Converter	250	-2.0	100	2.2	1.7	2000000	Triode Plate 250 v. max.[10]			
7T7	Pentode Amp	7.0	0.32	8	7	.005	Class A Amp	250	-1.0	150	4.1	10.8	900000	4900	--	--	--
7V7	Sharp Cutoff Pentode	7.0	0.48	9.5	6.5	.004	Class A Amp	300	160'	150	3.9	10	300000	5800	--	--	--
7W7	Sharp Cutoff Pentode	7.0	0.48	9.5	7.0	.0025	Class A Amp	300	-2.2	150	3.9	10	300000	5800	--	--	--
7X7	Duo-Diode Triode	6.3	0.3	--	--	--	Class A Amp	250	-1.0	--	--	1.9	67000	1500	100	--	--
9C26	Power Triode	6	285	34	62	1.0	Class B Amp and Mod	8000	-200	--	--	4.5	--	--	--	4000	25 kw
							Class B Amp	7500	-175	--	--	1.5	--	--	--	--	4 kw
							Class C Amp	7500	-600	--	--	1.7	--	--	--	--	10.5kw
							Class C Amp and Osc.	7500	-400	--	--	1.6	--	--	--	--	9 kw
							Class C Amp	7500	-400	--	--	1.6	--	--	--	--	11 kw
10	Triode Power Amp	7.5	1.25	4.0	3.0	7.00	Class A Amp	425	-39.0	--	--	18.0	5000	1600	8.0	10200	1.6

11	Triode Detector Amp	1.1	0.25	--	--	--	Class A Amp	135	-10.5	--	--	3.0	15000	440	6.6	--	--
12	Triode Detector Amp	1.1	0.25	--	--	--	Class A Amp	135	-10.5	--	--	3.0	15000	440	6.6	--	--
12A5	Pentode Power Amp	12.6	0.3	9.0	9.0	0.3	Class A_1 Amp	100	-15	100	3/6.5	17/19	50000	1700	--	4500	0.8
		6.3	0.6					180	-25	180	8/14	45/48	35000	2400	--	3300	3.4
12A6	Beam Power Amp	12.6	0.15	--	--	--	Class A Amp	250	-12.5	250	3.5	30	70000	3000	--	7500	3.4
12A7	Rectifier Amp	12.6	0.3	--	--	--	Class A Amp	135	-13.5	135	2.5	9.0	102000	975	100	13500	0.55
12A8GT	Heptode	12.6	0.15	9.5	12	0.26	Converter	250	-3.0	100	3.2	3.3	Anode-grid(No. 2)250 v. max. thru 20000ohms				
12AH7GT	Twin Triode	12.6	0.15				Class A Amp[11]	180	-6.5	--	--	7.6	8400	1900	16	--	--
12AL5	Twin Diode	12.6	0.15	2.5	--	--	Detector	R. M. S. voltage per plate=117, D. C. output=9 MA. per plate; Peak MA. per									
								plate=54; Peak inverse voltage=330									
12AT6	Duplex Diode Triode	12.6	0.15	2.3	1.1	2.10	Class A Amp	250	-3.0	--	--	1.0	58000	1200	70	--	--
12AT7	Double Triode	6.3	0.3	2.5[7]	0.45[7]	1.45[7]	Class A_1 Amp	250	-2	--	--	10	10000	5500	55	--	--
		12.6	0.15	2.5[8]	0.35[8]	1.45[8]	Each Unit	180	-1	--	--	11	9400	6600	62	--	--

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

11
12



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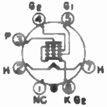

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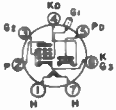

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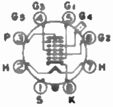

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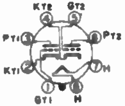

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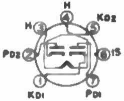

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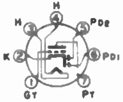

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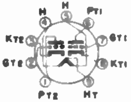
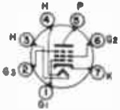


12AT7

RECEIVING TUBES



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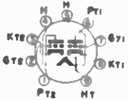
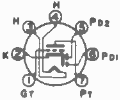


12AU7
12AX7
12AY7



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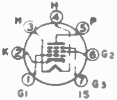
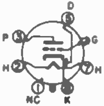


12AW6
12AW7



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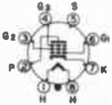


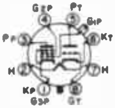
12B7ML

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm^{34} Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
12AU6	Sharp Cutoff Pentode	12.6	0.15	5.5	5.0	.0035	Class A_1 Amp	250	-1.0	150	4.3	10.8	1000000	5200	--	--	--
12AU7	Twin Triode Amp	6.3	0.3	1.6^{7}	0.5^{7}	1.5^{7}	Class A_1 Amp	250	-8.5	--	--	10.5	7700	2200	17	--	--
		12.6	0.15	1.6^{8}	0.35^{8}	1.5^{8}											
12AV6	Duo-Diode Hi-Mu Triode	12.6	0.15	--	--	--	Class A_1 Amp	250	-2	--	--	1.2	62500	1600	100	--	--
12AW6	Sharp Cutoff Pentode	12.6	0.15	6.5	1.5	0.025	Pentode Amp	250	200^{1}	150	2.0	7.0	800000	5000	--	--	--
							Triode Amp^{24}	250	825^{1}	--	--	5.5	11000	3800	42	--	--
12AW7	Sharp Cutoff Pentode	12.6	0.15	6.5	1.5	0.025	Class A_1 Amp	250	200^{1}	150	2.0	7.0	800000	5000	--	--	--
12AX7	Double Triode	12.6	0.15	1.6^{7}	0.46^{7}	1.7^{7}	Class A_1 Amp	250	-2	--	--	1.2	62500	1600	100	--	--
		6.3	0.3	1.6^{8}	0.34^{8}	1.7^{8}		100	-1	--	--	0.5	8000	1250	100	--	--
12AY7	Double Triode	12.6	150MA	1.3	0.6	1.3	Class A Amp	250	-4	--	--	3		1750	40	--	--
		6.3	300MA														
12B6M	Diode Triode	12.6	0.15	--	--	--	Class A Amp	250	-2.0	--	--	0.9	91000	1100	100	--	--
12B7	Remote Cutoff Pentode	14	0.16	6.0	7.0	.005	Class A Amp	250	-3.0	100	2.6	9.2	800000	2000	--	--	--
12B7ML	Pentode Amplifier	12.6	0.15	--	--	--	Class A Amp	250	-3.0	100	2.6	9.2	800000	2000	--	--	--

12B8GT	Triode Pentode	12.6	0.3				Class A Amp[25]	100	-1	--	--	0.6	73000	1500	110	--	--
							Class A Amp[26]	100	-3	100	2	8	170000	2100	360	--	--
12BA6	Remote Cutoff Pentode	12.6	0.15	5.5	5.0	.0035	Class A Amp	250	68[1]	100	4.2	11.0	1500000	4400	--	--	--
12BA7	Pentagrid Converter	12.6	0.15	9.5	8.3	--	Converter	250	-1	100	10	3.8	1000000	3.5	--	--	--
12BD6	Remote Cutoff Pentode	12.6	0.15	4.3	5.0	.004	Class A Amp	250	-3	100	3.5	9.0	700000	2000	--	--	--
12BE6	Pentagrid Converter	12.6	0.15				Converter	250	-1.5	100	7.8	3.0	1000000	475	--	--	--
12BF6	Duo Diode Triode	12.6	0.15	1.8	1.1	2.00	Class A Amp	250	-9	--	--	9.5	8500	1900	16	--	--
12C8	Duplex Diode Pentode	12.6	0.15	6	9	.005	Class A Amp	250	-3.0	125	2.3	9.0	650000	1125	730	--	--
12E5GT	Triode Amp	12.6	0.15	3.4	5.5	2.60	Class A Amp	250	-13.5	--	--	50	--	1450	13.8	--	--
12F5GT	Triode Amp	12.6	0.15	1.9	3.4	2.40	Class A Amp	250	-2.0	--	--	0.9	66000	1500	100	--	--
12G7G	Duplex Diode Triode	12.6	0.15	--	--	--	Class A Amp	250	-3.0	--	--	--	58000	1200	70	--	--
12J5GT	Triode Amp	12.6	0.15	3.4	3.6	3.40	Class A Amp	250	-8.0	--	--	9	7700	2600	20	--	--
12J7GT	Sharp Cutoff Pentode	12.6	0.15	4.2	5.0	3.8	Class A Amp	250	-3.0	100	0.5	2.0	1500000	1225	1500	--	--
								250	-4.3	100	Cathode Current 0.43 MA.				--	.5 meg.	--
12K7GT	Remote Cutoff Pentode	12.6	0.15	4.6	12	.005	R. F. Amp	250	-3.0	125	2.6	10.5	600000	1650	990	--	--

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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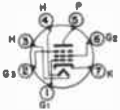
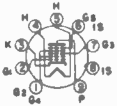


12BA6
12BD6



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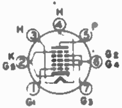

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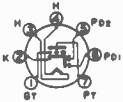

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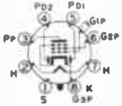

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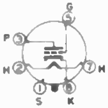
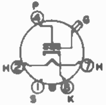


12E5GT
12J5GT



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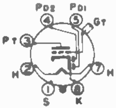

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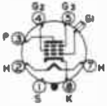
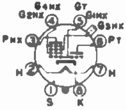


12J7GT
12K7GT

RECEIVING TUBES



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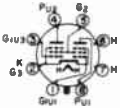

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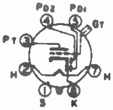

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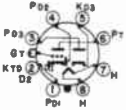

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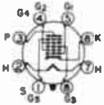

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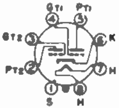

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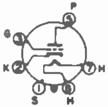

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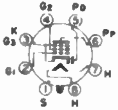

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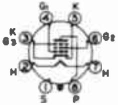
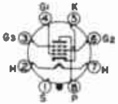


12SG7
12SH7



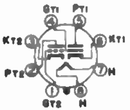
12SJ7
12SK7

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
12K8	Triode Hexode Converter	12.6	0.15	--	--	--	Converter	250	-3.0	100	6	2.5	Triode plate(No.2)100 v., 3.8 MA.				
12L8GT	Twin Pentode	12.6	0.15	5	6	0.70	Class A_1 Amp	180	-9.0	180	2.8	13.0	160000	2150	--	10000	1.0
12Q7GT	Duplex Diode Triode	12.6	0.15	2.2	5	1.60	Class A Amp	250	-3.0	--	--	1.1	58000	1200	70	--	--
12S8GT	Triple Diode Triode	12.6	0.15	2.0	3.8	1.2	Class A Amp	250	-2.0	--	--	0.9	91000	1100	100	--	--
12SA7	Heptode	12.6	0.15	9.5	12	0.13	Converter	250	0	100	8.0	3.4	800000	Grid No. 1 resistor 20000 ohms			
12SC7	Twin Triode	12.6	0.15	2.2	3.0	2.0	Class A Amp	250	-2.0	--	--	2.0	53000	1325	70	--	--
12SF5	High-Mu Triode	12.6	0.15	4	3.6	2.40	Class A Amp	250	-2.0	--	--	0.9	66000	1500	100	--	--
12SF7	Diode Var. Mu Pentode	12.6	0.15	5.5	6.0	.004	Class A Amp	250	-1.0	100	3.3	12.4	70000	2050	--	--	--
12SG7	Medium Cutoff Pentode	12.6	0.15	8.5	7.0	.003	Class A Amp	250	-2.5	150	3.4	9.2	over 1 meg	4000	--	--	--
12SH7	Sharp Cutoff Pentode	12.6	0.15	8.5	7.0	.003	H. F. Amp	250	-1.0	150	4.1	10.8	900000	4900	--	--	--
12SJ7	Sharp Cutoff Pentode	12.6	0.15	--	--	--	Class A Amp	250	-3.0	100	0.8	3	1500000	1650	2500	--	--
12SK7	Remote Cutoff Pentode	12.6	0.15	6.0	7.0	.003	R. F. Amp	250	-3.0	100	2.4	9.2	800000	2000	1600	--	--

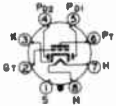
12SL7GT	Twin Triode	12. 6	0. 15	--	--	--	Class A Amp	250	-2. 0	--	--	2. 3[4]	44000	1600	70	--	--
12SN7GT	Twin Triode	12. 6	0. 3	--	--	--	Class A Amp	250	-8. 0	--	--	9. 0[4]	7700	2600	20	--	--
12SQ7	Duplex-Diode Triode	12. 6	0. 15	3. 2	3. 0	1. 60	Class A Amp	250	-2. 0	--	--	0. 8	91000	1100	100	--	--
12SR7	Duplex Diode Triode	12. 6	0. 15	3. 6	2. 8	2. 40	Class A Amp	250	-9. 0	--	--	9. 5	8500	1900	16	10000	0. 28
12SW7	Duplex Diode Triode	12. 6	0. 15	3. 0	2. 8	2. 4	Class A_1 Amp	250	-9	--	--	9. 5	8500	1900	16	--	--
12SX7	Twin Triode	12. 6	0. 3	3. 0	0. 8	3. 6	Class A_1 Amp[11]	250	-8	--	--	9	7700	2600	20	--	--
12SY7	Heptode Converter	12. 6	0. 15				Converter	250	-2	100	8. 5	3. 5	1000000	450	--	--	--
14A4	Triode Amp	14	0. 16	3. 4	3. 0	4. 00	Class A Amp	250	-8	--	--	9. 0	7700	2600	20	--	--
14A5	Beam Power Amp	14	0. 16	--	--	--	Class A_1 Amp	250	-12. 5	250	3.5/5.5	30/32	70000	3000	--	7500	2. 8
14A7	Remote Cutoff Pentode	14	0. 16	6. 0	7. 0	. 005	Class A Amp	250	-3. 0	100	2. 6	9. 2	800000	2000	--	--	--
14AF7	Twin Triode	14	0. 16	2. 2	1. 6	2. 30	Class A Amp	250	-10	--	--	9	7600	2100	16	--	--
14B6	Duplex Diode Triode	14	0. 16	--	--	--	Class A Amp	250	-2. 0	--	--	1. 0	91000	1100	100	--	--

BOTTOM VIEWS SHOWN

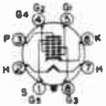
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



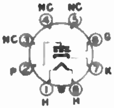
12SL7GT
12SN7GT
12SX7



12SQ7
12SR7
12SW7



12SY7



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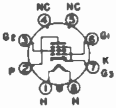

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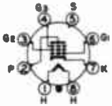
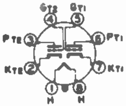


14A7



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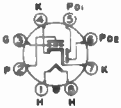
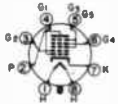


14B6

RECEIVING TUBES



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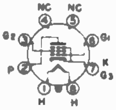

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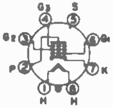
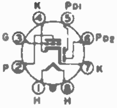


14C7
14H7



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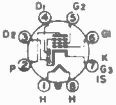

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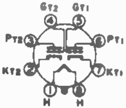
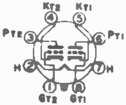


14F7
14N7



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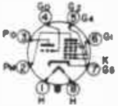


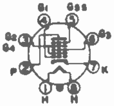
14J7

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[10] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
14B8	Pentagrid Converter	14	0.16				Converter	250	-3.0	100	2.7	3.5	36000	Anode grid 250 Volts Max.[10]			
14C5	Beam Power Amp	14	0.24	--	--	--	Class A Amp	250	-12.5	250	4.5/7.0	45/47	52000	4100	218	5000	4.5
14C7	R. F. Pentode	14	0.16	6.0	6.5	.007	Class A Amp	250	-3.0	100	0.7	2.2	1000000	1575	--	--	--
14E6	Duplex Diode Triode	14	0.16	--	--	--	Class A Amp	250	-9.0	--	--	9.5	8500	1900	16	--	--
14E7	Duplex Diode Pentode	14	0.16	4.6	5.3	.005	Class A Amp	250	-3.0	100	1.6	7.5	700000	1300	--	--	--
14F7	Twin Triode	14	0.16	--	--	--	Class A Amp	250	-2.0	--	--	2.3	44000	1600	70	--	--
14F8	Twin Triode	12.6	0.15	2.8	1.4	1.2	Class A_1 Amp	250	-2.5	--	--	10.0	10400	5000	--	--	--
								180	-1.0	--	--	12.0	8500	7000	--	--	--
14H7	Semi-Var. Mu Pentode	14	0.16	8.0	7.0	.007	Class A Amp	250	-2.5	150	3.5	9.5	800000	3800	--	--	--
14J7	Triode-Hexode Converter	14	0.16				Converter	250	-3.0	100	2.9	1.3	Triode Plate 250 Volts Max.[10]				
14N7	Twin Triode	14	0.32	--	--	--	Class A Amp	250	-8.0	--	--	9.0	7700	2600	20	--	--

14Q7	Heptode Pentagrid Conv.	14	0.16	--	--	--	Converter	250	0	100	8.0	3.4	800000	Grid No. 1 resistor 20000 ohms			
14R7	Duplex Diode Pentode	14	0.16	5.6	5.3	.004	Class A Amp	250	-1.0	100	1.7	5.7	1000000	3200	--	--	--
14S7	Triode Heptode	14	0.16				Converter	250	-2.0	100	3	1.8	1250000	525	--	--	--
14V7	H. F. Pentode	14	0.24	--	--	--	Class A Amp	300	-2.0	150	3.9	9.6	300000	5600	--	--	--
14W7	Pentode	14	0.24				Class A Amp	300	-2.2	150	3.9	10	300000	5800	--	--	--
15	Sharp Cutoff Pentode	2.0	0.22	2.3	7.8	0.01	R. F. Amp	135	-1.5	67.5	0.3	1.85	800000	750	600	--	--
18	Pentode	14	0.30	--	--	--	Class A_1 Amp	315	-22.0	315	8.0	42	75000	2650	200	7000	5.0
19	Twin Triode Amp	2.0	0.26	--	--	--	Class B Amp	135	0	--	--	--	Load plate-to-plate			10000	2.1
19BG6G	Beam Pentode	18.9	300	11	6.5	0.65	Horiz. Defl. Amp	500	-50	350	6	100	--	--	--	--	--
19J6	Twin Triode	18.9	0.15	2.0	0.4	1.5	Class A_1 Amp	100	50[1]	--	--	8.5[6]	7100	5300	38	--	--
19T8	Triple Diode Triode	18.9	0.15	1.5	1.1	2.4	Class A_1 Amp	250	-3	--	--	1.0	5800	1200	70	--	--
20	Triode Power Amp	3.3	0.132	2.0	2.3	4.10	Class A Amp	135	-22.5	--	--	6.5	6300	525	3.3	6500	0.11

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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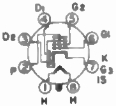
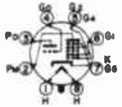


14R7



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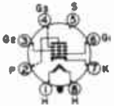

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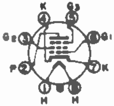

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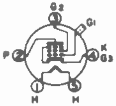

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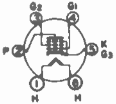

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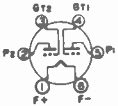

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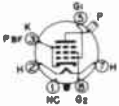
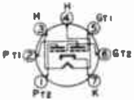
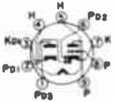


19BG6G

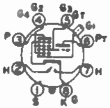


19J6



19T8

20



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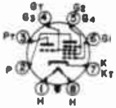
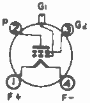


21A7



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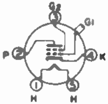
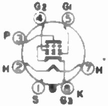
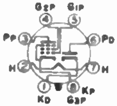


24A



25A6
25B6G



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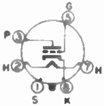

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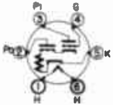


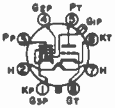
25B5

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
20J8GM	Triode Heptode Conv.	20	0. 15	--	--	--	Converter	250	-3. 0	100	3. 4	1. 5	Triode plate (No. 6) 100 v. 1. 5 ma.				--
21A7	Triode Hexode Conv.	21	0. 16	--	--	--	Converter	250	-3. 0	100	2. 8	1. 3	--	275	--	--	--
								150	-3. 0	TRIODE		3. 5	--	1900	32	--	--
22	Tetrode R. F. Amp	3. 3	0. 132	3. 5	10	0. 02	Class A Amp	135	-1. 5	67. 5	1. 3	3. 7	325000	500	162	--	--
24A	Tetrode R. F. Amp	2. 5	1. 75	5. 3	10. 5	. 007	Screen Grid R. F. Amp	250	-3. 0	90	1. 7	4. 0	600000	1050	630	--	--
							Bias Detector	250	-5. 0	20/45	Plate current adjusted to 0. 1 ma. with no signal						--
25A6	Pentode Power Amp	25	0. 3	8. 5	12. 5	0. 20	Class A Amp	135	-20. 0	135	8	37	35000	2450	85	4000	2. 0
25A7GT	Rectifier Power Pentode	25	0. 3	--	--	--	Class A Amp	100	-15. 0	100	4	20. 5	50000	1800	90	4500	0. 77
25AC5GT	Triode Power Amp	25	0. 3	--	--	--	Class A Amp	110	15. 0	--	--	45	--	3800	58	2000	2. 0
								165	Used in dynamic-coupled circuit with 6AF5G driver							3500	3. 3
25B5	Direct-Coupled Triodes	25	0. 3	--	--	--	Class A Amp	110	0	110	7	45	11400	2200	25	2000	2. 0
25B6G	Pentode Power Amp	25	0. 3	--	--	--	Class A Amp	95	-15. 0	95	4	45	--	4000	--	2000	1. 75

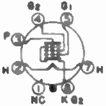
25B8GT	Triode Pentode	25	0, 15	Triode Section			Class A Amp	100	-1	--	--	0, 6	73000	1500	110	--	--
				Pentode Section			Class A Amp	100	-3	100	2	8	170000	2100	360	--	--
25C6G	Beam Power Amp	25	0, 3	--	--	--	Class A_1 Amp	135	-13, 5	135	3.5/11.5	58/60	9300	7000	--	2000	3, 6
25D8GT	Diode Triode Pentode	25	0, 15	--	--	--	Triode Amp	100	-1, 0	--	--	0, 5	91000	1100	100	--	--
							Pentode Amp	100	-3, 0	100	2, 7	8, 5	200000	1900	--	--	--
25L6	Beam Power Amp	25	0, 3	16	13, 5	0, 30	Class A_1 Amp	110	-8, 0	110	3,5/10,5	45/48	10000	8000	80	2000	2, 2
25N6G	Direct-Coupled Triodes	25	0, 3	--	--	--	Class A Amp	110	0	110	7	45	11400	2200	25	2000	2, 0
25S	Duplex-Diode Triode	2, 0	0, 06	1, 6	1, 9	3, 6	Triode Class A	135	-3, 0	--	--	0, 8	35000	575	20	--	--
26	Triode Amp	1, 5	1, 05	2, 8	2, 5	8, 10	Class A Amp	180	-14, 5	--	--	6, 2	7300	1150	8, 3	--	--
26A6	Remote Cutoff Pentode	26, 5	0, 07	6, 0	5, 0	, 0035	Class A_1 Amp	250	125[1]	100	4	10, 5	1000000	4000	--	--	--
26A7GT	Twin Beam-Power Audio Amp	26, 5	0, 6				Class A Amp	26. 5	-4, 5	26, 5	2/5, 5	20/20,5	2500	5500	--	1500	0, 2
							Class AB Amp[33]	26, 5	-7, 0	26, 5	2/8, 5	19/30	--	--	--	2500[6]	0, 5
26C6	Duplex Diode Triode	26, 5	0, 07	1, 8	1, 4	2	Class A_1 Amp	250	-9	--	--	9, 5	8500	1900	16	--	--
26D6	Pentagrid Converter	26, 5	0, 07				Converter	250	-1, 5	100	7, 8	3, 0	1000000	475	--	--	--

BOTTOM VIEWS SHOWN

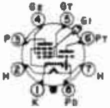
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



25B8GT



25C6G
25L6



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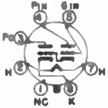

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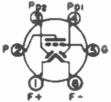
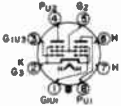


25S

26

26A6



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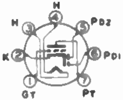

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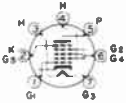
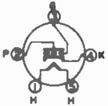


26D6

RECEIVING TUBES



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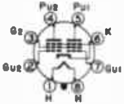
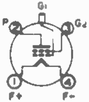


28D7

30
31



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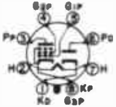

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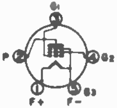

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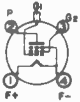

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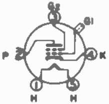

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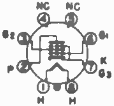
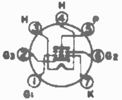


35A5



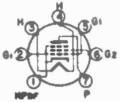
35B5

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[35] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
27	Triode Detector Amp	2. 5	1. 75	3. 1	2. 3	3. 3	Class A Amp	250	-21	--	--	5. 2	9250	975	9. 0	--	--
							Bias Detector	250	-30. 0	Plate current adjusted to 0. 2 MA. with no signal							
28D7	Double Beam Power Amp	28. 0	0. 4	--	--	--	Class A Amp	28	390[1]	28[11]	0. 7[11]	9. 0[11]	--	--	--	4000[11]	0. 08[11]
									180[1]	28[23]	1. 2[23]	18. 5[23]	--	--	--	6000[9]	0. 175[23]
30	Triode Detector Amp	2. 0	0. 06	--	--	--	Class A Amp	180	-13. 5	--	--	3. 1	10300	900	9. 3	--	--
31	Triode Power Amp	2. 0	0. 13	3. 5	2. 7	5. 7	Class A Amp	180	-30. 0	--	--	12. 3	3600	1050	3. 8	5700	0. 375
32	Sharp Cutoff Pentode	2. 0	0. 06	5. 3	10. 5	.015	R. F. Amp	180	-3. 0	67. 5	0. 4	1. 7	1200000	650	780	--	--
32L7GT	Diode.Beam Tetrode	32. 5	0. 3	--	--	--	Class A Amp	110	-7. 5	110	3	40	15000	6000	--	2500	1. 5
33	Pentode Power Amp	2. 0	0. 26	8	12	1	Class A Amp	180	-18. 0	180	5. 0	22. 0	55000	1700	90	6000	1. 4
34	Variable Mu Pentode	2. 0	0. 06	6	11	.015	R. F. Amp	180	-3. 0	67. 5	1. 0	2. 8	1000000	620	620	--	--
35	Remote Cutoff Pentode	2. 5	1. 75	5. 3	10. 5	. 007	Screen-Grid RF Amp	250	-3. 0	90	2. 5	6. 5	400000	1050	420	--	--
35A5	Beam Power Amp	35	0. 15	--	--	--	Class A$_1$ Amp	110	-7. 5	110	317	40/41	14000	5800	--	2500	1. 5
35B5	Beam Power Amp	35	0. 15	11	6. 5	0. 4	Class A$_1$ Amp	110	-7. 5	110	7	41	--	5800	--	2500	1. 5

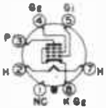
35C5	Beam Power Amp	35	0.15	12	6.2	0.57	Class A_1 Amp	110	-7.5	110	3/7	40/41	--	5800	--	2500	1.5
35L6G	Beam Power Amp	35	0.15	13	9.5	0.80	Class A_1 Amp	110	-7.5	110	3/7	40/41	13800	5800	--	2500	1.5
36	Tetrode R. F. Amp	6.3	0.3	3.8	9	.007	R. F. Amp	250	-3.0	90	1.7	3.2	550000	1080	595	--	--
37	Triode Detector Amp	6.3	0.3	3.5	2.9	2	Class A Amp	250	-18.0	--	--	7.5	8400	1100	9.2	--	--
38	Pentode Power Amp	6.3	0.3	3.5	7.5	0.3	Class A Amp	250	-25.0	250	3.8	22.0	100000	1200	120	10000	2.5
39/44	Remote Cutoff Pentode	6.3	0.3	3.8	10	.007	R. F. Amp	250	-3.0	90	1.4	5.8	1000000	1050	1050	--	--
40	Triode Voltage Amp	5.0	0.25	2.8	2.2	2.00	Class A Amp	180	-3.0	--	--	0.2	150000	200	30	--	--
41	Pentode Power Amp	6.3	0.4	--	--	--	Class A Amp	250	-18.0	250	5.5	32.0	68000	2200	150	7600	3.4
42	Pentode Power Amp	6.3	0.7	--	--	--	Class A Amp	250	-16.5	250	6.5	34.0	100000	2200	220	7000	3.0
43	Pentode Power Amp	25	0.3	8.5	12.5	0.20	Class A Amp	95	-15.0	95	4.0	20.0	45000	2000	90	4500	0.90
44	Super-Control RF Pentode	6.3	0.3	3.8	10	.007	R. F. Amp	250	-3.0	90	1.4	5.8	1000000	1050	1050	--	--
45	Triode Power Amp	2.5	1.5	4	3	7	Class A Amp	275	-56.0	--	--	36.0	1700	2050	3.5	4600	2.00
46	Dual Grid Power Amp	2.5	1.75	--	--	--	Class A Amp[14]	250	-33.0	--	--	22.0	2380	2350	5.6	6400	1.25
							Class B Amp[15]	400	0	--	--	12	Power output for 2tubes			5800	20.0

BOTTOM VIEWS SHOWN

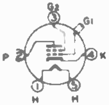
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



35C5



35L6G



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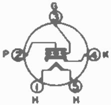

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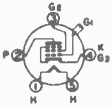
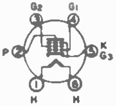
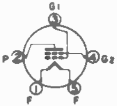


38
39/44
44

40
45

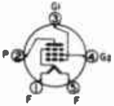


41
42
43



46

RECEIVING TUBES



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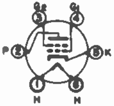

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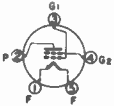

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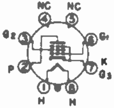

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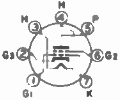

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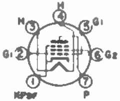

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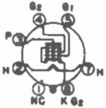


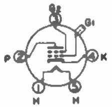
50C6GT
50L6GT

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[30] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
47	Pentode Power Amp	2.5	1.75	8.6	13	1.2	Class A Amp	250	-16.5	250	6.0	31.0	60000	2500	150	7000	2.7
48	Tetrode Power Amp	30	0.4	--	--	--	Class A Amp	96	-19.0	96	9.0	52.0	--	3800	--	1500	2.0
49	Dual Grid Power Amp	2.0	0.12	--	--	--	Class A Amp[14]	135	-20.0	--	--	6.0	4175	1125	4.7	11000	0.17
							Class B Amp[16]	180	0	--	--	Power output for 2 tubes				12000	3.5
50	Triode Power Amp	7.5	1.25	4.2	3.4	7.10	Class A Amp	450	-84.0	--	--	55.0	1800	2100	3.8	4350	4.6
50A5	Beam Power Amp	50	0.15	--	--	--	Class A_1 Amp	110	-7.5	110	4/11	49/50	10000	8200	--	2000	2.2
50B5	Beam Power Amp	50	0.15	13	6.5	0.50	Class A Amp	110	-7.5	110	4.0	49.0	14000	7500	--	3000	1.9
50C5	Beam Power Amp	50	0.15	--	--	--	Class A_1 Amp	110	-7.5	110	4/8.5	49/50	10000	7500	--	2500	1.9
50C6GT	Beam Power Amp	50	0.15	--	--	--	Class A_1 Amp	135	-13.5	135	3.5/11.5	58/60	9300	7000	--	2000	3.6
50L6GT	Beam Power Amp	50	0.15	--	--	--	Class A Amp	110	-7.5	110	4/11	49/50	--	8200	82	2000	2.2

51	Remote Cutoff Pentode	2.5	1.75	5.3	10.5	.007	Screen Grid RF Amp	250	-3.0	90	2.5	6.5	400000	1050	420	--	--
52	Dual Grid Triode	6.3	0.3	--	--	--	Class A Amp^{14}	110	0	--	--	43.0	750	3000	5.2	2000	1.5
							Class B 2 Tubes^{16}	180	0	--	--	3.0^{16}	--	--	--	10000	5.0
53	Twin Triode Amp	2.5	2.0	--	--	--	Class B Amp	250	0	--	Power output is for one tube at					8000	8.0
								300	0	--	stated load Plate-to-Plate					10000	10.0
55	Duplex Diode Triode	2.5	1.0	1.5	4.3	1.5	Class A Amp	250	-20.0	--	--	8.0	7500	1100	8.3	20000	0.35
56	Triode Amp., Detector	2.5	1.0	3.2	2.4	3.2	Class A Amp	250	-13.5	--	--	5.0	9500	1450	13.8	--	--
56AS	Triode Amp	6.3	0.4	--	--	--	Class A Amp	250	-13.5	--	--	5.0	9500	1450	13.8	--	--
57	Sharp Cutoff Pentode	2.5	1.0	--	--	--	R. F. Amp	250	-3.0	100	0.5	2.0	1500000	1225	1500	--	--
57AS	Sharp Cutoff Pentode	6.3	0.4	--	--	--	R. F. Amp	250	-3.0	100	0.5	2.0	1500000	1225	1500	--	--
58	Remote Cutoff Pentode	2.5	1.0	4.7	6.3	.007	Screen Grid RF Amp	250	-3.0	100	2.0	8.2	800000	1600	1280	--	--
58AS	Remote Cutoff Pentode	6.3	0.4	--	--	--	R. F. Amp.	250	-3.0	100	2.0	8.2	800000	1600	1280	--	--
59	Pentode Power Amp	2.5	2.0	--	--	--	Class A Triode^{13}	250	-28.0	--	--	26.0	2300	2600	6.0	5000	1.25
							Class A Pentode	250	-18.0	250	9.0	35.0	40000	2500	100	6000	3.0
70A7GT	Diode Beam Tetrode	70^{22}	0.15	--	--	--	Class A Amp	110	-7.5	110	3.0	40	--	5800	80	2500	1.5

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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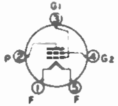

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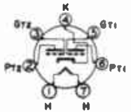

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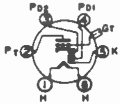

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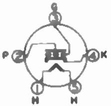

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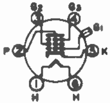
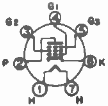
56AS



57
57AS
58
58AS



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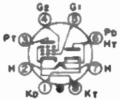
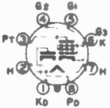


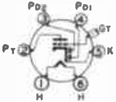
70A7GT

RECEIVING TUBES



70L7GT

71A
99



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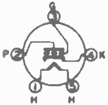
85AS



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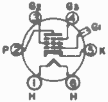

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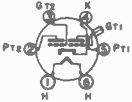


79

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[16] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
70L7GT	Diode Beam Tetrode	70	0.15	--	--	--	Class A_1 Amp	110	-7.5	110	3/6	40/43	15000	7500	--	2000	1.8
71A	Triode Power Amp	5.0	0.25	3.2	2.9	7.50	Class A Amp	180	-43.0	--	--	20.0	1750	1700	3.0	4800	0.79
75	Duplex Diode Triode	6.3	0.3	1.7	3.8	1.7	Triode Amp	250	-1.35	--	--	0.4	91000	1100	100	--	--
76	Triode Detector Amp	6.3	0.3	3.5	2.5	2.8	Class A Amp	250	-13.5	--	--	5.0	9500	1450	13.8	--	--
77	Sharp Cutoff Pentode	6.3	0.3	4.7	11	.007	R. F. Amp	250	-3.0	100	0.5	2.3	1500000	1250	1500	--	--
78	Variable Mu Pentode	6.3	0.3	4.5	11	.007	R. F. Amp	250	-3.0	100	1.7	7.0	800000	1450	1160	--	--
79	Twin Triode Amp	6.3	0.6	--	--	--	Class B Amp	250	0	--	--	10.6 power output is for 1 tube				14000	8.0
85	Duplex Diode Triode	6.3	0.3	1.5	4.3	1.5	Class A Amp	250	-20.0	--	--	8.0	7500	1100	8.3	20000	0.35
85AS	Duplex Diode Triode	6.3	0.3	--	--	--	Class A Amp	250	-9.0	--	--	5.5	--	1250	20	--	--
89	Power Amp Pentode	6.3	0.4	--	--	--	Triode Amp[18]	250	-31.0	--	--	32.0	2600	1800	4.7	5500	0.9
							Pentode Amp	250	-25.0	250	5.5	32.0	70000	1800	125	6750	3.4
99	Triode Detector Amp	3.3	0.063	2.5	2.5	3.30	Class A Amp	90	-4.5	--	--	2.5	15500	425	6.6	--	--

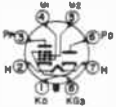
101D	Detector Amp Triode	4.2	1.0	--	--	--	Class A Amp	135	-9.0	--	--	9.0	--	1070	6.0	--	--
101F	Detector Amp Triode	4.0	.505	--	--	--	Class A Amp	130	-8.0	--	--	7.0	6010	1095	6.5	--	--
112A	Triode Detector Amp	5.0	.25	--	--	--	Class A Amp	180	-13.5	--	--	7.7	4700	1600	8.5	--	--
117L7GT	Rectifier-Amplifier	117	.09	--	--	--	Class A Amp	105	-5.2	105	4/5.5	43	17000	5300	--	4000	0.85
117M7GT	Rectifier-Amplifier	117	.09	--	--	--	Class A Amp	105	-5.2	105	4/5.5	43	17000	5300	--	4000	0.85
117N7GT	Rectifier-Amplifier	117	.09	--	--	--	Class A Amp	100	-6.0	100	5.0	51	16000	7000	--	3000	1.2
117P7GT	Rectifier-Amplifier	117	.09	--	--	--	Class A Amp	105	-5.2	105	4/5.5	43	17000	5300	--	4000	0.85
182B	Triode Amp	5.0	1.25	--	--	--	Class A Amp	250	-35.0	--	--	18.0	--	1500	5.0	--	--
183	Power Triode	5.0	1.25	--	--	--	Class A Amp	250	-60.0	--	--	25.0	18000	1800	3.2	4500	2.0
210T	Triode	7.5	1.25	--	--	--	Class A Amp	350	-32.0	--	--	16.0	5150	1550	8.0	11000	0.9
								425	-40.0	--	--	18.0	5000	1600	8.0	102000	1.6
446A	"Lighthouse" UHF Triode	6.3	0.75	--	--	--	Osc., Amp., Converter	250	200	--	--	15.0	--	4500	45.0	--	--
446B	"Lighthouse" UHF Triode	6.3	0.75	--	--	--	Osc., Amp., Converter	250	200	--	--	15.0	--	4500	45.0	--	--
464A	"Lighthouse" UHF Triode	6.3	0.75	--	--	--	Class A Amp	250	100	--	--	25.0	--	7000	--	--	--
482B	Triode Amp	5.0	1.25	--	--	--	Class A Amp	250	-35.0	--	--	18.0	--	1500	5.0	--	--
483	Power Triode	5.0	1.25	--	--	--	Class A Amp	250	-60.0	--	--	25.0	18000	1800	3.2	4500	2.0

BOTTOM VIEWS SHOWN

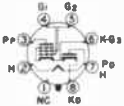
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

101D
101F

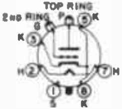
112A
182B
183
210T
482B
483



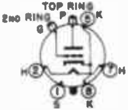
117L7GT
117M7GT



117N7GT
117P7GT

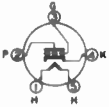


'446A
446B



464A

RECEIVING TUBES



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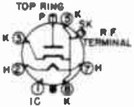

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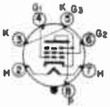

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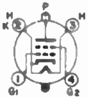

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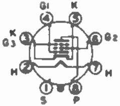

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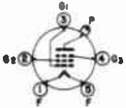

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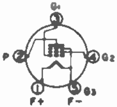

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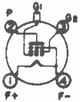

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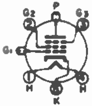


954

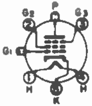
Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
485	Triode	3.0	1.3	--	--	--	Class A Amp	180	-9.0	--	--	6.0	9300	1350	12.5	--	--
559	U.H.F. Diode	6.3	0.75	--	--	--	Detector	5.0	--	--	24.0	--	--	--	--	--	--
713A	H. F. Pentode	6.3	0.175	--	--	--	Class A Amp	120	-2	120	2.5	7.5	250000	--	--	--	--
715C	Pulse Amp Tetrode	26±2.5	2.1	37.5	7.5	2	Modulator	15000	-800	1250	.0015	15	--	--	--	800	--
717A	Sharp Cutoff Pentode	6.3	0.175	--	--	--	Class A Amp	120	-2.0	120	2.5	7.5	390000	4000	--	--	--
840	Pentode	2.0	0.13	--	--	--	Class A Amp	180	-3.0	67.5	0.7	1.0	1000000	400	400	--	--
864	Triode Amp	1.1	0.25	--	--	--	Class A Amp	90	-4.5	--	--	2.9	13500	610	8.2	--	--
950	Pentode Power Amp	2.0	0.12	--	--	--	Class A Amp	135	-16.5	135	2.0	7.0	100000	1000	125	13500	0.575
951	Pentode R. F. Amp	2.0	0.06	5	11	.007	R. F. Amp	180	-3.0	67.5	0.6	1.7	1500000	650	1000	--	--
								90	-3.0	67.5	0.7	1.6	1000000	600	550	--	--
954	Pentode Detector	6.3	0.15	3.4	3.0	0.007	Class A Amp	250	-3.0	100	0.7	2.0	1.5 meg	1400	2000	--	--
	Amp						Bias Detector	250	-6.0	100	--	Plate current to be adjusted to .1MA with no signal					

955	Triode Detector Amp., Osc.	6.3	0.15	1.0	0.6	1.40	Class A Amp	250	-7.0	--	--	6.3	11400	2200	25	--	--
								90	-2.5	--	--	2.5	14700	1700	25	--	--
956	Variable Mu Pentode R. F. Amp	6.3	0.15	3.4	3.0	0.007	Class A Amp	250	-3.0	100	2.7	6.7	700000	1800	1440	--	--
							Mixer	250	-10.0	100	--	--	Osc. Peak Volts -7 min.				--
957	Triode Det., Amp., Osc.	1.25	0.05	0.3	0.7	1.20	Class A Amp	135	-5.0	--	--	2.0	20800	650	13.5	--	--
958	Triode AF Amp. Osc	1.25	0.1	0.6	0.8	2.60	Class A Amp	135	-7.5	--	--	3.0	10000	1200	12	--	--
958A	Triode AF Amp. Osc.	1.25	0.1	0.6	0.8	2.60	Class A Amp	135	-7.5	--	--	3.0	10000	1200	12	--	--
959	Pentode Detector, Amp	1.25	0.05	1.8	2.5	0.015	Class A Amp	145	-3.0	67.5	0.4	1.7	800000	600	480	--	--
1201	U. H. F. Triode	6.3	0.15	3.6	2.8	1.50	Class A Amp	180	-3	--	--	5.5	12000	--	36	--	--
1201A	U. H. F. Triode	6.3	0.15				Class A Amp	180	-3.0	--	--	5.5	120000	--	36	--	--
1203	U. H. F. Diode	6.3	0.15				UHF Diode Detector	10 V. RMS		--	--	9.0	Resonant frequency 613 Meg.				
1203A	U. H. F. Diode	6.3	0.15				UHF Diode Detector	10 V. RMS		--	--	9.0	Resonant frequency 613 Meg.				
1204	Sharp Cutoff Pentode	6.3	0.15	3.5	4.0	0.06	Class A Amp	250	-2	100	0.6	1.75	800000	1200	--	--	--
1206	Dual Tetrode	6.3	0.30	3.4	2.6	0.15	R. F. Amp"	250	-2.5	100	0.8	4.5	225000	2100	--	--	--

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

955



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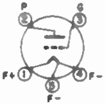

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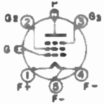

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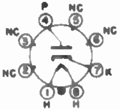

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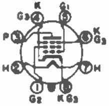

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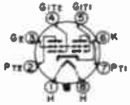

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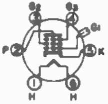

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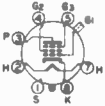

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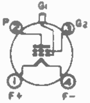

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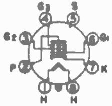

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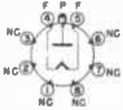

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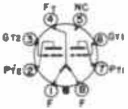
Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
1221	Pentode RF Amp	6.3	0.3	--	--	--	Class A Amp	250	-3.0	100	0.5	2.0	1500000	1225	1500	non microphonic	
1223	Sharp Cutoff Pentode	6.3	0.3	--	--	--	Class A Amp	250	-3.0	100	0.5	2.0	1500000	1225	1500	--	--
1229	Tetrode	2.0	0.06	--	--	--	Class A Amp	Special type 32 for low grid-current applications									--
1230	Triode	2.0	0.06	3.0	2.1	6.0		Special type 30 for low grid-current applications									--
1231	Pentode Amp	6.3	0.45	8.5	6.5	.015	Class A Amp	300	200^1	150	2.5	10	700000	5500	3850	--	--
1232	Sharp Cutoff Pentode	7.0	0.48	9	7	.007	Class A Amp	250	-2.0	100	2.0	6.0	800000	4500	--	--	--
1247	Diode	0.7	0.065	--	--	--	R. F. Probe	--	--	Max. A.C. volts - 300 rms D.C. plate current - 0.4 MA.							
1273	Nonmicrophonic Pentode	7.0	0.32	6.0	6.5	.007	Class A_1 Amp	250	-3.0	100	0.7	2.2	1000000	1575	--	--	--
								100	-1.0	100	1.8	5.7	400000	2275	--	--	--
1276	*Triode Power Amp	4.5	1.14	--	--	--	Class A Amp	250	-45	--	--	60	800	5250	4.2	2500	3.5
1280	Pentode	12.6	0.15	6.0	6.5	.007	Class A_1 Amp	250	-3.0	100	0.7	2.2	1000000	1575	Special non microphonic		
1284	U.H.F. Pentode	12.6	0.15	5.0	6.0	0.01	Class A Amp	250	-3.0	100	.2.5	9.0	800000	2000	--	--	--

1291	U. H. F. Twin Triode	2. 8^{21}	0. 11	1. 4	2. 6	2. 6	Class A Amp	90	0	--	--	5. 2	11350	1850	21	--	--
1293	U. H. F. Triode	1. 4	0. 11	1. 7	3. 0	1. 7	Class A Amp	90	0	--	--	4. 7	10750	1300	14	--	--
1294	U. H. F. Diode	1. 4	0. 15	--	--	--	U. H. F. Detector	Max RMS voltage per plate - 30 Max. D. C. output current - 340 MA.									
1299	U. H. F. Tetrode	2. 8^{21}	0. 11	7. 5	6. 5	0. 30	Class A Amp	135	-6	90	0. 7	5. 7	--	2200	--	13000	500
1603	Sharp Cutoff Pentode	6. 3	0. 3	--	--	--	Class A Amp	250	-3. 0	100	0. 5	2. 0	1500000	1225	1500	--	--
1609	Pentode Amp	1. 1	0. 25	--	--	--	Class A Amp	135	-1. 5	67. 5	0. 65	2. 5	400000	725	300	--	--
1611	Pentode Power Amp	6. 3	0. 7	--	--	--	Audio Amp	250	-16. 5	250	6. 5	36^{4}	80000	2500	200	7000	3. 2
1612	Pentode Amp	6. 3	0. 3	7. 5	11	0. 001	Class A Amp	250	-3. 0	100	6. 5	5. 3	600000	1100	880	--	--
1620	Sharp Cutoff Pentode	6. 3	0. 3	--	--	--	Class A Amp	250	-3. 0	100	0. 5	2. 0	1. 5meg	1225	1500	--	--
1621	Power Amp Pentode	6. 3	0. 7	--	--	--	Class AB$_2$ Amp^{E}	300	-30. 0	300	6. 5/13	38/69	--	--	--	4000^{5}	5. 0
							Class A$_1$ Amp$^{2-5}$	330	500^{1}	--	--	55/59	--	--	--	5000^{5}	2. 0
1622	Beam Power Amp	6. 3	0. 9	--	--	--	Class A$_1$ Amp	300	-20. 0	250	4/10. 5	86/125	--	--	--	4000	10. 0

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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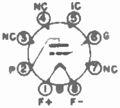

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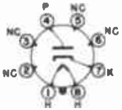

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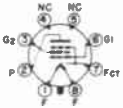

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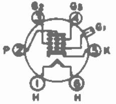

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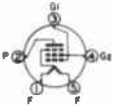

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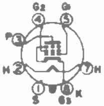

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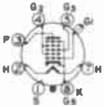

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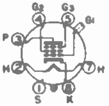

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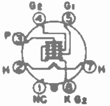

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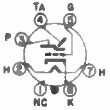

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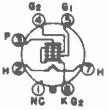

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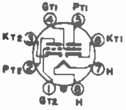

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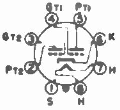

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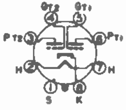

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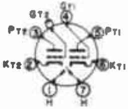

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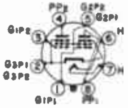

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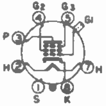

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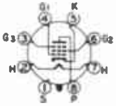

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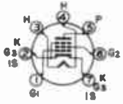

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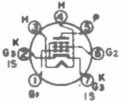
Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
1629	Electron-Ray Tube	12.6	0.15	--	--	--	Indicator Tube	250	0	--	--	0.25	Target Current 4 MA.				
1631	Beam Power Amp	12.6	0.45	--	--	--	Class A Amp	250	170[1]	250	5.4/7.2	75/78	--	--	--	2500	6.5
								300	220[1]	200	3.0/4.6	51/54.5	--	--	--	4500	6.5
1632	Beam Power Amp	12.6	0.6	--	--	--	Class A Amp	110	-8.0	110	3.5/10.5	45/48	10000	8000	80	2000	2.2
1633	Twin Triode	25	0.15	--	--	--	Class A Amp	250	-8.0	--	--	9.0[6]	7700	2600	20	--	--
1634	Twin Triode	12.6	0.15	--	--	--	Class A Amp	250	-2.0	--	--	2.0	53000	1325	70	--	--
1635	Twin Triode Amp	6.3	0.6	--	--	--	Class B Amp	400	0	--	--	10/63	--	--	--	14000	17
1642	Twin Triode Amp	6.3	0.6	--	--	--	Class A Amp	250	-16.5	--	--	8.3	7600	1375	10.4	--	--
1644	Twin Pentode	12.6	0.15	--	--	--	Class A Amp	180	-9.0	180	2.8/4.6	13	160000	2150	--	10000	1.0
1851	TV Amp Pentode	6.3	0.45	11.5	5.2	0.02	Class A Amp	300	-2.0	150	2.5	10	750000	9000	6750	--	--
1852	TV Amp Pentode	6.3	0.45	11	5	0.015	Class A Amp	300	160[1]	150	2.5	10	1000000	9000	6750	--	--
1853	TV Amp Pentode	6.3	0.45	8	5	0.015	Class A Amp	300	-3.0	200	3.2	12.5	700000	5000	3500	--	--
5590	Pentode	6.3	0.15	3.4	2.9	0.01	Class A_1 Amp	90	820[1]	90	1.4	3.9[1]	300000	2000	--	--	--

5591	R. F. Pentode	6.3	0.15	3.9	2.85	0.01	Class A_1 Amp	180	200^1	120	2.4	1.7	690000	5100	3500	--	--
5633	Remote Cutoff Pentode	6.3	0.15	4.0	2.8	0.01	Class A_1 Amp	100	150^1	100	2.8	7.0	200000	3400	--	--	--
5634	Sharp Cutoff Pentode	6.3	0.15	4.4	2.8	0.01	Class A_1 Amp	100	150^1	100	2.5	6.5	240000	3500	--	--	--
5637	Triode	6.3	0.15	2.6	0.7	1.4	Class A_1 Amp	100	820^1	--	--	1.4	26000	2700	70	--	--
5638	Audio Pentode	6.3	0.15	4.0	3.0	0.22	Class A_1 Amp	100	270^1	100	1.25	4.8	150000	3300	--	--	--
5640	Audio Beam Tetrode	6.3	0.45	--	--	--	Class A_1 Amp	100	-9	100	2.2	31.0	15000	5000	--	3000	1.25
5645	Triode	6.3	0.15	2.0	1.0	1.8	Class A_1 Amp	100	560^1	--	--	5.0	7400	2700	20	--	--
5687	Double Triode	12.6 6.3	.45 .90	4	0.45	3.1	Class A_1 Amp	120	-2	--	--	34	2000	10000	20	--	--
								180	-7	--	--	23	2750	6400	17.5	--	--
								250	-12.5	--	--	16	4000	4100	16.5	--	--
5691	Hi-Mu Twin Triode	6.3	0.6	2.4^7	2.3^7	3.6^7	Class A Amp	250	-2	--	--	2.3^8	44000	1600	70	--	--
				2.7^8	2.7^8	3.6^8											
5692	Med.-Mu Twin Triode	6.3	0.6	2.3^7	2.5^7	3.5^7	Class A Amp	250	-9	--	--	6.5^8	9100	2200	18	--	--
				2.6^8	2.7^8	3.3^8											
5693	Sharp Cutoff Pentode	6.3	0.3	5.3	6.2	0.005	Class A Amp	250	-3	100	0.85	3.0	1000000	1650	--	--	--

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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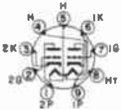

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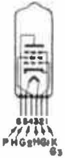

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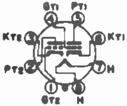

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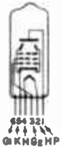

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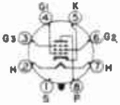

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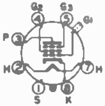

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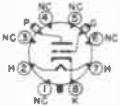

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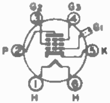

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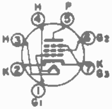
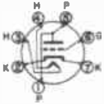


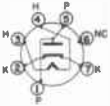
9001
9003



9002

9004

9005

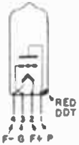


9006

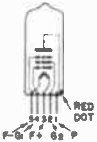
Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[34] Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
7000	Low Noise Amp	6. 3	0. 3	--	--	--	Class A Amp	250	-3. 0	100	0. 5	2. 0	1. 5meg	1225	1500	--	--
7193	Triode Amp	6. 3	0. 3	--	--	--	Class A Amp	300	-10. 5	--	--	11. 0	6600	3000	20	--	--
7700	Sharp Cutoff Pentode	6. 3	0. 3	--	--	--	Class A Amp	250	-3. 0	100	0. 5	2. 0	1500000	1225	1500	--	--
9001	Sharp Cutoff Pentode	6. 3	0. 15	3. 6	3. 0	0. 01	Class A Amp	250	-3. 0	100	0. 7	2. 0	1 meg +	1400	--	--	--
							Mixer	250	-5. 0	100	Osc. peak volt. 4 volts			550	--	--	--
9002	Triode Detector Amp., Osc.	6. 3	0. 15	1. 2	1. 1	1. 40	Class A Amp	250	-7. 0	--	--	6. 3	11400	2200	25	--	--
								90	-2. 5	--	--	2. 5	14700	1700	25	--	--
9003	Remote Cutoff Pentode	6. 3	0. 15	3. 6	3. 0	0. 01	Class A Amp	250	-3. 0	100	2. 7	6. 7	700000	1800	--	--	--
							Mixer	250	-10. 0	100	Osc. peak voltage 9 v.			600	--	--	--
9004	U. H. F. Diode	6. 3	0. 15	--	--	--	Detector		Max. A. C. voltage - 117 Max. D. C. output current - 5 MA.								
9005	U. H. F. Diode	3. 6	0. 165	--	--	--	Detector		Max. A. C. voltage - 117 Max. D. C. output current - 1 MA.								
9006	U. H. F. Diode	6. 3	0. 15	--	--	--	Detector		Max. A. C. voltage - 270 Max D. C. output current - 5 MA.								

CK501	Pentode Voltage Amp	1.25	.033	--	--	--	Class A Amp	30	0	30	0.06	0.3	1000000	325	--	--	--
CK501X								45	-1.25	45	0.055	0.28	1500000	300	--	--	--
CK502	Pentode Output Amp	1.25	.033	--	--	--	Class A Amp	30	0	30	0.13	0.55	500000	400	--	60000	.003
CK502AX	Miniature Pentode	1.25	.030	--	--	--	Power Output	45	-1.5	45	0.11	0.45	350000	500	--	100000	.006
CK503	Pentode Output Amp	1.25	.033	--	--	--	Class A Amp	30	0	30	0.33	1.5	150000	600	--	20000	.006
CK503AX	Miniature Pentode	1.25	.03	--	--	--	Power Output	45	-2.5	45	0.18	0.5	400000	475	--	50000	.010
CK504	Pentode Output Amp	1.25	.033	--	--	--	Class A Amp	30	-1.25	30	0.09	0.4	500000	350	--	60000	.003
CK505	Pentode Voltage Amp	.625	.03	--	--	--	Class A Amp	30	0	30	0.07	0.17	1100000	140	--	--	--
								45	-1.25	45	0.08	0.2	2000000	150	--	--	--
CK505AX	Miniature Pentode	.625	.03	--	--	--	Voltage Amp	30	0	30	0.07	0.2	500000	180	VG 35	1000000	--
CK506	Pentode Output Amp	1.25	.05	--	--	--	Class A$_1$ Amp	45	-4.5	45	0.4	1.25	120000	500	--	30000	.025
CK506AX	Miniature Pentode	1.25	.050	--	--	--	Power Output	45	-4.5	45	0.4	1.25	120000	500	--	30000	.025
CK507	Pentode Output Amp	1.25	.05	--	--	--	Class A$_1$ Amp	45	-2.5	45	0.21	0.6	360000	500	--	50000	.010
CK507AX	Miniature Pentode	1.25	.05	--	--	--	Power Output	45	-2.5	45	0.21	0.6	300000	500	--	50000	.012
CK509	Triode Voltage Amp	.625	.03	--	--	--	Class A Amp	45	0	--	--	0.15	150000	160	16	1000000	--
CK509AX	Miniature Triode	.625	.030	--	--	--	Voltage Amp	45	0	--	--	0.15	150000	160	VG 16	1000000	--
CK510	Dual Space Charge Tetrode	.625	.05	--	--	--	Class A Amp	45	0	0.2	200μa	60μa	500000	65	32.5	--	--
CK510AX	Twin Space Charge Tetrode	.625	.50	--	--	--	Class A Amp	45	0		0.2	.060	500000	65	32.5	--	--
CK512	Low Microphonic Pentode	.625	.02	--	--	--	Voltage Amp	22.5	0	22.5	0.04	0.125	--	160	--	--	--
CK515BX	Triode Voltage Amp	.625	.03	--	--	--	Class A Amp	45	0	--	--	0.15	--	160	24	1000000	--

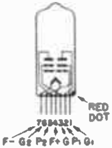
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



CK509AX

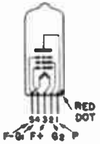


CK501
CK501X
CK502AX
CK503
CK503AX
CK504
CK505
CK505AX
CK506AX
CK507AX



CK510AX

RECEIVING TUBES



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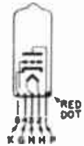
CK521AX
CK522AX
CK569AX



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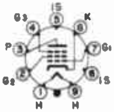
CK619CX

CK551AXA



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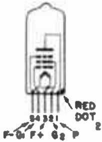

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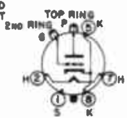
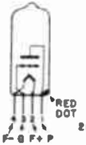
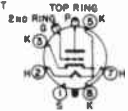


GL2C44
GL464A



CK556AX
CK568AX



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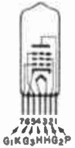
GL446B



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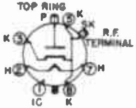

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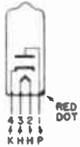


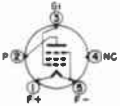
CK606BX

Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm Micro-mhos	Amp Factor	Load Resistance Ohms	Output Watts
		Volts	Amps	In	Out	Plate Grid											
CK520AX	Audio Pentode	.625	.05	--	--	--	Class A_1 Amp	45	-2.5	45	.07	0.24	--	180	--	--	.0045
CK521AX	Audio Pentode	1.25	.05	--	--	--	Class A_1 Amp	22.5	-3	22.5	0.22	0.8	--	400	--	--	.006
CK522AX	Audio Pentode	1.25	.02	--	--	--	Class A_1 Amp	22.5	0	22.5	0.08	0.3	--	450	--	--	.0012
CK551AXA	Diode Pentode	1.25	.03	--	--	--	Detector Amp	22.5	0	22.5	0.04	0.17	--	235	--	--	--
CK553AX	R. F. Pentode	1.25	.05	--	--	--	Class A_1 Amp	22.5	0	22.5	0.13	0.42	--	550	--	--	--
CK556AX	U. H. F. Triode	1.25	.125	--	--	--	R. F. Osc.	135	-5	--	--	4.0	--	1600	--	--	--
CK568AX	U. H. F. Triode	1.25	.07	--	--	--	R. F. Osc.	135	-6	--	--	1.9	--	650	--	--	--
CK569AX	R. F. Pentode	1.25	0.05	--	--	--	Class A_1 Amp	67.5	0	67.5	0.48	1.8	--	1100	--	--	--
CK605CX	Sharp Cutoff Pentode	6.3	0.2	--	--	--	Class A_1 Amp	120	-2	120	2.5	7.5	--	5000	--	--	--
CK606BX	Single Diode	6.3	0.15	--	--	--	Detector	150 AC	--	--	--	9.0 DC	--	--	--	--	--
CK608CX	U. H. F. Triode	6.3	0.2	--	--	--	500-MC. Osc.	120	-2	--	--	9.0	--	5000	--	--	0.75
CK619CX	Hi-Mu Triode	6.3	0.2	--	--	--	Class A_1 Amp	250	-2	--	--	4.0	--	4000	--	--	--
EF50	Sharp Cutoff Pentode	6.3	0.3	8	5	.007	I. F. -R. F. Amp	250	150'	250	3.1	10	600000	6300	--	--	--
GL2C44	U. H. F. Triode	6.3	0.75	--	--	--	Class A Amp and Mod.	250	100'	--	--	25.0	--	7000	--	--	--
GL446A GL446B	U. H. F. Triode	6.3	0.75	--	--	--	Osc. Amp. or Converter	250	200'	--	--	15.0	--	4500	45	--	--
GL464A	U. H. F. Triode	6.3	0.75	--	--	--	Class A Amp and Mod.	250	100'	--	--	25.0	--	7000	--	--	--
GL559	U. H. F. Diode	6.3	0.75	--	--	--	Detector	5.0	--	--	--	24.0	--	--	--	--	--

HY113	Triode Amp	1.4	.07	--	--	--	Class A Amp	45	-4.5	--	--	0.4	25000	250	6.3	40000	.0065
HY114	Triode	1.4	.12	--	--	--	UHF Osc., Det., Amp.	130	Osc. grid current 3 MA.			15.0	20000	1000	20	--	--
HY115	Pentode Voltage Amp	1.4	.07	--	--	--	Class A Amp	45	-1.5	22.5	0.008	0.03	5200000	58	300	--	--
								90	-1.5	45	0.1	0.48	1300000	270	370	--	--
HY123	Triode Amp	1.4	.07	--	--	--	Class A Amp	45	-4.5	--	--	0.4	25000	250	6.3	40000	.0065
HY125	Pentode Power Amp	1.4	.07	--	--	--	Class A Amp	45	-3.0	45	0.2	0.9	825000	310	255	50000	.0115
								90	-7.5	90	0.5	2.6	420000	450	190	28000	.09
HY145	Pentode Voltage Amp	1.4	.07	--	--	--	Class A Amp	45	-1.5	22.5	0.008	0.03	5200000	58	300	--	--
								90	-1.5	45	0.1	0.48	1300000	270	370	--	--
HY155	Pentode Power Amp	1.4	.07	--	--	--	Class A Amp	45	-3.0	45	0.2	0.9	825000	310	225	50000	.0115
								90	-7.5	90	0.5	2.6	420000	450	190	28000	.09
HY245	Pentode Voltage Amp	1.25	.028	--	--	--	Class A Amp	45	0	45	0.2	0.4	1000000	375	--	--	--
HY255	Pentode Power Amp	1.25	.028	--	--	--	Class A Amp	45	-1.5	45	0.35	1.1	--	450	--	--	--
HY615	Triode	6.3	.15	--	--	--	UHF Osc., Det., Amp.	300	Osc. grid current 3 MA.			20	20000	2200	22.0	--	4.0
LA	Pentode Power Amp	6.3	.3	--	--	--	Class A Amp	100	-6.5	100	1.6	9.0	83250	1200	--	110000	.31
								180	-12.0	180	3.9	22.0	45500	2200	--	8000	1.40
M54	Tetrode Power Amp	.625	.04	--	--	--	Class A Amp	30	0	30	.06	0.5	130000	200	26	35000	.005
M64	Tetrode Voltage Amp	.625	.02	--	--	--	Class A Amp	30	0	--	--	0.03	200000	110	25	--	--
M74	Tetrode Voltage Amp	.625	.02	--	--	--	Class A Amp	30	0	7.0	0.01	0.02	500000	125	70	--	--
NU2C35	Special Hi-Mu Triode	6.3	.3	5.2	2.3	0.62	Shunt Volt. Regulator	8000	-200	--	--	5.0	525000	950	500	--	--

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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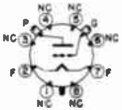
HY123



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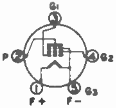

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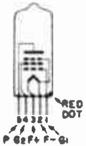
HY145
HY155



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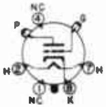

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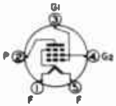

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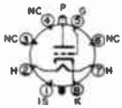
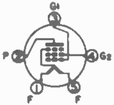
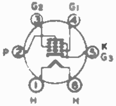


NU2C35

RECEIVING TUBES



PZ



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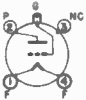

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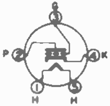

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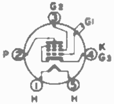
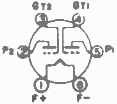


RK17

RK24
RK42



RK43

SD917A

SD828A

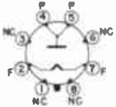
Designation	Type	Cathode		Capacitance - MMF			Application	Plate Volts	Grid Volts	Screen Volts	Screen Ma.	Plate Ma	Plate Resistance Ohms	Gm[16] Micro-mhos	Output Watts	Load Resistance Ohms	Amp Factor
		Volts	Amps	In	Out	Plate Grid											
PZ	Power Amp Pentode	2.5	1.75	--	--	--	Class A Amp	250	-16.5	250	6.0	31.0	60000	2500	150	7000	2.7
PZH	Power Amp Pentode	2.5	1.75	--	--	--	Amplifier	250	-16.5	250	6.5	34.0	80000	2500	--	7000	3.2
								285	-20.0	285	7.0	38.0	78000	2550	--	7000	4.8
RK15	Triode Power Amp	2.5	1.75	--	--	--	Class B Amp[16]	400	0	--	--	12	Power output for 2 tubes			5800	20.0
RK16	Triode Power Amp	2.5	2.0	--	--	--	Class A Triode[13]	250	-28.0	--	--	26.0	2300	2600	6.0	5000	1.25
RK17	Pentode Power Amp	2.5	2.0	--	--	--	Class A Amp	250	-16.5	250	6.5	34.0	100000	2200	220	7000	3.0
RK24	Triode	2.0	0.12	--	--	--	Class A Amp	180	-13.5	--	--	8.0	5000	1600	8.0	12000	0.25
RK42	Triode Amp	1.5	0.6	--	--	--	Class A Amp	180	-13.5	--	--	3.1	10300	900	9.3	--	--
RK43	Twin Triode Amp	1.5	0.12	--	--	--	Class A Amp	135	-3	--	--	4.5	14500	900	13	--	--
SD917A	Triode	6.3	0.15	2.6	0.7	1.4	Class A_1 Amp	100	820[1]	--	--	1.4	26000	2700	70	--	--
SD828A	Audio Pentode	6.3	0.15	4.0	3.0	0.22	Class A_1 Amp	100	270[1]	100	1.25	4.8	150000	3300	--	--	--
SD828E	Sharp Cutoff Pentode	6.3	0.15	4.4	2.8	0.01	Class A_1 Amp	100	150[1]	100	2.5	6.5	240000	3500	--	--	--

SN944	Remote Cutoff Pentode	6.3	0.15	4.0	2.8	0.01	Class A_1 Amp	100	150[1]	100	2.8	7.0	200000	3400	--	--	--
SN947C	Audio Beam Tetrode	6.3	0.45	--	--	--	Class A_1 Amp	100	-9	100	2.2	31.0	15000	5000	--	3000	1.25
SN955B	Dual Triode	6.3	0.45	2.8	1.0	1.3	Class A_1 Amp[11]	100	100[1]	--	--	5.5	8000	4250	34	--	--
SN957A	Triode	6.3	0.15	2.0	1.0	1.8	Class A_1 Amp	100	560[1]	--	--	5.0	7400	2700	20	--	--
SN1006	Triode	6.3	0.15	--	--	--	Class A_1 Amp	100	820[1]	--	--	1.4	29000	2400	70	--	--
SN1007A	Mixer	6.3	0.15	5.0	2.8	.003	Mixer	100	150[1]	100	5.0	4.0	230000	900	--	--	--
VT52	Triode	7.0	1.18	5.0	3.0	7.7	Class A_1 Amp	220	-43.5	--	--	29.0	1650	2300	3.8	3800	1.0
X6030	Diode	3.0	0.6	--	--	--	Noise Diode	1400	--	--	--	0.535	--	--	--	--	--
XXB	Twin Triode Frequency Converter	2.8	0.05	--	--	--	Converter	90	0	--	--	4.5[7]	11200[7]	1300[7]	14.5	--	--
		1.4	0.10									4.5[8]	11200[8]	1300[8]			
		3.2	--						-3	--	--	1.4[7]	1900[7]	760[7]	14.5	--	--
		1.6	--									1.4[8]	1900[8]	760[8]		--	--
XXD	Twin Triode	12.6	0.15	--	--	--	Class A Amp	250	-10	--	--	9.0	--	2100	16	--	--
XXL	Triode Osc.	7.0	0.32	--	--	--	Osc.	250	-8.0	--	--	8.0	--	2300	20	--	--
XXFM	Twin-Diode Triode	6.3	0.3	--	--	--	Class A Amp	250	-1	--	--	1.9	6700	1500	100	--	--
								100	0	--	--	1.2	85000	1000	85	--	--

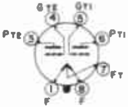
BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

VT52



X6030



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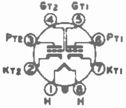

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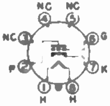

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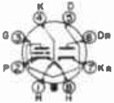
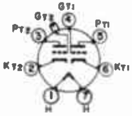
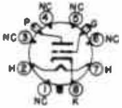


XXFM

TRANSMITTING TUBES

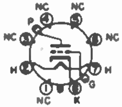


2C21

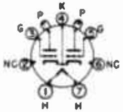


2C22

2C25



2C26A



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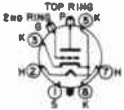


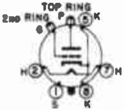
2C40
2C43

Designation	Type	Cathode		Amp Factor	Maximum			Ratings				Interelectrode Cap.[37]			Typical					Operations				
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
2C21[23]	Triode	6.3	0.6		5.0	250	40	12				1.6″	1.6″	2.0″	C-Amp, Osc.[23]	250	40	-60	12				1.0		7
2C22	Triode	6.3	0.3	20	3.5	500						2.2	3.6	0.7	C-Telegraphy										
2C25	Triode	7.0	1.18	8.0	15	450	60	15				6.0	8.9	3.0	C-Amp, Osc.	450	65	-100	15				3.2		19
															C-Telephony	350	50	-100	12				2.2		12
2C26A	Triode	6.3	1.10	16.3	10						250	2.6	2.8	1.1											
2C34	Triode	6.3	0.8	13	10	300	80	20			250	3.4	2.4	0.5	C-Amp, Osc.[23]	300	80	-36	20				1.8		16
2C39	Triode	6.3	1.1	100	100	1000	60	40			500	6.5	1.95	0.03		600	60	-35	40				5.0		20
2C40	Triode	6.3	0.75	36	6.5	500	25				500	2.1	1.3	0.05	C-Amp, Osc.	250	20	-5	0.3						0.075
2C43	Triode	6.3	0.9	48	12	500	40				1250	2.9″	1.7″	0.05″	C-Amp, Osc.	470	38[2]								9[2]

2C44	Triode	6.3	0.75		5.0	500	40				500	2.7	2.0	0.1	C-Amp Osc	250									
2C45	Triode	7.0	1.18	3.6	10	250	40					5.0	7.7	3.0	A, Audio	250	29	-40							1
2E22		6.3	1.5		30	750			250	10		13	0.2	8.0	C-Amp, Osc	500	100	-60	6.0	250	16	22.5	0.55		34
															C-Amp, Osc	750	100	-60	6.0	250	16	22.5	0.55		53
															Supp-Modul-Amp	750	55	-65	6.5	250	29	-90	0.6		16.5
2E24	Beam Tetrode	6.3	0.65		9.0	500			200	2.3	125	8.5	0.11	6.5	C-Telephony	400	50	-45	2.5	180	8.0		0.15		13.5
																500	54	-45	2.5	180	8.0		0.16		18.0
					13.5	600			200	2.5					C-Telegraphy	400	75	-45	3.0	200	10.0		0.19		20
																600	66	-50	3.0	195	10		0.21		27
2E25	Beam Tetrode	6.0	0.8		15	450			250	4.0	125	8.5	0.15	6.7	C-Amp Osc.	450	75	-45	3.0	250	15		0.4		24
															C-Telephony	400	60	-45	3.0	200	12		0.4		16
2E26	Beam Tetrode	6.3	0.8		13.5	600			200	2.5	125	13	0.2	7.0	C-Telegraphy	600	66	-45	3.0	185	10		0.17		27
															C-Telephony	500	54	-50	2.5	180	9.0		0.15		18
					9.0	500			200	2.3					AB$_2$-Audio[2]	500	22/150	-15		125	32[4]		0.36[4]	8000	54

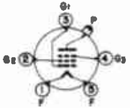
BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



2C44

2C45



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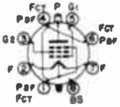

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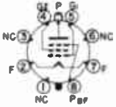

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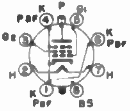
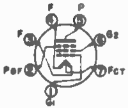


2E26

TRANSMITTING TUBES



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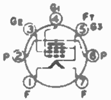
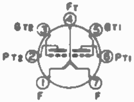
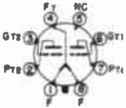


3A4



3A5



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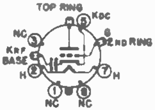

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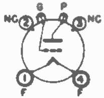


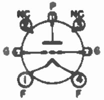
3C24

Designation	Type	Cathode		Amp Factor	Maximum				Ratings			Interelectrode Cap.[37]			Typical					Operations					
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
2E30	Beam Pentode	6.0	0.7		10	250			250	2.5	160	10	0.5	4.5	C-Telegraphy	250	50	-50	2.5	200	10		0.2		7.5
															AB$_2$- Audio[2]	250	40/120	-30	2.3	250	4/20		0.2	3800	17
3A4		1.4 2.8	0.2 0.1		2.0	150			135	0.9	10	4.8	0.2	4.2	C-Telegraphy	150	18.3	-28	0.13	135	6.5	0			1.2
3A5[23]	Triode	1.4 2.8	0.22 0.11	15	2.0	150	30	5.0			40	0.9"	3.2"	1.0"	C-Amp., Osc[23]	150	30	-35	5.0				0.2		2.2
3B7[23]	Triode	1.4 2.8	0.22 0.11	20		180	25				125	1.4"	2.6"	2.6"	C-Telegraphy	180	25	0							2.8
3C22	Triode	6.3	2.0	40	125	1000	150	70			500	4.9	2.4	0.05	C-Amp., Osc.	1000	150	-200	70						65
3C24	Triode	6.3	3.0	23	25	2000	75	25			60	2.0	1.6	0.2	C-Amp., Osc.	2000	63	-170	17				4.5		100
												1.7	1.5	0.3		1500	67	-110	15				3.1		75
																1000	72	-80	15				2.6		47
															B, Audio[2]	2000	16/80	-85	290[5]				1.1[4]	55500	110

3C28	Triode	6.3	3.0	23	25	2000	75	25			100	2.1	1.8	0.1	C-Amp., Osc.	2000	63	-170	17				4.5		100
																1500	67	-110	15				3.1		75
																1000	72	-80	15				2.6		47
3C34	Triode	6.3	3.0	23	25	2000	75	25			60	2.5	1.7	0.4	C-Amp., Osc.	2000	63	-170	17				4.5		100
																1500	67	-110	15				3.1		75
																1000	72	-80	15				2.6		47
3C37	Triode	6.3	2.5	23	150	1000					500	4.2	3.5	0.6											
3D6		2.8 1.4	0.11 0.22			150			135		50	7.5	0.3	6.5	C - Amp Telegraphy	180	23	-20		135	6.0				1.4
3D23	Beam Tetrode	6.3	3.0		35						250	6.5	0.2	1.8	C-Telegraphy	1500	110	-300	15	375	22		45		130
															C-Telephony	1000	85	-200	10	300	14		2.0		60
3D24	Beam Tet	6.3	3.0		45	2000			400	10	125	6.5	0.2	2.4	C-Amp., Osc.	2000	90	-300	10	375	20		4.0		140
3DX3		6.3	3.0		25	1500			200		250				C-Telegraphy	1000	75	-155	2.8	200			0.57		50

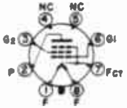
BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 745



3C28

3C34



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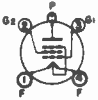

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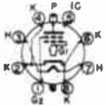
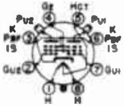


3D24

3DX3

TRANSMITTING TUBES



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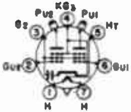
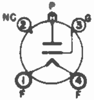
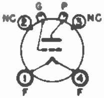


3E29



3-25A3
3-50A4



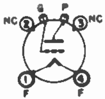
3-25D3
3-50D4
3-50G2

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations									
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
3E22[23]	Twin Beam	12.6	0.8		30	560			225	6.0		14[11]	0.22[11]	8.5[11]	C-Telegraphy[23]	600	160	-55	7.0	200	20		0.45		72
	Tetrode	6.3	1.6												C-Telephony[23]	560	160	-50	6.5	200	20		0.4		67
3E29[23]	Twin	12.6	1.125		30	750			225	6	200	14.5[11]	0.12[11]	7.0[11]	C-Grid Modulat.	500	120	-38	2	200	10		0.5		23
	Beam	6.3	2.25		28	600			225	7					C-Telephony	425	212	-60	11.0	200	35		0.8		63
	Pentode				40	750			240	7					C-Telegraphy	500	240	-45	12.0	200	32		0.7		83
3-25A3	Triode	6.3	3.0	24	25	2000	75	25			60	2.7	1.5	0.3	C-Amp., Osc.	2000	63	-130	18				4.0		100
																1500	67	-95	13				2.2		75
																1000	72	-70	9				1.3		47
															B - Audio[2]	2000	16/80	-80	270[9]				0.7[4]	55500	110
3-25D3	Triode	6.3	3.0	23	25	2000	75	25			60	2.0	1.6	0.2	C-Amp., Osc.	2000	63	-170	17				4.5		100
												1.7	1.5	0.3		1500	67	-110	15				3.1		75
																1000	72	-80	15				2.6		47
															B - Audio[2]	2000	16/80	-85	290[9]				1.1[4]	55500	110
3-50A4	Triode	5.0	4.0	39	50	2000	150	50			100	4.1	1.8	0.3	C-Telegraphy	2000	125	-135	45				13		200
															C-Telephony	1500	100	-120	30				5.0		120
3-50D4											100	2.5	1.8	0.4	B - Audio[2]	2000	34/167	-40	255[9]				4.0[4]	27500	235
3-50G2	Triode	7.5	3.25	10.6	50	1250	125	25			60	2.2	2.6	0.3	C-Telegraphy	1250	125	-225	20				7.5		115
															C-Telephony	1250	125	-325	20				10		115
															Grid Modul.-Amp	1250	60	-200	2.0				3.0		25

3-75A2	Triode	5.0	6.25	12	75	3000	225	35			40	2.6	2.4	0.4	C-Telegraphy	2000	150	-300	21				8		225
															B - Audio[2]	2000	50/250	-160	535[9]				5 [4]	18000	350
3-75A3	Triode	5.0	6.25	20	75	3000	225	40			40	2.7	2.3	0.3	C-Telegraphy	2000	150	-200	32				10		225
															B - Audio[2]	2000	50/225	-90	350[9]				3 [4]	19300	300
3-100A2	Triode	5.0	6.3	14	100	3000	225	50			40	2.3	2.0	0.4	C-Telegraphy	3000	165	-400	30				20		400
															C-Telephony										
															Grid Modul.-Amp	3000	00	-560	2.0				7.0		90
															B - Audio[2]	3000	40/215	-185	640[9]				6.0[4]	30000	450
3-100A4	Triode	5.0	6.3	40	100	3000	225	60			40	2.9	2.0	0.4	C-Telegraphy	3000	165	-200	51				18		400
															C-Telephony										
															Grid Modul.-Amp	3000	70	-400	3.0				7.0		100
															B - Audio[2]	3000	40/215	-65	335[9]				5.0[4]	31000	650
3-150A2	Triode	5/10	12.51 6.25	12	150	3000	450	75			40	4.5	4.4	0.7	C-Telegraphy	3000	250	-400	40				20		600
															B - Audio[2]	3000	65/335	-260	675[9]				3.0[4]	20400	700
3-150A3	Triode	5/10	12.51 6.25	20	150	3000	450	85			40	5.7	4.5	0.8	C-Telegraphy	3000	250	-300	70				27		600
															B - Audio[2]	3000	67/335	-150	430[9]				3.0[4]	20300	700

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



3-75A2
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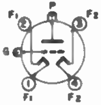
3-100A4



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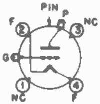
TRANSMITTING TUBES



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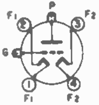

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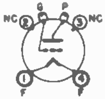


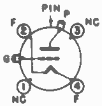
4C22

		Cathode			Maximum Ratings							Interelectrode Cap.[37]			Typical Operations										
Designation	Type	Volts	Amps	Amp Factor	Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
3-250A2	Triode	5. 0	10.5	14	250	4000	350	50			40	3. 7	3. 1	0. 7	C-Telegraphy	3000	335	-350	45				29		750
															C-Telephony	3000	335	-350	45				29		750
															B - Audio[2]	3000	100/500	-175	840[9]				17[4]	13000	1000
3-250A4	Triode	5. 0	10.5	37	250	4000	350	100			40	5. 0	2. 9	0. 7	C-Telegraphy	2000	350	-120	100				34		500
															C-Telephony	3000	330	-210	75				42		750
															Grid Modul., Amp	3000	125	-160	4. 5				20		125
															B - Audio[2]	3000	100/560	-65	460[9]				24[4]	12250	1150
3-300A2	Triode	5/10	25/ 12. 5	12	300	3000	900	150			40	8. 5	9. 1	0. 6	C Amplifier	1500	665	-250	90				33		700
															B - Audio[2]	3000	130/667	-260	650[9]				6. 0[4]	10200	1400
3-300A3	Triode	5/10	25/ 12. 5	20	300	3000	900	170			40	13. 5	10. 2	0. 7	C-Amplifier	1500	667	-125	115				25		700
															B - Audio[2]	3000	134/667	-150	420[9]				6. 0[4]	10200	1400
3X100A11	Triode	6. 3	1. 1	100	100	1000	60	40			500	6. 5	1. 95	0. 03		600	60	-35	40				5. 0		20
3X150A3	Triode	6. 3	2. 5	23	150	1000					500	4. 2	3. 5	0. 6											
3X2500A3	Triode	7. 5	48	20	2500	5000	2000	500			110	48	20	1. 2	C-Telegraphy	4000	1600	-360	420				237		5000
4C22	Triode	10	2	23	75	1750	150	30			30	3. 5	4. 5	1. 4	C-Telegraphy	1500	150	-200	18				6		170
															C-Telephony	1250	110	-250	21				8		105
															B - Audio	1750	270	-62					9	1600	360

4C32	Triode	10	4.5	30	200	3000	300	60			60	5.5	5.8	1.1	C-Amp., Osc.	2000	275	-165	20				10		400
															C-Telephony	2000	250	-200	20				15		375
4C34	Triode	11-12	4.0	23	200	3000	275	60			60	6.0	6.5	1.4	C-Telegraphy	3000	250	-400	28				16		600
															C-Telephony	2000	250	-300	36				17		385
															B - Audio^2	3000	60/360	-115	450^9				13^4	20000	780
4C36	Triode	5	7.5	29	125	4000					60	3.2	3.0	0.4	C-Amp., Osc.								18		480
4D21	Beam Tetrode	5	6.5		125	3000	225	15	400	20	120	10.8	.05	3.1	C-Telegraphy	3000	167	-150	9	350	30		2.5		375
															C-Telephony	2500	152	-210	9	350	30		3.3		300
															AB$_2$- Audio	300	260	-51		260	3.5		2.5	27700	520
4D22	Beam Tetrode	25.2	0.8		50	750			350	14	60	28	.27	13	C-Telegraphy	750	240	-100	12	300	26		1.5		135
		12.6	1.6													600	215	-100	10	300	30		1.25		100
4D23		5.0	7.5		150	4000			400		120	11.6	.06	4.35	C-Telegraphy	3000	200	-290	7	400	27		2.6		450
															C-Telephony	2500	180	-425	9	400	27		4		350
															AB$_2$- Audio^2	2500	284^4	-95		400	7^4		1.8^4	19100	460
4D32	Beam Tetrode	6.3	3.75		50	750			350	14	60	28	0.27	13	C-Telephony	600	220	-100	10		28		1.25		100
															AB$_2$- Audio^2	600	100/365	-25	70^9	250	26^4		0.45^4	3000	125
															C-Telephony	550	175	-100	6		17		0.6		70
4E27	Beam	5.0	7.5		75	4000			750	30	75	12	0.06	6.5	C-Telegraphy	2000	150	-200	6	500	11	60	1.4		230
															C-Telephony	1800	135	-130	8	400	11	60	1.7		178
															Supp-Mod-Amp	2000	55	-130	3.0	500	27	-300	0.4		35

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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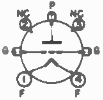

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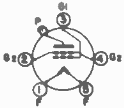
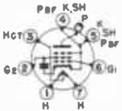


4D21
4D23



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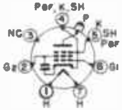

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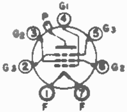
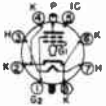


4E27

TRANSMITTING TUBES



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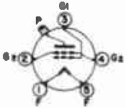
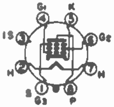
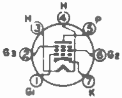


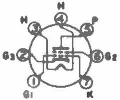
4-65A
4-125A
4-250A
4-400A



6AG7



6AK6



6AQ5

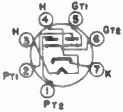
Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations										
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
4X150A	Tetrode	6.0	2.8		150	1000			300	15	165	14.1	.02	4.7	C-Telegraphy	1000	200	-80	7	250	39		0.69		148
																750	200	-80	6.5	250	37		0.63		110
																600	200	-75	6	250	35		0.52		85
4X500A	Beam Tet	5	13.5		500	4000	350	50	6.2	30	110	12.8	.05	5.6	C-Telegraphy	3000	600	-200	45	400	95		18		1180
4-65A	Beam Tetrode	6.0	3.5		65	3000	400			10	160	8.0	.08	2.1	C-Telegraphy	3000	115	-90	10	250	20		1.7		280
						2500	400								C-Telephony	2500	108	-150	8	250	16		1.9		225
						3000	600								AB_2 - Audio	1800	50/220	-35	180	250	0/25		2.2[4]	20000	270
4-125A	Beam Tetrode	5.0	6.2		125	3000			400	20	120	10.3	.03	3.0	C-Telegraphy	3000	167	-150	9	350	30		2.5		375
															C-Telegraphy	2500	150	-330	13	350	30		6		300
4-250A	Beam Tetrode	5.0	14.5		250	4000			600	50	85	12.7	.06	4.5	C-Telegraphy	4000	250	-250	13	500	22		4.1		750
																2500	325	-100	22	500	70		3.7		562
4-400A		5.0	14.5		400	4000			600	35	110	12.5	.12	4.7	C-Teleg or Phone	4000	270	-170	10	300	22.5		10		720
4-750A	Tetrode	7.5	20		750	6000	700					26.85	.24	7.78	C-Telegraphy										
6AG7	Beam Pent	6.3	0.65		9.0	375			250	1.5	10	13	.06	7.5	C-Telegraphy	375	30	-75	5.0	250	9.0				7.5
6AK6	Pentode	6.3	0.15		3.5	375			250	1.0	54	3.6	.12	4.2	C-Telegraphy	375	15	-100	3.0	250	4.0				4.0
6AQ5	Beam Tet	6.3	0.45		8.0	350			250	2.0	54	7.6	.35	6.0	C-Telegraphy	350	47	-100	5.0	250	7.0				11

6C4	Triode	6.3	0.15	18	5.0	350	25	8.0			54	1.8	1.6	1.3	C-Amp., Osc.	300	25	-27	7.0				0.35		5.5
6C24	Triode	11	12.1		600						160	4.6	4.4	3.2	B-Amplifier	3000	800	-95					30		1640
															C-RF CW	3000	500	-250	150				75		1100
															C-RF Modulat.	2500	400	-350	135				75		810
6F4	Triode	6.3	0.225	17	2.0	150	20	8.0			500	2.0	1.9	0.6	C-Amp., Osc.	150	20	-15	7.5				0.2		1.8
6F6 6F6G	Pentode	6.3	0.7		12.5	400			275	3.0		6.5	0.2	13	C-Telegraphy	400	50	-100	5.0	275	11				14
											10	8.0	0.5	6.5	C-Telephony	275	42	-35	2.8	200	10		.16		6.0
6J6[23]	Triode	6.3	0.45	32	1.5	300	30	16			250	2.2"	1.6"	0.4"	C-Telegraphy[23]	150	30	-10	16				.35		3.5
6L6	Beam Tetrode	6.3	0.9		21	400			300	3.5	10	10	0.4	12	C-Amp., Osc.	400	100	-125	5.0	300	12				28
6L6G												11.5	0.9	9.5	C-Telephony	325	65	-70	9.0	250			.8		11
6L6GX		6.3	0.9		21	500			300	3.5		11	1.5	7.0	C-Telegraphy	500	90	-50	2.0	250	9.0		.25		30
															C-Telephony	325	90	-45	3.0	225	9.0		.25		20
6N4	Triode	6.3	0.2	32	3.0	180	12				500	3.1	2.35	0.55	C-Amp., Osc.	100									
6N7[23]	Triode	6.3	0.8	35	5.5"	350	30"	5.0"			10				C-Amp., Osc.[23]	350	60	-100	10						14.5
6V6GT	Beam Tet	6.3	0.45		8.0	350			250	2.0	10	9.5	0.7	7.5	C-Telegraphy	350	47	-100	5.0	250	7.0				11
7C24	Triode	12.6	29	25	2000	5000	1400	300			110	19	16	45	C-Telegraphy	5000	1000	-400	275				710		4550
															C-Telephony	4000	800	-350	250				525		2600
															B - Audio	5000	2000	-200					110	6000	7000

BOTTOM VIEWS SHOWN

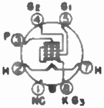
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

6C4

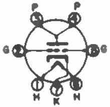


6J6

6C24

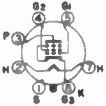


6L6
6L6G
6L6GX
6V6GT



6F4

6N4



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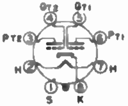
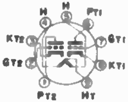
6F6G



6N7

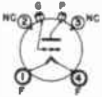
TRANSMITTING TUBES

10
10Y

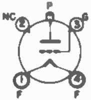


12AU7

15E



24G
25TG
35TG



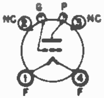
25T
35T

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations									
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
10	Triode	7.5	1.25	8.0	15	450	65	15				3.0	8.0	4.0	C-Telegraphy	450	65	-100	15				3.2		19
															C-Telephony	350	50	-100	12				2.2		12
															B - Audio[2]	425	55[4]	-50	130[9]				2.5[4]	8000	25
10Y	Triode	7.5	1.25	8	15	450	65	15			8	4.1	7.0	3.0	C-Amp., Osc.	450	65	-100	15				3.2		19
															C-Telephony	350	50	-100	12				2.2		12
12AU7[23]	Triode	6.3	0.3	18	2.75[11]	350	12[11]	3.5[11]			54	1.5[11]	1.5[11]	0.5[11]	C-Amp., Osc.[23]	350	24	-100	7						6.0
15E	Triode	5.5	4.2	25	20						600	1.4	1.15	0.3											
24G	Triode	6.3	3.0	23	25	2000	75	25			80	2.0	1.6	0.2	C-Amp Osc.	2000	63	-170	17				4.5		100
												1.7	1.5	0.3		1500	67	-110	15				3.1		75
															B-Audio[2]	1000	72	-80	15				2.6		47
																2000	16/80	-85	290[9]				1.1[4]	55500	110
25T	Triode	6.3	3.0	24	25	2000	75	25			60	2.7	1.5	0.3	C-Amp., Osc.	2000	63	-130	18				4.0		100
																1500	67	-95	13				2.2		75
															B-Amp., Audio[2]	1000	72	-70	9				1.3		47
																2000	16/80	-80	270[9]				0.7[4]	55500	110
25TG	Triode	6.3	3	23	25	2000	75	25			80	1.7	1.5	0.3	C-Telegraphy	2000	63	-170	17				4.5		100
35T	Triode	5.0	4.0	39	50	2000	150	60			100	4.1	1.8	0.3	C-Telegraphy	2000	125	-135	45				13		200
															C-Telephony	1500	100	-120	30				5.0		120
35TG											100	2.5	1.8	0.4	B - Audio[2]	2000	34/167	-40	255[9]				4.0[4]	27500	235

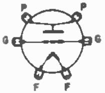
50T	Triode	5.0	6.0	12	75	3000	100	30				2.0	2.0	0.4	C-Amplifier	3000	100	-600	25						250
53A	Triode	5.0	12.5	35	35	15000						3.6	1.9	0.4	Osc. at 300 Mc		Approximately 50 Watts Output								
75TH	Triode	5.0	6.25	20	75	3000	225	40			40	2.7	2.3	0.3	C-Telegraphy	2000	150	-200	32				10		225
															B-Audio[2]	2000	50/225	-90	350[9]				3[4]	19300	300
75TL	Triode	5.0	6.25	12	75	3000	225	35			40	2.6	2.4	0.4	C-Telegraphy	2000	150	-300	21				8		225
															B-Audio[2]	2000	50/250	-160	535[9]				5[4]	18000	350
100TH	Triode	5.0	6.3	40	100	3000	225	60			40	2.9	2.0	0.4	C-Telegraphy	3000	165	-200	51				18		400
															C-Telephony										
															Grid Modul., Amp	3000	70	-400	3.0				7.0		100
															B - Audio[2]	3000	40/215	-65	335[9]				5.0[4]	31000	650
100TL	Triode	5.0	6.3	14	100	3000	225	50			40	2.3	2.0	0.4	C - Telegraphy	3000	165	-400	30				20		400
															C - Telephony										
															Grid Modul., Amp	3000	60	-560	2.0				7.0		90
															B - Audio[2]	3000	40/215	-185	640[9]				6.0[4]	30000	450
111H	Triode	10	2.5	23	75	1500	160	30			30	5.0	4.6	2.9	C-Telegraphy	1500	150	-200	18				6.0		170
															C-Telephony	1250	110	-250	21				8.0		105
															B-Audio[2]	1750	40/270	-62	324[9]				5.0	16000	350
150T	Triode	5.0	10	13	150	3000	200	50				3.0	3.5	0.5	C-Telegraphy	3000	200	-600	35						450
152TH	Triode	5/10	12.5/6.25	20	150	3000	450	85			40	5.7	4.5	0.8	C-Telegraphy	3000	250	-300	70				27		600
															B - Audio[7]	3000	67/335	-150	430[9]				3.0[4]	20300	700

BOTTOM VIEWS SHOWN

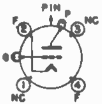
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



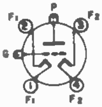
50T
75TH
75TL
100TH
100TL
111H



53A

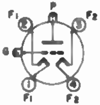


150T

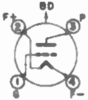


152TH

TRANSMITTING TUBES



152TL



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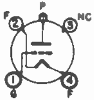
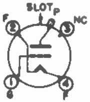
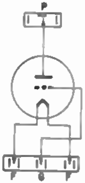


203H



203Z



204A

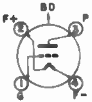
205D
205F

Designation	Type	Cathode		Amp Factor	Maximum			Ratings				Interelectrode Cap.[37]			Typical						Operations			
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
152TL	Triode	5/10	12.51 /6.25	12	150	3000	450	75			40	4.5	4.4	0.7	C-Telegraphy	3000	250	-400	40				20		600
															B-Audio[2]	3000	65/335	-260	675[9]				3.0[4]	20400	700
203A	Triode	10	3.25	25	100	1250	175	60			15	6.5	14.5	5.5	C-Telegraphy	1250	150	-125	25				7.0		130
															C-Telephony	1000	150	-135	50				14		100
															B-Audio[2]	1250	26/320	-45	330[9]				11[4]	9000	260
203H	Triode	10	3.25	25	100	1500	175	60			15	6.5	11.5	1.5	C-Telegraphy	1500	170	-200	12				3.8		200
															C-Telephony	1250	167	-160	19				5.0		160
															B- Audio[2]	1500	30/320	-52	304[9]				5.5[4]	11000	340
203Z	Triode	10	3.25	85	65	1250	175								B - Audio	1250	350	-415					6.75	8000	300
204A	Triode	11	3.85	23	250	2500	275	80			3	12.5	15	2.3	C-Telegraphy	2500	250	-200	30				15		450
															C-Telephony	2000	250	-250	35				20		350
															B - Audio[2]	3000	80/372	-100	500[9]				18[4]	20000	700
205D	Triode	4.5	1.6	7.2	14	400	50	10			6	5.2	4.8	3.3	C-Amp., Osc.	400	45	-112	10				1.5		10
															C-Telephony	350	35	-144	10				1.7		7.1
205F	Triode	4.5	1.6	7.3	14	400	50	10			6	5.2	3.3	4.8	C-Telegraphy	400	45	-122					1.5		10
															C-Telephony	350	35	-144					1.7		7
															A - Audio	400	30	-29						7600	1.3

211	Triode	10	3.25	12	100	1250	175	50			15	6.0	14.5	5.5	C-Telegraphy	1250	150	-225	18				7.0		130
												6.0	9.25	5.0	C-Telephony	1000	150	-260	35				14		100
															B - Audio[2]	1250	20/320	-100	410[3]				8.0[4]	9000	260
211C	Triode	10	3.25	12	125	1250	210	50				5.5	9	3.5	C-Telegraphy	1250	200	-250	10				3.5		170
															C-Telephony	1250	166	-300	8				3.5		148
															B - Audio	1250	400	-90					4.5	6700	320
211D	Triode	10	3.25	12	100	1250	175	50				7	14	6	C-Telegraphy	1250	150	-200	30				11		125
															C-Telephony	1000	150	-175	30				10		100
															B - Audio	1250	300	-80					25	8000	200
211H	Triode	10	3.25	12.5	125	1500	210	50				5.5	7.2	1.9	C-Telegraphy	1500	200	-300	10				4		220
															C- Telephony	1250	166	-300	8				3.5		148
															B - Audio	1500	400	-110					5	8200	400
212E	Triode	14	4.0	16	275	3000	350	75			1.5	14.9	18.8	8.6	C-Telegraphy	3500	270	-275	60				28		760
															C-Telephony	3500	270	-450	45				30		760
															B - Audio[5]	2000	40/300	-105					50[6]	8000	650
227A	Triode	10.5	10.7	31	100							3.0	2.2	0.30	Osc. at 200 Mc										
241B	Triode	14	4.0	16	275	3000	350	75			1.5	14.9	18.8	8.6	C-Telegraphy	3500	270	-275	60				28		760
															C-Telephony	3500	270	-450	45				30		760
															B - Audio[7]	2000	40/300	-105					50[8]	8000	650

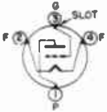
BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

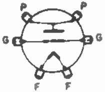


211
211C
211D

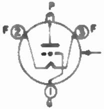
211H



212E



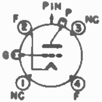
227A



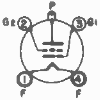
241B

TRANSMITTING TUBES

242A
242B
242C



250TH
250TL



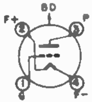
254A
254B

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[17]			Typical Operations										
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
242A	Triode	10	3.25	12.5	85	1250	150	50			6	6.5	13	4.0	C-Telegraphy	1250	150	-175							130
															C-Telephony	1000	150	-160	50						100
242B	Triode	10	3.25	12.5	100	1250	150	50			6	7.0	13.6	6.0	C-Telegraphy	1250	150	-175							130
															C-Telephony	1000	150	-160	50						100
242C	Triode	10	3.25	12.5	100	1250	150	50			6	6.1	13.0	4.7	C-Telegraphy	1250	150	-175							130
															C-Telephony	1000	150	-160	50						100
															B - Audio[2]	1250	25/150	-80					25[4]	7600	200
250TH	Triode	5.0	10.5	37	250	4000	350	100			40	5.0	2.9	0.7	C-Telegraphy	2000	350	-120	100				34		500
															C-Telephony	3000	330	-210	75				42		750
															Grid Modul., Amp	3000	125	-160	4.5				20		125
															B - Audio[2]	3000	100/560	-65	460[5]				24[4]	12250	1150
250TL	Triode	5.0	10.5	14	250	4000	350	50			40	3.7	3.1	0.7	C -Telegraphy	3000	335	-350	45				29		750
															C-Telephony	3000	335	-350	45				29		750
															Grid Modul., Amp	3000	125	-450	2.0				15		125
															B - Audio[2]	3000	100/500	-175	840[5]				17[4]	13000	1000
254A	Tetrode	5.0	3.25		20	750			175	5.0		4.6	0.1	9.4	C-Amplifier	750	60	-90		175					25
254B	Tetrode	7.5	3.25		25	750			150	5.0		11.2	.085	5.4	C-Amplifier	750	75	-135		150					30

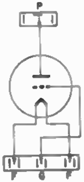
261A	Triode	10	3.25	12	100	1250	150	50			30	6.5	9.0	4.0	C-Telegraphy	1250	125	-175							100
															C-Telephony	1000	150	-160	50						100
															B - Audio[2]	1250	20/150	-90					25[4]	7200	200
270A	Triode	10	4.0	16	350	3000	375	75			7.5	18	21	2.0	C-Telegraphy	3000	350	-375							700
															C-Telephony	2250	300	-300	80						450
276A	Triode	10	3.0	12	100	1250	125	50			30	6.0	9.0	4.0	C-Telegraphy	1250	125	-175							100
															C-Telephony	1000	125	-160	50						85
															B - Audio[2]	1250	20/125	-90					25[4]	9000	175
282A		10	3.0		70	1000			250	5		12.2	0.2	6.8	C-Telegraphy	1000	100	-160		150					33
															C-Telephony	750	100	-180	50	150					50
284B	Triode	10	3.25	5.0	100	1250	150	100				4.2	7.4	5.3	C-Telegraphy	1250	150	-500							125
															C-Telephony	1000	150	-430	50						100
															B - Audio[2]	1250	15/150	-245					10[4]	7200	200
284D	Triode	10	3.25	4.8	85	1250	150	100				6.0	8.3	5.6	C-Telegraphy	1250	150	-500							125
															C-Telephony	1000	150	-450	50						100
															B - Audio[2]	1250	30/200	-250						11200	140
295A	Triode	10	3.25	25	100	1250	175	50				6.5	14.5	5.5	C-Telegraphy	1250	150	-125							125
															C-Telephony	1000	150	-125	50						100
															B - Audio[2]	1250	12/160	-40					20[4]	9000	250

BOTTOM VIEWS SHOWN

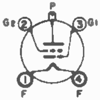
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



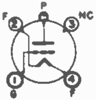
261A
276A
284D
295A



270A



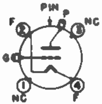
282A



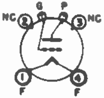
284B

TRANSMITTING TUBES

TRANSMITTING TUBES

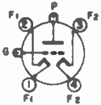


300T

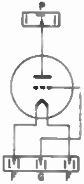


304B

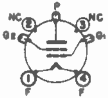
303A



304TH
304TL



304A



305A

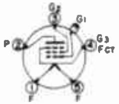
Designation	Type	Cathode		Amp Factor	Maximum			Ratings				Interelectrode Cap.[37]			Typical					Operations					
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
300T	Triode	8.0	11.5	16	300	3500	350	75				4.0	4.0	0.6	C-Telegraphy	2000	300	-225							400
303A	Triode	10	3.25	25	100	1250	175	60			15	6.5	14.5	5.5	C-Telegraphy	1250	150	-125	25				7.0		130
															C-Telephony	1000	150	-135	50				14		100
															B - Audio[2]	1250	26/320	-45	330[9]				11[4]	9000	260
304A	Triode	11	3.85	23	250	2500	275	60			3	12.5	15	2.3	C-Telegraphy	2500	250	-200	30				15		450
															C-Telephony	2000	250	-250	35				20		350
															B - Audio[2]	3000	80/372	-100	500[9]				18[4]	20000	700
304B	Triode	7.5	3.25	11	50	1250	100	25			100	2.0	2.5	0.7	C-Telegraphy	1250	100	-200							85
															C-Telephony	1000	100	-180							65
304TH	Triode	5/10	25/12.5	20	300	3000	900	170			40	13.5	10.2	0.7	C-Amplifier	1500	667	-125	115				25		700
															B - Audio[2]	3000	134/667	-150	420[9]				6.0[4]	10200	1400
304TL	Triode	5/10	25/12.5	12	300	3000	900	150			40	8.5	9.1	0.6	C-Amplifier	1500	665	-250	90				33		700
															B - Audio[2]	3000	130/667	-260	650[9]				6.0[4]	10200	1400
305A	Tetrode	10	3.1		60	1000			200	6		105	0.14	5.4	C-Telegraphy	1000	125	-200		200					85
															C-Telephony	800	125	-270		200					70

305D	Triode	4.5	1.6	7.3	14	400	50	10			6	5.2	4.8	3.3	C-Telegraphy	400	45	-122					1.5		10
															C-Telephony	350	35	-144					1.7		7
															A - Audio	400	36	-29						7600	1.3
306A	Pentode	2.75	2.0		15	300			300	6.0		13	0.35	13	AB$_2$ - Audio[2]	450	44/150	-30	3.0	250	10/40		0.9[4]	6000	40
															C-Telephony	300	36	-50	3.0	180	15				7.0
307A	Pentode	5.5	1.0		15	500			250	6.0		15	0.55	12	C-Telephony	500	60	-35	1.4	250	13	0			20
															Supp.Modul., Amp	500	40	-35	1.5	200	20	-50			6.0
308B	Triode	14	4.0	8.0	250	2250	325	75			1.5	13.6	17.4	9.3	C-Telegraphy	1750	300	-345							350
																1500	300	-300							300
															B - Audio[2]	1750	30/300	-215					35[4]	5200	575
310	Triode	7.5	1.25	8.0	20	600	70	15			6	4.0	7.0	2.2	C-Telegraphy	600	65	-150	15				4.0		25
															C-Telephony	500	55	-190	15				4.5		18
311	Triode	10	3.25	12	100	1250	175	50			15	6.0	14.5	5.5	C-Telegraphy	1250	150	-225	18				7.0		130
												6.0	9.25	5.0	C-Telephony	1000	150	-260	35				14		100
															B-Audio[2]	1250	20/320	-100	410[3]				8.0[4]	9000	260
311CH	Triode	10	3.25	12	125	1750	200	50			30	5.5	8.0	4.5	C-Telegraphy	1750	200	-200	20				4.5		260
															C-Telephony	1250	166	-200	8				3.5		148
															B - Audio[2]	1500	400[4]	-110						8200	400

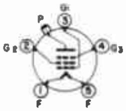
BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

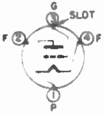
305D
310



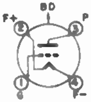
306A



307A



308B



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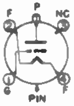
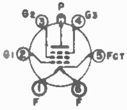


311CH

TRANSMITTING TUBES



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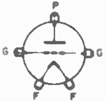
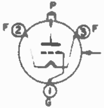
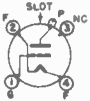


327A
327B



312E



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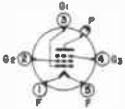


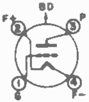
322A

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations										
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
312A	Pentode	10	2.8		50	1250			500	20		15.5	0.15	12.3	C-Telegraphy	1250	100	-55	5.5	300	36	20	0.7		90
															C-Telephony	1000	95	-40	7.0		35	40	1.0		65
															Supp.Modul., Amp	1250	50	-50	5.0		42	-85	.55		23
312E	Triode	14	4.0	16	275	3000	350	75			1.5	14.9	18.8	8.6	C-Telegraphy	3500	270	-275	60				28		760
															C-Telephony	3500	270	-450	45				30		760
															B - Audio[2]	2000	40/300	-105					50[4]	8000	650
316A	Triode	2.0	3.65	6.5	30	450	80	12			500	1.2	1.6	0.8	C-Telegraphy	450	80		12						7.5
															C-Telephony	400	80		12						6.5
322A	Pentode	10	5		125	2000	175	50	600		20	17.5	0.15	29	C-Telegraphy	2000	160	-90	12	500	45	40	2		210
															C-Telephony	1600	150	-80	20	500	55	40	4		155
															Supp.Modul.	1500	100	-100	20	310	70	-90	3.5		50
327A	Triode	10.5	10.7	31	100							3.4	2.3	0.35	Osc. at 200 Mc										
327B	Triode	10.5	10.6	30	75							3.4	2.45	0.3											
331A	Triode	10	3.25	45	125	1500	210	60			30	8.5	6.5	10.5	C-Telegraphy	1500	200	-105	40				8.5		215
															C-Telephony	1250	160	-160	60				16		140
															B - Audio	1500	400	-16					7	8200	370

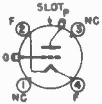
342B	Triode	10	3.25	12.5	100	1250	150	50			[illegible]	7.0	13.6	6.0	C-Telegraphy	1250	150	-175							130
															C-Telephony	1000	150	-160	50						100
356A	Triode	5.0	5.0	50	50	1500	120	35			60	2.25	2.75	1.0	C-Telegraphy	1500	100	-60							100
															C-Telephony	1250	100	-100	35						85
361A	Triode	10	3.25	12	100	[illegible]	150	50			30	6.5	9.0	4.0	C-Telegraphy	1250	125	-175							100
															C-Telephony	1000	150	-160	50						100
															B - Audio[2]	1250	20/150	-90					25[4]	7200	200
376A	Triode	10	3.0	12	100	1250	125	50			30	6.0	9.0	4.0	C-Telegraphy	1250	125	-175							100
															C-Telephony	1000	125	-160	50						85
															B-Audio[2]	1250	20/125	-90					25[4]	9000	175
446B	Triode	6.3	.75	45	3.75	400	20					2.2	1.6	0.02	C-Telegraphy	250	25								
450TH	Triode	7.5	12	38	450	6000	600	125				8.8	5.0	0.8	C-Telegraphy	5000	450	-300	90				46		1800
															C-Telephony	4000	400	-400	70				100		1250
															B - Audio	5000	620	-115					10	18600	2200
450TL	Triode	7.5	12	16	450	5000	450	75				7.3	5.2	0.9	C-Telegraphy	5000	450	-500	54				42		1800
															C-Telephony	4000	400	-700	70				100		1250
															B - Audio	5000	620	-240					15	18600	2200
464A	Triode	6.3	.75	48	5	500	40				1250	2.7	2.0	0.1	C-Telegraphy	450									
527	Triode	5.5	135.0	38	300						200	19.0	12.0	1.4	Osc. at 200 Mc	Approximately 250 Watts Output									

BOTTOM VIEWS SHOWN

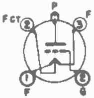
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



342B
361A
376A



450TH
450TL



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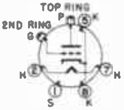
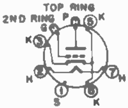
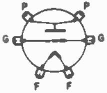


464A

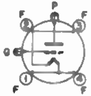


446B

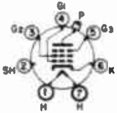


527

TRANSMITTING TUBES

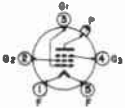


750TL



802

756
801
801A



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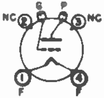


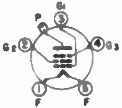
800

Designation	Type	Cathode		Amp Factor	Maximum				Ratings			Interelectrode Cap.[37]			Typical					Operations					
		Volts	Amps		Plate Dis.	Plate Volts	Plate Ma.	Grid Ma.	Screen Volts	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volt.	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volt.	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
703A	Triode	1.2	4/4.5	8	20	350	75	12			1400	0.9	1.1	0.6	C-Amplifier	350	75	-120	12						2/2.5
715B		26/28			50										C-Telegraphy	1500	125			300					
750TL	Triode	7.5	21	35	1000	7500	750	125				9.3	5.1	0.5	C-Telegraphy	6000	625	-700					93		3000
															B-Audio	6000	834	-350					30	16300	3500
756	Triode	7.5	2.0	8.0	40	850	110	25				3.0	7.0	2.7	C-Amplifier	850	110		25						
800	Triode	7.5	3.25	15	35	1250	80	25			60	2.75	2.5	2.75	C-Telegraphy	1250	70	-175	15				4.0		65
															C-Telephony	1000	70	-200	15				4.0		50
															B - Audio[2]	1250	30/130	-70	300[9]				3.4*	21000	106
801 801A	Triode	7.5	1.25	8.0	20	600	70	15			60	4.5	6.0	1.5	C-Telegraphy	600	35	-150	15				4.0		25
															C-Telephony	500	55	-190	15				4.5		18
															B-Audio[2]	600	130	-75	320[9]				3.0*	10000	45
802	Pentode	6.3	0.9		13	600			250	6.0	30	12	0.15	8.5	C-Telegraphy	600	55	-120	2.4	250	16	40	0.30		23
															C-Telephony	500	40	-40	1.5	245	15	40	0.10		12
															Supp. Modul., Amp	600	30	-100	5.0	250	24	-45	0.6		6.3
803	Pentode	10	5.0		125	2000			600	30	20	17.5	0.15	29	C-Telegraphy	2000	160	-90	12	500	45	40	2.0		210
															C-Telephony	1600	150	-60	25	400	45	100	5.0		155
															Supp. Modul., Amp	2000	80	-100	15		48	-110	2.5		53
															Grid Modul., Amp	2000	80	-80	4.0	600	20	40	2.0		53

804	Pentode	7.5	3.0		50	1500			300	15	15	16	0.01	14.5	C-Telegraphy	1500	100	-100	7.0	300	35	45	1.95		110
															C-Telephony	1250	75	-90	6.0	250	20	50	.75		65
															Grid Modul., Amp	1500	50	-130	3.7	300	13.5	45	1.3		28
															Supp. Modul., Amp	1500	50	-115	7.0	300	32	-50	0.95		28
805	Triode	10	3.25	40/60	125	1500	210	70			30	8.5	6.5	10.5	C-Telegraphy	1500	200	-105	40				8.5		215
															C-Telephony	1250	160	-160	60				13		140
															B-Audio[2]	1500	84/400	-16	280[9]				7.0[4]	8200	370
806	Triode	5.0	10	12.6	225	3300	300	50			30	6.1	4.2	1.1	C-Telegraphy	3300	300	-600	40				34		780
															C-Telephony	3000	195	-670	27				24		460
															B-Audio[2]	3300	80/475	-240	930[9]				35[4]	16000	1120
807	Beam Tetrode	6.3 12.6	0.9 0.45		30	750			300	3.5	60	11	0.2	7.0	C-Telegraphy	750	100	-45	3.5	250	6		0.22		50
															C-Telephony	600	100	-90	4.0	275	6.5		0.4		42.5
															AB_2 - Audio[2]	750	60/240	-32	92[9]	300	5/10		0.2[4]	6950	120
808	Triode	7.5	4.0	47	50	1500	150	35			30	5.3	2.8	0.15	C-Telegraphy	1500	125	-200	30				9.5		140
															C-Telephony	1250	100	-225	32				10.5		105
															B-Audio[2]	1500	30/190	-25	220[9]				4.8[4]	18300	185
809	Triode	6.3	2.5	50	30	1000	125				60	5.7	6.7	0.9	C-Telegraphy	1000	100	-75	25				3.8		75
															C-Telephony	750	100	-60	32				4.3		55
															B-Audio[2]	1000	40/200	-9	155[9]				2.7[4]	11600	145

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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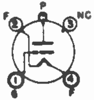

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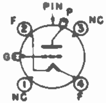

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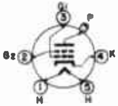

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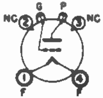

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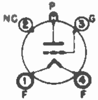
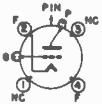


809

TRANSMITTING TUBES



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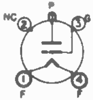


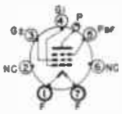
811
812
812A
812H

Designation	Type	Cathode		Amp Factor	Maximum				Ratings			Interelectrode Cap.[37]			Typical					Operations					
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
810	Triode	10	4.5	36	175	2500	300	75			30	8.7	4.8	12	C-Telegraphy	2500	300	-180	60				19		575
		5.0	9.0												C-Telephony	2000	250	-350	70				35		380
															Grid Modul., Amp	2250	100	-140	2.0				4.0		75
															B - Audio[2]	2250	70/450	-60	380[9]				13[4]	11600	725
811	Triode	6.3	4.0	160	55	1500	150	50			60	5.5	5.5	0.6	C-Telegraphy	1500	150	-113	35				8.0		170
															C-Telephony	1250	125	-125	50				11		120
															B-Audio[2]	1500	80/200	-9	150[9]				3.0[4]	17600	220
812	Triode	6.3	4.0	29	55	1500	150	35			60	5.3	5.3	0.8	C-Telegraphy	1500	150	-175	25				6.5		170
															C-Telephony	1250	125	-125	25				6.0		120
															B-Audio[2]	1500	50/200	-45	232[9]				4.7[4]	18000	225
812A	Triode	6.3	4.0	29	65	1500	175	35			60	5.4	5.5	0.77	C-Telegraphy	1500	173	-120	30				6.5		190
															C-Telephony	1250	140	-115	35				7.6		130
															B - Audio[2]	1500	28/310	-48	270[9]				5.0	13200	340
812H	Triode	6.3	4.0		85	1750	200	45			30	5.3	5.3	0.8	C-Telegraphy	1750	170	-175	26				6.5		225
																1250	125	-125	25				5.0		116
															C-Telephony	1500	165	-125	21				6.0		180
																1250	125	-125	25				6.0		120
															B - Audio[2]	1500	42/200	-46						18000	225

813	Beam Tetrode	10	5.0		100	2250			400	22	30	16.3	0.2	14	C-Telegraphy	2250	220	-155	15	400	40	0	4.0		375
															C-Telephony	2000	200	-175	16	350	40	0	4.3		300
															Grid Modul., Amp	2000	75	-120		400	3.0				50
															B - Audio[2]	2500	35/360	-95		750	1.2/55	0	0.35	17000	650
814	Beam Tetrode	10	3.25		65	1500			300	10	30	13.5	0.1	13.5	C-Telegraphy	1500	150	-90	10	300	24		1.5		160
															C-Telephony	1250	145	-150	10	300	20		3.2		130
															Grid Modul., Amp	1500	60	-120	2.5	250	3.0		4.2		35
815[23]	Twin Beam Tetrode	12.6 6.3	0.8 1.6		25	500			200	4.0	125	13.3[11]	0.2[11]	8.5[11]	C-Amp., Osc.	500	150	-45	2.5	200	17		0.13		56
															C-Telephony	400	150	-45	3.0	175	15		0.16		45
															AB$_2$ - Audio[23]	500	20/150	-15		125	32[4]		0.36[4]	8000	54
822 822S	Triode	10	4.0	30	200	2500	300	60			20 30	8.5	13.5	2.1	C-Telegraphy	2500	300	-190	51				17		600
															C-Telephony	2000	250	-75	43				13.7		405
															B- Audio[2]	3000	450[4]	-80	362[9]				8.0[4]	16000	1000
826	Triode	7.5	4.0	31	60	1000	125	40			250	3.7	2.9	1.4	C-Amp., Osc.	1000	125	-70	35				5.8		86
															C-Telephony	800	94	-98	35				6.2		53
															Grid Modul., Amp	1000	65	-125	9.5				8.2		25

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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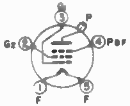

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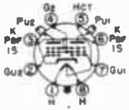

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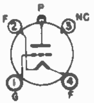

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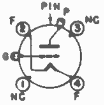

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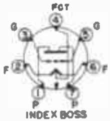

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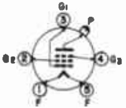

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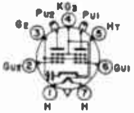


829
829A
829B

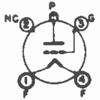
830

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations										
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volts	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volt.	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
827R	Beam Tetrode	7.5	25		800	3500	500	150	1000		127	21	0.18	13	C-Telegraphy	3500	428	-300	100	700	185		50		1050
															C-Telephony	3000	400	-325	125	750.	125		68		825
828	Beam Pentode	10	3.25		80	2000			750	23	30	13.5	0.05	14.5	C-Telegraphy	1500	180	-100	12	400	28	75	2.2		200
															C-Telephony	1250	160	-140	12	400	28	75	2.7		150
															Grid Modul.Amp	1500	80	-150	1.3	400	4.0	75	1.3		41
															AB$_1$ - Audio[8]	2000	50/270	-120	240[9]	750	2/60	60	0	18500	385
829[23]		6.3	2.25		40	500			225	40	200	14.5"	0.1"	7.0"	C-Telegraphy	500	240	-45	12	200	32		0.7		83
		12.6	1.12												C-Telephony	425	212	-60	11	200	35		0.8		63
															Grid Modul., Amp	500	120	-38	2.0	200	10		0.5		23
829A[23]		6.3	2.25		40	750			240	7.0	200	14.4"	0.1"	7.0"	C-Amp., Osc.	750	160	-55	12	200	30		0.8		87
		12.6	1.12												C-Telephony	600	150	-70	12	200	30		0.9		70
															Grid Modul., Amp	750	80	-55	0	200	5.0		0.7		24
829B[23]	Twin Beam Tetrode	12.6	1.125		30	750			225	6	200	14.5"	0.12"	7.0"	C-Grid Modulat.	500	120	-38	2	200	10		0.5		23
		6.3	2.25		28	600			225	7					C-Telephony	425	212	-60	11.0	200	35		0.8		63
					40	750			240	7					C-Telegraphy	500	240	-45	12.0	200	32		0.7		83
830	Triode	10	2.15	8.0	40	750	110	18			15	4.9	9.9	2.2	C-Amplifier	750	110	-180	18				7.0		55
															Grid Modul., Amp	1000	50	-200	2.0				3.0		15

830B	Triode	10	2.0	25	60	1000	150	30			15	5.0	11	1.8	C-Amp., Osc.	1000	140	-110	30				7.0		90
															C-Telephony	800	95	-150	20				5.0		50
															B- Audio[2]	1000	20/280	-35	270[9]				6.0[4]	7600	175
831	Triode	11	10	14.5	400	3500	350	75				3.8	4.0	1.4	C-Telegraphy	3500	275	-400	40				30		590
															C-Telephony	3000	200	-500	60				50		360
832[23]		6.3	1.6		15	500			250	5.0	200	7.5[11]	0.05[11]	3.8[11]	C-Telegraphy	500	72	-65	2.6	200	14		0.18		26
		12.6	0.8												C-Telephony	425	52	-60	2.4	200	16		0.15		16
832A[23]	Twin Beam	6.3	1.6		15	750			250	5.0	200	7.5[11]	0.05[11]	3.8[11]	C-Telegraphy	750	48	-65	2.8	200	15		0.19		26
	Tetrode	12.6	0.8												C-Telephony	300	36	-65	2.3	200	16		0.16		17
833A	Triode	10	10	35	300	3000	500	100			30	12.3	6.3	8.5	C-Telegraphy	2000	475	-200	65				25		740
															C-Telephony	2500	335	-300	75				30		635
834	Triode	7.5	3.1	10.5	50	1250	100	20			100	2.2	2.6	0.6	C-Telegraphy	1250	90	-225	15				4.5		75
															C-Telephony	1000	90	-310	17.5				6.5		58
835	Triode	10	3.25	12	100	1250	175	50			15	6.0	14.5	5.5	C-Telegraphy	1250	150	-225	18				7.0		130
												6.0	9.25	5.0	C-Telephony	1000	150	-260	35				14		100
															B - Audio[8]	1250	20/320	-100	410[9]				8.0[4]	9000	260

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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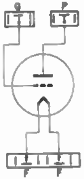

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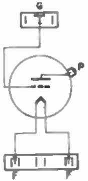

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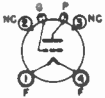

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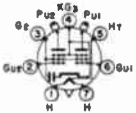

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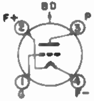

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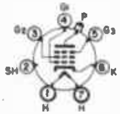

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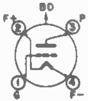

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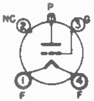

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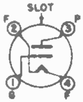

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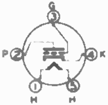


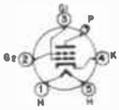
843

Designation	Type	Cathode		Amp Factor	Maximum				Ratings			Interelectrode Cap.[37]			Typical					Operations				
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
837	Pentode	12.6	0.7		12	500			300	8	20	16	0.2	10	C-Telegraphy	500	80	-70	4.0	200	15	40	0.4		28
															C-Telephony	400	45	-40	5.0	140	20	40	0.3		11
															Supp.Modul., Amp	500	30	-20	3.5		23	-65	0.1		5.0
838	Triode	10	3.25		100	1250	175	70			30	6.5	8.0	5.0	C-Telegraphy	1250	150	-90	30				6.0		130
															C-Telephony	1000	150	-135	60				16		100
															B - Audio[2]	1250	148/320	0	200[9]				7.5[4]	9000	260
841	Triode	7.5	1.25	30	15	450	60	20			6	4.0	7.0	3.0	C-Telegraphy	450	50	-34	15				1.8		15
															C-Telephony	350	50	-47	15				2.0		11
841A	Triode	10	2.0	14.6	50	1250	150	30				3.5	9.0	2.5	C-Amplifier										85
841SW	Triode	10	2.0	14.6	50	1000	150	30					9.0		C-Amplifier										
842	Triode	7.5	1.25	3	12	425						4	7	3	A - Audio	425	28	-100						8000	3
843	Triode	2.5	2.5	7.7	15	450	40	7.5			6	4.0	4.5	4.0	C-Amp., Osc.	450	30	-140	5.0				1.0		7.5
															C-Telephony	350	30	-150	7.0				1.6		5.0

844		2.5	2.5		15	500			180	3.0		9.5	0.15	7.5	C-Telegraphy	500	25	-125	5.0	175					9.0
															C-Telephony	500	20	-100		150					4.0
845	Triode	10	3.25	5.3	100	1250	120					6	13.5	6.5	A - Audio	1250	80	-195							30
849	Triode	11	5.0	19	400	2500	350	125			3	17	33.5	3.0	C-Telegraphy	2500	300	-250	20				8.0		560
															C-Telephony	2500	300	-300	30				14		425
849H	Triode	11	5	19	400	3000	350	35			3	17	33.5	3	C-Telegraphy	2500	300	-250	20				8		560
															C-Telephony	2000	300	-300	30				14		425
															B- Audio	2000	650	-105					16	6400	900
850	Tetrode	10	3.25		100	1250			175	10	15	17	0.25	25	C-Telegraphy	1250	160	-150	35	175			10		130
															C-Telephony	1000	125	-100	40	140			10		85
															Grid Modul., Amp	1250	110	-13		175					40
851	Triode	11	15.5	20.5	750	3000	1000	200			3	25.5	47	4.5	C-Telegraphy	2500	900	-250	100				45		1700
															B - Audio	3000	1200	-135					6	5600	2400
852	Triode	10	3.25	12	100	3000	150	40			30	1.9	2.6	1.0	C-Telegraphy	3000	85	-600	15				12		135
															C-Telephony	2000	67	-500	30				23		75
															B - Audio[3]	3000	14/130	-250	780[3]				3.5[4]	10250	320
860	Tetrode	10	3.25		100	3000			500	10	30	7.75	0.08	7.5	C-Amp., Osc.	3000	85	-150	15	300	25		7.0		165
															C-Telephony	2000	85	-200	38	220	25		17		105

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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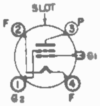

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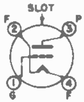

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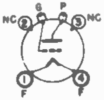

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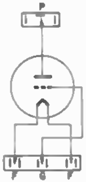

849
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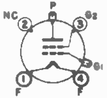
851



860

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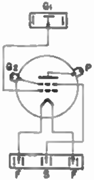

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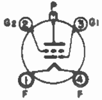

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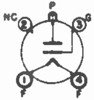

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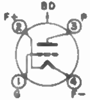

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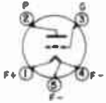


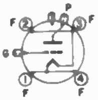
958A

Designation	Type	Cathode		Amp Factor	Maximum				Ratings			Interelectrode Cap.^{57}			Typical					Operations				
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class.	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
861	Tetrode	11	10		400	3500			750	35	20	14.5	0.1	10.5	C-Telegraphy	3300	300	-250	40	500	40		30		700
															C-Telephony	3000	200	-200	55	375			35		400
865	Tetrode	7.5	2.0		15	750			175	3.0	15	8.5	0.1	8.0	C-Telegraphy	750	40	-80	5.5	125			1.0		16
															C-Telephony	500	40	-120	9.0	125			2.5		10
930B	Triode	10	2.0	25	60	1000	150	30			15	5.0	11	1.8	C-Amp., Osc.	1000	140	-110	30				7.0		90
															C-Telephony	800	95	-150	20				5.0		50
															B - Audio^{2}	1000	20/280	-35	270^{9}				6.0^{4}	7600	175
938	Triode	10	3.25		100	1250	175	70			30	6.5	8.0	5.0	C-Telegraphy	1250	150	-90	30				6.0		130
															C-Telephony	1000	150	-135	60				16		100
															B-Audio^{2}	1250	148/320	0	200^{9}				7.5^{4}	9000	260
955	Triode	6.3	0.15	25	1.6	180	8	2.0			250	1.0	1.4	0.6	C-Amp., Osc.	180	7	-35	1.5						0.5
958A	Triode	1.25	0.1	12	0.6	135	7	1.0			500	0.6	2.6	0.8	C-Amp., Osc.	135	7	-20	1.0				0.035		0.6

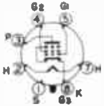
1000T	Triode	7.5	17	35	1000	7500	750	125				9.3	5.1	0.5	C-Telegraphy	6000	667	-350	110				60		3000
															B - Audio	6000	1110	-135					35	12200	4600
1500T	Triode	7.5	24	24	1500	8000	1250	175			40	9.9	7.2	1.5	C-Telegraphy	7000	860	-500	110				85		4500
															B- Audio	6000	1650	-190					115	8200	
1602	Triode	7.5	1.25	8.0	15	450	60	15			6	4.0	7.0	3.0	C-Telegraphy	450	55	-115	15				3.3		13
															C-Telephony	350	45	-135	15				3.5		8.0
															B - Audio^2	425	110^4	-50	260^9				2.5^4	8000	25
1608	Triode	2.5	2.5	20	20	425	95	25			45	8.5	9.0	3.0	C-Telegraphy	425	95	-90	20				3.0		27
															C-Telephony	350	85	-80	20				3.0		18
															B - Audio^2	425	190^4	-15	130^9				2.2^4	4800	50
1610	Pentode	2.5	1.75		6.0	400			200	2.0	20	8.6	1.2	13	C-Telegraphy	400	22.5	-50	1.5	150	7.0		0.1		5.0
1613	Pentode (Metal)	6.3	0.7		10	350			275	2.5	45	8.5	0.5	11.5	C-Telegraphy	350	50	-35	3.5	200	10		0.22		9
															C-Telephony	275	42	-35	2.8	200	10		0.16		6.0
1614	Beam Tetrode (Metal)	6.3	0.9		25	450			300	3.5	80	10	0.4	12.5	C-Telegraphy	450	100	-45	2.0	250	8		0.15		31
															C-Telephony	375	93	-50	2.0	250	7.0		0.15		24.5
															AB_1 - Audio^2	530	60/160	-36		340	20^4			7200	50
1619	Beam Tetrode (Metal)	2.5	2.0		15	400			300	3.5	45	10.5	0.35	12.5	C-Telegraphy	400	75	-55	5.0	300	10.5		0.36		19.5
															C-Telephony	325	62	-50	2.8	285	7.5		0.18		13
															AB_2 - Audio^2	400	75/150	-16.5		300	6.5/11.5	0	0.4^4	6000	36

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



1000T
1500T



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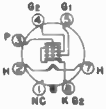

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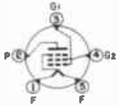

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1619

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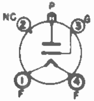

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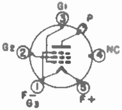

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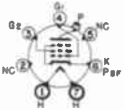

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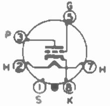

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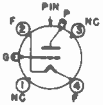

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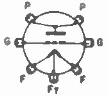


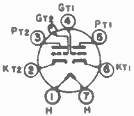
1628

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations									
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
1623	Triode	6.3	2.5	20	30	1000	100	25			60	5.7	6.7	0.9	C-Amp., Osc.	1000	100	-90	20				3.1		75
															C-Telephony	750	100	-125	20				4.0		55
															B - Audio[2]	1000	30/200	-40	230[9]				4.2[4]	12000	145
1624	Beam Tetrode	2.5	2.0		25	600			300	3.5	60	11	0.25	7.5	C-Telegraphy	600	90	-60	5.0	300	10		0.43		35
															C-Telephony	500	75	-50	3.3	275	9.0		0.25		24
															AB_2 - Audio[2]	600	42/180	-25	106[9]	300	5/15		1.2[4]	7500	72
1625	Beam Tetrode	6.3	0.9		30	750			300	3.5	60	11	0.2	7.0	C-Telegraphy	750	100	-45	3.5	250	6		0.22		50
		12.6	0.45												C-Telephony	600	100	-90	4.0	275	6.5		0.4		42.5
															AB_2 - Audio[2]	750	60/240	-32	92[9]	300	5/10		0.2[4]	6950	120
1626	Triode	12.6	0.25	5.0	5.0	250	25	8.0			30	3.2	4.4	3.4	C-Amp., Osc.	250	25	-70	5.0				0.5		4.0
1627	Triode	10	4.5	36	175	2500	300	75			30	8.7	4.8	12	C-Telegraphy	2500	300	-180	60				19		575
		5.0	9.0												C-Telephony	2000	250	-350	70				35		380
															Grid Modul., Amp	2250	100	-140	2.0				4.0		75
															B - Audio[2]	2250	70/450	-60	380[9]				13[4]	11600	725
1628	Triode	3.5	3.25	23	40	1000	60	15			500	2.0	2.0	0.4	C-Amp., Osc.	1000	50	-65	15				1.7		35
															C-Telephony	800	40	-100	11				1.6		22
															Grid Modul., Amp	1000	50	-120	3.5				5.0		20

1642	Twin Triode	6.3	.6	10.4		250						2.6 2.6	2.4 1.8	1.4 2.0	A - Audio	250	8.3	-16.5							
2000T	Triode	10	25	23	2000	8000	1750	200			40	12.7	8.5	1.7	C-Telegraphy	7000	1150	-600	120				115		6000
															B - Audio	7000	1860	-290					75	8500	9000
5514	Triode	7.5	3.0	145	65	1500	175	60			60	7.8	7.9	1.0	C-Telegraphy	1500	175	-106	60				12		200
															C-Telephony	1250	142	-84	60				10		135
															B-Audio^{2}	1500	350^{4}	-4.5	88^{4}				6.5^{4}	10500	400
5516	Beam Pentode	6.0	0.7		15	600			250	5.0	80	8.5	0.12	6.5	C-Telegraphy	600	75	-60	5.0	250	15		0.5		32
															C-Telephony	475	63	-90	4.0	250	10		0.5		22
															AB_2- Audio^{2}	600	36/140	-25	4^{4}	250	1/24		0.16	10500	67
5556	Triode	4.5	1.1	8.5	7.0	350	40	10			6	4.0	8.3	3.0	C-Telegraphy	350	35	-80	2				0.25		6
															C-Telephony	300	30	-100	2				0.3		4
5562	Beam Tetrode	6.3	3.0		45	2000			400	8	120	6.5	0.2	1.8	C-Telegraphy	1500	116	-300	12	375	21		3.6		135
															C-Telephony	1000	85	-200	10	300	14		2.0		60
5588	Triode			23	200	1000	300				1200	13	6.5	0.32	C-Telegraphy	1000	100	-200		300					

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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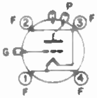

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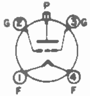

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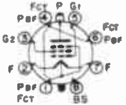

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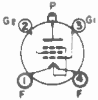

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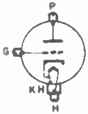

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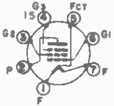

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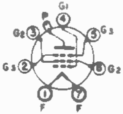

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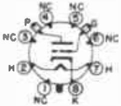

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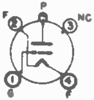

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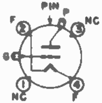

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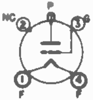


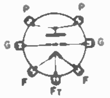
8005

Designation	Type	Cathode		Amp Factor	Maximum				Ratings			Interelectrode Cap.[37]			Typical				Operations					
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
5618		6.0	0.23		5.0	300			125	2.0	80	7.0	0.24	5.0	C-Amplifier Telegraphy	300	25	-45	1.5	75	7.0	0	0.3		5.4
		3.0	0.46																						
7193	Triode	6.3	0.3	20	3.5	500						2.2	3.6	0.7	C-Telegraphy										
8000	Triode	10	4.5	16.5	175	2500	300	45			30	5.0	6.4	3.3	C-Amp., Osc.	2500	300	-240	40				18		575
															C-Telephony	2000	250	-370	37				20		380
															Grid Modul., Amp	2250	100	-265	0				2.5		75
															B - Audio[‡]	2250	65/450	-130	560[9]				7.9[4]	12000	725
8001	Beam Pentode	5.0	7.5		75	4000			750	30	75	12	0.06	6.5	C-Telegraphy	2000	150	-200	6	500	11	60	1.4		230
															C-Telephony	1800	135	-130	8	400	11	60	1.7		178
															Supp. Modul. Amp	2000	55	-130	3.0	500	27	-300	0.4		35
8003	Triode	10	3.25	12	100	1500	250	50			30	5.8	11.7	3.4	C-Amp., Osc.	1350	245	-180	35				11		250
															C-Telephony	1100	200	-260	40				15		167
															B - Audio[‡]	1350	40/490	-100	480[9]				10.5[4]	6000	460
8005	Triode	10	3.25	20	85	1500	200	45			60	6.4	5.0	1.0	C-Telegraphy	1500	200	-130	32				7.5		220
															C-Telephony	1250	190	-195	28				9.0		170
															B - Audio[‡]	1500	40/310	-70	310[9]				4.0[4]	10000	300
8010R	Triode	6.3	2.4	30	50	1350	150	20			350	2.3	1.5	0.07	C-Amplifier										

8012	Triode	6.3	2.0	18	40	1000	80	20			500	2.7	2.8	0.35	C-Amp., Osc.	1000	50	-90	14				1.6		35
															C-Telephony	800	40	-105	10.5				1.4		22
															Grid Modul., Amp.	1000	50	-135	4.0				3.5		20
8012A	Triode	6.3	1.92	18	40	1000	80	20			500	2.7	2.5	0.4	C-Telegraphy	1000	50	-90	14				1.6		35
															C-Telephony	800	40	-105	10.5				1.4		22
8025	Triode	6.3	1.92	18	30	1000	65	20			500	2.7	2.8	0.35	C-Grid Modulat.	1000	50	-135	4				3.5		20
					20		65								C-Telephony	800	40	-105	10.5				1.4		22
					30		80	20							C-Telegraphy	1000	50	-90	14				1.6		35
8025A	Triode	6.3	1.92	18	30	1000	80	20			500	2.7	3.0	0.4	C-Telegraphy	1000	50	-90	14				1.6		35
															C-Telephony	800	40	-105	10.5				1.4		22
9002	Triode	6.3	0.15	25	1.6	250	8	2.0			250	1.2	1.4	1.1	C-Amp., Osc.	180	7	-35	1.5						0.5
AT 340		5	7.0		150	4000			400		120	9.04	0.19	4.16	C-Amp., Osc.	3000	165	-500		400	75		2.4		
DR123C	Triode	10	4.0	14.5	125	2000	300	75				6.5	8.5	3.3	C-Telegraphy	1500	250	-250	30				11		300
															C-Telephony	1500	160	-290	25				10		200
															B - Audio[2]	2000	30/175	-130	217[5]				34[4]	13800	522
DR200	Triode	10-11	3.4	18	150	2500	200	50			20	5.2	5.8	1.2	C-Telegraphy	2500	200	-300	18				8.0		380
															C-Telephony	2000	160	-350	20				9.0		250
															B-Audio[2]	2500	60/360	-130	400[5]				8.0[4]	16000	600
F123A	Triode	10	40	14.5	125	2000	300	75				6.5	8.5	3.3	C-Telegraphy	1500	250	-250	30				11		300
															C-Telephony	1500	160	-290	25				10		200
															B - Audio[2]	2000	30/175	-130	217[5]				3.4[4]	13800	522

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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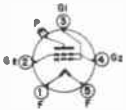

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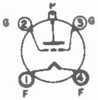

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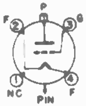

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F123A

8025
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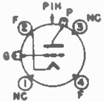

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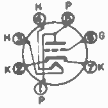

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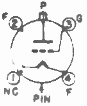

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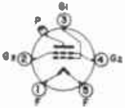

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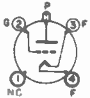


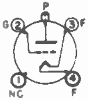
GL146
GL152

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations										
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
F127A	Triode	10	4.0	38	200	3000	325	70				13	4	13	C-Telegraphy	3000	250	-250	47				18		600
															C-Telephony	2500	200	-300	58				25.2		420
															B - Audio[2]	2800	20/400	-75	175[5]				6.65[4]	16600	820
F128A	Triode	11	13	36	700	3500	1000	175			30	12	4.5	15.5	C-Telephony	3500	854	-400	107				73		2360
															C-Telegraphy	3000	511	-300	38				19		1150
															B - Audio	3000	1000	-80					8.5	5400	2400
GL2C44	Triode	6.3	0.75		5.0	500	40				500	2.7	2.0	0.1	C-Amp., Osc.	250									
GL5C24	Triode	10	5.2	8	160	1750	107					5.6	8.8	3.3	A - Audio	1500	107	-155							55
															AB_1 - Audio[2]	1750	320[4]	-200	390[5]					8000	240
GL5D24		5.0	14.1		250	4000			350	50	85	12.7	0.06	4.5	C-Telegraphy	4000	250	-250	13	500	22		4.1		750
																2500	325	-100	22	500	70		3.7		562
GL146	Triode	10	3.25	75	125	1500	200	60			15	7.2	9.2	3.9	C-Amp., Osc.	1250	180	-150	30						150
															C-Telephony	1000	160	-200	40						100
															B - Audio[2]	1250	34/320	0						8400	250
GL152	Triode	10	3.25	25	125	1500	200	60			15	7.0	8.8	4.0	C-Amp., Osc.	1250	180	-150	30						150
															C-Telegraphy	1000	160	-200	30						100
															B - Audio[2]	1250	16/320	-40						8400	250

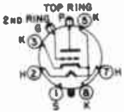
GL159	Triode	10	9.6	20	250	2000	400	100			15	11	17.6	5.0	C-Amp., Osc.	2000	400	-200	17				6.0		620
															C-Telephony	1500	400	-240	23				9.0		450
															B - Audio[8]	2000	30/660	-100	400[9]				4.0[4]	6880	900
GL169	Triode	10	9.6	85	250	2000	400	100			15	11.5	19	4.7	C-Amp., Osc.	2000	400	-100	42				10		620
															C-Telephony	1500	400	-100	45				10		450
															B - Audio[8]	2000	30/660	-18	220[9]				6.0[4]	7000	900
GL446A	Triode	6.3	0.75	45	3.75	400	20				500	2.2	1.6	0.02	C-Amp., Osc.	250									
GL446B	Triode	6.3	0.75	45	3.75	400	20				500	2.2	1.6	0.02	C-Amp., Osc.	250									
GL464A	Triode	6.3	0.75		5.0	500	40				500	2.7	2.0	0.1	C-Amp., Osc.	250									
GL592	Triode	10	5.0	24	200	3500	250	50			110	3.6	3.3	0.41	C-Amp., Osc.	2600	250	-240	45				18		425
															C-Telephony	2000	250	-500	50						
GL8012A	Triode	6.3	2.0	18	40	1000	80	20			500	2.7	2.8	0.35	C-Amp., Osc.	1000	50	-90	14				1.6		35
															C-Telephony	800	40	-105	10.5				1.4		22
												2.7	2.5	0.4	Grid Modul., Amp	1000	50	-135	4.0				3.5		20
HD203A	Triode	10	4.0	25	150	2000	250	60			15		12		C-Amplifier										375
HD211C	Triode	10	3.25	12.5	125	1500	210	50				5.5	7.2	1.9	C-Telegraphy	1500	200	-300	10				4		220
															C-Telephony	1250	166	-300	8				3.5		148
															B - Audio	1500	400	-110					5	8200	400

BOTTOM VIEWS SHOWN

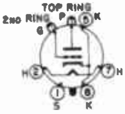
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



GL159
GL169



GL446A
GL446B



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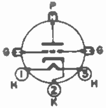

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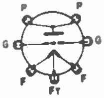
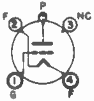
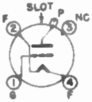


GL8012A

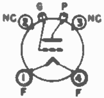


HD203A

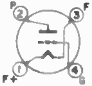


HD211C

TRANSMITTING TUBES



HF60
HF75
HF100



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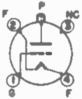
HF140



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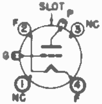

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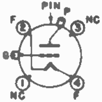


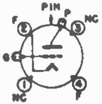
HF200

Designation	Type	Cathode		Amp Factor	Maximum				Ratings			Interelectrode Cap.[37]			Typical				Operations					
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
HF60	Triode	10	2.5	28	75	1600	160				30	5.4	5.2	1.5	C-Telegraphy	1600	158	-190	12				3.5		200
															C-Telephony	1250	113	-190	8				2.5		110
															B - Audio[2]	1600	50/248	-75	310[3]				3.0	13800	262
HF75	Triode	10	3.25	12.5	75	2000	120				75		2.0		C-Osc., Amp.	2000	120								150
HF100	Triode	10	2.5	23	75	1500	150	30			30	4.0	4.5	2.6	C-Telegraphy	1500	150	-200	18				6.0		170
															C-Telephony	1250	110	-250	21				8.0		105
															Grid Modul., Amp	1500	72	-280	1.5				6.0		42
															B - Audio[2]	1750	40/270	- 62	324[3]				9.0[4]	16000	350
HF120	Triode	10	3.25	12	100	1250	175	50			15	5.5	12.5	3.5	C-Amp., Osc.	1250	166	-300	8				3.5		148
HF125	Triode	10	3.25	25	100	1500	175				30		11.5		C-Amp., Osc.	1500	175								200
HF130	Triode	10	3.25	12.5	125	1250	210				20	5.5	9.0	3.5	C-Amp., Osc.	1250	200	-250	10				3.5		170
HF140	Triode	10	3.25	12	100	1250	175				15	5.5	13.0	4.5	C-Amp., Osc.	1250	166	-300	8				3.5		148
HF150	Triode	10	3.25	12.5	125	1500	210				30	5.5	7.2	1.9	C-Amp., Osc.	1500	200	-300	10				4		220
HF175	Triode	10	4.0	18	125	2000	250				25	4.8	6.3	2.7	C-Amp., Osc.	2000	200	-250	23				9		320
HF200	Triode	10-11	3.4	18	150	2500	200	50			20	5.2	5.8	1.2	C-Telegraphy	2500	200	-300	18				8.0		380
															C-Telephony	2000	160	-350	20				9.0		250
															B - Audio[2]	2500	60/360	-130	460[3]				8.0[4]	16000	600

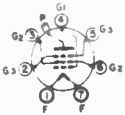
HF250	Triode	10.5	4.0	18	150	2500	200				20		5.8		C-Amp., Osc.	2500	200								375
HF300	Triode	11-12	4.0	23	200	3000	275	60			60	6.0	6.5	1.4	C-Telegraphy	3000	250	-400	28				16		600
											20				C-Telephony	2000	250	-300	36				17		385
															B - Audio[2]	3000	60/360	-115	450[9]				13[4]	20000	780
HK24	Triode	6.3	3.0	25	25	2000	75	30			60	2.5	1.7	0.4	C-Telegraphy	2000	56	-140	18				4.0		90
															C-Telephony	1500	50	-145	25				5.5		60
HK24G	Triode	6.3	3	23	25	2000	75	25			60	1.7	1.5	0.3	C-Telegraphy	2000	63	-170	17				4.5		100
HK54	Triode	5.0	5.0	27	50	3000	150	30			100	1.9	1.9	0.2	C-Telegraphy	3000	100	-290	25				10		250
															C-Telephony	2500	100	-250	20				8.0		210
															B - Audio[2]	2500	20/150	-85	360[9]				5.0	40000	275
HK57	Pentode	5.0	5.0		50	3000	150	15	500	10	200	7.3	0.05	3.1	C-Telegraphy	3000	100	-175	1	450	2	0	0.18		250
															C-Telephony	2000	88	-145	1.5	450	2	30	0.2		135
HK154	Triode	5.0	6.5	6.7	50	1500	175	30			60	4.3	5.9	1.1	C-Telegraphy	1500	167	-590	20				15		200
															C-Telephony	1250	170	-460	20				12		162
															Grid Modul., Amp	1500	52	-450					5.0		28
HK158	Triode	12.6	2.5	25	50	2000	200	40			60	4.7	4.6	1.0	C-Amp., Osc.	2000	125	-150	25				6.0		200
															C-Telephony	2000	105	-140	25				5.0		170
HK252L	Triode	5/10	13/6.5	10	150	3000	500	75			125	7.0	5.0	0.4	C-Amp., Osc.	3000	250	-400	30				15		610
															C-Telephony	2500	250	-350	35				16		500

BOTTOM VIEWS SHOWN

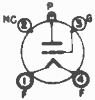
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



HF250
HF300



HK57



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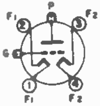
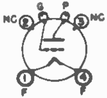
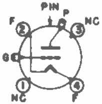


HK252L

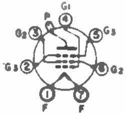


HK24G
HK54
HK154
HK158

TRANSMITTING TUBES



HK254
HK354
HK354C
HK354D
HK354E
HK354F



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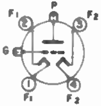
HK257B



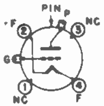
HK304L

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations										
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
HK254	Triode	5.0	7.5	25	100	4000	200	40			50	3.3	3.4	1.1	C-Telegraphy	4000	120	-380	35				20		475
															C-Telephony	3000	135	-290	40				23		320
															Grid Modul., Amp	3000	51		3.0				4.0		58
															B - Audio[2]	3000	40/240	-100	456[9]				7.0[4]	30000	520
HK257 HK257B	Beam Pentode	5.0	7.5		75	4000			750	25	75	13.8	0.04	6.7	C-Telegraphy	2000	150	-200	6.0	500	11	60	1.4		230
											120				C-Telephony	1800	135	-130	8.0	400	11	60	1.7		178
															Supp.Modul., Amp	2000	55	-130	3.0	500	27	-300	0.4		35
HK304L	Triode	5/10	26/13	10	300	3000	1000	150				12	9.0	0.8	C-Telephony	1500	300	-200	75						300
HK354 HK354C	Triode	5.0	10	14	150	4000	300	50			30	4.5	3.8	1.1	C-Telegraphy	4000	245	-690	50				48		830
															C-Telephony	3000	210	-550	50				35		525
															Grid Modul., Amp	3000	78	-400	3.0				12		85
															B - Audio[2]	3000	65/313	-205	630[9]				20[4]	22000	665
HK354D	Triode	5.0	10	22	150	4000	300	55			30	4.5	3.8	1.1	C -Telegraphy	3500	240	-490	50				38		690
															C-Telephony	3500	210	-425	55				36		525
HK354E	Triode	5.0	10	35	150	4000	300	60			30	4.5	3.8	1.1	C-Telegraphy	3500	240	-448	60				45		690
															C-Telephony	3000	210	-437	60				45		525
HK354F	Triode	5.0	10	50	150	4000	300	75			30	4.5	3.8	1.1	C-Telegraphy	3500	250	-368	75				50		720
															C-Telephony	3000	210	-312	75				45		525

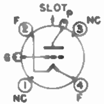
HK454H	Triode	5.0	11	30	250	5000	375	85			100	4.6	3.4	1.4	C-Telegraphy	3500	270	-275	60				28		760
HK454L	Triode	5.0	11	12	250	5000	375	60			100	4.6	3.4	1.4	C-Telephony	3500	270	-450	45				30		760
HK654	Triode	7.5	15	22	300	4000	600	100			20	6.2	5.5	1.5	C-Telegraphy	2000	500	-380	75				57		720
															C-Telephony	2000	450	-365	110				70		655
															Grid Modul., Amp	3500	150	-210	15				15		210
HK854H	Triode	7.5	12	30	450	6000	600	110			125	8	4	0.5	C-Telegraphy	5000	450	-310	75				40		1820
															C-Telephony	4000	475	-285	100				50		1520
															B - Audio	4000	670	-140					45	14500	1970
HK854L	Triode	7.5	12	14	450	6000	600	80			125	6	5	0.5	C-Telegraphy	5000	450	-575	45				40		1800
															C-Telephony	4000	475	-625	65				58		1520
															B - Audio	4000	660	-315					45	14500	1880
HV12	Triode	10	4.0	12	200	2500	200	60			30	8.5	12.8	1.7	C-Telegraphy	2500	300	-240	30				10		575
															C-Telephony	2000	300	-370	40				20		485
															B - Audio[‡]	2000	50/275	-160	350[*]				7.0[*]	14400	400
HV18	Triode	0-11	3.4	18	150	2500	200	50			20	5.2	5.8	1.2	C-Telegraphy	2500	200	-300	18				8.0		380
															C-Telephony	2000	160	-350	20				9.0		250
															B - Audio[‡]	2500	60/360	-130	460[*]				8.0[*]	16000	600
HV27	Triode	10	4.0	27	200	2500	300	60			30	8.5	13.5	2.1	C-Telegraphy	2500	300	-175	50				15		585
															C-Telephony	2000	250	-195	45				15		400

BOTTOM VIEWS SHOWN

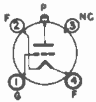
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



HK454H
HK454L
HK654
HV18

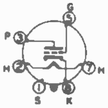


HK854H
HK854L



HV12
HV27

TRANSMITTING TUBES



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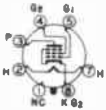

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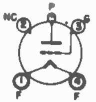
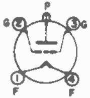
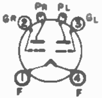
HY24



HY25
HY40



HY30Z



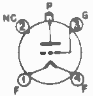
HY31Z

Designation	Type	Cathode		Amp Factor	Maximum				Ratings			Interelectrode Cap.[37]			Typical						Operations			
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
HY6J5GTX	Triode	6.3	0.3	20	3.5	330	20	4.0			60	4.2	3.8	5.0	C-Amp., Osc.	330	20	-30	2.0				0.2		3.5
															C-Telephony	250	20	-30	2.5				0.3		2.5
HY6L6GTX		6.3	0.9		21	500			300	3.5	60	11	0.5	7.0	C-Amp., Osc.	500	90	-50	2.0	250	9.0		0.5		30
															C-Telephony	400	90	-45	3.0	225	9.0		0.8		20
HY6V6GTX		6.3	0.5		13	350			225	2.5	60	9.5	0.7	9.5	C-Telegraphy	300	60	-45	2.5	200	7.5		0.3		12
															C-Telephony	250	60	-45	2.0	200	6.0		0.4		10
HY24	Triode	2.0	0.13	9.3	2.0	180	20	4.5			60	2.7	5.4	2.3	C-Telegraphy	180	20	-45	4.5				0.2		2.7
															C-Telephony	180	20	-45	4.5				0.3		2.5
HY25	Triode	7.5	2.25	55	25	800	75	25			60	4.2	4.6	1.0	C-Telegraphy	750	75	-45	15				2.0		42
															C-Telephony	700	75	-45	17				5.0		39
HY30Z	Triode	6.3	2.25	87	30	850	90	25			60	6.0	4.9	1.0	C-Amp., Osc.	850	90	-75	25				2.5		58
															C-Telephony	700	90	-75	25				3.5		47
HY31Z[33]	Triode	6.3	3.5	45	30	500	150	30			60	5.0[11]	5.5[11]	1.9[11]	C-Telegraphy	500	150	-45	25				2.5		56
															C-Telephony	400	150	-100	30				3.5		45
HY40	Triode	7.5	2.25	25	40	1000	125	25			60	6.1	5.6	1.0	C-Telegraphy	1000	125	-90	20				5.0		94
															C-Telephony	850	125	-90	25				5.0		82
															Grid Modul., Amp	1000	125								20

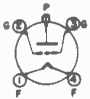
HY40Z	Triode	7.5	2.6	80	40	1000	125	30			60	6.2	6.3	0.8	C-Telegraphy	1000	125	-27	25				5.0		94
															C-Telephony	850	100	-30	30				7.0		82
															Grid-Modul.Amp	1000	60								20
HY51A	Triode	7.5	3.5	25	65	1000	175	25			60	6.5	7.0	1.1	C-Telegraphy	1000	175	-75	20				7.5		131
HY51B		10	2.25												C-Telephony	1000	130	-67.5	15				7.5		104
															Grid Modul., Amp	1000	100								33
HY51Z	Triode	7.5	3.5	85	65	1000	175	35			60	7.9	7.2	0.9	C-Telegraphy	1000	175	-22.5	35				10		131
															C-Telephony	1000	160	-30	35				10		104
															Grid Modul., Amp	1000	100								33
HY57	Triode	6.3	2.25	50	40	850	110	25			60	4.9	5.1	1.7	C-Telegraphy	860	110	-48	15				2.5		70
															C-Telephony	700	90	-45	17				5.0		47
															Grid Modul., Amp	850	70								20
HY60	Beam Tetrode	6.3	0.5		15	425			225	2.5	60	10	0.2	8.5	C-Telegraphy	435	60	-62.5	3.0	200	8.5		0.3		18
															C-Telephony	325	60	-45	2.5	200	7.0		0.2		14
HY61	Beam Tetrode	6.3	0.9		25	600			300	3.5	60	11	0.2	7.0	C-Telegraphy	600	85	-50	4.0	250	9.0		0.4		40
															C-Telephony	475	100	-50	3.5	250	9.0		0.2		27
															AB_1 - Audio[3]	600	200[4]	-30		300	10[4]		0.1[4]		80
HY63	Beam Tetrode	2.5 1.25	.1125 .275		3.0	200			100	0.6	60	8.0	0.1	8.0	C-Telegraphy	200	20	-22.5	2.0	100	4.0		0.1		3.0
															C-Telephony	180	15	-35	2.0	100	3.0		0.2		2.0

BOTTOM VIEWS SHOWN

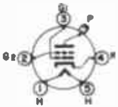
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



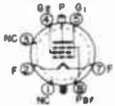
HY40Z
HY51A
HY51B
HY57



HY51Z

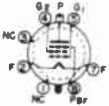


HY60
HY61



HY63

TRANSMITTING TUBES



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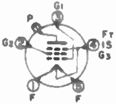

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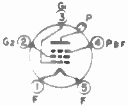

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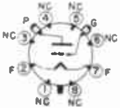


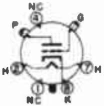
HY75
HY75A
HY114
HY114B

Designation	Type	Cathode		Amp Factor	Maximum			Ratings				Interelectrode Cap.[37]			Typical					Operations					
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
HY65	Beam Tetrode	6.3	0.85		15	450			250	4.0	60	9.1	0.18	7.2	C-Amp., Osc.	450	75	-45	3.0	250	15		0.5		24
															C-Telephony	350	63	-45	3.0	200	12		0.5		16
HY67		6.3	4.5		65	1250			300	10			0.19	14.5	C-Telegraphy	1250	175	-80	10	300	22.5		1.5		152
		12.6	2.75												C-Telephony	1000	145	-150	14	300	17.5		2.0		101
															Grid Modul., Amp	1250	78			300					32.5
HY69	Beam Tetrode	6.3	1.5		40	600			300	5.0	60	15.4	0.23	6.5	C-Amp., Osc.	600	100	-60	4.0	250	12.5		0.25		42
															C-Telephony	600	100	-60	5.0	250	12.5		0.35		42
															Modul. Doubler	600	90	-300	6.0	200	11.5		2.6		27
															AB$_2$ - Audio[2]	600	200[4]	-35	5.0[4]	300	18[4]		0.3[4]		80
HY75	Triode	6.3	2.5	10	15	450	80	20			60	1.8	3.8	1.0	C-Amp., Osc.	450	80	-50	12						21
															C-Telephony	450	80	-60	12						16
HY75A	Triode	6.3	2.6	9.6	15	450	90	25			175	1.8	2.6	1.0	C-Telegraphy	450	90	-140	20				5.2		26
															C-Telephony	400	90	-140	20				5.2		21
HY114	Triode	1.4	.12	20		180	15	3				1.2	1.7	0.6	C-Telephony	180	15		3						2
HY114B	Triode	1.4	.155	13	1.8	180	12	3.0			300	1.0	1.3	1.0	C-Amp., Osc.	180	12	-30	2.0				0.2		1.4
															C-Telephony	180	12	-35	2.5				0.3		1.4

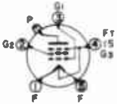
HY615	Triode	6.3	.175	20	3.5	300	20	4.0			300	1.4	1.6	1.2	C-Amp., Osc.	300	20	-35	2.0				0.4		4.0
															C-Telephony	300	20	-35	3.0				0.8		3.5
HY801A	Triode	7.5	1.25	8.0	20	600	70	15			60	4.5	6.0	1.5	C-Telegraphy	600	70	-200	15				4.0		30
															C-Telephony	500	60	-200	15				4.5		22
HY1231Z[21]	Triode	12.6	1.7	45	30	500	150	30			60	5.0"	5.5"	1.9"	C-Telegraphy	500	150	-45	25				2.5		56
															C-Telephony	400	150	-100	30				3.5		45
HY1269	Beam Tetrode	6.3 12.6	3.5 1.75		40	750			300	5.0	6	16.0	0.25	7.5	C-Amp., Osc.	750	120	-70	4	300	15		0.25		63
															C-Telephony	600	100	-70	5	250	12.5		0.5		42
															Grid Modul., Amp	750	80			300					20
															AB_2- Audio[2]	600	200[4]	-35		300			0.3		80
HYE1148	Triode	6.3	.175	20	3.5	300	20	4.0			300	1.4	1.6	1.2	C-Amp., Osc.	300	20	-35	2.0				0.4		4.0
															C-Telephony	300	20	-35	3.0				0.8		3.5
PE340		5.0	7.5		150	4000			400		120	11.6	.06	4.35	C-Telegraphy	3000	200	-290	7	400	27		2.6		450
															C-Telephony	2500	180	-425	9	400	27		4		350
															AB_2- Audio[2]	2500	284[4]	-95		400	7[4]		1.8[4]	19100	460
RK10	Triode	7.5	1.25	8.0	15	450	6.5	15			60	3.0	8.0	4.0	C-Telegraphy	450	65	-100	15				3.2		19
															C-Telephony	350	50	-100	12				2.2		12
															B - Audio[2]	425	55[4]	-50	130[6]				2.5[4]	8000	25
RK11	Triode	6.3	3.0	20	25	750	105	35			60	7.0	7.0	0.9	C-Telegraphy	750	105	-120	21				3.2		55
															C-Telephony	600	85	-120	24				3.7		38

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

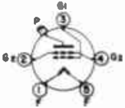


HY615
HYE1148

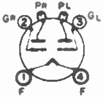


HY1269

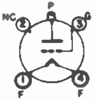
HY801A
RK10



PE340



HY1231Z

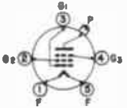


RK11

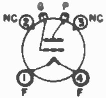
RK28		10	5.0		100	2000			400	35		15	0.02	15	C-Telegraphy	2000	150	-100	13	400	55	45	2.0		210
															C-Telephony	1500	135	-100	13	400	52	45	2.0		155
															Supp.Modul., Amp	2000	85	-100	13	400	65	-45	1.8		60
															Grid Modul., Amp	2000	80	-140	4.0	400	20	45	0.9		75
RK28A	Pentode	10	5.0		125	2000			400	35		15	0.02	15	C-Telegraphy	2000	170	-100	10	400	60	45	1.6		250
															C-Telegraphy	1500	135	-100	10	400	54	45	1.6		150
															Grid Modul., Amp	2000	80	-55	2.0	400	18	45	0.5		60
															Supp.Modul., Amp	2000	90	-115	11.5		52	-45	1.5		60
RK30	Triode	7.5	3.25	15	35	1250	80	25			60	2.75	2.5	2.75	C-Telegraphy	1250	90	-180	18				5.2		85
															C-Telephony	1000	80	-200	15				4.5		60
RK31	Triode	7.5	3.0	170	40	1250	100	35			30	7.0	1.0	2.0	C-Telegraphy	1250	100	-80	30				3.0		90
															C-Telephony	1000	100	-80	28				3.5		70
RK32	Triode	7.5	3.25	11	50	1250	100	25			100	2.5	3.4	0.7	C-Telegraphy	1250	100	-225	14				4.8		90
															C-Telephony	1000	100	-310	21				8.7		70
RK33[23]	Triode	6.3	0.6		5.0	250	40	12				1.6	1.6	2.0	C-Amp., Osc.[23]	250	40	-60	12				1.0		7
RK34[23]	Triode	6.3	0.8	13	10	300	80	20			250	3.4"	2.4"	0.5"	C-Amp., Osc.[23]	300	80	-36	20				1.8		16
RK35	Triode	7.5	4.0	9.0	50	1500	125	20			60	3.5	2.7	0.4	C-Telegraphy	1500	115	-250	15				5.0		120
															C-Telephony	1250	100	-250	14				4.6		93
															Grid Modul., Amp	1500	37	-180					2.0		25

BOTTOM VIEWS SHOWN

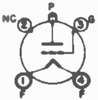
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



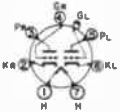
RK28
RK28A



RK30
RK32
RK35



RK31



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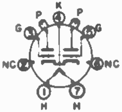
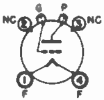
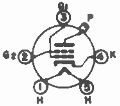


RK34

TRANSMITTING TUBES

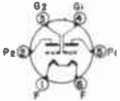


RK36
RK37
RK38



RK39
RK41

RK42



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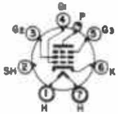


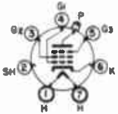
RK44

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations										
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
RK36	Triode	5.0	8.0	14	100	3000	165	35			60	4.5	5.0	1.0	C-Telegraphy	2000	150	-360	30				15		200
															C-Telephony	2000	150	-360	30				15		200
															Grid Modul., Amp	2000	72	-270	1.0				3.5		42
RK37	Triode	7.5	4.0	28	50	1500	125	35			60	3.5	3.2	0.2	C-Telegraphy	1500	115	-130	30				7.0		122
															C-Telephony	1250	100	-150	23				5.6		90
															Grid Modul., Amp	1500	50	-50					2.4		26
RK38	Triode	5.0	8.0		100	3000	165	40			60	4.6	4.3	0.9	C-Telegraphy	2000	160	-200	30				10		225
															C-Telephony	2000	160	-200	30				10		225
															Grid Modul., Amp	2000	80	-150	2.0				5.5		60
RK39	Beam Pent	6.3	0.9		25	600			300	3.5	30	13	0.2	10	C-Telegraphy	600	93	-90	3.0	300	10		0.38		36
RK41		2.5	2.4												C-Telephony	475	85	-50	2.5	250	9.0		0.2		26
RK42	Triode	1.5	.06	8		180	7.5					3	6	2.1	A - Audio	180	3.9	-13.5							
RK43	Twin Triode	1.5	.12	13		135	15	3				1.9	4.2	2.1	C-Telegraphy	135	14	-20	3				.2		1.25
															B -Audio	135	12.5	-6	1				.027	24000	.95
RK44	Pentode	12.6	0.7		12	500			300	8	20	16	0.2	10	C-Telegraphy	500	80	-70	4.0	200	15	40	0.4		28
															C-Telephony	400	45	-40	5.0	140	20	40	0.3		11
															Supp.Modul.Amp	500	30	-20	3.5		23	-65	0.1		5.0

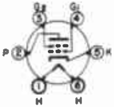
RK45	Pentode	12.6	.45		10	500	60	10	250	8		10	.02	10	C-Telegraphy	500	55	-90	4	200	38	+45	.5		22
															C-Telephony	400	43	-90	6	150	30	0	.8		13.5
RK46	Pentode	12.6	2.5		40	1250		15	300	15		14	.01	12	C-Telegraphy	1250	92	-100	11.5	300	36	45	1.6		84
															C-Telephony	1000	75	-100	10	300	30	0	1.3		52
RK47	Beam Tetrode	10	3.25		50	1250			300	10		13	0.12	10	C-Telegraphy	1250	138	-70	7.0	300	14		1.0		120
															C-Telephony	900	120	-150	6.0	300	17.5		1.4		87
															Grid Modul., Amp	1250	60	-30	0.9	300	2.0		4.0		25
RK48 RK48A	Beam Tetrode	10	5.0		100	2000			400	22		17	.13	13	C-Telegraphy	2000	180	-100	6.5	400	40		1.0		250
															C-Telephony	1500	148	-100	6.5	400	50		1.0		165
															Grid Modul., Amp	1500	77	-145	1.5	400	10		1.6		40
RK49	Beam Tetrode	6.3	0.9		21	400			300	3.5		11.5	1.4	10.6	C-Telegraphy	400	95	-50	3.0	250	8.0		0.2		25
															C-Telephony	300	60	-45	5.0	200	15		0.34		12
RK51	Triode	7.5	3.75	20	60	1500	150	40			60	6.0	6.0	2.5	C-Telegraphy	1500	150	-250	31				10		170
															C-Telephony	1250	105	-200	17				4.5		96
															Grid Modul., Amp	1500	60	-130	0.4				2.3		128.
RK52	Triode	7.5	3.75	170	60	1500	130	50			60	6.6	12	2.2	C-Telegraphy	1500	130	-120	40				7.0		135
															C-Telephony	1250	115	-120	47				8.5		102
															B - Audio[2]	1250	40/300	0	180[3]				7.5[4]	10000	250
RK56	Tetrode	6.3	0.55		8.0	300			300	4.5	60	10	0.2	9.0	C-Telegraphy	400	62	-40	1.6	300	12		0.1		12.5
															C-Telephony	250	50	-40	1.6	200	10		0.28		8.5

BOTTOM VIEWS SHOWN

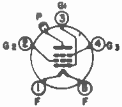
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



RK45



RK49



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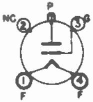
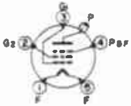
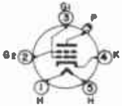


RK51
RK52

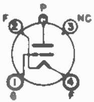


RK47
RK48
RK48A

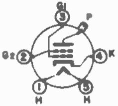


RK56

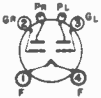
TRANSMITTING TUBES



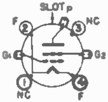
RK57
RK58



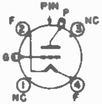
RK64



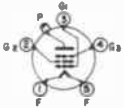
RK59



RK65



RK63
RK63A



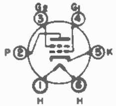
RK66
RK75

Designation	Type	Cathode		Amp Factor	Maximum				Ratings			Interelectrode Cap.[37]			Typical				Operations					
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
RK57	Triode	10	3.25		125	1500	210	70			30	6.5	8.0	5.0	C-Telegraphy	1500	200	-105	40				8.5		215
															C-Telephony	1250	160	-160	60				16		140
															B-Audio[2]	1500	84/400	-16	280[9]				7.0[4]	8200	370
RK58	Triode	10	3.25		100	1250	175	70				8.5	6.5	10.5	C-Telegraphy	1250	150	-90	30				6.0		130
															C-Telephony	1000	150	-135	50				16		100
RK59[23]	Triode	6.3	1.0	25	15	500	90	25				5.0[11]	9.0[11]	1.0[11]	C-Amp., Osc.	500	90	-60	14				1.3		32
RK63	Triode	5.0	10	37	200	3000	250	60				2.7	3.3	1.1	C-Telegraphy	3000	233	-200	45				17		525
RK63A		6.3	14												C-Telephony	2500	205	-200	50				19		405
															Grid Modul., Am.p	3000	100	-250	7.0				12.5		100
RK64	Pentode	6.3	0.5		6.0	400			100	3.0	60	10	0.4	9.0	C-Telegraphy	400	35	-30	3.0	100	10	30	0.18		10
															C-Telephony	300	26	-30	4.0		8.0	30	0.2		6.0
RK65	Tetrode	5.0	14		215	3000			500	35	60	10.5	0.24	4.75	C-Telegraphy	3000	240	-100	24	400	70		6.0		510
															C-Telephony	2500	200	-150	22		70		6.3		380
RK66	Tetrode	6.3	1.5		30	600			300	3.5	60	12	0.25	10.5	C-Amp., Osc.	600	90	-60	5.0	300	11		0.5		40
															C-Telephony	500	75	-50	3.2		8.0		0.23		25
RK75	Pentode	5.5	1.0		15	500			250	6.0		15	0.55	12	C-Telegraphy	500	60	-35	1.4	250	13	0			20
															Supp.Modul., Amp	500	40	-35	1.5	200	20	-50			6.0

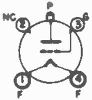
RK100	Triode	6.3	0.9	40	15	150	250	100				23	19	3.0	C - Osc.	110	80		8.0						3.5
															C - Amp.	110	185		40				2.1		12
T20	Triode	7.5	1.75	20	20	750	85	25			60	4.9	5.1	0.7	C-Telegraphy	750	85	-85	18				3.6		44
															C-Telephony	750	70	-140	15				3.6		38
T21	Beam Tetrode	6.3	0.9		21	400			300	3.5	30	13	0.7	12	C-Telegraphy	400	95	-50	3.0	250	8.0		0.2		25
															C-Telephony	350	65	-45	5.0	200	17		0.35		14
T40	Triode	7.5	2.5	25	40	1500	150	40			60	4.5	4.8	0.8	C-Amp., Osc.	1500	150	-140	28				9.0		158
															C-Telephony	1250	115	-115	20				5.25		104
T55	Triode	7.5	3.0	20	55	1500	150	40			60	5.0	3.9	1.2	C-Telegraphy	1500	150	-170	18				6.0		170
															C-Telephony	1500	125	-195	15				5.0		145
T60	Triode	10	2.5	20	60	1600	150	50			60	5.5	5.2	2.5	C-Amp., Osc.	1500	150	-150	50				9.0		100
T100	Triode	10	2.5	23	75	1500	150	30			30	4.0	4.5	2.6	C-Telegraphy	1500	150	-200	18				6.0		170
															C-Telephony	1250	110	-250	21				8.0		105
															Grid Modul., Amp	1500	72	-280	1.5				6.0		42
															B - Audio[2]	1750	40/270	-62	324[5]				9.0[4]	16000	350
T125	Triode	10	4.5	25	125	2500	250	60			60	6.3	6.0	1.3	C-Telegraphy	2500	240	-200	31				11		475
															C-Telephony	2000	200	-215	28				10		320
T200	Triode	10	5.75	16	200	2500	350	60			30	9.5	7.9	1.6	C-Telegraphy	2500	350	-280	54				25		685
															C-Telephony	2000	300	-260	54				23		460

BOTTOM VIEWS SHOWN

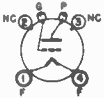
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



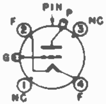
RK100
T21



T20
T40
T55

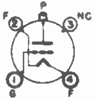


T60
T100



T125
T200

TRANSMITTING TUBES



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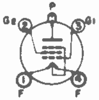
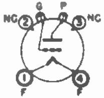
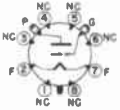
T822



TB35



TF100
TW75



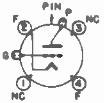
TUF20

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations										
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
T300	Triode	11	6.0	23	200	3000	300					6.0	7.0	1.4	C-Telegraphy	3000	250	-400	28				20		600
															C-Telephony	2000	250	-300	36				17		385
															B - Audio[2]	2500	60/450	-100					7.5[4]		750
T814	Triode	10	4.0	12	200	2500	200	60			30	8.5	12.8	1.7	C-Telegraphy	2500	300	-240	30				10		575
															C-Telephony	2000	300	-370	40				20		485
															B - Audio[2]	2000	50/275	-160	350[8]				7.0[4]	14400	400
T822	Triode	10	4.0	27	200	2500	300	60			30	8.5	13.5	2.1	C-Telegraphy	2500	300	-175	50				15		585
															C-Telephony	2000	250	-195	45				15		400
TB35	Beam Tetrode	6.3	3.0		35						250	6.5	0.2	1.8	C-Telegraphy	1500	110	-300	15	375	22		4.5		130
															C-Telephony	1000	85	-200	10	300	14		2.0		60
TF100	Triode	10	2	23	75	1750	150	30			30	3.5	4.5	1.4	C-Telegraphy	1500	150	-200	18				6		170
															C-Telephony	1250	110	-250	21				8		105
															B - Audio	1750	270	-62					9	16000	350
TUF20	Triode	6.3	2.75	10	20	750	75	20			250	1.8	3.6	.095	C-Amp., Osc.	750	75	-150	20				1.5/2		40
TW75	Triode	7.5	4.15	20	75	2000	175	60			60	3.35	1.5	0.7	C-Amp., Osc.	2000	150	-175	37				12.7		225
															C-Telephony	2000	125	-260	32				13.2		198

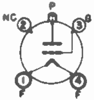
TW150	Triode	10	4.1	35	150	3000	200	30				3.9	2.0	0.8	C-Amp., Osc.	3000	200	-170	45				17		470
															C-Telephony	3000	165	-260	40				17		400
TZ20	Triode	7.5	1.75	62	20	750	85	30			60	5.3	5.0	0.6	C-Telegraphy	750	85	-40	28				3.75		44
															C-Telephony	750	70	-100	23				4.8		38
															B - Audio[2]	800	10/136	0	160[9]				1.8[4]	12000	70
TZ40	Triode	7.5	2.5	62	40	1500	150	45			60	4.8	5.0	0.8	C-Amp., Osc.	1500	150	-90	38				10		165
															C-Telephony	1250	125	-100	30				7.5		116
															B - Audio[2]	1500	250[4]	-9	285[9]				6.0[4]	12000	250
UE100	Triode	10	2.5	23	75	1750	150	30			30	3.5	4.5	1.4	C-Telegraphy	1500	150	-200	18				6.0		170
															C-Telephony	1250	120	-250	21				8.0		105
															B - Audio[2]	1750	540[4]	-62					8.0	16000	350
UE468	Triode	10	4.05	18	150	2500	200	60			30	8.8	7.0	1.25	C-Telegraphy	2500	200	-300	18				8.0		380
															C-Telephony	2000	160	-350	20				9.0		250
															B - Audio[2]	2500	320[4]	-130	410[9]				2.5	16000	500
UH35	Triode	5.0	4.0	30	70	1500	150	35			60	1.4	1.6	0.2	C-Telegraphy	1500	150	-170	30				7.0		170
															C-Telephony	1500	100	-120	30				5.0		120
UH50	Triode	7.5	3.25	10.6	50	1250	125	25			60	2.2	2.6	0.3	C-Telegraphy	1250	125	-225	20				7.5		115
															C-Telephony	1250	125	-325	20				10		115
															Grid Modul., Amp	1250	60	-200	2.0				3.0		25

BOTTOM VIEWS SHOWN

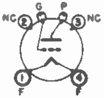
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



TW150



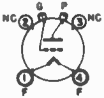
TZ20
TZ40
UH35



UE100
UH50

UE468

TRANSMITTING TUBES



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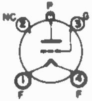
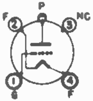


V70B
V70C
V70D



V70
V70A

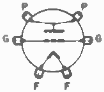
VT25A

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations									
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
UH51	Triode	5.0	6.5	10.6	50	2000	175	25			60	2.2	2.3	0.3	C-Telegraphy	2000	150	-500	20				15		225
															C-Telephony	1500	165	-400	20				15		200
															Grid Modul., Amp	1500	85	-400	2.0				8.0		65
V70	Triode	10	2.5	14	70	1500	140	25				5.0	9.0	2.3	C-Telegraphy	1500	130	-215	6.0				3.0		140
															C-Telephony	1250	130	-250	6.0				3.0		120
V70A	Triode	10	2.5	25	70	1500	140	20				5.0	9.5	2.0	C-Telegraphy	1000	140	-110	30				7.0		90
															C-Telephony	800	95	-150	20				5.0		50
V70B	Triode	10	2.5	14	70	1500	140	25				5.0	9.0	2.3	C-Telegraphy	1500	130	-215	6.0				3.0		140
															C-Telephony	1250	130	-250	6.0				3.0		120
V70C	Triode	10	2.5	25	70	1500	140	20				5.0	9.5	2.0	C-Telegraphy	1000	140	-110	30				7.0		90
															C-Telephony	800	95	-150	20				5.0		50
V70D	Triode	7.5	3.25		85	1750	200	45			30	4.5	4.5	1.7	C-Telegraphy	1500	165	-90	19				3.9		195
																1750	170	-100	19				3.9		225
															C-Telephony	1500	165	-90	19				3.7		185
																1250	127	-72	16				2.6		122
VT25A	Triode	7	1.18	8	15	450	60	15				4.1	7.0	3.0	C-Telegraphy	450	65	-100	15				3.2		19
															C-Telephony	350	50	-100	12				2.2		12

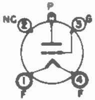
VT127A	Triode	5.0	10.4	15.5	100	300		30			150	2.7	2.3	0.35	C-Amp., Osc.	3000	165	-400	30				20		400
WE251A	Triode	10	16	10.5	1000	3000	600				30				C-Telegraphy										1000
WE268A	Triode	5	3.25	5	25	750	60				30				C-Telegraphy										
WE279A	Triode	10	21	10	1200	3000	800				20				C-Telegraphy										
WE300B	Triode	5	1.2	3.8	40	450	100					9	1.5	4.3	A - Audio	450	80	-97							14.6
WE304A	Tetrode	7.5	3.25	11	50	1250	100	25			100	2.0	2.5	0.7	C-Telegraphy	1250	100	-200							85
															C-Telephony	1000	100	-180							65
WE339A	Pentode	5	1.2		45	575	125		96						C-Telegraphy										
WE350A	Tetrode	6.3	1.6		30	600	125		430						C-Telegraphy										
WE356B	Triode	5	5	50	60	1500	120	35			100	2.25	2.75	1	C-Telegraphy										
WE357B	Triode	5	5		350	4000	500		30		100				C-Telegraphy										

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

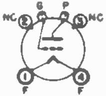


VT127A



WE268A

WE300B



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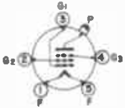

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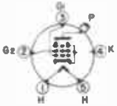
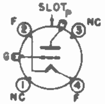


WE350A

WE356B

WE357B

TRANSMITTING TUBES



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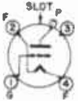

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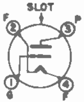
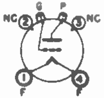


WL469



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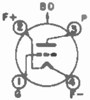
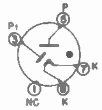


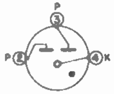
ZB120

Designation	Type	Cathode		Amp Factor	Maximum Ratings							Interelectrode Cap.[37]			Typical Operations										
		Volts	Amps		Plate Dis.	Plate Volt.	Plate Ma.	Grid Ma.	Screen Volt.	Screen Dis.	Freq. Full	Grid to Fil.	Grid to Plate	Plate to Fil.	Class	Plate Volts	Plate Ma.	Grid Volts	DC Grid Ma.	Screen Volts	Screen Ma.	Suppressor Volts	Driving Power	Impedance P to P	Output Watts
WL460	Triode	10	3.85	18	200	2500	210	60			20	5	6.5	1.5	C-Telegraphy	2500	200	-300	18				8		375
															C-Telephony	2000	160	-350	20				9		250
															B - Audio	2500	360	-130						16000	600
WL468	Triode	10	4	12	200	2500	210	60			30	8.5	14.0	4	C-Telegraphy	2000	200	-300	9				8		300
															B - Audio	2000	275	-160					7	14400	400
WL469	Triode	10	3	12	100	1250	125	50			30	6	9	4	C-Telegraphy	1250	125	-225	20				7		100
															C-Telephony	1000	125	-260	35				14		85
															B - Audio	1250	250	-95					7.5	9000	175
ZB60	Triode	10	2.5	80	75	1600	160	40			30	6.1	5.8	1.85	C-Telegraphy	1500	158	-95	31				6.0		190
															B- Audio[2]	1500	30/305	-9	208[6]				12.5	11200	320
ZB120	Triode	10	2.0	90	75	1250	160	40			30	5.3	5.2	3.2	C-Telegraphy	1250	160	-135	23				5.5		145
															C-Telephony	1000	120	-150	21				5.0		95
															Grid Modul., Amp	1250	95		8.0				1.5		45
															B - Audio[2]	1500	60/296	-9	196[6]				5.0[4]	11200	300

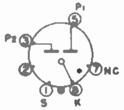
RECTIFIER TUBES



0Y4

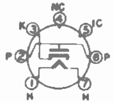


0Z3

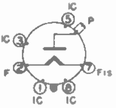


0Z4
0Z4A

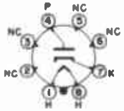
1
1V



1A3



1B3GT



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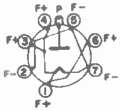
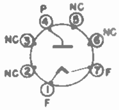
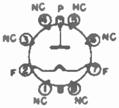


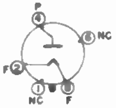
1Z2



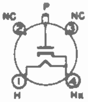
2B25



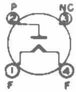
2V3G



2W3
2X3G

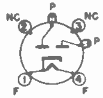


2X2
2X2A
2Y2



2Z2

3B21
3B22

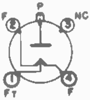


3B23

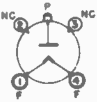
BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

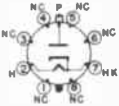
Designation	Type	Cathode			Max. A.C. Voltage Per Plate	D.C. Output Ma.	Max. Inverse Peak Volt.	Peak Plate Ma.
		Type	Volts	Amps				
OY4	Half Wave Gas	Cold	Connections 7 and 8		95	75	300	500
OZ3	Full Wave Gas	Cold			350	30 - 75	1250	200
OZ4	Full Wave Gas	Cold			350	30 - 75	1250	200
OZ4A	Full Wave Gas	Cold				110	880	
1	Half Wave Mercury Vapor	Htr	6.3	0.3	350	50	1000	400
1A3	H. F. Diode Rec.	H	1.4	0.15	0.5		300	5.0
1B3GT	Half Wave Hi-Vac.	Fil	1.25	0.2		2.0	40000	17
1B48	Half Wave Gas	Cold			800	6	2700	50
1R4	UHF Diode	H	1.4	0.15	30	340		
1V	Half Wave Hi-Vac.	H	6.3	0.3	350	50		
1Z2	Half Wave Hi-Vac.	F	1.5	0.3	7800	2	20000	10
2B25	Half Wave Hi-Vac.	F	1.4	0.11	1000	1.5		9
2V3G	Half Wave Hi-Vac.	F	2.5	5.0		2.0	16500	12
2W3	Half Wave Hi-Vac.	F	2.5	1.5	350	55		
2X2	Half Wave Hi-Vac.	H	2.5	1.75	4500	7.5		
2X2A*	Half Wave Hi-Vac.	H	2.5	1.75	4500	7.5		
2X3G	Half Wave	F	2.5	2.0	350	125	1400	375
					500	125	1400	375
2Y2	Half Wave Hi-Vac.	F	2.5	1.75	4400	5.0		
2Z2	Half Wave Hi-Vac.	F	2.5	1.5	350	5.0		
3B21	Full Wave		2.5	5.5			340	3000
3B22	Full Wave		2.5	6.25			725	4000
3B23	Full Wave		2.5	8.0	1250		3500	600



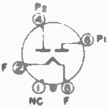
3B24



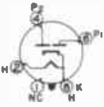
3B25



3B26

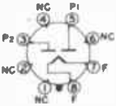


5AZ4
5R4GY
5T4
5U4G
5W4
5Y3G

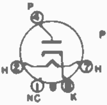


5V4G
5Z4

5X3
5Z3



5X4G
5Y4G



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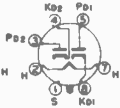

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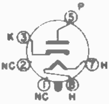

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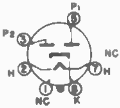

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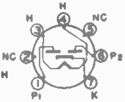
6X5



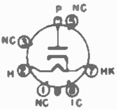
6X4

BOTTOM VIEWS SHOWN

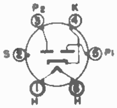
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

Designation	Type	Cathode			Max. A.C. Voltage Per Plate	D.C. Output Ma.	Max. Inverse Peak Volt.	Peak Plate Ma.
		Type	Volts	Amps				
3B24	Half Wave Hi-Vac	F	5.0	3.0		60	20000	300
			2.5	3.0		30	20000	150
3B25	Half Wave Gas	F	2.5	5.0		500	4500	2000
3B26	Half Wave Hi-Vac.	H	2.5	4.75		20	15000	8000
4B22	Full Wave	F	2.5	12.0			340	15000
4B23	Full Wave	F	2.5	17.0			425	15000
4B24	Full Wave	F	2.5	11.0			725	10000
4B25	Full Wave	F	2.5	17.0			700	9400
4B26	Full Wave	F	2.2	18.0			375	36000
4B27	Full Wave	F	2.5	10.0			1000	3100
4B28	Full Wave	F	2.2	18.0			300	36000
5AZ4	Full Wave Hi-Vac.	F	5.0	2.0	350[30]	125	1400	375
					500[29]	125		
5R4GY	Full Wave Hi-Vac.	F	5.0	2.0	900[30]	150[30]	2800	650
					950[29]	175[29]		
5T4	Full Wave Hi-Vac.	F	5.0	3.0	450	250	1250	800
5U4G	Full Wave Hi-Vac.	F	5.0	3.0	500	250	1400	
5V4G	Full Wave Hi-Vac.	H	5.0	2.0	400	200	1100	
5W4	Full Wave Hi-Vac.	F	5.0	1.5	350	110	1000	
5X3	Full Wave Hi-Vac.	F	5.0	2.0	1275	30		
5X4G	Full Wave Hi-Vac.	F	5.0	3.0	500	250	1400	
5Y3G	Full Wave Hi-Vac.	F	5.0	2.0	350[30]	125	1400	375
					500[29]	125		
5Y4G	Full Wave Hi-Vac.	F	5.0	2.0	350[30]	125	1400	375
					500[29]	125		
5Z3	Full Wave Hi-Vac.	F	5.0	3.0	500	250	1400	
5Z4	Full Wave Hi-Vac.	H	5.0	2.0	400	125	1100	
6H4GT	Diode		6.3	0.15	100			4.0
6H6	Twin Diode		6.3	0.3	100	4.0		
6W4GT	Damper Service	H	6.3	1.2		125	2000	600
	Half Wave Hi-Vac.					125	1250	600
6W5G	Full Wave Hi-Vac.	H	6.3	0.9	350	100	1250	350
6X4	Full Wave Hi-Vac.	H	6.3	0.6	325	70	1250	210
6X5	Full Wave Hi-Vac.	H	6.3	0.5	350	75		

RECTIFIER TUBES

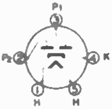


6Y3G



6Y5

6Z3
12Z3
14Z3
25Z3



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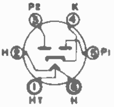

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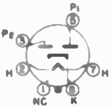

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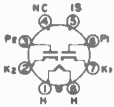
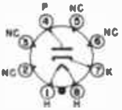


7A6



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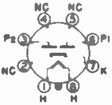
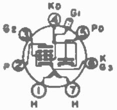
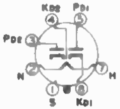


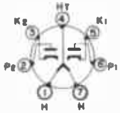
7Y4
7Z4
14Y4



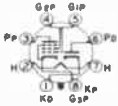
12A7



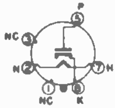
12H6
25X6GT



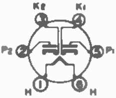
12Z5



25A7GT



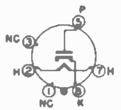
25Y4GT



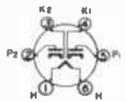
25Y5

Designation	Type	Cathode Type	Cathode Volts	Cathode Amps	Max. A.C. Voltage Per Plate	D.C. Output Ma.	Max. Inverse Peak Volt.	Peak Plate Ma.
6Y3G	Half Wave Hi-Vac.	H	6.3	0.7	5000	7.5		
6Y5	Full Wave Hi-Vac.	H	6.3	0.8	350	50		
6Z3	Half Wave Hi-Vac.	F	6.3	0.3	350	50		
6Z4	F W H-V with Con. input filt.	H	6.3	0.5	325	60	1250	180
	With Choke input filter				450	60	1250	180
6Z5	Full Wave Hi-Vac.	H	6.3	0.6	230	60		
6ZY5G	Full Wave Hi-Vac.	H	6.3	0.3	350	35	1000	150
7A6	Twin Diode	H	7.0	0.16	150	10		
7C4/1203	U. H. F. Diode		6.3	0.15	150	8		
7Y4	Full Wave Hi-Vac.	H	6.3	0.5	350	60		
7Z4	Full Wave Hi-Vac.	H	6.3	0.9	450[29] 325[30]	100	1250	300
12A7	Hi-Vac. Pentode	H	12.6	0.3	125	30		
12H6	Twin Diode		12.6	0.15	100	40		
12Z3	Half Wave Hi-Vac	H	12.6	0.3	250	60		
12Z5	Voltage Doubler Hi-Vac.	H	12.6	0.3	225	60		
14Y4	Full Wave Hi-Vac.	H	12.6	0.3	450[29] 325[30]	70	1250	210
14Z3	Half Wave Hi-Vac.	H	12.6	0.3	250	60		
15R	Half Wave		5	4			20000	150
25A7GT	Hi-Vac. Pentode	H	25	0.3	125	75		
25X6GT	Voltage Doubler Hi-Vac.	H	25	0.15	125	60		
25Y4GT	Half Wave Hi-Vac.	H	25	0.15	125	75		
25Y5	Voltage Doubler Hi-Vac.	H	25	0.3	250	85		
25Z3	Half Wave Hi-Vac.	H	25	0.3	250	50		

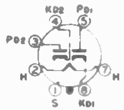
RECTIFIER TUBES



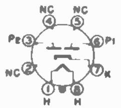
25Z4
35Z4GT



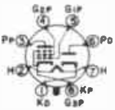
25Z5



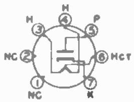
25Z6
35Z6G
50Y6GT
50Z6G



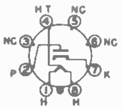
28Z5



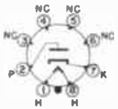
32L7GT



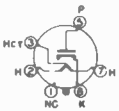
35W4



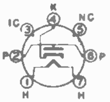
35Y4



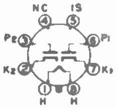
35Z3



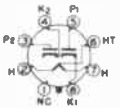
35Z5G
40Z5GT
45Z5GT



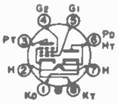
45Z3



50X6



50Y7GT
50Z7G

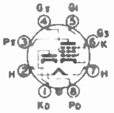


70A7GT

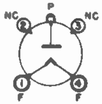
BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

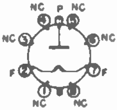
Designation	Type	Cathode Type	Cathode Volts	Cathode Amps	Max. A.C. Voltage Per Plate	D.C. Output Ma.	Max. Inverse Peak Volt.	Peak Plate Ma.
25Z4	Half Wave Hi-Vac	H	25	0.3	125	125		
25Z5	Hi-Vac. Doubler	H	25	0.3	125	100		500
25Z6	Hi-Vac. Doubler	H	25	0.3	125	100		500
28Z5	Full Wave Hi-Vac.	H	28	0.24	450[29] 325[30]	100		300
32L7GT	Hi-Vac. Tetrode	H	32.5	0.3	125	60[33]		
35W4	Half Wave Hi-Vac.	H	35[31]	0.15	125	100[32]	330	600
35Y4	Half Wave Hi-Vac.	H	35[31]	0.15	235	60[33] 100[32]	700	600
35Z3	Half Wave Hi-Vac.	H	35	0.15	117	100	700	600
35Z4GT	Half Wave Hi-Vac.	H	35	0.15	250	100	700	600
35Z5G	Half Wave Hi-Vac.	H	35[31]	0.15	125	60[33] 100[32]		
35Z6G	Voltage Doubler Hi-Vac.	H	35	0.3	125	110		500
40Z5GT	Half Wave Hi-Vac.	H	40[31]	0.15	125	60[33] 100[32]		
45Z3	Half Wave Hi-Vac.	H	45	0.075	117	65	350	390
45Z5GT	Half Wave Hi-Vac.	H	45[31]	0.15	125	60[33] 100[32]		
50X6	Voltage Doubler Hi-Vac.	H	50	0.15	117	75	700	450
50Y6GT	Full Wave Hi-Vac.	H	50	0.15	125	85		
50Y7GT	Voltage Doubler Hi-Vac.	H	50[31]	0.15	117	65	700	
50Z6G	Voltage Doubler Hi-Vac	H	50	0.3	125	150		
50Z7G	Voltage Doubler Hi-Vac.	H	50	0.15	117	65		
70A7GT	Hi-Vac. Tetrode	H	70	0.15	117	60		



70L7GT

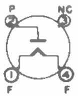


72
100R

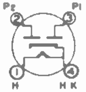


73

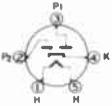
80
82
83



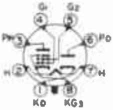
81



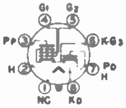
83V



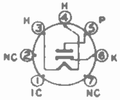
84



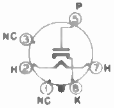
117L7GT
117M7GT



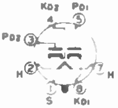
117N7GT
117P7GT



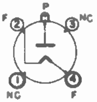
117Z3



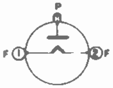
117Z4GT



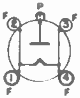
117Z6GT



217A
217C



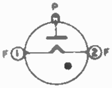
222A
233A
253A
255B



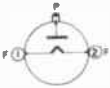
249B

Designation	Type	Cathode			Max. A.C. Voltage Per Plate	D.C. Output Ma.	Max. Inverse Peak Volt.	Peak Plate Ma.
		Type	Volts	Amps				
70L7GT	Hi-Vac. Tetrode	H	70	0.15	117	70		350
72	Half Wave Hi-Vac.	F	2.5	3.0		30	20000	150
73	Half Wave Hi-Vac.	F	2.5	4.5		20	13000	3000
80	Full Wave Hi-Vac.	F	5.0	2.0	350^{30}	125	1400	375
					$500^{[illegible]}$	125		
81	Half Wave Hi-Vac.	F	7.5	1.25	700	85		
82	Full Wave Mercury Vapor	F	2.5	3.0	500	125	1400	400
83	Full Wave Mercury Vapor	F	5.0	3.0	500	250	1400	800
83V	Full Wave Hi-Vac.	H	5.0	2.0	400	200	1100	
84	Full Wave Hi-Vac.	H	6.3	0.5	350	60	1000	
100R	Half Wave Hi-Vac.	F	5	6.2	10000	100	40000	750
117L7GT	Hi-Vac. Tetrode	H	117	0.09	117	75		
117M7GT								
117N7GT	Hi-Vac. Tetrode	H	117	0.09	117	75	350	450
117P7GT	Hi-Vac. Tetrode	H	117	0.09	117	75	350	450
117Z3	Half Wave Hi-Vac.	H	117	0.04	117	90	330	540
117Z4GT	Half Wave Hi-Vac.	H	117	0.04	117	90	350	
117Z6GT	Voltage Doubler Hi-Vac.	H	117	0.075	235	60	700	360
217A	Half Wave Hi-Vac.	F	10	3.25			3500	600
217C	Half Wave Hi-Vac.	F	10	3.25			7500	600
222A	Half Wave	F	21.5	41			25000	
233A	Half Wave	F	21.5	41			50000	
249B	Half Wave Mercury Vapor	F	2.5	7.5	3180	375	10000	1500
253A	Half Wave Mercury Vapor	F	2.5	3.0			3500	1000
255B	Half Wave	F	5.0	19			20000	

RECTIFIER TUBES

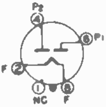


258B
267B
315A



266B
266C

274A

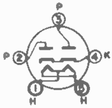


274B

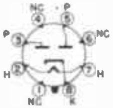
301A

314A

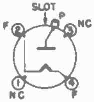
319A
321A



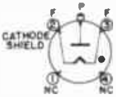
345A



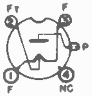
351A



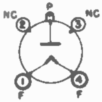
575A



673



705A



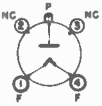
816
836
866
866A
866B

857B

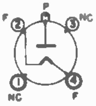
866JR

869B

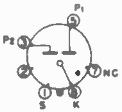
Designation	Type	Cathode Type	Cathode Volts	Cathode Amps	Max. A.C. Voltage Per Plate	D.C. Output Ma.	Max. Inverse Peak Volt.	Peak Plate Ma.
258B	Half Wave Mercury Vapor	F	2.5	7.5			7500	2500
266B	Half Wave	F	5.0	4.2			22000	
266C	Half Wave	F	5.0	42			22000	
267B	Half Wave Mercury Vapor	F	5.0	6.75			7500	4000
274A	Full Wave	F	5.0	2.0			1650	525
274B	Full Wave	F	5.0	2.0			1650	525
301A	Full Wave Mercury Vapor	F	5.0	3.0			1800	2000
314A	Full Wave	F	5.0	5.0			300	
315A	Half Wave Mercury Vapor	F	5.0	10.0			12500	4000
319A	Half Wave Mercury Vapor	F	5.0	6.75			7500	4000
321A	Half Wave Mercury Vapor	F	5.0	10.0			12500	4000
345A	Full Wave	H	6.3	1.0			1375	
351A	Full Wave	H	6.3	1.0			1375	
575A	Half Wave Mercury Vapor		5	10			15000	6000
673	Half Wave Mercury Vapor		5	10			15000	6000
705A	Half Wave Hi-Vac.	F	2.5	5.0		50	35000	375
			5.0	5.0		100	35000	750
816	Half Wave Mercury Vapor	F	2.5	2.0	2200	125	7500	500
836	Half Wave Hi-Vac.	H	2.5	5.0			5000	1000
857B	Half Wave	F	5.0	30			22000	40000
866	Half Wave Mercury Vapor	F	2.5	5.0	3500	250	10000	1000
866A								
866B	Half Wave Mercury Vapor	F	5.0	5.0			8500	1000
866 JR.	Half Wave Mercury Vapor	F	2.5	2.5	1250	250[36]		
869B	Half Wave	F	5.0	18			15000	15000



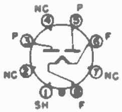
871
878
879
1616
8013A



872
975A

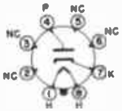


1003

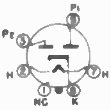


1005

1006
1275



1203
1294



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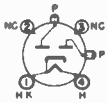

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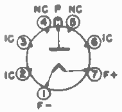

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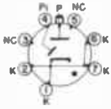

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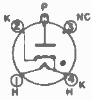

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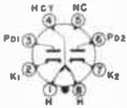

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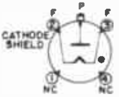

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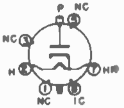
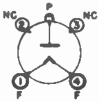
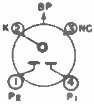


8016

Designation	Type	Cathode			Max. A.C. Voltage Per Plate	D.C. Output Ma.	Max. Inverse Peak Volt.	Peak Plate Ma.
		Type	Volts	Amps				
870A	Half Wave	H	5.0	65.0			16000	
871	Half Wave Mercury Vapor	F	2.5	2.0	1750	250	5000	500
872/872A	Half Wave Mercury Vapor	F	5.0	7.5		1250	10000	5000
878	Half Wave Hi-Vac.	F	2.5	5.0	7100	5	20000	
879	Half Wave Hi-Vac.	F	2.5	1.75	2650	7.5	7500	100
975A	Half Wave Mercury Vapor	F	5.0	10.0		1500	15000	6000
1003	Full Wave Gas	Cold				110	880	
1005	Full Wave Gas	F	6.3	0.1		70	450	210
1006	Full Wave Gas	F	1.75	2.25		200	1600	
1203	U.H.F. Diode		6.3	0.15	150	8		
1274	Full Wave Hi-Vac.	H	6.3	0.6	350	60		
1275	Full Wave Hi-Vac.	F	5.0	1.75	500	250	1400	
1294	U.H.F. Diode		1.4	0.15	30	340		
1616	Half Wave Hi-Vac.	F	2.5	5.0		130	6000	800
1641	Full Wave Hi-Vac.	F	5.0	3.0		50	4500	
						250	2500	
1654	Half Wave Hi-Vac.	F	1.4	0.05	2500	1	7000	6
2000	Half Wave Gas	F	2.2	18.0			375	36000
5517	Half Wave Gas	Cold			1200	6		50
5558	Half Wave Mercury Vapor		5	4.5			1000	15000
5641	Half Wave		6.3	0.45	300			45.0
5642	Half Wave Hi-Vac.		1.25	0.14			10000	23
5679	Vac. Tube Volt-Meter	H	6.3	0.15	150	10		
8008	Half Wave Mercury Vapor	F	5.0	7.5		1250	10000	5000
8013A	Half Wave Hi-Vac	F	2.5	5.0		20	40000	150
8016	Half Wave Hi-Vac.	F	1.25	0.2		2.0	10000	7.5



8020
CE220
HY866JR
RK21

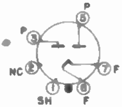


BA
BH

BR

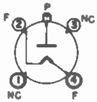
CK1005

CK1006

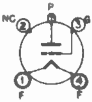


CK1007

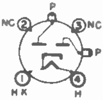
DR3B27
G-84



HK253
RK19



KY21

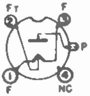


RK22
RK60

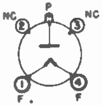
BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

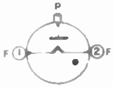
Designation	Type	Cathode			Max. A.C. Voltage Per Plate	D.C. Output Ma.	Max. Inverse Peak Volt.	Peak Plate Ma.
		Type	Volts	Amps				
8020	Half Wave Hi-Vac.	F	5.0	5.5	10000	100	40000	750
			5.8	6.5	12500	100	40000	750
BA	Full Wave Gas	Cold			350	350	Tube drop 80 v.	
BH	Full Wave Gas	Cold			350	125	Tube drop 90 v.	
BR	Half Wave Gas	Cold			300	50	Tube drop 60 v.	
CE 220	Half Wave Hi-Vac.	F	2.5	3.0		20	20000	100
CK1005	Full Wave Gas	F	6.3	0.1		70	450	210
CK1006	Full Wave Gas	F	1.75	2.25		200	1600	
CK1007	Full Wave Gas	F	1.0	1.2		110	980	
CK1009	Full Wave Gas	Cold				350	1000	
DR3B27	Half Wave Hi-Vac.	F	2.5	5.0	3000	250	8500	1000
F-266B	Half Wave Mercury Vapor		5	30			22000	4000
G-84	Half Wave Hi-Vac.	F	2.5	1.5	350	50		
HK253	Half Wave Hi-Vac.	F	5.0	10		350	10000	1500
KY21	Half Wave Mercury Vapor		2.5	10			11000	3000
HY866 JR	Half Wave Mercury Vapor	F	2.5	2.5	1750	250[36]	5000	
RK19	Full Wave Hi-Vac.	H	7.5	2.5	1250	200[30]	3500	600
RK21	Half Wave Hi-Vac.	H	2.5	4.0	1250	200[30]	3500	600
RK22	Full Wave Hi-Vac.	H	2.5	8.0	1250	200[30]	3500	600
RK60	Full Wave Hi-Vac.	F	5.0	3.0		50	4500	
						250	2500	



RK705A

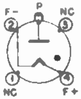


RK866
RK21
T249B
Z225



WE253A
WE258B
WE267B

WE301A



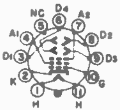
WE319A
WE321A

BOTTOM VIEWS SHOWN

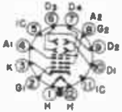
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

Designation	Type	Cathode			Max. A.C. Voltage Per Plate	D.C. Output Ma.	Max. Inverse Peak Volt.	Peak Plate Ma.
		Type	Volts	Amps				
RK705A	Half Wave Hi-Vac.	F	2.5	5.0		50	35000	375
			5.0	5.0		100	35000	750
RK866	Half Wave Mercury Vapor	F	2.5	5.0	3500	250	10000	1000
RX21	Half Wave Mercury Vapor		2.5	10			11000	3000
SN946	Diode		6.3	0.15	150			9.0
SN954	Half Wave		6.3	0.45	300			45
SN956B	Half Wave Hi-Vac.		1.25	0.14			10000	23
T249B	Half Wave Mercury Vapor		2.5	7.5			10000	1500
WE253A	Half Wave Mercury Vapor		2.5	3			3500	1000
WE258B	Half Wave Mercury Vapor		2.5	7.5			7500	2500
WE267B	Half Wave Mercury Vapor		5	6.75			7500	4000
WE301A	Full Wave Mercury Vapor		5	3			1800	2000
WE319A	Half Wave Mercury Vapor		5	6.75			7500	4000
WE321A	Half Wave Mercury Vapor		5	10			12500	4000
Z225	Half Wave Mercury Vapor	F	2.5	5.0		250	10000	1000

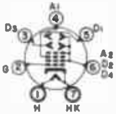
CATHODE RAY TUBES



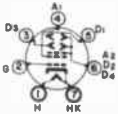
2AP1-11
2AP1A



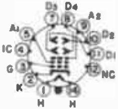
2BP1
2BP11



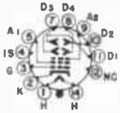
3AP1
906-P1-
4-5-11



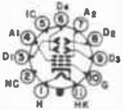
3AP1A
3AP4
3AP5



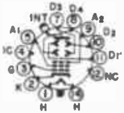
3BP1-
4-11



3BP1A
3DP1



3EP1
1806P1



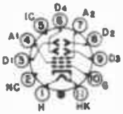
3FP7

Designation	Deflection	Focus	Defl. Angle	Cathode Volts	Cathode Amps	Hi-V Contact	Nominal Diam. Inches	Overall Length Inches	Anode No. 2 Voltage	Anode No. 1 Voltage	Cut-off Grid Voltage	Grid No. 2 Volt.	Signal Swing Volt.	Max. Input Volt.[38]	Screen Input Power[39]	Deflection Sensitivity[41] D'	D'	Color
2AP1-11 2AP1A	Electrostatic	Electrostatic		6.3	0.6		2	7-5/8	1000	250	-60			660		0.11	0.13	G
									500	125	-30					0.22	0.26	
2BP1	Electrostatic	Electrostatic		6.3	0.6		2	7-13/16	2000	300/560	-135			500		270^{40}	174^{40}	G
									1000	150/280	-67.5			500		135^{40}	67^{40}	
2BP11	Electrostatic	Electrostatic		6.3	0.6		2	7-13/16	2000	300/560	-135			500		270^{40}	174^{40}	Photo recrd
									1000	150/280	-67.5			500		135^{40}	87^{40}	
3AP1 906P1-4-5-11	Electrostatic	Electrostatic		2.5	2.1		3		1500	430	-50			550	10	0.22	0.23	G
									1000	285	-33					0.33	0.35	
									600	170	-20					0.55	0.58	
3AP1A	Electrostatic	Electrostatic		2.5	2.1		3	11-1/2	1000	285	-34			600	10	0.22	0.23	G
									1500	475	-50					0.55	0.58	
3AP4	Electrostatic	Electrostatic		2.5	2.1		3		1000	285	-33			550	10	0.22	0.23	W
3AP5									1500	430	-50					0.33	0.35	B
3BP1 4-11-1A	Electrostatic	Electrostatic		6.3	0.6		3		1500	430	-45			550		0.17	0.22	G
									2000	575	-60					0.13	0.17	
3DP1	Electrostatic	Electrostatic		6.3	0.6		3	10-1/4	1500	430	-40			550		0.12	0.17	G
									2000	575	-60					0.16	0.2	
3EP1 1806P1	Electrostatic	Electrostatic		6.3	0.6		3		2000	575	-60			550		0.115	0.154	G
									1500	430	-45					0.153	0.205	
3FP7	Electrostatic	Electrostatic		6.3	0.6		3		2000	575	-60			550		0.1	0.14	B

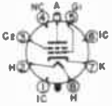
3GP1 - 4-5-11	Electrostatic	Electrostatic		6. 3	0. 6		3		1500	550	-50			550		0. 21	0. 24	W. G
									1000	234	-33					0. 32	0. 36	B
3HP7	Electromagnetic	Electromagnetic		6. 3	0. 6		3		4000		-27	150						B
3JP1-2-4-7-11	Electrostatic	Electrostatic		6. 3	0. 6		3	10	2000	575	-60			550		0. 13	0. 17	G. B
									1500	430	-45					0. 17	0. 23	W
3KP1	Electrostatic	Electrostatic		6. 3	0. 6		3	11-3/4	1000	300	-45	1000		500		68^{40}	136^{40}	G
									2000	600	-90	2000				52^{40}	104^{40}	
3KP4	Electrostatic	Electrostatic		6. 3	0. 6		3	11-1/2	2000	450	-64	2000						
3MP1	Electrostatic	Electrostatic		6. 3	0. 6		3		1000	200 350	-68					190^{40}	180^{40}	G
3NP4	Magnetic	Magnetic	42°	6. 3	0. 6	Cup	2-1/2	10	24000		-65							
5AP1 5AP4	Electrostatic	Electrostatic		6. 3	0. 6		5		2000	575	-35			500	10	0. 17	0. 21	G
									1500	430	-27					0. 23	0. 28	W
5BP1 1802-P1	Electrostatic	Electrostatic		6. 3	0. 6		5		2000	450	-40			500	10	0. 3	0. 33	G
									1500	337	-30					0. 4	0. 45	
5BP2 5BP4 5BP5	Electrostatic	Electrostatic		6. 3	0. 6		5	16-3/4	1500	310	-21			500	10	0. 4	0. 45	B-W
									2000	425	-35					0. 3	0. 33	W
																		B
5CP1 - 2 - 4 - 5 - 7 - 11	Electrostatic	Electrostatic		6. 3	0. 6	Snap Term.	5		2000	575	-60			550		0. 28	0. 32	W
									1500	430	-45					0. 37	0. 43	G
									2000	575	-60					0. 36	0. 41	B
5CP1A	Electrostatic	Electrostatic		6. 3	0. 6	Rec. Small Ball	5	17-1/8	1500	430	-45			550		0. 37	0. 43	G
5FP1 - 2 4 - 11	Electromagnetic	Electromagnetic		6. 3	0. 6		5		7000	250	-45							G. W
									4000	250	-45							B

BOTTOM VIEWS SHOWN

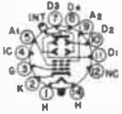
KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



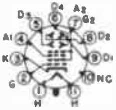
3GP1-4-5-11
5AP1-4
5BP1
5BP2-4-5
1802-P1



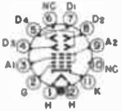
3HP7



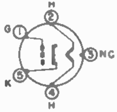
3JP1-2-4-7-11
5CP1-2-
4-5-7-11



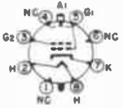
3KP1
3KP4



3MP1

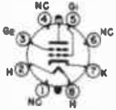


3NP4

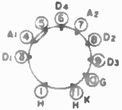


5FP1-
2-4-11

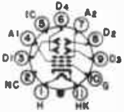
CATHODE RAY TUBES



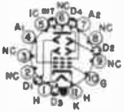
5FP4A
5FP7



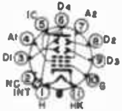
5GP1
5HP1A-4
5NP1



5HP1



5JP1-
2-4-5-11



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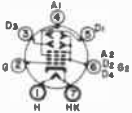
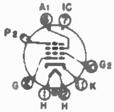
2-4-5-11

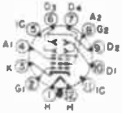


5MP1-
4-5-11

5RP1-
2-4-11



5TP4



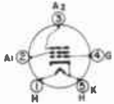
5UP1
5UP7
5UP11

Designation	Deflection	Focus	Defl. Angle	Cathode Volts	Cathode Amps	Hi-V Contact	Nom-inal Diam. Inches	Overall Length Inches	Anode No. 2 Voltage	Anode No. 1 Voltage	Cut-off Grid Voltage	Grid No. 2 Volt.	Signal Swing Volt.	Max. Input Volt[38]	Screen[39] Input Power	Deflection Sensitivity[41] D' D'	D' D'	Color
5FP4A	Electromagnetic			6.3	0.6		5				-45			250				W
5FP7	Electromagnetic			6.3	0.6		5		4000		-45	250						B
5GP1	Electrostatic			6.3	0.6		5		1500	337	-30			550		52[40]	54[40]	G
5HP1	Electrostatic			6.3	0.6		5		2000	425	-40			500		0.3	0.33	G
									1500	310	-30					0.4	0.44	
5HP1A 5HP4	Electrostatic			6.3	0.6		5		1500	337	-30			500		0.3	0.33	
									2000	425	-40					0.4	0.44	W
5JP1 - 2 4 - 5 - 11	Electrostatic			6.3	0.6		5		2000	520	-75			500		0.25	0.28	W.G
									1500	390	-56					0.33	0.37	B
5LP1 - 2 4 - 5 - 11	Electrostatic			6.3	0.6		5		2000	500	-60			500		0.25	0.28	W
									1500	375	-45					0.33	0.37	G
									1000	250	-30					0.49	0.56	B
5MP1 - 4 5 - 11	Electrostatic			2.5	2.1		5		1500	375	-50			660		0.39	0.42	W.G
									1000	250	-33					0.58	0.64	B
5NP1	Electrostatic			6.3	0.6		5		1500	337	-30			500		64[40]	57[40]	G
5RP1 - 2 - 4 - 11	Electrostatic			6.3	0.6		5		3000		-90			1200		0.12	0.12	G.W
									2000	575	-60					0.18	0.18	B
5TP4	Magnetic	Electrostatic	50°	6.3	0.6	Cavity Cap	5	11-3/4	27000	4900	-70	200						W
5UP1 5UP7 5UP11	Electrostatic	Electrostatic		6.3	0.6		5	15-1/8	2500	640	-90			500		38.5[40]	77[40]	G
									2500	340	-90			500		28[40]	56[40]	Y
									1000	320	-45			500		31[40]	62[40]	B
									1000	170	-45			500		23[40]	46[40]	

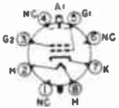
7AP4	Electromagnetic			2.5	2.1		7		3500	1000	-67.5				2.5			W
7BP1 - 2 4 - 7-11	Electromagnetic			6.3	0.6		7		7000	250	-45							W. G
									4000	250	-45							B
7CP1	Electromagnetic			6.3	0.6		7		7000	1470	-45	250						G
									4000	840	-45	250						
7CP4	Electromagnetic			6.3	0.6		7		6000	1140	-45	250						W
7DP4	Magnetic	Electrostatic	50°	6.3	0.6	Rec. Small Cav.	7	14-1/16	6000	1430	-45	250						W
7EP4	Electrostatic	Electrostatic		6.3	0.6		7	15-1/2	2500	650	-60		38			110^{40}	95^{40}	W
7GP4	Electrostatic	Electrostatic		6.3	0.6		7	14-1/2	3000	1200	-84	3000				123^{40}	102^{40}	W
7HP4	Magnetic	Magnetic		6.3	0.6	Ball Cap	7-3/16	13	6000		-55		250					W
7JP4	Electrostatic	Electrostatic		6.3	0.6		7	14-1/2	6000	2400	-168					246^{40}	204^{40}	W

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743

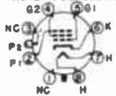


7AP4

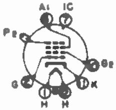


7BP1

TWO WAY MAGNETIC DEFLECTION



7CP1
7CP4



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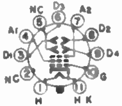

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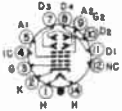
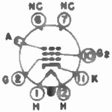
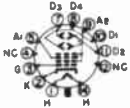


7GP4

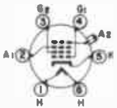


7HP4

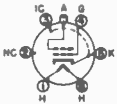


7JP4

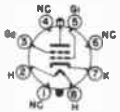
CATHODE RAY TUBES



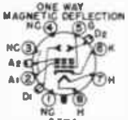
9AP4
12AP4
1804-P4
1803-P4



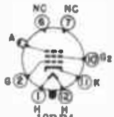
9CP4
12CP4



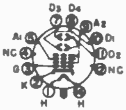
9GP7
9LP7



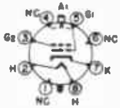
9JP1
1809-P1



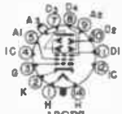
10BP4
10CP4
10EP4
10FP4
12JP4
12KP4
12LP4



10HP4



12DP4

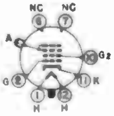


12GP7

Designation	Deflection	Focus	Defl. Angle	Cathode		Hi-V Contact	Nominal Diam. Inches	Overall Length Inches	Anode No. 2 Voltage	Anode No. 1 Voltage	Cut-off Grid Voltage	Grid No. 2 Volt.	Signal Swing Volt.	Max. Input Volt.[39]	Screen Input Power[38]	Deflection Sensitivity[41]		Color
				Volts	Amps											D1 D2	D3 D4	
9AP4	Electromagnetic	Electrostatic		2.5	2.1	Metal Cap	9	21	7000	1425	-40	250	25		10			W
1804-P4									6000	1225	-38							
9CP4	Electromagnetic			2.5	2.1		9		7000		-110		25		10			W
9GP7	Electromagnetic			6.3	0.6		9		4000		-45	250						W
9JP1	Electrost. Magnetic			2.5	2.1		9		5000	1570	-90			3000	0.136			G
1809-P1									2500	785	-45				0.272			
9LP7	Electromagnetic			6.3	0.6		9		4000		-80	250						B
10BP4	Magnetic	Magnetic	50°	6.3	0.6	Recessed Cavity	10	17-5/8	12000	9000	-45	250						W
10CP4	Magnetic	Magnetic	50°	6.3	0.6	Small Ball Cap	10 1/2	16-5/8	8000		-55	250	38					
10EP4	Magnetic	Magnetic	50°	6.3	0.6	Small Ball Cap	10-1/2	17-5/8	12000	8000	-45	250	38					W
10FP4	Magnetic	Magnetic	50°	6.3	0.6	Cavity	10	17-5/8	12000	9000	-27/-63	250						W
10HP4	Electrostatic	Electrostatic		6.3	0.6		10	19-5/8		4000	-48					104[40]	80[40]	W
12AP4	Electromagnetic		40°	2.5	2.1	Metal Cap	12	25	7000	1460	-75	250	25		10			W
1803-P4									6000	1240								
12CP4	Electromagnetic			2.5	2.1	Cavity Button	12	18-3/4	7000		-110		25		10			W
12DP4	Electromagnetic		50°	6.3	0.6	Metal Cap	12	20-1/8	7000	250	-45							W
									4000	250	-45							
12GP7	Electrostatic			6.3	0.6		12		4300	1230	-140					73[40]	69[40]	B
12JP4	Magnetic	Magnetic	50°	6.3	0.6	Reces. Ball Cap	12	17-1/2	10000		-45	250						
12KP4	Magnetic	Magnetic	54°	6.3	0.6	Cavity	12	17-5/8	9000		-45	250						
12LP4	Magnetic	Magnetic	54°	6.3	0.6	Reces. Cav. Cap	12	18-3/4	11000		-27/-63	250						W

12QP4	Magnetic	Magnetic	54°	6.3	0.6	Small Ball Cap	12 7/16	17 1/2	10000		-33 -77	250	30				W
12RP4	Magnetic	Magnetic	56°	6.3	0.6	Ball	12	17 1/2	12000		-33 -77	300					W
12TP4	Magnetic	Magnetic	54°	6.3	0.6	Cavity	12 7/16	18 3/4	12000		-33 -77	300					W
12UP4	Magnetic	Magnetic	54°	6.3	0.6		12 7/16	18 5/8	12000		-33 -77	300					W
12VP4	Magnetic	Magnetic	55°	6.3	0.6	Cavity	12 7/16	18	12000		-33 -77	300					W
14BP4 **	Magnetic	Magnetic		6.3	0.6	Cavity	9 [illegible] x12 [illegible]	16 13/16	12000		-33 -77	300					W
14CP4 **	Magnetic	Magnetic		6.3	0.6	Cavity	9 [illegible] x12 [illegible]	16 3/4	14000		-33 -77	300					W
14DP4 **	Magnetic	Magnetic		6.3	0.6	Cavity	[illegible]	16 3/4	14000		-33 -77	300					W
14FP4 **	Magnetic	Magnetic		6.3	0.6	Cavity	9 11/16 x12 1/2	16 1/8	14000		-33 -77	300					W
15AP4	Magnetic	Magnetic	57°	6.3	0.6	Reces. Ball Cap	15	20 1/2	15000	8000	-33 -77	300					W
15CP4	Magnetic	Magnetic	57°	6.3	0.6	Cavity Button	15 1/2	21 1/2	9000		-33 -77	300					W
15DP4	Magnetic	Magnetic	57°	6.3	0.6	Ball	15 1/2	20 1/2	15000		-33 -77	300					W
16AP4	Magnetic	Magnetic	53°	6.3	0.6	Metal Cone Lip	16	22 1/4	14000	9000	-33 -77	300					W
16CP4	Magnetic	Magnetic	52°	6.3	0.6	Cavity	15 7/8	21 1/2	15000		-33 -77	300					W
16DP4	Magnetic	Magnetic	60°	6.3	0.6	Cavity	15 7/8	20 3/4	15000		-33 -77	300					W
16EP4	Magnetic	Magnetic	60°	6.3	0.6		15 7/8	19 5/8	14000		-33 -77	300					W
16FP4	Magnetic	Magnetic	62°	6.3	0.6	Ball	16 1/8	20 1/4	16000		-33 -77	300					W
16GP4	Magnetic	Magnetic	70°	6.3	0.6		15 7/8	17 11/16	14000		-33 -77	300					W
16HP4	Magnetic	Magnetic	60°	6.3	0.6	Cavity	15 7/8	21 1/4	14000		-33 -77	300					W
16JP4	Magnetic	Magnetic	60°	6.3	0.6	Cavity	16 1/8	20 3/4	14000		-33 -77	300					W
16KP4 **	Magnetic	Magnetic		6.3	0.6	Cavity	11 1/2 x14 3/4	18 3/4	16000		-33 -77	300					W
16LP4	Magnetic	Magnetic	52°	6.3	0.6	Cavity	15 7/8	22 1/4	14000		-33 -77	300					W
16MP4	Magnetic	Magnetic	60°	6.3	0.6	Cavity	16 1/8	21 3/4	14000		-33 -77	300					W
16QP4 **	Magnetic	Magnetic		6.3	0.6	Cavity	11 1/2 x14 1/2	19 9/64	16000		-33 -77	300					W
16RP4 **	Magnetic	Magnetic		6.3	0.6	Cavity	11 1/2 x14 3/4	18 3/4	14000		-33 -77	300					W
16SP4	Magnetic	Magnetic	70°	6.3	0.6	Cavity	15 7/8	17 5/16	14000		-33 -77	300					W
16TP4 **	Magnetic	Magnetic		6.3	0.6	Cavity	11 1/2 x14 1/2	18 1/2	14000		-33 -77	300					W
16UP4 **	Magnetic	Magnetic		6.3	0.6	Cavity	11 1/2 x14 3/4	18 1/2	15000		-33 -77	300					W

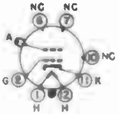
BOTTOM VIEWS SHOWN



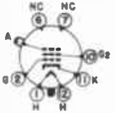
12QP4
12RP4
12TP4
12UP4
14BP4
14CP4
14DP4
14FP4
15AP4
15CP4
15DP4
16AP4
16CP4
16DP4
16EP4
16FP4
16GP4
16HP4
16JP4
16KP4
16LP4
16MP4
16QP4
16RP4
16SP4
16TP4
16UP4

** Rectangular type

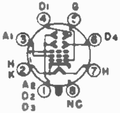
12VP4



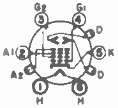
CATHODE RAY TUBES



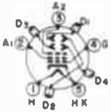
16VP4 17AP4 19FP4
16WP4 19AP4 19GP4
16XP4 19DP4 20BP4
16YP4 19EP4 22AP4



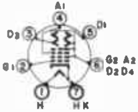
24XH
902A



904



905A
907



908A

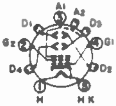
Designation	Deflection	Focus	Defl. Angle	Cathode Volts	Cathode Amps	Hi-V Contact	Nominal Diam. Inches	Overall Length Inches	Anode No. 2 Voltage	Anode No. 1 Voltage	Cut-off Grid Voltage	Grid No. 2 Volt.	Signal Swing Volt.	Max. Input Volt.	Screen Input Power	Deflection Sensitivity D' D'	Deflection Sensitivity D" D'	Color
16VP4	Magnetic	Magnetic	70°	6.3	0.6	Cavity	$15\frac{7}{8}$	$17\frac{3}{16}$	15000		-33 -77	300						W
16WP4	Magnetic	Magnetic	70°	6.3	0.6	Cavity	$15\frac{7}{8}$	$17\frac{3}{4}$	15000		-33 -77	300						W
16XP4**	Magnetic	Magnetic		6.3	0.6	Cavity	$11\frac{1}{2}\times14\frac{3}{4}$	$18\frac{3}{4}$	15000		-33 -77	300						W
16YP4	Magnetic	Magnetic	70°	6.3	0.6	Cavity	$15\frac{1}{8}$	$17\frac{5}{16}$	14000		-33 -77	300						W
17AP4**	Magnetic	Magnetic		6.3	0.6	Cavity	$12\frac{1}{4}\times15\frac{5}{8}$	$18\frac{5}{8}$	16000		-33 -77	300						W
19AP4	Magnetic	Magnetic	66°	6.3	0.6	Cavity	$18\frac{5}{8}$	$21\frac{1}{4}$	19000		-33 -77	300						W
19DP4	Magnetic	Magnetic	66°	6.3	0.6	Cavity	$18\frac{7}{8}$	$21\frac{1}{4}$	19000		-33 -77	300						W
19EP4**	Magnetic	Magnetic		6.3	0.6	Cavity	$17\times13\frac{5}{8}$	$21\frac{1}{8}$	19000		-33 -77	300						W
19FP4	Magnetic	Magnetic	66°	6.3	0.6	Cavity	$18\frac{7}{8}$	22	19000		-33 -77	300						W
19GP4	Magnetic	Magnetic	66°	6.3	0.6	Cavity	$18\frac{7}{8}$	$21\frac{1}{4}$	19000		-33 -77	300						W
20BP4	Magnetic	Magnetic	54°	6.3	0.6	Metal Cap	20	28	20000		-33 -77	300						W
22AP4	Magnetic	Magnetic	70°	6.3	0.6		$21\frac{11}{16}$	$22\frac{7}{8}$	19000		-33 -77	300	38					W
24XH	Electrostatic			6.3	0.6		2		600	120	-60				10	0.14	0.16	B
902A	Electrostatic			6.3	0.6		2	$7\frac{5}{8}$	400	100	-80			350	5	93^{40}	78^{40}	G
									600	150	-80					139^{40}	117^{40}	
904	Electrostatic Magnetic			2.5	2.1		5		4600	970	-75	250		4000	10	0.09		G
905A	Electrostatic			2.5	2.1	Small Cap	5	$16\frac{7}{8}$	1500	420	-39					86^{40}	73^{40}	G
									2000	560	-52					115^{40}	97^{40}	
907	Electrostatic			2.5	2.1		5		2000	450	-35			1000	10	0.19	0.23	B
908A	Electrostatic			2.5	2.1		3	$11\frac{7}{8}$	1500	430	-50			500		0.223	0.233	B
									1000	287	-33			500		0.334	0.348	

** Rectangular type

912	Electrostatic			2.5	2.1		5	17 7/8	10000	2000	-66	250		7000	10	0.041	0.051	G
913	Electrostatic			6.3	0.6		1	4 3/4	500	100	-65			250	5	0.07	0.10	G
914A	Electrostatic			2.5	2.1		9		7000	1450	-50	250		3000	10	323^{40}	254^{40}	G
1805 P1	Electrostatic			6.3	0.6		5		2000	575	-35			500	10	0.17	0.21	G
1805 P4									1500	430	-27					0.23	0.28	W
1811 P1	Electromagnetic			6.3	0.6		7		7000	1470	-45	250						G
									4000	840	-45	250						
1813 P7	Electromagnetic			6.3	0.6		7		4000		-45	250						B
2001	Electrostatic			6.3	0.6		1		500	100	-65	250			5	0.07	0.10	G
2002	Electrostatic			6.3	0.6		2		600	120						0.16	0.17	G
2005	Electrostatic	Electrostatic		2.5	2.1		5		2000	1000	-35	200			10	0.5	0.56	
K1003	Electrostatic	Electrostatic		2.5	2.1	Metal Cap	12	23 1	5000	1375	-100							
TP400A	Magnetic	Magnetic		6.3	0.6	Cavity	4	12 3/4	20000		-70							

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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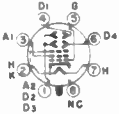

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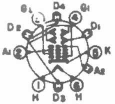

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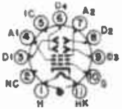

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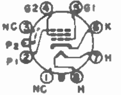
1805P4

TWO WAY MAGNETIC DEFLECTION



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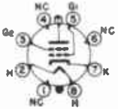

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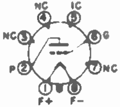

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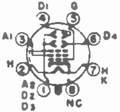

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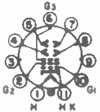

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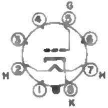
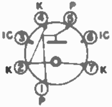


TP400A

CONTROL & REGULATOR TUBES



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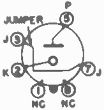

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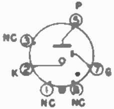

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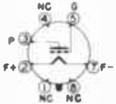

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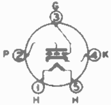


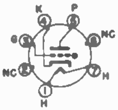
2B4

Designation	Type	Cathode			Application	Peak Anode Volt.	Peak Inverse Anode V.	Peak Anode Ma.	Anode Ma.	Min. Supply Volt.	Operating Volt.	Operating Ma.	Grid Resistor	Tube Voltage Drop	Preheat Time Sec.
		Type	Volts	Amps											
OA2	Voltage Regulator	Cold			Voltage Regulator					185	150	5 - 30			
OA3	Voltage Regulator	Cold			Voltage Regulator					105	75	5 - 40			
OA4G	Gas Triode Starter -anode type	Cold			Relay Service	225		100			105 to	25			
						Starter tied to Anode					130 rms				
CB2	Voltage Regulator	Cold			Voltage Regulator					133	108	5 - 30			
OB3	Voltage Regulator	Cold			Voltage Regulator					125	90	5 - 40			
OC3	Voltage Regulator	Cold			Voltage Regulator					135	105	5 - 40			
OD3	Voltage Regulator	Cold			Voltage Regulator					185	150	5 - 40			
1B47	Voltage Regulator				Voltage Regulator					225	82	1 - 2			
1C21	Gas Triode	Cold			Relay Tube	125/			25	66	125			73	
	Glow Discharge Type				Voltage Regulator	145			0.1	180	145			55	
2A4G	Gas Triode Grid Type	F	2.5	2.5	Control Tube	200	200	1250	100					15	2
2B4	Gas Triode Grid Type	H	2.5	1.4	Sweep Circuit Osc.	300			300			1.0	0.1 - 10	19	

2C4	Gas Triode (Thyratron)	H	2.5	0.65	Grid Controlled Rec.	350	350	22				5		17	30
2D21	Gas Tetrode	H	6.3	0.6	Grid Controller Rec.	650	1300	500	500		650	100	0.1-10	8	10
					Relay Tube	400					400		1.0		10
3C23	Gas and Mercury Vapor Grid Type	F	2.5	7.0	Grid Controlled Rec.	1000	1250	6000	6000		500	1500	-4.5	15	15
											100	1500	-2.5	15	
3C31/C1B	Thyratron Gas Triode	F	2.5	6.0	Grid Controlled Rec.	450	700	7700				640		14	40
3D22	Thyratron Tetrode	H	6.3	2.6	Grid Controlled Rec.	650	1350	6000				750		10	30
6D4	Gas Triode	H	6.3	0.25	Control Tube	350	350	110				25		18	30
6Q5G	Gas Triode Grid Type	H	6.3	0.6	Sweep Circuit Osc.	300	300		300			1.0	0.1-10	19	30
17	Mercury Vapor Triode	F	2.5	5.0	Grid-Controller Rec.	7500			2000			500	200-3000		
						2500				-5	1000	250		10 - 24	
128AS	Gas Triode Grid Type	H	2.5	1.75	Relay Tube	400			300			1.0	300	13	
346B	Gas Triode Grid Type	Cold			Rec. Relay or Regulator	200	200								80
359A	Gas Triode Grid Type	Cold			Rec. Relay or Regulator	165	165								85
393A	Thyratron Gas Mercury Triode	F	2.5	7.0	Grid -Controlled Rec.	1250	12	6000				1500			15
394A	Thyratron Gas Mercury Triode	F	2.5	3.2	Grid-Controlled Rec.	1250	1250	2500				640			15

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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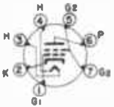

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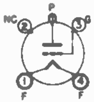

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3C31
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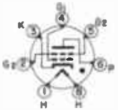

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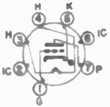

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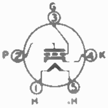

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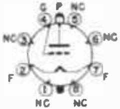
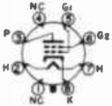


394A

CONTROL & REGULATOR
TUBES

CONTROL & REGULATOR TUBES



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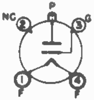

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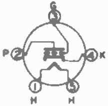

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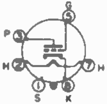

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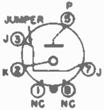


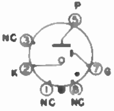
1265
1266

Designation	Type	Cathode			Application	Peak Anode Volt.	Peak Inverse Anode V.	Peak Anode Ma.	Anode Ma.	Min. Supply Volt.	Operating Volt.	Operating Ma.	Grid Resistor	Tube Voltage Drop	Preheat Time Sec.
		Type	Volts	Amps											
395A	Gas Triode	Cold			Rec. Relay or Regulator	140	140							80	
502A	Thyratron Mer. Vapor Triode	H	6.3	0.6	Grid Controlled Relay Rec.	650	1300	500			400	500		11	10
627	Thyratron Mer. Vapor Triode	F	2.5	6.0	Grid Controlled Relay Rec.	1250	2500	2500				640		12	10
629	Thyratron Gas Triode	H	2.5	2.6	Grid Controlled Rec.	350	350	200				40		15	30
727A	Gas Triode	Cold			Rec. Relay or Regulator										
874	Voltage Regulator				Voltage Regulator					125	90	10 - 50			
876	Current Regulator				Current Regulator						40 - 60	1.7			
884	Gas Triode Grid Type	H	6.3	0.6	Sweep Circuit Osc.	300	300	300	300			2	25000		30
885	Gas Triode Grid Type	H	2.5	1.4	Grid Controlled Rec.	350	300	300	300			75	25000		30
886	Current Regulator				Current Regulator						40 - 60	2.05			
967	Mercury Vapor Triode	F	2.5	5.0	Grid Controlled Rec.	2500	5000	2000	500	-5				10 - 24	5
991	Voltage Regulator	Cold			Voltage Regulator			3		87	55 - 60	2.0			
1265	Voltage Regulator	Cold			Voltage Regulator					130	90	5 - 30			
1266	Voltage Regulator	Cold			Voltage Regulator						70	5 - 40			

1267	Gas Triode	Cold			Relay Tube	225 Starter tied to Anode		100			105 to 130 rms	25			
2050	Gas Tetrode	H	6. 3	0. 6	Grid Controlled Rec.	650	1300	500	500			100	0. 1 - 10	8	10
2051	Gas Tetrode	H	6. 3	0. 6	Grid Controlled Rec.	350	700	375				75	0. 1 - 10	14	10
2523N1	Gas Triode Grid Type	H	2. 5	1. 75	Relay Tube	400			300			1. 0	300	13	
5651	Voltage Regulator	Cold			Voltage Regulator	115				115	87	1. 5 - 3. 5			
C5B	Thyratron Gas Triode	F	2. 5	23. 0	Grid Controlled Rec.	750	1250	30000			5000		12	60	
C6J	Thyratron Gas Triode	F	2. 5	20. 0	Grid Controlled Rec.	750	1250	77000			6400		14	60	
FG17	Thyratron Mercury Triode	F	2. 5	5. 0	Relay or Grid Controlled Rec	2500	5000	2000			500			5	
FG27A	Thyratron Mercury Triode	F	5. 0	4. 7	Relay or Grid Controlled Rec	1000	1000	10000			2500			60	
FG32	H. W. Mercury Rec.	H	5. 0	4. 6	Rectifier	1000	1000	15000			2500			300	
FG57	Thyratron Mercury Triode	H	5. 0	4. 6	Relay or Grid Controlled Rec	1000	1000	15000			2500			300	
FG67	Thyratron Mercury Triode	H	5. 0	4. 6	Inverter or Grid Contr. Rec.	1000	1000	15000			2500			300	
FG81A	Thyratron Gas Triode	F	2. 5	5. 0	Relay or Grid Controlled Rec.	500	500	2000			500				5
FG105	Thyratron Mercury Triode	H	5. 0	10. 0	Grid Controlled Rec.	10000	10000	16000			4000			300	
KY21	Gas Triode Grid Type	F	2. 5	10. 0	Grid Controlled Rec.						3000	500			

BOTTOM VIEWS SHOWN

KEY TO SOCKET PIN-INDEX, PAGE 742 —— CHART NUMERICAL NOTATIONS, PAGE 743



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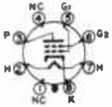

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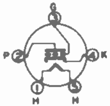

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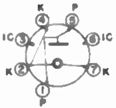

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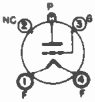

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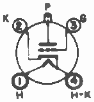
FG81A
KY21

FG27A



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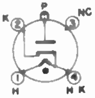
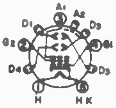


FG32

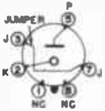
CONTROL & REGULATOR
TUBES



KY866

RK61

RK62



VR75
VR90
VR105
VR150

Designation	Type	Cathode			Application	Peak Anode Volt.	Peak Inverse Anode V.	Peak Anode Ma.	Anode Ma.	Min. Supply Volt.	Operat-ing Volt.	Operating Ma.	Grid Resistor	Tube Voltage Drop	Preheat Time Sec.
		Type	Volts	Amps											
KY866	Mercury Vapor Triode	F	2. 5	5. 0	Grid Controlled Rec,	10000			1000	0 - 150					
RK61	Thyratron	F	1. 4	0. 05	Radio Controlled Relay	45			1. 5	30		0.5 - 1.5	3	30	
RK62	Gas Triode Grid Type	F	1. 4	0. 05	Relay Tube	45			1. 5		30 - 45	0.1 - 1.5		15	
RM208	Permatron	F	2. 5	5. 0	Controlled Rec.	7500			1000					15	
RM209	Permatron	F	5. 0	10. 0	Controlled Rec.	7500			5000					15	
VR75	Voltage Regulator	Cold			Voltage Regulator					105	75	5 - 40			
VR90	Voltage Regulator	Cold			Voltage Regulator					125	90	5 - 40			
VR105	Voltage Regulator	Cold			Voltage Regulator					135	105	5 - 40			
VR150	Voltage Regulator	Cold			Voltage Regulator					185	150	5 - 40			

INDEX