THE RADIO MANUAL

STERLING

THIRD EDITION

D. VAN NOSTRAND COMPANY, Inc.

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THE
RADIO MANUAL

FOR RADIO ENGINEERS, INSPECTORS, STUDENTS, OPERATORS AND RADIO FANS

By

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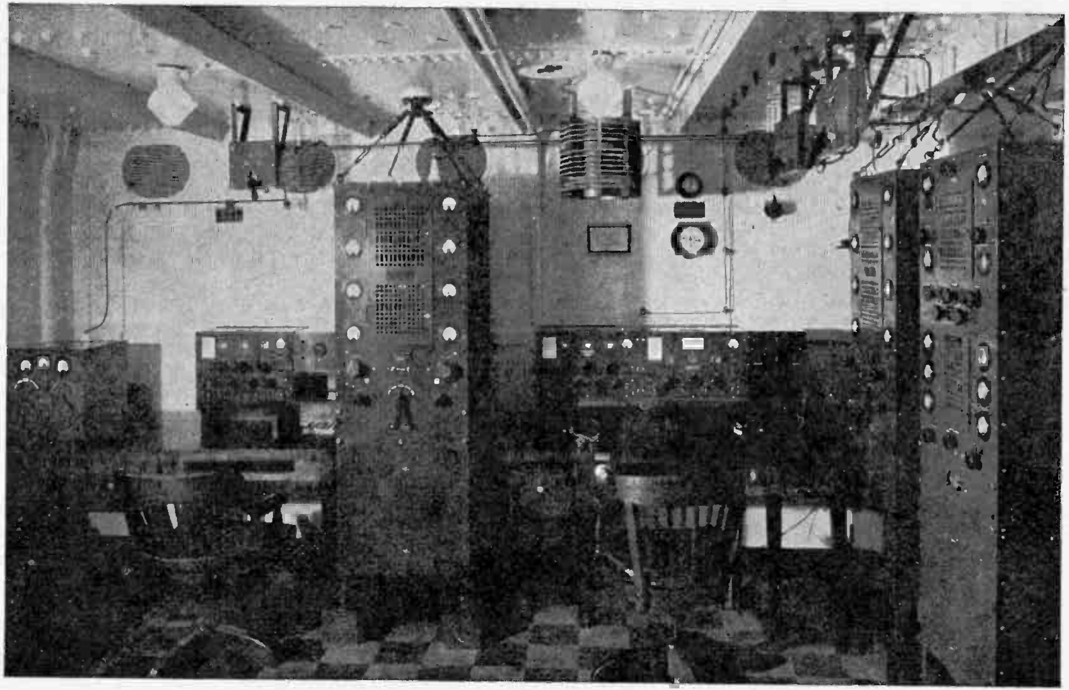

(Frontispiece)

A Modern Shipboard Radiotelegraph Installation aboard S.S. Manhattan,
Showing Low, Intermediate and High Frequency Transmitters and Receivers.
(Courtesy of Mackay Radio and Telegraph Company.)

PREFACE

This edition of the Radio Manual has been prepared to serve as a guide and text book for those entering the radio profession as engineers, inspectors, operators, as well as those already engaged in such activity. For the transport pilot, sportsman and student flyer this edition supplies information on the principles of operation and the practical use of radio aids to air navigation, including problems in orientation, homing, instrument flying and blind landing systems. In addition, some elementary radiotelephone (broadcast) engineering has been included as have radio frequency measurements and monitors and instantaneous recordings.

Chapter four, entitled The Electron Tube, was written by Robert S. Kruse, E.E., an internationally known radio engineer. Chapter five, which discusses radio and audio frequency amplifiers, oscillators, computations of the power and harmonic output of amplifiers, coupling and neutralizing circuits, was written by Wm. R. Foley, E.E., and edited by Mr. Kruse. Chapters six and seven are devoted particularly to radio telephony and broadcasting technique. Mr. Foley rendered assistance in the composition of Chapter six.

The plan of furnishing descriptions and maintenance instructions for representative commercial apparatus, which in the previous editions met with popular approval, has been retained in the chapters devoted to broadcast, ship, aircraft and police station transmitters, receivers and associated apparatus. This material has, by permission of the manufacturers, been taken directly and with very few changes from the instruction books supplied with the apparatus. The type numbers of the apparatus and the peculiar language of the art have been left in the text so that one may have a better opportunity to read one's way into current practice. Radio schools and students will find this material helpful in their study courses. Representative types of apparatus have been chosen. It should not be assumed that the types described are superior to those manufactured or distributed by other concerns, nor do they constitute recommendation on the part of the Federal Communications Commission by whom the author is employed. The decisions as to types are solely those of the author.

A survey conducted by the author and publishers overwhelmingly indicated that students preparing for radio operator license examinations and commercial operators prefer to have one book which includes technical as well as legal information concerning stations they expect to operate or are operating. Accordingly in this edition there have been included extracts of the Communications Act of 1934, rules and regulations of the Federal Communications Commission and the General Radio Regulations annexed to the Telecommunication of Madrid as revised by the International Convention of Cairo, to the extent that they pertain to radio operator license examinations and the routine operation of stations.

The author desires to express his sincere appreciation for the cooperation extended by various individuals, commercial concerns and government agencies in the preparation of this edition. To name each would require space much beyond that allocated to the preface; however, credit has been given in the proper places. The author would appreciate having any exceptions brought to his attention.

Omissions, ambiguities and errors are inevitably present in the text, and it is requested that they be brought to the attention of the author in care of the publishers.

All statements and conclusions found in this edition are the personal responsibility of the author and do not in any way whatsoever represent opinions and conclusions of the Federal Communications Commission. The author wishes to express his sincere thanks to the members of the Commission for permitting him to participate in this project which was accomplished solely on his own time and apart from his official duties.

GEO. E. STERLING.

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CHAPTER I

ELEMENTARY ELECTRICITY AND MAGNETISM

1. **Electricity and Matter**—One often hears an expression among laymen such as—"No one knows what electricity is"—and the statement usually concludes with "scientists know only how to use it." On the contrary, scientists and physicists not only know how to use electricity but they are able to tell exactly its nature and composition and to explain its relation to matter. In fact, more is known about electricity than about anything else in nature and that knowledge of electrical phenomena has served as a key to unlock doors leading to knowledge in other matters which completely eluded us before.

Matter is today regarded as composed of minute bodies called atoms. These atoms are exceedingly tiny and even the most powerful microscope cannot show us an atom nor even a thousand of them grouped together. We become aware of them entirely through ingenious indirect experiments the story of which is an enchanted romance itself. It is most unfortunate that we have not the time to tell it here.

2. **Protons**—A proton possesses opposite electrical characteristics from that of an electron. Protons are considered then as particles of positive electricity. A body having a deficiency of electrons, that is, having more protons than electrons is said to be positively electrified.

3. **Electrons**—Each atom is composed of many minute particles called electrons and protons. These electrons and protons are exactly alike in all atoms, no matter whether it be an atom of iron, one of lead, one of mercury, of potassium, or any one of other ninety-two elements known to chemistry.

In every case, an electron, when detached from its atom, shows none of the properties of ordinary matter. In other words, it will not react chemically with other electrons to produce a new substance. An electron separated from an atom of iron would be precisely the same as an electron separated from an atom of gas such as hydrogen or oxygen. Electrons are always considered as particles of negative electricity. The reason for this is, that for many years physicists have been in the habit of speaking of positively-electrified and negatively-electrified bodies. When the electron was first discovered it was found that it could be freed by attracting it with a positively-electrified body, whereas, it was repelled by one negatively electrified. However, at this date physicists consider a negatively-electrified body as one in which there is an excess of electrons, that is, within one atom there are many more electrons than there are protons.

4. Arrangement of Electrons and Protons within an Atom—Each kind of atom has its own particular arrangement of electrons and protons. However, in each atom there appears to be at the center a compact group containing all the protons and some of the electrons, therefore, it exhibits a positive charge. This is the nucleus of the atom. Farther out from the nucleus are a number of scattered electrons. Each electron moves in its own orbit. There are always enough electrons surrounding the uncharged atom to neutralize the excess number of protons in the nucleus. In its normal uncharged state the atom exerts no force on charged bodies in its vicinity. However, if an electron is separated from an atom, for instance, by a collision, a free electron will be strongly attracted by the positively charged atom and it will combine with it thus restoring the atom to its normal uncharged state.

The recombining of a free electron with a positively charged atom does not occur instantly because the electron does not drop into the place of the missing electron and stop suddenly. Instead, it oscillates before setting down and in most cases the frequency of its oscillation is such that the wave motion produced in the surrounding ether is of a frequency which can be seen by the eye and is therefore called light. Incidentally, the rate of oscillation depends on the substance, that is, the kind of atom we are watching and therefore atoms of different kinds radiate different colors of light. This color is characteristic of that substance, and one of our most useful methods of identifying substances depends on such characteristic radiation as the intense orange red of neon when excited by an electric current as in the familiar advertising signs.

Any body in which the electrons and protons are equal will be electrically neutral, that is, it will be neither negatively or positively electrified. This is the normal condition of all bodies. In other words, they are uncharged.

From the above paragraphs three general statements can be made as follows:

A body having an excess of electrons is said to be negatively electrified or charged.

A body having a deficiency of electrons is said to be positively electrified or charged.

An uncharged body is one in which the electrons and protons are equal in number.

a. Charging a Body by Friction—A very simple example of frictional electricity can be shown by the old experiment of tearing a sheet of paper into small bits and picking them up by means of a hard rubber rod which has been well rubbed with a piece of woolen cloth or fur. If the rod is clean, the day dry (and preferably cold), and the paper thoroughly dried by heating, one will find the bits of paper to jump to the rod and cling there with surprising enthusiasm. The friction between the rod and wool produced a charge on each. In other words, electrons were removed from the wool by friction and remained on the rubber rod. As already stated, however, the electrons added to the rod do not change its atomic structure, neither is there any change made in the atomic composition of the wool by removing electrons from it. Nevertheless, from an electrical standpoint the rod now has a surplus of electrons and is therefore negatively charged while the wool having lost electrons, has less than its normal number, and is therefore positively charged.

b. Relation of Charged Bodies—When the negatively charged rubber rod is brought near the bits of paper the extra electrons on the rod are attracted by a lack of electrons on the paper. Whenever in any body the number of electrons are not equal it is natural for shifts and readjustments to occur until an uncharged condition is attained. In this particular case the paper lacked electrons and was therefore positively charged and the surplus electrons on the rod tried to equalize the unbalanced condition.

The space surrounding the charged rod and paper was subject to a strain enabling it to act on the charged paper with a force which in this case was attractive, as manifested by the small bits of paper jumping to the rod. The moment they touched the rod the electrons and protons in each body became equalized and the attractive force disappeared.

Another simple experiment can be performed by the use of a bit of pith from a corn stem and a glass rod. The pith from the corn stem should be whittled into fine bits by a razor blade. Now if the glass rod is rubbed vigorously with a piece of silk and then brought close to the pith, it will be noticed that the pith is attracted by the glass rod. Allow the glass rod to touch the pith ball. The ball has now become charged with electricity of the same polarity as that of the rod. It acquired the charge by contact. It will now be noticed that the rod repels the pith ball. The condition now exists where like charges repel.

From these experiments one can make the following statements relative to the relation of charges.

1. Unlike charges attract. (Positive and negative charges attract each other.)

2. Like charges repel. (A negative charge repels a negative charge, likewise a positive charge repels a positive charge.)

3. Whenever a charged body is acted upon by another charged body so as to produce a force, either attractive or repulsive, the space surrounding the charged body is subject to a strain or stress. The space in which this stress occurs is called the electric field. It is sometimes called an electrostatic field.

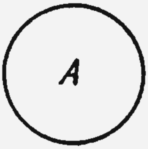


FIG. 1. Uncharged Body.

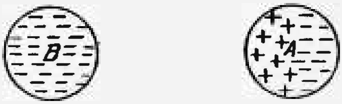


FIG. 2. Body A Charged by Electrostatic Induction from Charged Body B.

The strength of the electric field extends in all directions from the body, the strength of the field decreasing with distance.

c. Induced Charges—Consider the case of the uncharged pith ball. Let it be represented in its uncharged condition as in figure 1. When the charged glass rod was brought near the pith ball the negative electrons on the rod as indicated by *B* of figure 2 repelled those on the side of the pith ball nearest the rod giving that side a deficit of electrons on a positive charge as indicated by the small circle *A*. The other side to which the electrons rushed has a negative charge. Removing the glass rod allows the electrons to flow back into their proper place, thus discharging the body. The charge produced on the pith ball is called an induced charge.

The arrangement shown in figure 4 will permit that body to hold more than its ordinary amount of electrons. The lines represent two conductors and the space between the lines a nonconductor. If the conductors are charged, it will be seen that they attract and bind each other and hence, the conductors are able to hold a greater number of electrons than they could if they were not near each other but at entirely different places. It is a general rule that a negatively charged conductor can hold more electrons if there be nearby another conductor which is charged positively at the same time. Such an arrangement of two oppositely charged conductors is called a condenser, because it permits us to concentrate, or condense, a large amount of electricity on each of the two conductors. Familiar forms of condensers consist of copper or tinfoil separated by mica insulation. An equally familiar form uses air insulation and makes one plate (or set of plates) movable so as to vary the capacity, which is the name used for the ability of the condenser to hold electricity. Such a condenser illustrates the point that the capacity increases as the two conductors approach each other.

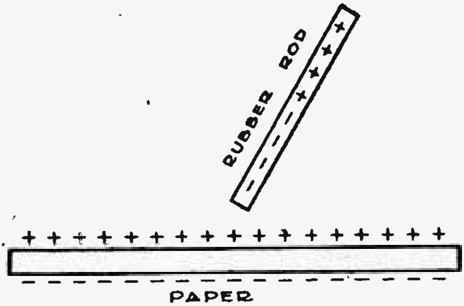


FIG. 3. Electrons Drawn to Upper Side of Paper by Charged Rubber Rod.

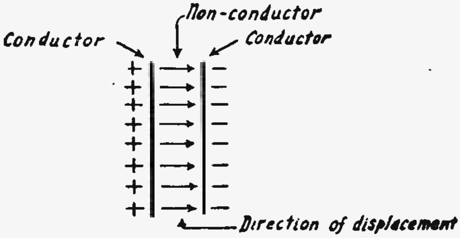


FIG. 4. A Charged Condenser.

5. Potential—When we speak of electric potential we mean electrical pressure. When more electrons are crowded upon a conductor its potential rises in just exactly the same manner that the pressure in an automobile tire rises when more air is crowded into it. It will be seen later that just as we can produce air pressure by rotating centrifugal pumps or by ordinary plunger pumps so also we can produce electrical pressures by a variety of means including batteries and generators. We have already seen how a small electrical pressure can be created by rubbing a glass rod with a silk cloth and how this pressure tends to drive electricity from one point to another so forcibly as to carry light substances with it. We will see later how the pressures created by batteries and generators will cause large currents of electricity to flow and thereby to operate all the machinery of radio transmission and reception.

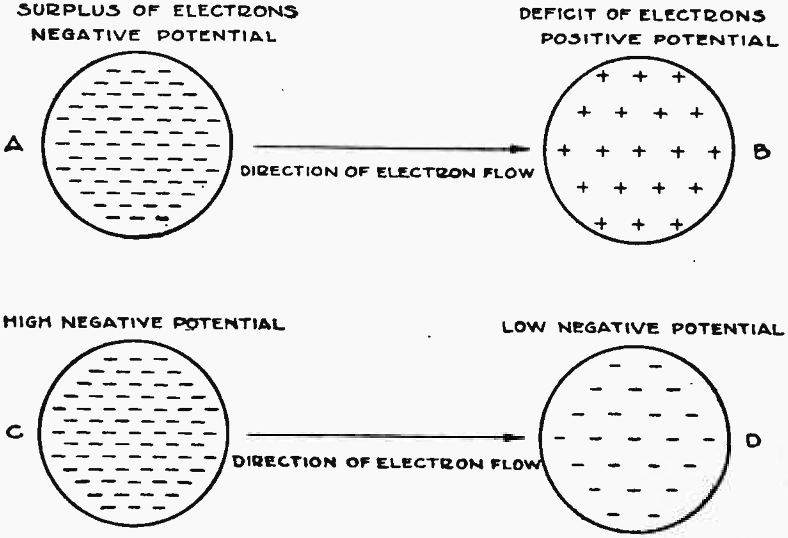


Fig. 5. Creation of Electron Flow by a Difference in Potential.

a. Electrons and Difference of Potential—Consider a pair of bodies charged as shown in the top portion of figure 5 as *A* and *B*.

A has an excess of electrons, thus it has a force trying to discharge electrons—it has a negative potential. *B* has a deficit of electrons, thus it has a force trying to attract electrons—it has a positive potential. If given a path, electrons would flow from *A* to *B*. Consequently the flow of electrons would constitute a flow of electric current, as electrons really are the current. The number of electrons flowing from *A* to *B* would depend upon the difference of potential between *A* and *B*. The electrons would continue to flow until there was no longer a difference of potential, that is, *A* and *B* would then have the same number of electrons.

Consider the pair *C* and *D*. Both have a negative potential, but *C* has a larger negative potential than *D* as it has relatively more electrons than *D*. Hence, there is a difference of potential equal to potential *C* minus potential *D*. If given a path, the electrons would flow from *C* to *D* and the movement of electrons would constitute a flow of current from *C* to *D*.

6. Lightning a Movement of Electrons—When a cloud and the earth are oppositely charged there is a possibility of a lightning discharge occasioned by the readjustment of electrons in order to restore the cloud to an uncharged condition. The readjustment or movement of electrons must wait until the cloud obtains sufficient charge to make the electrons leap through the air between earth and sky, depending upon which is positively charged.

6a. The Lightning Flash—As the charges on earth and cloud are increased or one moves close to the other a difference of potential is created sufficient to permit the electrons to stream from one body to the other. In their passage an electron may collide with uncharged molecules of air, as the result of which an electron may be separated from a neutral molecule. The molecule which has thus lost an electron becomes positively charged and in this state is called an "ion." The free electron knocked off from the molecule follows the other electrons and the ion proceeds in an opposite direction. With the electrons moving in one direction and the ion in the opposite there is a possibility of another collision, that is, another electron will collide with an ion and the electron combines with the ion, thus restoring the molecule to its uncharged state. As explained in a previous paragraph the free electron does not instantly recombine with the positive ion but instead oscillates before settling down and the frequency at which it oscillates is such as to produce a wave motion which can be seen by the eye as a flash of light. Several thousands of such collisions occur during the discharge period and consequently the intensity of the flash is enormous.

6b. Direction of Current and Electron Flow—Before the discovery of the electron, scientists assumed that the flow of current was from the point of positive potential to the point of negative potential. At this date, however, all scientists agree that the electrons in motion are the current and therefore current flows from a negative to a positive potential. Later on it will be shown how well this fits in with the explanation of the movement of electrons in a vacuum tube.

7. Electromotive Force—The difference of potential between two bodies or between two points of the same body is measured in volts. Because a difference of potential will always cause a current to flow, provided a path is furnished, it is also called electromotive force (e.m.f.); the force of which makes the electrons move. Therefore, a volt is the unit of e.m.f.

8. Current—Current strength, that is, the number of electrons moving per second is measured in amperes.

9. Conductors and Non-Conductors—In order for a current to flow a path must be furnished for the electrons. A body that permits electrons to move about in it is called a conductor. A body in which all the electrons are not free to move is called a non-conductor. Other names for a non-conductor are insulator, or dielectric. Different bodies permit different degrees of freedom and hence there are various grades of conductivity. If the electrons are very free to move they find little opposition in their passage, i.e., they encounter little resistance. If the electrons are not free to move they find much opposition to their passage, i.e., they encounter a high resistance.

10. Resistance—The property of matter by which it opposes the passage of electrons is called resistance. The resistance of a column of pure mercury 106.3 centimeters long, weighing 14.4521 grams, at a temperature of 32 degrees Fahrenheit is one ohm. It is called an ohm because the first man to investigate resistance was Simon Ohm. Since the resistance of any metal rises when the metal is heated our " standard ohm " must always be measured at the same temperature and for this there has been chosen the temperature of 32 degrees Fahrenheit as stated above (zero degrees Centigrade).

The resistance of a conductor depends upon the kind of material in the conductor, the length of the conductor, the cross-sectional area, and to some extent upon the temperature of the conductor. To be exact, it increases directly with the length of the conductor and decreases with an increase of cross-sectional area. In radio it also increases with an increase of frequency.

11. Production of an Electric Current—From the foregoing discussion it is seen that a current will flow along a conductor if there is a difference of potential created. The current will be maintained if the difference of potential is maintained. Take a zinc rod and a copper rod and immerse them in sulphuric acid. Test the ends of the copper and zinc for charges and it will be found that the copper has a positive charge and the zinc a negative charge. Therefore, a difference of potential exists. Connect the copper and zinc by a wire and a current will flow. Disconnect the wire and test the copper and zinc again. The result will be the same. That is to say, this combination will maintain a difference of potential and hence will produce a steady current.

The sulphuric acid eats the zinc (chemical action) and gives it electrons, taking them away from the copper. Such an arrangement is called a cell. See figure 6. Two or more cells together are called a battery. There are many combinations of materials that will give the same result. The combination always consists of two dissimilar metals and an acidic or basic solution. The voltage of such a cell is never more than 2 volts. Such cells are called primary cells. The difference between a primary cell and a storage battery lies in the fact that the primary cell cannot be renewed by passing an electric current through it while a storage battery can. Zinc is employed in all cells, other than storage cells, in common use. It is always the negative pole or terminal. The positive pole is usually copper or carbon.

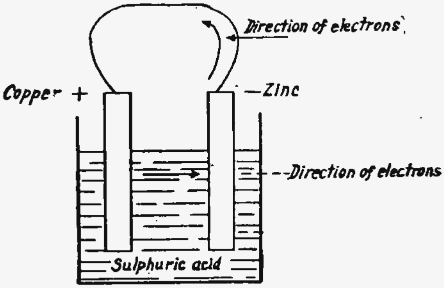
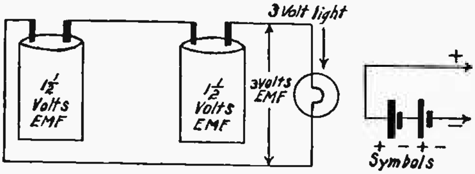
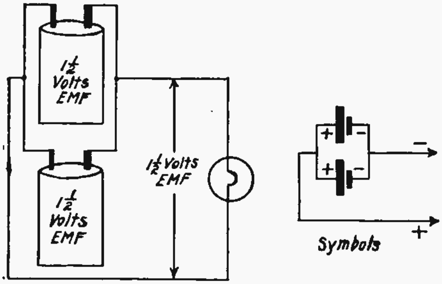


FIG. 6. Primary Cell.

12. Series and Parallel Connections—Cells may be connected in series or parallel. When connected in series the resultant voltage is the sum of the voltage of each cell. When connected in parallel the resultant voltage is the same as that of any one cell. The rule is to connect cells so that the resistance inside the cells is equal to that outside the cells. Using storage batteries this rule resolves itself into the following fact: The only time batteries are used in parallel is when current, taken all from one battery, would be so large as to damage the battery.



Series connection of cells



Parallel connection of cells

FIG. 7. Series and Parallel Connection of Cells.

13. Application of Ohm's Law—The value of volts, amperes and ohms are so taken that the following statement, known as Ohm's law, is true: amperes = volts over resistance or the three forms of Ohm's law may be shown as follows:

Standard Units	Formulas	Examples
$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$	$I = \frac{E}{R}$	$5 \text{ Amps.} = \frac{10 \text{ Volts}}{2 \text{ Ohms}}$
Volts = Ohms × Amperes	$IR = E$	5 Amps. × 2 Ohms = 10 Volts
$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$	$R = \frac{E}{I}$	$2 \text{ Ohms} = \frac{10 \text{ Volts}}{5 \text{ Amps.}}$

14. **Resistances**—Resistances connected in series have a greater resistance than any one alone. Their total resistance is the sum of the separate resistances.

Formula

$$R = R_1 + R_2 \qquad \text{(resistances in series).}$$

Two resistances connected in parallel have a smaller total resistance than either of them. If they are of equal values, the total resistance is one half of the resistance of one. If there are three resistances of equal values the total resistance would be one third of the resistance of one.

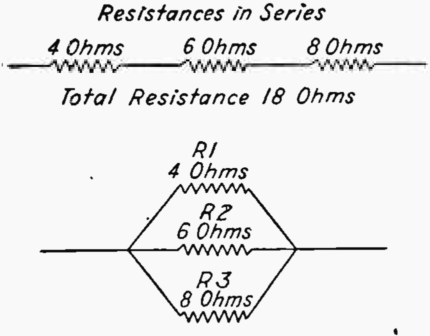


FIG. 8. Series and parallel connection of resistance.

When the resistances are of unequal values their total resistance is computed as follows:

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

where R = the total resistance.

Example: Resistances of 4 ohms, 6 ohms and 8 ohms are placed in series. Their total resistance is $4 + 6 + 8 = 18$ ohms. Connected in parallel their total resistance is:

$$R = \frac{1}{\frac{1}{4} + \frac{1}{6} + \frac{1}{8}} = \frac{1}{\frac{13}{24}} = 1.8 \text{ ohms.}$$

It is now clear that two or more resistances in parallel will conduct an electric current more freely than one.

It should be remembered that Ohm's law is true for the whole or any part of an electrical circuit. However, it will be seen later that Ohm's law is not applicable to all radio circuits.

15. **Effects of Current**—The passage of current through a conductor can be determined by two principal effects:

1. Heating effect.
2. Magnetic effect.

When a current of electricity flows through a conductor, it encounters frictional resistance and a certain amount of energy is transformed into heat. The heat generated increases directly as the resistance; also the heat generated increases directly as the square of the current, and the time during which the current flows. This is expressed:

$$J = I^2 \times RT$$

(where J is the joule, I the current, R the resistance and T the time in seconds).

The joule is defined as that amount of energy which is expended during one second, by current of one ampere flowing through a resistance of one ohm. The joule per second is the practical unit of electrical power which has been named the watt.

Since power is the rate of doing work per unit of time, one watt per second would equal one joule. The power may be also expressed in the units of electromotive force and current strength. The power in watts in a given circuit in which direct current is flowing is equal to the product obtained by multiplying the current in amperes by the electromotive force in volts or:

$$\text{Watts} = I \times E.$$

The magnetic effect may be described as follows: Figure 9 shows a coil of wire wound around a soft iron bar and carrying a steady current furnished by the battery. While the current is flowing the bar will be found to have acquired the power to attract pieces of small steel or iron. If the current from the battery is broken the bar will not have the power of attraction for the iron or steel. Thus the current flowing through the solenoid has given it a new property called magnetism, and since it has this property only when the electric current flows it is called an "electromagnet."

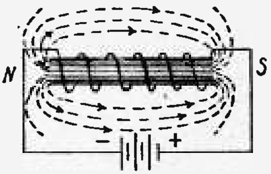


FIG. 9. Electro-Magnet.

If the soft iron bar is replaced by a bar of hard steel and the current is permitted to flow through the solenoid for a considerable length of time it will be found that the steel retains the property of attraction long after the circuit is broken from the battery. A piece of magnetized steel which retains its magnetism is called a "permanent magnet."

It will be found that the iron likewise has retained the property of attraction, but to a smaller degree than that of the hard steel. The steel is said to have a high degree of "retentivity," while the iron has but little retentivity.

The lines of force retained by a piece of iron after the magnetizing current has been turned off are called the "residual lines of force" and the iron is said to have "residual magnetism." Residual magnetism plays an important part in the operation of some types of generators which will be described later.

If a permanent magnet is dropped into a box of iron filings it will be noticed that there are two places on the steel magnet to which the iron filings cling most strongly. These places are near the ends of the bar and are called the "poles" of the magnet.

The poles always appear in pairs and are named north poles and south poles, because of the following fact: If the magnet is suspended in such a way that it is balanced and free to turn around in a horizontal plane as in figure 10, it will be noted that the magnet will always come to rest pointing in an approximate north-south line. The same end or pole will always point northward; this is called the north or north seeking pole while the other end is called the south or south seeking pole.

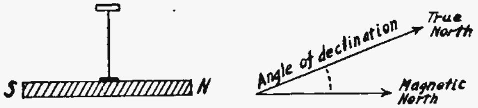


Fig. 10. Suspended Magnet Attracted by Earth's Magnetic Pole.

The following experiment will indicate the power of attraction and repulsion of the poles of magnets. The north pole of the suspended magnet will be repelled when approached by the north pole of the other magnet; likewise, the south pole will be repelled when approached by another south pole, whereas if the north pole is approached by a south the suspended magnet will be attracted. Again if the south pole of the suspended magnet is approached by a north pole the suspended magnet will again be attracted. From this experiment it will be found that like poles repel; unlike poles attract. This clarifies somewhat a statement in the preceding paragraph wherein it was noted that the end of the magnet pointing toward the earth's north pole was the north seeking pole. It is commonly called the north pole of the magnet, but according to the theory of attraction and repulsion of the poles of the magnet a north pole could not be attracted by the earth's north magnetic pole.

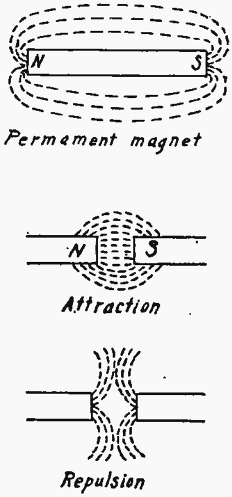


FIG. 11. Relation of Fields of a Magnet.

16. Angle of Declination—A magnet balanced upon a pivot and free to swing in a horizontal plane is called a compass. It takes a north and south direction. This is explained by saying that the earth has effective magnetic poles. These effective magnetic poles are near but do not exactly coincide with the geographical poles. Hence, there is an angle between true north and the direction which the compass points, magnetic north. This angle is called "angle of declination."

17. Magnet Field—If the field surrounding a magnet were to be examined it would be found to consist of definite closed lines. The lines are called the magnetic lines of force. The magnetic lines of force start at a north pole and pass through a south pole back to the north pole. See figure 11. They make various routes depending upon the magnetic substance near them but they always come back to their source. The space through which they pass is called the "magnetic field."

18. Permeability—Whether a body will be acted upon by a magnet depends upon its ability to carry magnetic lines of force. This property of carrying lines of force is called permeability. Different kinds of iron have different degrees of permeability. The magnetic strength of an electromagnet or solenoid varies as the product of the amperes passing through the conductor and the number of turns or commonly called the "ampere turns." For example 100 amperes through 50 turns of wire gives the same result as 20 amperes through 250 turns, for 100 × 50 and 20 × 250 = 5000.

The magnetic strength of such a coil is also dependent upon the permeability of the iron; that is to say, the iron, in effect, increases many times the lines of force.

19. Theory of Magnetism—The following experiments and results give the base for a theory of magnetism. Take a magnet and strike it. The magnetism gradually disappears.

Take a bar magnet, cut it into pieces. Each piece will be found to be a magnet, no matter how small it is.

Take a magnet and heat it. The magnet becomes very much weaker and eventually loses its magnetism.

Take a piece of steel and stroke it with a magnet. The steel will become a permanent magnet.

Now when it is remembered that heat is caused by rapid vibration of the small particles of which a body is composed and that the final division of the magnet is also these small particles, it is easy to draw the conclusion that these small particles are magnets. The small particles are called molecules and hence this is known as the "molecular theory of magnetism."

It is not thought that these molecules are magnets sometimes and at other times not magnets. It is thought that these molecules are magnets always. If iron molecules are always magnets, why is it that a piece of iron is not always a magnet?

Consider the diagram of figure 11*a*. The small lines represent the molecules. It is seen that if they are arranged in a disorderly way the lines of force emanating from one molecular magnet go to the nearest south pole of another molecular magnet and so on back to their origin without going outside of the iron bar. Hence, there are no magnetic lines of force outside of the iron bar. Therefore, it is not a magnet.

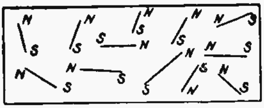


FIG. 11*a*. Arrangement of Molecules in Iron Bar Not Magnetized.

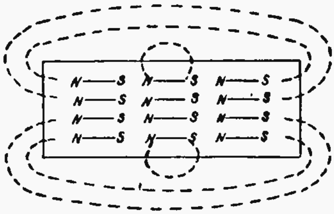


FIG. 11*b*. Arrangement of Molecules when Iron Bar is Magnetized.

If the iron bar is stroked by a magnet the molecules arrange themselves in an orderly manner as shown in figure 11*b*. The magnetic lines of force emanating from one molecular magnet pass to the next one and then to the next and to get back to their source must go outside of the iron for they cannot double back on themselves. Hence, the iron bar is now a magnet.

20. Voltmeters and Ammeters—The fact that an electric current is always surrounded by a magnetic field is used in the construction of voltmeters and ammeters. The simplest kind of an ammeter is made by placing a compass in the center of a coil of wire. The deflection of the needle is greater, the greater the strength of current.

Another type of ammeter and the one most commonly used is made by having the magnet stationary and the coil movable. The moving coil principle was developed by a French scientist named D'Arsonval and is spoken of as the D'Arsonval movement. Figure 12 shows the arrangement of this instrument.

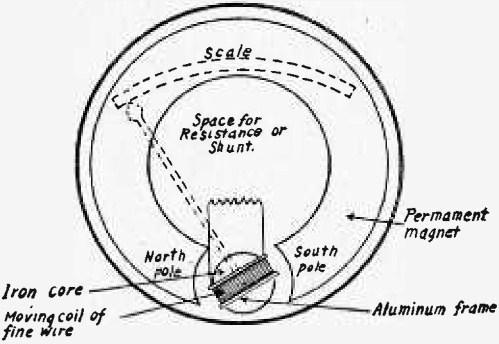


FIG. 12. Ammeter with D'Arsonval Movement.

Between the pole faces of a permanent magnet is placed an iron core, allowing a gap between it and the pole faces large enough to permit an aluminum frame to swing freely. On this frame is wound a coil of very fine wire, through which a certain percentage of the current to be measured passes. As this current passes through the coil, the latter becomes an electromagnet with north and south poles, which are immediately affected by the north and south poles of the permanent magnet. Obeying the magnetic law that like poles repel and unlike poles attract, the north end of the electromagnet is drawn toward the south pole of the permanent magnet and vice versa—which means that the aluminum frame is swung around and the pointer attached to the frame travels across the scale. Every meter of this type is in reality a millivoltmeter (millivolt—1/1000 of a volt) as the coil is built in such a way that a small current flowing through it causes the action described.

Permanent magnets can be weakened by jarring and age; hence, makers of really good meters use carefully aged tungsten steel magnets.

21. Use of Shunt and Multiplier—A voltmeter is always shunted (connected in parallel) across the load whose voltage is to be measured. It is made with an extremely high resistance sometimes connected externally or when possible within the meter case. This resistance takes only a small current.

The ammeter is always connected in series with the load. It has a low resistance. In some ammeters only a constant fractional part of the total current passes through the coil, the remainder being conducted by the shunt which is calibrated for the particular ammeter.

An example will describe how these resistances and shunts are calibrated.

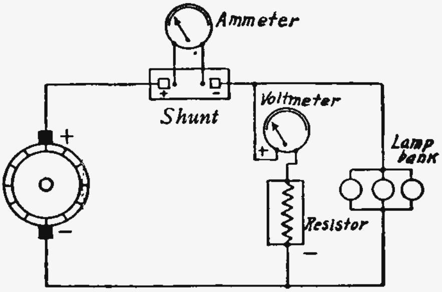


FIG. 13. Method of Connecting Voltmeter and Ammeter. Voltmeter Employing Resistor and Ammeter Employing Shunt.

If there are 10 feet of fine wire on the aluminum frame having a resistance of 1 ohm per foot, the total resistance is 10 ohms.

The frame is then set in position and it is found that 1/10 volt (100 millivolts) is necessary to send the pointer across the scale, i.e., the frame moves through approximately 10 degrees because of the magnetic pull exerted. Then according to Ohm's law $I = .100/10 = .010$ ampere, which is the amount of current used under .100 volt pressure to cause full scale deflection, and the balance must be used in resistance.

For an ammeter capable of measuring 5 amperes the current is permitted to flow through a shunt and just enough is permitted to flow through the coil to cause a full scale deflection. Suppose it is desired to construct a 5-ampere meter. The start is made with a small meter, for instance, a .01 ampere (1/100 ampere) meter. The maximum current that it is desired to measure is 5 amperes. This can be done by splitting the current so that only 1/100 of an ampere goes through the meter while 4.99 amperes go around through another path. Figure 13 shows such an arrangement. The resistance of the other path, called a shunt, must accordingly be 1/499 of the meter resistance.

22. Telephone Receivers—The telephone receiver is an application of the property of magnetism. The telephone receiver, as used for ordinary telephone work, consists of a case holding a permanent horseshoe magnet, two coils of wire and a soft iron diaphragm, the latter being clamped by its rim with its plane at right angles and close to but not touching the poles of the permanent magnet. The extensions on the permanent magnet are fitted with bobbins which are wound with many turns of fine wire. The diaphragm is left free to vibrate except at its rim. The distance from the pole pieces to the diaphragm is normally fifteen thousandths of an inch (.015 inch).

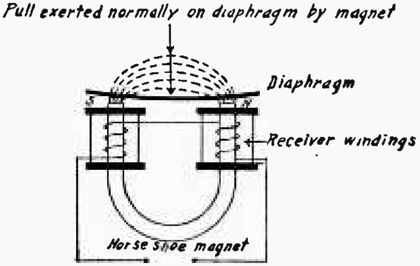


FIG. 13*a*. Construction of Telephone Receiver.

The action of the receiver is as follows: The permanent magnet attracts the diaphragm of the receiver, holding it under a steady attraction. If a varying or alternating current passes through the coils of the receiver, the strength of the magnet is varied. The pull on the diaphragm is therefore varied and if the changes in the current passing through the coils are rapid they will cause the diaphragm to vibrate accordingly.

Thus if the current passing through the coils is varied at the frequencies used in speech the diaphragm will vibrate accordingly reproducing the voice of the speaker.

The diaphragm is lacquered on one side and enameled on the other. The lacquered side should be toward the magnet. As the efficiency of a receiver depends greatly upon the smallest practical air gap which is considered with the vibrations of the diaphragm, the side nearer the magnet is covered with a coat of lacquer, which is much thinner than the coat of enamel on the other side. The lacquer and enamel serve to protect the diaphragm from rust. The pole pieces of the magnet are lacquered for the same purpose.

As the receiver has a permanent north and south pole, current flowing in a given direction will either increase or decrease the strength of both poles, at the same time the coils being connected so as to accomplish this.

The distinctive features of telephone receivers for radio work are lightness of the moving part and the employment of a great many turns of the wire around the magnet poles. The lightness of the moving parts enables them to follow and respond to rapid pulsations of current. The large number of turns of wire causes a relatively large magnetic field to be produced by a feeble current. The combined effect is to give a device which will respond to very feeble currents.

The resistance of the windings of each of a pair of receivers for radio work is seldom less than 500 ohms, the values of resistance being measured with direct current. For radio work the windings of the two receivers constituting a pair are almost always connected in series.

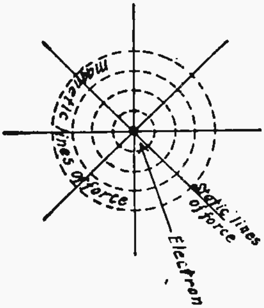


FIG. 14. Electron in Motion Produces Magnetic Lines of Force.

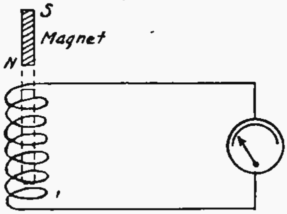


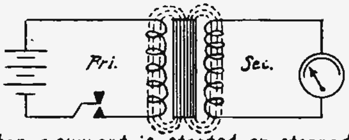
FIG. 15. Production of Current by Electro-Magnetic Induction.

23. Induction—A great discovery in electricity was the fact that a magnetic field in motion would cause a movement of electrons; that is, the production of current. The following experiment will illustrate this fact.

Take a coil of wire as in figure 15, drop a magnet end first through the coil. The needle of the milliammeter will move, indicating the presence of a current. It will quickly come to rest. Draw out the magnet. The needle moves again; but this time in the opposite direction. Reverse the magnet and repeat above. It will be noticed that the needle moves but in the opposite direction to its movement before the magnet was reversed. Use two magnets. The needle moves farther than with one magnet. Try moving the magnet faster and slower; the faster it moves the more the needle moves—i.e., the stronger the current. Notice that a current flows when and only when there is relative movement between the magnet and the coil. Try moving the coil instead of the magnet—the results are the same.

Substitute a piece of unmagnetized steel for the magnet. There is no current. The difference between the magnet and the steel is that the magnet is surrounded by magnetic lines of force. These experiments show that whenever a conductor is cut by magnetic lines of force there is a current produced. A current was produced by "electromagnetic induction."

Investigate further by having a current produce the magnetic lines of force and they in turn producing a current. Substitute an electromagnet for the magnet used in the previous experiment. Arrange a circuit as in figure 16. Press the key. The milliammeter needle moves in one direction and then comes to rest. Break the current by means of the key—the m.a. needle moves in the opposite direction and then comes to rest.



When a current is started or stopped in the primary circuit an EMF is induced in the secondary by electro-magnetic induction.

FIG. 16. Production of Current in a Secondary Circuit by Electro-Magnetic Induction.

Insert an iron core in the coil of wire. The results are similar but the current induced is much stronger. In this experiment the conductor has been cut by magnetic lines of force. The circuit with the key is called the primary circuit—the other circuit, the secondary circuit, making the circuit in the primary allows a current to pass in it which sets up a magnetic field. This magnetic field building up from the wire outward cuts the secondary, thus causing a current. When the primary circuit is broken the magnetic field collapses, and the secondary is again cut by lines of force, but this time going in the opposite direction.

All these experiments produce current by electromagnetic induction. The facts of electromagnetic induction may be summed up in the following way:

Whenever variable magnetic lines of force cut a conductor, or a closed circuit made by a conductor, there is an e.m.f. created in the conductor whose direction is such as to oppose the e.m.f. that produced it. The value of this back e.m.f. is proportional to the rate of change of the lines of force.

24. Self-Induction—Consider the circuit shown in figure 17. Close the key and a current will flow through the circuit. This current does not flow instantaneously so that it reaches a point *A* before it does *B*. The current passing through the turns of the coil sets up magnetic lines of force which cut the turns of wire producing an e.m.f. whose direction is such as to oppose the passage of the original current in the circuit. When the key is opened the lines of force collapse on the coil inducing an e.m.f. in the same direction as the original current and will try to keep the current flowing. Induction in the same circuit is called "self-induction."

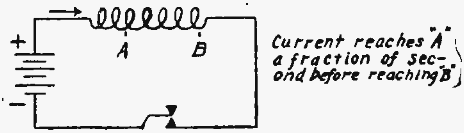


FIG. 17. Counter E.M.F. of Self-Induction.

25. Mutual Induction—Mutual induction is the interaction between two circuits by which a changing current in one sets up through electromagnetic induction a current in the other. Consider the circuit in figure 18. Whenever a current is started,

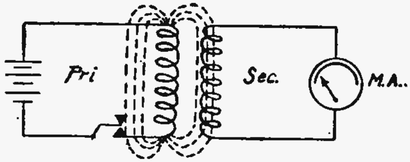


FIG. 18. Induced Current by Mutual Induction.

stopped, or varied in the primary coil, the magnetic lines of force set up around it cut the winding of the secondary, inducing an e.m.f. in the secondary circuit. A transfer of electrical energy has taken place between two circuits which have no electrical conducting path between them. Induction between two separate circuits is called "mutual induction."

The mutual induction of two given circuits depends upon the size and construction of the circuits themselves, their distance apart, their relative positions in space, and the nature of the material between them. All these factors necessarily affect the magnetic flux interlinked with both circuits. The effects of mutual inductance fall off rapidly as the distance between two circuits is increased. Mutual inductance is measured in the same unit as self-inductance.

Mutual inductance is of particular importance in radio circuits. The phenomena of mutual inductance are the essential principles involved in the operation of many different types of electrical apparatus, of which some are considered in the following pages.

26. Inductance—Inductance is defined as that property of a circuit which opposes a change in the flow of current through it. Inductance is electrical inertia.

Opposition to a change in the flow of current depends upon the amount of self-inductance, or upon the amount of self-inductance and mutual inductance combined. Every circuit possesses self-inductance, but only a circuit a part of which is a primary coil possesses mutual inductance. The inductance of a circuit is, therefore, the amount of self-inductance it possesses plus any mutual inductance which it may also possess. The unit of inductance is the "henry."

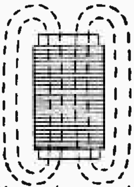
A circuit has an inductance of 1 henry when a current changing at the rate of 1 ampere per second induces an e.m.f. of 1 volt.

At radio frequencies where small values of inductance are employed the unit is subdivided and expressed as follows:

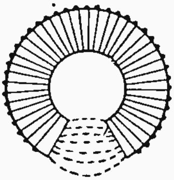
1 milli-henry (m.h.) — .001 h.
1 micro-henry (μ. h.) — .000001 h.

In self-induction this e.m.f. is set up as a counter e.m.f. in the circuit itself; in mutual induction, it is set up in the secondary circuit. In either case its effect is to oppose any change of flow of current through the circuit and is the measurement of opposition to that change. In any given conductor, the time it takes the current to build up to its maximum or to decrease to zero is influenced by the opposition to its increase or decrease in strength, that is, it is influenced by the inductance of the conductor. The greater the inductance, the longer the time required for the current to reach its maximum strength.

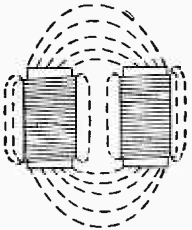
The inductance of a circuit conductor, coil or of any apparatus is a property of that thing just as resistance is one of its properties. The impressed voltage does not affect the inductance. A conductor has inductance whether current flows in it or not.



a- Single layer solenoid.



b- Toroidal coil.



c—Binocular coil.

FIG. 19. Practical Forms of Inductance Coils Showing Electro-Magnetic Field Surrounding Each.

27. **Practical Forms of Inductors**—The most commonly employed inductance at radio frequencies consists of a single layer coil wound as an air core solenoid. Other forms consist of multi-layer coils either in the form of spider web or honeycomb coil, so called on account of their peculiar construction.

More recently there have appeared the toroidal and the binocular coil, so called from their shape. The extent of the magnetic field can be greatly restricted by altering the shape of the coil. By bending the coil into the shape of a "toroid" as *b*, figure 19, the field or magnetic flux is circulated around the center of the coil and confined to the limits of the coil.

Another scheme used to confine the magnetic field of a coil is what is called the "binocular coil." This form of coil is shown as *c*, figure 19. Here the coil is broken in two with the two halves placed side by side, the windings of each being connected in series. The flux passes through one half and returns through the other half. Both the toroid and the binocular type coils are used in older radio receivers and their purpose is to confine the magnetic fields of the coils to prevent their reaction on earlier stages in the line of amplification.

28. **Iron Core Inductance**—This form of inductor is made by winding many turns of wire on an iron core. The core may be of the open or closed type. An iron core inductance acts as an impedance to the flow of alternating or pulsating current. It is usually found in circuits of audio frequency. It ranges in value from 1 henry to 200 henrys in inductance. The use of such coils will be shown in later chapters.

29. Capacity Effects—When water is poured into a container the pressure in the container depends on how high the level of the water is raised; the pressure will be directly proportional to the quantity of water put into the container, and inversely proportional to its size and shape. The size and shape will qualify what might be called the capacity of the container. If the container is connected to a tank containing water, a discharge will flow into it until the levels or pressures are the same in both, and the greater the capacity of the container the more water will flow in to equalize the pressures.

30. Dielectric Current—Similarly, if a perfect insulating material, with no other conductors near it, is charged by connecting it by contact or by a wire to a source of e.m.f., a charge will flow into it until the two are at the same potential. A small sensitive indicator of current connected in figure 20 will show a sudden deflection each time the key is closed and will soon return to zero. The momentary flow of current is due to the production of an electric strain or displacement of electricity. This is resisted by a sort of elastic reaction of the insulator that may be called electric stress. On account of this reaction of the electric stress, the electric strain due to a steady applied e.m.f. reaches a steady value, and the current becomes zero. When the electric strain is allowed to diminish a current again exists in the opposite direction. A current of this kind, called a "displacement current," exists only when the electric strain or displacement is changing. When considering the existence of electric strain or displacement in an insulating material the material is called a "dielectric" and the displacement current is sometimes called a "dielectric current." The electric displacement is a movement of electrons with the positive protons of each molecule of the substance gathered at one end and the negative at the other. A dielectric in such a strained condition possesses a charge of electricity and is sometimes called electricity in "electrostatic" form or electricity at rest.

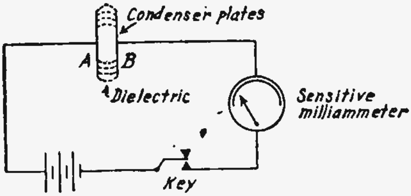


FIG. 20. Production of Displacement Current in a Condenser.

31. Condensers—A condenser is constructed of several conductors placed parallel to each other and separated by an insulator called the dielectric. It usually takes the form of one metallic plate or set of plates joined together and separated from a similar plate or set of plates by a dielectric of glass, ebonite, paraffin, oil, mica or air.

The capacity of a condenser depends on:

(*a*) The area of the plates.
(*b*) The distance between the plates.
(*c*) The material of the dielectric.

If an experiment is made of the effects of glass and air as the dielectric of a condenser, it will be found that the glass increases the capacity 6 to 10 times as much as the air.

The "dielectric constant" of a substance is, therefore, its effect when used as a dielectric as compared with an air dielectric. The following table shows the dielectric constants of various materials used as dielectrics in condensers.

Material	Dielectric Constant
Air	1.0
Glass	4.0 to 10
Mica	4.0 to 8
Hard Rubber	2.0 to 4
Paraffin	2 to 3
Paper, dry	1.5 to 3
Paper (Treated as used in cables)	2.5 to 4
Moulded Insulating Material, Shellac base	4 to 7
Moulded Insulating Material, "Bakelite"	5 to 7.5
Transformer Oil	2.5
Water, distilled	81.0

A wide variation is seen in the values given for some substances. The different grades and kinds of different materials vary considerably in many of their physical properties, including their electrical properties. For instance photo glass as used for plates has a higher dielectric constant than that of plain window glass. Moulded insulating material known to the trade as bakelite has a much higher dielectric constant than other substitutes commonly spoken of as moulded "mud."

If the voltage applied is from a source of alternating current, the values of the dielectric constant may differ considerably from the values of direct current. This is particularly true if the alternating current has a very high frequency, such as used in radio communication.

Dielectric materials are not perfect insulators, but do have a very small conductivity. A charge in a condenser will be slowly dissipated if allowed to stand with its terminals disconnected. This is called the " leakage " of the condenser. A condenser of which the dielectric is moulded " mud " or paper which has not been treated will sometimes discharge due to leakage within a few minutes. The lower the degree of conducting the longer the charge will remain in the condenser.

The thinner the dielectric, everything else being equal, the greater the capacity. The breaking down potential for a dielectric depends on its thickness as well as on the material; consequently, the thickness of the dielectric which must be used in a condenser depends on the potential strain it will be required to stand as well as the material used in the dielectric. Thus, the dielectric strength is measured by the voltage which will break down the insulation of unit thickness of the material.. The values vary according to the shape of the electrodes between which the dielectric is placed. Thus, when capacity is increased by decreasing the thickness of the dielectric for a given potential, there is a certain thickness for each dielectric that may be used and the best dielectric has not necessarily the highest dielectric strength.

The larger the capacity of a condenser the more charge is required to bring it to a given potential. Thus, the potential is directly proportional to the charge and inversely proportional to the capacity as in the water analogy, or in the symbols:

$$E \doteq \frac{Q}{C} \quad \text{or} \quad C = \frac{Q}{E} \quad \text{or} \quad Q = C \times E,$$

E = potential,
Q = quantity or charge,
C = capacity.

Unit capacity would be that of a condenser which is raised to unit potential by unit charge. The practical unit of capacity is called the " farad." A condenser whose capacity is one farad would be raised to a potential of one volt by a charge of one coulomb. A farad is far too large a unit for ordinary purposes and the following sub-divisions are generally employed in practice as follows:

1. " μ fd." = .000001 farad,
*1 " $\mu\,\mu$ fd." = .000000000001 farad.

(* Sometimes written "pfd" mean pico farad, will probably replace micro-micro-farad.)

32. Dielectric Hysteresis—If a charged condenser is discharged and left undisturbed for, say, 30 seconds, a small second discharge can be obtained from it, and sometimes a third one. This is due to the fact that when charged the strain across the dielectric causes the charges to leave the plates and really settle on the surface of the dielectric, through which they are bound by electric lines of force, or ether strain in the dielectric. When the opposite sets of plates are suddenly discharged through a circuit joining them, such as a wire or a spark gap, the following electrons rushing around the circuit neutralize the positive and negative charges but some are still left straining across the dielectric, trying as it were to get across that way instead of taking the easier path that has suddenly been provided for them; the dielectric does not entirely recover from the strain when the discharge takes place. The charge which flowed out instantaneously upon discharge is called the "free charge." The charge which flows out the second or third time is called the "absorbed" or "residual charge." In condensers made with oil or well-selected mica for the dielectric, absorption is small. This absorption is manifest by heat in the dielectric and represents a loss of energy.

33. Series and Parallel Connection of Condensers—Condensers may be connected either in series or in parallel. If connected in parallel, the combined capacity is equal to the sum of their capacities, or:

$$C = C_1 + C_2 + C_3.$$

Connecting them in parallel is equivalent to adding the plate areas. If three condensers of similar construction each having a capacity of .004 μ fd. are connected in parallel, the resulting capacity would be .012 μ fd.

If condensers are connected in series the resulting capacity is less than one alone. If the condensers have equal values of capacity, their combined capacity is obtained by merely dividing the capacity of one by the number of condensers in series, but if they have unequal values, the resulting capacity is equal to the reciprocal of the sum of the reciprocals or,

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

If three condensers of .004 μ fd. are connected in series, the resulting capacity would be .0013 μ fd. If three condensers of

.002, .003, and .004 μ fd. were connected in series the resulting capacity would be .00092 μ fd.

The voltage that several equal condensers in series will safely stand is as many times greater than the voltage of one as there are condensers in series. Advantage of this is often taken in building condensers for high voltages. Using this principle, a .004 μ fd. condenser to stand 20,000 volts can be made of twenty 1000-volt sections of .08 μ fd. each, all connected in series.

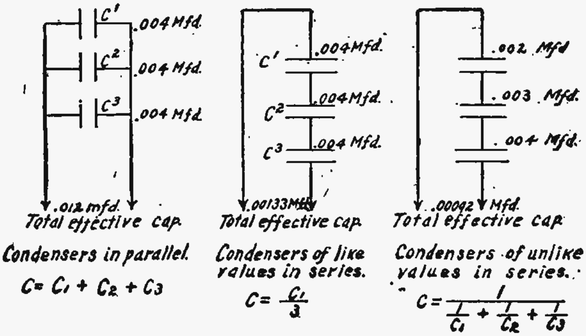


FIG. 21. Series and Parallel Connection of Condensers.

Transmitting condensers are sometimes protected by having a safety gap mounted on their terminals. The gap is so spaced that should the condenser be subjected to an excessive voltage a discharge will take place across the gap, thus lowering the potential of the condenser and preventing a rupture of the dielectric.

It has been shown that a condenser when first connected to a charging source has zero potential, and as the current flows, the potential rises until the voltage of the condenser is equal to the voltage of the charging circuit; the flow of current then stops. If the charging potential is decreased, the condenser will start to discharge and current will flow out in the opposite direction to which it was charged. The voltage of the condenser tends to set up a back pressure which tends to drive the charging current back. The effect of capacity in a circuit increases the time required to obtain a maximum flow of current through the circuit. Inductance in a circuit tends to prolong the flow of current while capacity tends to extinguish it or hold it back. The effects of counter e.m.f. of inductance and capacity produce a great effect on the flow of alternating current.

34. **Alternating Current**—An alternating current differs from

a direct or steady current due to the fact that it is changing in direction and strength.

From zero potential it starts to flow in one direction; reaching a maximum value it gradually returns to zero potential, only to flow again but in the opposite direction, reaching a maximum value in this direction and again returning to zero potential. This constitutes what is called one complete cycle. Each cycle is composed of two alternations. One alternation is the flow of current in one direction starting from zero rising to a maximum value and returning to zero again. The highest value of current reached during an alternation is called its amplitude. The number of complete cycles occurring during a second of time is called the frequency of the current. Thus a 500-cycle generator produces 1000 alternations of current per second. The process is conveniently pictured by what is commonly called a "sinewave" as shown in figure 22.

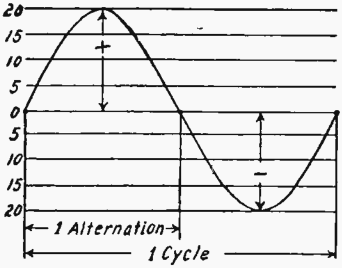


FIG. 22. Curve of One Complete Cycle of Alternating Current.

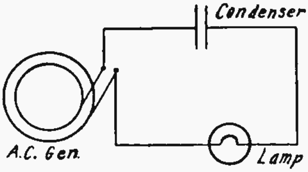


FIG. 23. Condenser in Series with A.C. Circuit.

It can be shown that the voltage and current curves of an alternating current may be irregular or distorted in form and if pictured graphically will show besides the fundamental, other frequencies which are multiples of the fundamental and are known as harmonics. If a harmonic is double the frequency of the fundamental it is known as the second harmonic; if three times, the third harmonic and so on. The fundamental is known as the 1st harmonic. Harmonic frequencies are quite common to radio frequency currents as will be shown later.

Alternating currents having a frequency below 10,000 cycles per second are called audio frequency currents and those above 10,000 cycles are called radio frequency currents.

An alternating current can flow in a condenser in the form of a dielectric current. An alternating e.m.f. in a circuit with a condenser will have the effect of allowing the current to flow through the condenser. Consider the arrangement as shown in figure 23. A very small lamp and a condenser of at least 20 micro-farads are connected in series with an alternating current generator. As long as the circuit is closed the lamp will be lighted indicating the passage of current.

If direct current was applied to this circuit the lamp would be lighted only momentarily such as when the circuit was closed or until the condenser was charged to the same e.m.f. as the applied e.m.f. With an alternating e.m.f. in the condenser circuit the alternating current is constantly flowing into and out of the condenser to keep the voltage between the plates equal to the instantaneous value of the applied e.m.f. The current is largest at those moments when the applied e.m.f. is changing most rapidly, it is zero at the moments when the e.m.f. is for a moment stationary at its maximum values.

35. **Impedance**—The flow of direct current through a given circuit is opposed only by the ohmic resistance, but the flow of alternating current is opposed by the counter e.m.f. of self-induction as well as ohmic resistance. The effect of self-induction in a direct current circuit is only momentary, the effects being observed only when the current is changing in value such as would occur when the circuit is closed or opened. Consider the circuit as shown in figure 24. The presence of the choke coil retards the flow of current when the key is closed and tends to prolong it after the key is opened. If the battery were to be replaced by an alternating current generator there would be a constant opposition to the alternations of current, i.e., the counter e.m.f. self-induction of the choke would retard an alternation from reaching its maxi-

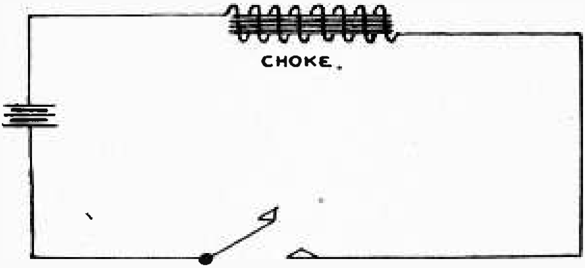


FIG. 24. Reactance Coil.

mum amplitude and would also tend to delay it from falling to zero. The counter e.m.f. of self-induction is called reactance and as it is a certain form of resistance it is convenient to measure it in ohms. The combined opposition of reactance and ohmic resistance is called impedance (expressed as Z) and it also is measured in ohms. However, the combined resistance, or impedance of a circuit in which there are values of reactance and ohmic resistance is not found by adding the values of each but expressed as follows:

$$\text{Impedance or } Z = \sqrt{R^2 + X^2}.$$

Where $R =$ resistance of circuit in ohms.
$X =$ reactance of circuit in ohms.

The counter e.m.f. occasioned by a circuit loaded with inductance is termed "inductive reactance." It is expressed:
Inductive reactance $= 6.28 \times FL$.

$F =$ frequency in cycles per second.
$L =$ the inductance in henrys.

From the formula it can be seen that the higher the frequency the greater will be the inductive reactance. At radio frequencies (frequencies in excess of 100,000 cycles) the reactance of a given coil reaches high values.

The counter e.m.f. occasioned by a condenser in series with an alternating current is called capacity reactance. It is expressed:

$$\text{Capacity Reactance} = \frac{1}{6.28 \times FC}.$$

$F =$ frequencies in cycles per second.
$C =$ capacity of condenser in farads.

A condenser offers less obstruction to the flow if the alternations are rapid than if they are slow.

36. Phase Displacement—If an alternating current circuit is composed of resistance only, the current and voltage sinusoids reach their maximum points at the same instant and simultaneously pass through zero. By introducing inductance in the circuit the current curve reaches the maximum at a time later than does the voltage curve, the interval of time depending on the value of the inductance and the frequency of the circuit. This difference in time is called phase displacement. Such a circuit is said to have a "lagging phase." See left hand drawing of figure 25.

If a condenser was placed in the same circuit and capacity reactance predominated the opposite condition would exist, that is, the current would " lead " the voltage, reaching its maximum at a time before the latter. A circuit of this type is said to have a " leading phase."

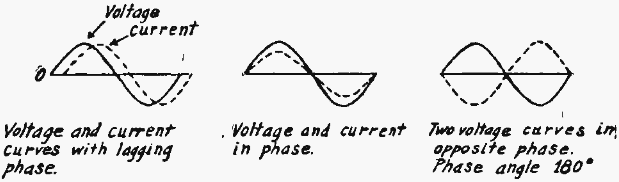


FIG. 25. Curves Showing Lagging and Leading Phases.

Difference in phase is nothing more than difference in position in the cycle. Phase displacement is expressed in terms of the degrees of a circle, i.e., an alternating current is said to have an angle of lag of a certain degree depending upon the constants of the circuit.

The effect of phase displacement on the power of the circuit is to reduce the value of power for the same value of current and voltage as compared to the power in a purely resistance circuit. Whenever an alternating current load contains reactance elements, then the product of E and I does not give the power put into that load. This product must be corrected by being multiplied by the " power factor " which is always smaller than one and is usually given in percent. Since one generally does not know the power factor it is therefore best to use a watt-meter which makes the multiplication and correction automatically.

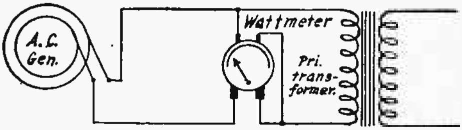


FIG. 26. Wattmeter Connections.

37. Single and Polyphase Alternating Current—An alternating current having but one e.m.f. is known as a single phase current. An a.c. having two or more e.m.f.'s differing by a fixed amount is called a polyphase current.

If three conductors were spaced on an armature 120 degrees apart and revolved between the poles of a U magnet there would be generated in the conductors three e.m.f.'s differing in phase by 120 degrees. If the three conductors are connected to an external circuit the system would be known as a three-phase circuit.

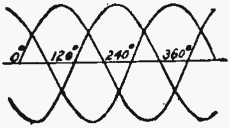


FIG. 27. Voltage Curve of Three-Phase Alternating Current.

38. Effective Value of Alternating E.M.F. and Current—In order to determine the effectiveness of an alternating current the root of the average square (r.m.s.) of the instantaneous values of current is taken and is expressed in terms of the strength of a given direct current which would produce the same power or heating effect.

Example: If 10 amperes of direct current pass through a resistance of 2 ohms the power of the current converted to heat will be I^2R or $10^2 \times 2 = 200$ watts.

If an alternating current is passed through the same resistance and is adjusted as to strength that 200 watts are consumed in heat there will be 10 amperes of alternating current flowing.

The effective value of alternating current is .707 of the maximum value per alternation. The maximum value of the current in figure 22 is 20 amperes. Its effective value is $20 \times .707 = 14.14$ amperes. The current rises and falls uniformly between the value of $+20$ amperes and -20 amperes, producing the same heating effect as a direct current of 14.14 amperes.

The maximum voltage per alternation of an a.c. circuit is 1.41 times the effective value. The maximum voltage per alternation in 110 volt a.c. circuits is then 155 volts.

Commercial alternating currents are usually of sine form at the generator although many things can happen after that to distort the wave form. Alternating current meters read in "effective value," or "direct current equivalent," so one needs no mathematics to determine the effective values of such currents.

39. Hot Wire and Thermo-Couple Ammeters—Radio frequency currents are measured by the heating effect of a piece of wire or strip of metal. Such instruments are called "thermal ammeters." They are divided into two classes called "hot-wire" and "thermo-couple" ammeters.

The hot-wire ammeter depends for its action upon the expansion of a metal wire when it is heated. Figure 28 illustrates the principle. The wire *AB* is connected with the radio frequency current. The resistance of the wire is such that it will stretch when heated by the r.f. current. The spring *S* exerts a pulling action on the slackened wire through the thread *T*. The resultant motion causes the needle *N* to move over the scale. The degree of movement depends upon the amount of current flowing in the wire *AB*. The scale is calibrated in amperes so that the position of the needle shows directly how large the current is.

The thermo-couple ammeter depends for its action on the e.m.f. produced by heating two dissimilar metals. The value of e.m.f depends on the combination of metals and ordinarily increases directly as the temperature is increased.

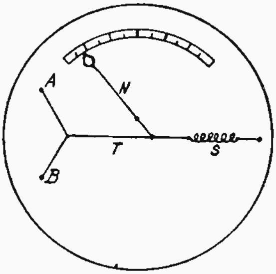


FIG. 28. Principle of Hot-Wire Ammeter.

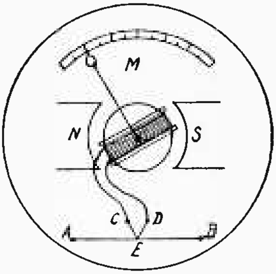


FIG. 29. Principle of Thermal Ammeter.

The theory of operation can be explained by referring to figure 29. The two dissimilar metals *C* and *D* make contact with the hot wire *AB,* in which the radio frequency current is flowing. The e.m.f. produced by the heat at the junction *E* is communicated to the direct current ammeter *M*. As previously explained, the heat due to a given number of amperes of alternating current is the same as that of an equal number of amperes, direct current. A deflection of the needle of the ammeter indicates the effective value of current as alternating current meters of radio frequency variety read in "effective value" just as do ordinary 60-cycle or 500-cycle instruments.

40. Skin Effect—The resistance offered by a wire to radio frequency current is not the same as for a direct current. The resistance increases with frequency. Radio frequency currents are conducted only on the surface of the wire, hence, it is the surface area and not the cross-sectional area which is the most important in determining the resistance to currents of high frequency. Stranded wire or tubing, or metal strip is often used in connecting up radio apparatus, because the same amount of copper has much more surface in such shapes than when it is formed into solid wire. It should be remembered, however, that it is possible to carry this to extremes. It is common for radio amateurs to use large strip copper where there are only small currents. There is no point in this and it needlessly complicates the apparatus.

41. Frequency Meters—The speed of induction motors, motor generators and other alternating current apparatus depends on the frequency of the supply circuit. Change in frequency is accompanied by a change in speed. Changes in frequency cause corresponding changes in the reactance of circuits, which may be a considerable disadvantage. A consideration of these facts leads one to appreciate the need for a reliable frequency meter.

Weston frequency meters are found on the switchboards of almost all radio transmitters of the spark type. They are employed in the power circuit of transformers at frequencies of the order of 500 and 1,000 cycles per second and are known as the resonant type of frequency meter, model 355, type 2.

The type 2 instrument is self contained, i.e., the reactors, resistors and condenser are contained within the instrument case.

Figure 30 illustrates diagrammatically the electrical circuits of the instrument. The vertical field coils designated as 1 are connected to the line through a resistor *R*, a condenser *C*, and two protecting reactors, *X*-1 and *X*-2. The horizontal field coils 2 having a reactor *X* in series with them, the coils and the reactor are shunted by the condenser *C*.

By referring to figure 30 it will be seen that the current which passes through the reactor *X* traverses field coils 2. This is a lagging current. It produces in coil 2 a magnetic field tending to hold the needle in a plane perpendicular to the coils. This lagging current also traverses coil 1.

The current which passes through the condenser *C* likewise traverses coils 1 but this is a leading current. The resultant of the lagging and leading currents in coils 1 produces a magnetic field tending to displace the needle from the normal position.

When the frequency is lower than normal the lagging component of the current in coils 1 preponderates because of the decrease in reactance of reactor *X* and the increase in reactance of condenser *C*. Therefore, the effect of the resultant current in coils 1 is to deflect the needle to the left of its normal position.

When the frequency is higher than normal the leading component of the current in coils 1 preponderates as the reactance of *X* is increased and that of *C* decreased. The resultant current now causes the needle to deflect to the right of its normal position.

At normal frequency the effect of the fundamental of the current passing through coils 2 is very greatly magnified by the circuits 2, *X*, *C*, becoming resonant.

Because of this the current passing through coils 2 is very large while what passing through coils 1 is only the small line current. Thus the action of coils 2 on the needle is so great and that of coils 1 so small that the needle remains in its normal position. The resonant feature enables a large torque to be obtained with a very small current being taken from the circuit.

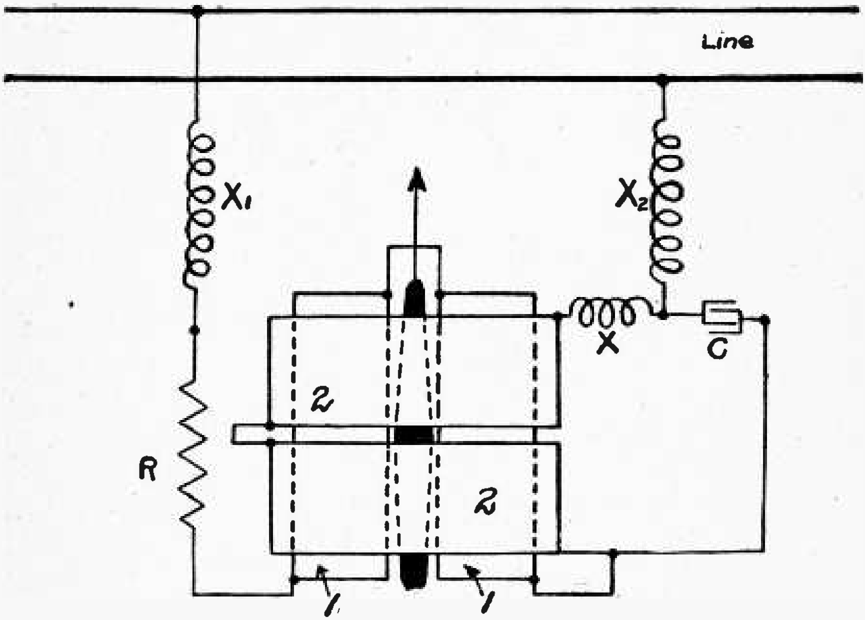


FIG. 30. Circuit of Frequency Meter.

Because the resonant circuit amplifies the effect of the fundamental only and the reactors *X*-1 and *X*-2 together with the resistor *R* prevent the passage of harmonics through the field coils 1, this instrument is not at all affected by distorted wave form, indicating with the same degree of accuracy on a sinusoidal wave form or on a wave having practically a rectangular form.

Model 355, type 2, instruments are designed for a normal voltage range from 110 to 220 volts, with an overload capacity, which allows the voltage to reach 350 volts without injuring the instrument. This renders the instrument suitable for use on radio telegraph sets where the open circuit voltage is high but the operating voltage considerably lower.

42. **Resonance in Alternating Current Circuits**—By the proper selection of inductance and capacity values in an alternating current circuit the counter e.m.f.'s can be made to balance and the reactance therefore reduces to zero. The circuit then acts as if neither inductance nor capacity were present and the flow of current is governed solely by the ohmic resistance. When this condition exists the circuit is said to be a resonant circuit as the frequency of the circuit corresponds to the frequency of the current flowing in the circuit. The frequency at which this occurs is called the "resonant frequency." Every combination of capacity and inductance has its reactance equal to each other at some frequency or other, which is usually a frequency different from the one that it is desired to work at. Therefore, it is convenient to have either the inductance or the capacity or both variable so that the "resonant frequency" can be adjusted to that desired.

The inductive and capacity reactance will be equal in such a circuit if the following condition exists:

43. **Inductive Reactance** = Capacity Reactance, or

$$6.28FL = \frac{1}{6.28FC}.$$

44. **Reactance Coils**—Reactance coils consisting of several turns of insulated wire wound on an iron core are connected in series with alternating current circuits at commercial frequencies to either secure resonance at a certain frequency or to provide an inductive reactance whereby the current flowing in the circuit is retarded. The reactance of such coils is made variable by either providing taps on the windings connected to a suitable switch or the reactance value can be changed by moving the core in and out of the windings.

Reactance coils having air cores are employed in radio frequency circuits and are known as radio frequency choke coils. The reactance of such a coil is very high at such frequencies. They are used to prevent the flow of radio frequency currents in some branch of the circuit.

The reactance of a given coil at radio frequencies may be of such a high value that little or no current would flow unless a certain amount of capacity was inserted in the circuit in the form of a condenser. By making the values of both inductance and capacity variable the inductive reactance can be made to equal the capacity reactance and then the current will build up to large values. If a condenser of .00015 farad were connected in series with a 60-cycle alternator the capacitive reactance would be:

$$\text{Cap. Reactance} = \frac{1}{6.28 \times 60 \times .00015}$$
$$= 17.6 \text{ ohms approx.}$$

If resonance were desired in such a circuit it would be necessary to insert an inductance of .046 henry approx. as:

$$6.28FL = \frac{1}{6.28FC}.$$

Substituting,

$$6.28 \times 60 \times .046 = \frac{1}{6.28 \times 60 \times .00015}.$$

In order to transfer energy from one circuit to another by magnetic induction as is done in radio telegraphy and telephony the circuit to which energy is to be transferred must be in resonance with the first circuit.

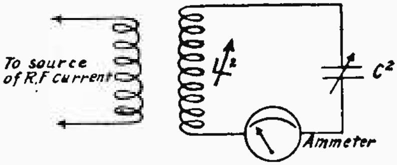


FIG. 31. Showing How Resonance is Obtained in an Alternating Current Circuit.

It can be adjusted to resonance by trying different values of inductance and capacity until the current indicating device of the second circuit shows a maximum deflection.

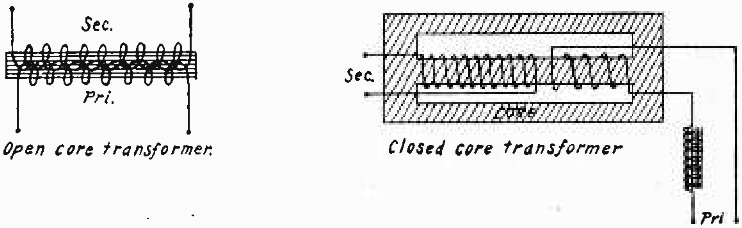
The process of adjusting the circuits to resonance is called "tuning." Figure 31 shows the arrangement of two radio frequency circuits electromagnetically coupled whereby they can be tuned to resonance by choosing different values of inductance or capacity.

45. Alternating Current Transformers—There are two kinds of alternating current transformers commonly employed in radio telegraphy and telephony. The purpose of one is to change or transform alternating current of low voltage and comparatively large current to alternating current of higher voltage and smaller current or vice versa.

The transformer which is used to produce a higher voltage is called a "step-up" transformer. A transformer used to produce a lower voltage than the input is called a "step-down" transformer.

The step-up transformer is employed to produce high voltages to charge condensers in a spark system for radio transmission. It is also used to produce high voltages for the plate supply of vacuum tube transmitters. The step-down transformer is used to operate the filaments of vacuum tubes.

46. Construction—An alternating current transformer consists of two windings so placed as to have appreciable mutual inductance. The winding or coil to which the input power is delivered is called the "primary" and the winding which delivers the "output" to the load circuit is called the secondary. These windings are placed over an iron core which is common to each and increases their mutual inductance.



Open core transformer.

Closed core transformer

FIG. 32. Open and Closed Core Transformers.

In some transformers the path of the magnetic flux is partly through the air; such a transformer is called an "open-core" transformer. A transformer on which the magnetic flux is entirely through iron is called a "closed core" transformer. The two different types are shown in figure 32. A closed core transformer has a very small leakage flux. Very little flux exists in the air surrounding the core due to the complete path of high permeability offered by the closed core. Usually the primary consists of several coils or "pies" connected in series and placed directly over the center of the iron core with strips of wood to space the winding from the core in order to allow ventilation.

The secondary also consists of several pies connected in series and slipped over the primary with an insulating tube between them.

Transformers having air cores are employed at radio frequencies. The mutual inductance of such windings of an air-core

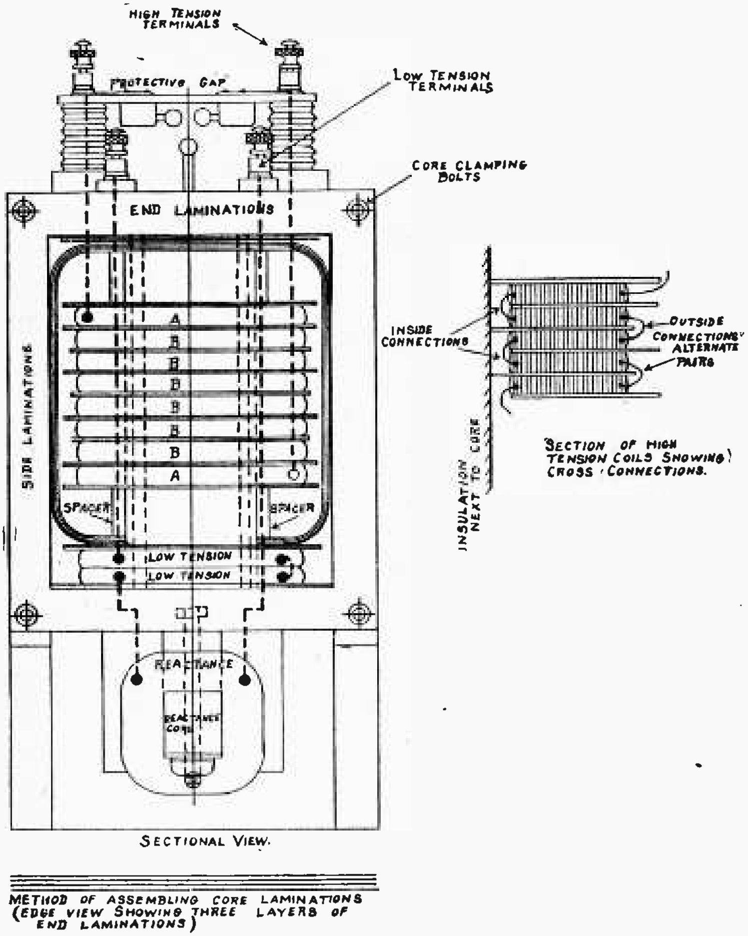


FIG. 33. Sectional View of Closed Core Transformer.

transformer is comparatively small. At low frequencies the efficiency of such transformers is very low. If such transformers were to be employed at high powers it would become very expensive.

The core of an alternating current transformer employed at 60 cycles is constructed of many thin sheets or laminations of silicon steel. By the use of silicon steel laminations the losses due to eddy currents are reduced and the transformer can be operated at higher flux densities than one which is not laminated.

47. Ratio of Transformation—If the primary of a step-up transformer has 100 turns and the secondary 1000 turns, the turn ratio is expressed as 1 to 10.

When an e.m.f. of 200 volts is applied to primary an e.m.f. of 2000 volts will be induced in the secondary, and if the primary current is 50 amperes, the secondary current will be 5 amperes. From this it can be seen that the larger the number of turns on the secondary as compared to the primary the larger will be the voltage induced in the secondary, and if the voltage is stepped up the current is reduced or will have a smaller value than that of the primary. The secondary of a step-down transformer, therefore, has fewer turns than the primary but the wire must be larger.

48. Transformer Operation—The primary circuit of the transformer is connected in series with a source of alternating current which magnetizes the iron core, periodically causing a varying flux to flow through the iron core in accordance with the alternations of current. The variable flux cuts the windings of the secondary, thereby inducing an e.m.f. in this winding, and if the secondary is a closed circuit a current will flow. The current will flow in the secondary in such a direction as to tend to cause a magnetic flux in the core in a direction opposite to the direction of the flux caused by the current flowing in the primary. The flux existing in the iron core must be of sufficient magnitude to induce in the primary winding a back e.m.f. of the same value as the terminal voltage. In order to maintain the flux constant, the current flowing in the primary winding must increase to a value such that the increase in the primary ampere-turns is sufficient to overcome the opposing magnetic effect of the secondary ampere-turns. This reduces the effective inductance of the primary to such a value that sufficient primary current is available in order to maintain a constant flux; when the load is on the secondary the effective inductance of the primary becomes quite small.

49. Losses—The principal losses in a power transformer are of two kinds, the "copper losses" and the "core or iron losses." The copper losses in the primary and secondary windings are equal to the current squared times the resistance. The "core losses" are of two kinds, the first of which is the "eddy current" losses due to currents induced in the iron core. By the use of laminations in the core the eddy current loss is considerably reduced. Due to the constant reversals of magnetism within the core considerable energy is expended in changing the positions of the molecules of the iron laminations. This expenditure of energy is known as the "hysteresis" loss. The core losses occur as long as a voltage is applied to the primary and are nearly the same whether the secondary is delivering a load current or not.

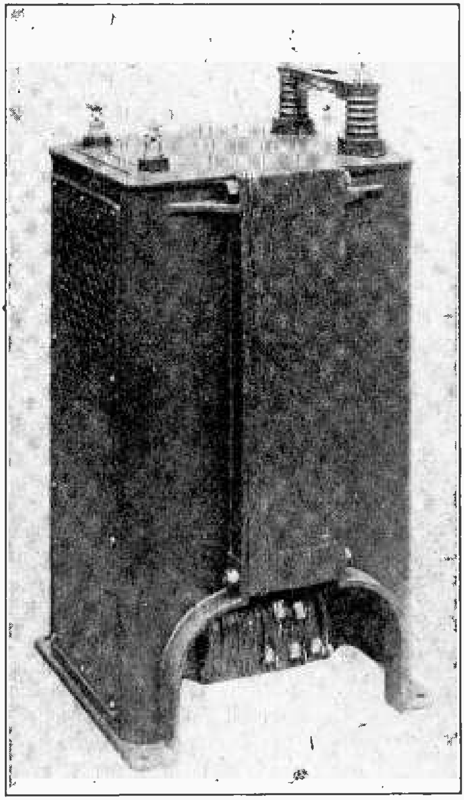


FIG. 33*a*. 2 KW. 500-Cycle Transformer. (American Transformer Co.)

50. Cooling—The losses in a transformer represent electrical energy converted into heat. Some means must be provided for dissipating this heat, or the temperature of the transformer may rise, until it is destroyed. Radio transformers of small size are usually cooled by simply being exposed to the air. The exposed surface of the winding is sufficient to dissipate the heat. Large transformers are cooled by immersing the windings in oil.

51. Reactance Regulator—The low frequency power circuit of a radio spark transmitter is usually adjusted so that it is resonant at a frequency approximately 15 percent below the best operating frequency. This prevents the note of the transmitter from "mushing" when the key is closed. It is accomplished by connecting a reactance coil in series with the primary windings of the transformer. Such a reactance is either variable in steps or is of a fixed value and adjusted at the factory by the manufacturer.

52. Method of Connection of Two-Phase and Three-Phase A.C. Transformers[1]—Two-phase circuits nearly always have four wires and are equivalent to two single phase circuits in which the currents have the same frequency and always preserve a definite phase relation to each other. Both phases are used for motors, half the power being drawn from each phase so that the same transformer capacity must be connected to each phase. For lamps, the transformers are connected the same as to single-phase circuits, care being taken to divide the load between the two phases as nearly equal as possible. If two transformers are connected in parallel, both primaries must be connected to the same phase as in figure 34. If connected to different phases secondary currents will

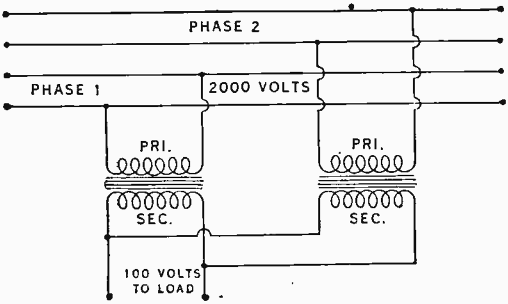


FIG. 34. Parallel Connections of Step-Down Transformers to Two-Phase Current.

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be out of phase and local currents will circulate through the secondary coils, resulting in waste of energy and unnecessary heating.

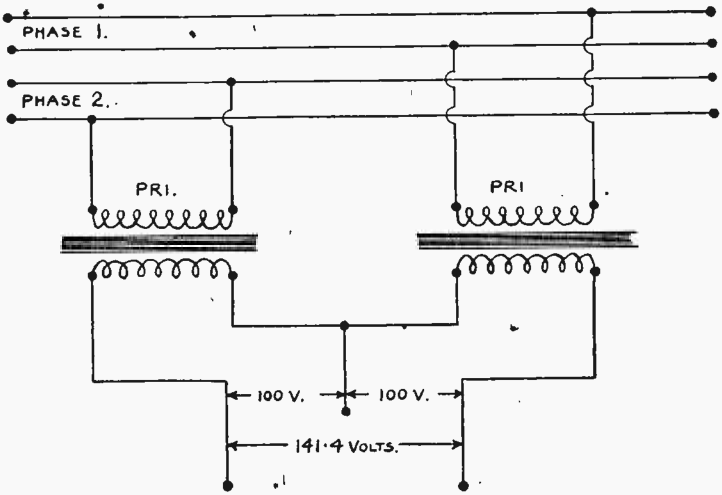


FIG. 34*a*. Two-Phase, Three-Wire System.

The secondaries of a pair of transformers may be connected in series with one primary connected to each phase of the line circuit, thus forming a two-phase, three-wire secondary system.

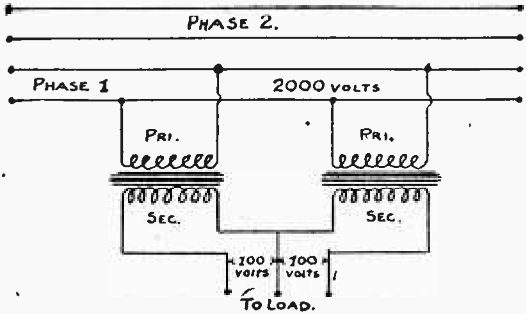


FIG. 34*b*. Secondaries in Series and Primaries Connected to Same Phase

See figure 34*a*. This method is seldom used, since the voltages on the two sides of such a system are easily unbalanced.

The secondaries may be connected in series and both primaries connected to the same phase as in figure 34*b*, forming the regular three-wire secondary system. The voltage between the outside secondary wires is the sum of the voltages on the two sides.

53. Three-Phase Circuits—When three transformers are connected as in figure 35, two coils are in series across each phase. This is called a *Y* or star connection. When the primaries are connected *Y*, the secondaries are usually connected in the same way.

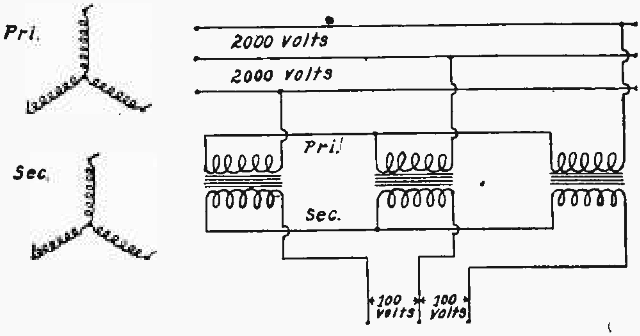


FIG. 35. "Y" or Star Connection of Three-Phase Transformers.

The terminals of the transformers may be connected, as in figure 36, thus forming a delta (Δ) or mesh connection.

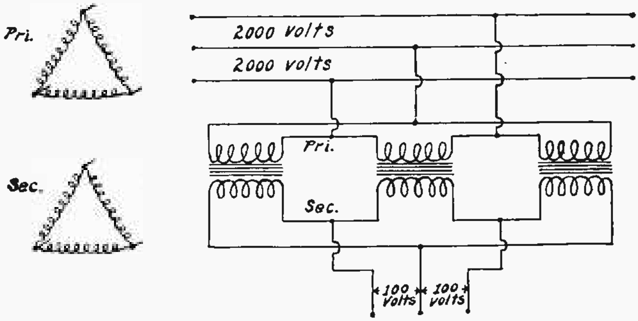


FIG. 36. Delta (Δ) or Mesh Connection of Three-Phase Transformers.

In special cases, the primaries may be connected delta and the secondaries *Y* of the same transformers. Figure 37 shows such connection, as employed in radio telephony for producing high voltages for the plate supply of rectifier tubes which after rectification and filtering is used as the d.c. supply to the other tubes of the transmitter.

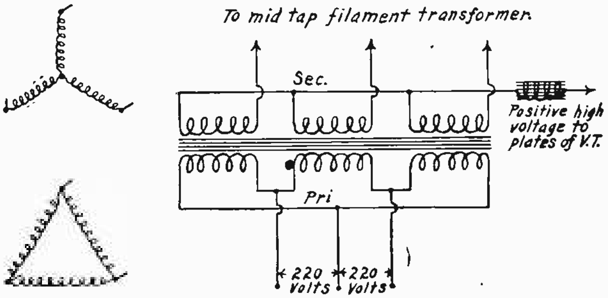


FIG. 37. Delta Connection of Primaries and Star Connection of Secondaries as Used for Plate Supply for Radio Transmitters.

54. Induction Coil—High voltages for charging the condensers of spark transmitters may be obtained from the secondary of an induction coil.

An induction coil is operated from direct current. It is limited in the amount of power that can be used. The vibrator on such coils requires very careful adjustments in order to produce a steady spark note. Such coils are still in use on vessels as the emergency apparatus and are operated from an auxiliary storage battery usually of 24 volts.

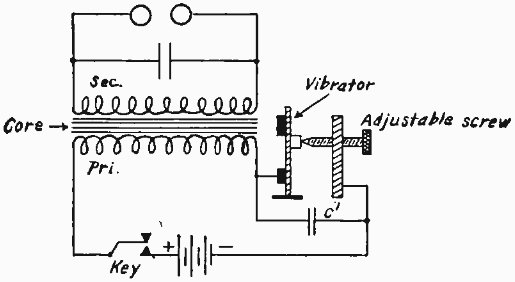


FIG. 38. Induction Coil.

55. Construction and Operation—The coil is constructed of two coils wound on an open core of soft laminated iron. The primary has few turns of large wire and the secondary many turns of fine wire. Connected in series with the primary is an adjustable vibrator fitted with a soft iron armature and so constructed that it can be attracted by the magnetic flux of the iron core. Each time the vibrator is attracted by the core it is thereby drawn away from the stationary contact through which the primary circuit is brought to another contact mounted on the vibrator itself. Thus the movement of the vibrator breaks the primary circuit, stopping the primary current. The magnetism of the core now collapses suddenly, thereby inducing a momentary current surge in the secondary. When the magnetism of the core has died out the vibrator is released and thereupon flies back again completing the primary circuit. The core then becomes remagnetized and the whole thing happens over again a considerable number of times per second. The frequency of operation depends upon the weight of the vibrator and the stiffness and length of the spring. An interrupted current flows through the primary as long as the key is closed. The changing primary current produces a variable magnetic flux which cuts the turns of the secondary and a current will flow due to the e.m.f. induced in the secondary windings. The current in the secondary flows in one direction as the current is made and as the current is broken it flows in the opposite direction. As the current breaks much faster than it makes, the induced e.m.f. is much higher on the break. This is caused by the self induction of the primary winding.

56. Radio Frequency Waves—Radio communication is the setting up of waves in the ether and the receiving of these waves at some point distant from the sending station. Consider the waves that are produced on the surface of a body of water as represented in figure 39. The straight line *C* represents the surface of water when it is at rest. The curves represent the surface of the water at some distant point. The tops of the curves are the crests or highest points reached by the waves. One complete wave extends from *C* to *C*-1 or from *B* to *B*-1. The distance from *C* to *C*-1 or from *B* to *B*-1 is called the wave length and in radio is always indicated by the Greek letter λ called lambda. A wave length then is the distance from any point on a wave to the corresponding point on the next wave.

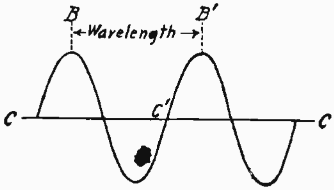


FIG. 39. Graphical Representation of Water Waves.

Water waves are carried along by water. Water is their medium. Radio waves are carried along by the medium called **ether.** Light and heat waves are also ether waves. The speed of all etherical waves is the same, viz.: 186,000 miles (300,000,000 meters) per second, but the wave length of each is different. In the water waves the wave length was found to be the distance from the crest of one wave to the crest of its successor. Radio waves are measured from one maximum of electric or magnetic force to the next maximum.

There is a definite relation between the length of a wave and its velocity. The following experiment will confirm this. Stand on the shore and estimate the length of the water waves as they pass by. Assume the distance from crest to crest of a wave to be 12 feet. The number of waves passing per second is 10 and is called the frequency of the waves. What is the velocity? If each wave is 12 feet long and 10 pass per second the velocity must be $12 \times 10 = 120$ feet per second. This is a general rule and can be expressed: $V =$ Number or frequency × Wave Length.

57. Wave Length—It has already been stated that radio waves travel 300,000,000 meters per second. The velocity never changes. Substituting in the formula stated above the wave length of the radio waves can always be determined if the frequency is known. The length of radio waves is always expressed in meters. Likewise if the wave length is known the frequency of the waves can be determined as follows:

$$F = \frac{V}{\lambda}, \qquad \lambda = \frac{V}{F}.$$

Example: What is the frequency if the wave length is 300 meters?

$$F = \frac{300,000,000}{300} = 1,000,000.$$

The frequency of radio waves is expressed in cycles per second. The frequency of the waves in the problem above is 1,000,000 cycles per second. With the development of short wave lengths (wave lengths less than 100 meters), by the amateur experimenters, the expression of frequencies in cycles of such waves necessitated the use of large numerals. It is more easily expressed in kilocycles or megacycles. 1 kilocycle = 1,000 cycles, 1 megacycle = 1,000,000 cycles. The frequency of 1,000,000 cycles can then be expressed as 1,000 kilocycles or 1 megacycle.

Referring again to figure 39, it will be noted that the waves are divided into two parts: One above the straight line and the other below it. In one part the water has moved upwards, in the other the water has moved downwards. This is true of all waves. The maximum value that the wave moves upward or downward is called the amplitude of the wave. It is the amplitude of a wave that determines how much energy the wave contains.

Radio waves are made up of two parts, i.e., electro-static lines of force and magnetic lines of force. Experiment shows that electro-static lines of force travel at right angles to the magnetic lines of force. The magnetic lines of force always travel parallel with the ground, sweeping back and forth; and the electro-static lines of force travel perpendicular to the ground, sweeping it up and down. Both the electro-static and the electro-magnetic lines of force reverse their direction every half wave length. One wave constitutes an electro-static field which travels first in one direction and then in the other. The same is true of the electro-magnetic wave.

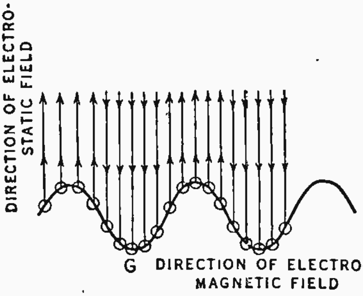


FIG. 40. Components of Radio Wave Showing Direction of Movement.

58. Antenna System—In order to produce electro-magnetic and electro-static waves in the antenna system and have them radiated into space it is necessary to excite the antenna by connecting it to a source of alternating current. A 60-cycle alternator such as produces house current would not do. In order to secure resonance in such a circuit, it would require an antenna of tremendous dimensions. The radiation from such an antenna would be negligible at a frequency of 60 cycles. The frequency of the alternating current in the antenna must be very high in order for the radiated waves to produce any distant effect in a receiving antenna circuit. The frequency of the alternating current necessary to produce radio waves is between 10,000 and 600,000,000 cycles, per second. The radiation from a vertical antenna of a single wire is illustrated in figure 41. It is called a Marconi antenna. Marconi made the first use of grounded antennas. The wires of an antenna are considered one plate of a condenser and the ground the other. If the antenna of figure

41 is connected to a source of radio frequency current the field of the antenna and earth is surrounded by lines of force, which die away when a discharge current flows, and are set up when the charging current flows; thus an increasing or decreasing electric strain is identified with a current in one direction or the other resulting in a wave motion.

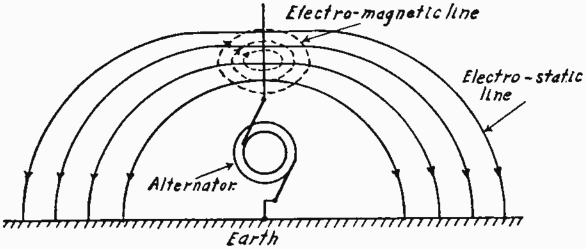


FIG. 41. Radio Waves Surrounding Grounded Antenna.

As already stated the wave motion consists of an expanding static field which is accompanied by a magnetic field, both being radiated at right angles to each other and to the direction of propagation.

The natural or fundamental wave length of an antenna is determined by its height, length, the number of wires, and its geometrical shape.

The higher the antenna, the more the energy radiated. The natural wave length of the antenna is the wave length without any inductance coils or condensers in series with it. In order to operate the antenna at a wave length below the fundamental wave length it is necessary to employ a condenser in series with the antenna. The wave length of an antenna is increased by adding inductance at its base. Every antenna has a certain amount of distributed inductance and capacity. The inductance of the wires forms the distributed inductance. The distributed capacity is formed by the wires acting as one plate of a condenser and the ground the other. The capacity of the condenser thus formed is dependent upon the length and number of wires in the antenna and the distance between each wire, as well as the height of the antenna above the ground. When another capacity is connected in series with the capacity of the antenna the same effect is produced as two condensers in series. The capacity is thereby reduced. The fundamental wave length can be calculated directly from the dimensions but as such formulæ are too complicated for the average operator they will not be shown here. However, an approximation can be made as follows: For a simple vertical grounded antenna, the approximate fundamental wave length is 4.2 times the total length of the antenna in meters including lead in. When four wires are employed in the flat top the constant 4.4 should be used.

The various methods employed to excite an antenna will be shown in a later chapter devoted to short wave length transmission as used by amateurs.

59. Damped Waves—The waves as illustrated in figure 42 are called damped waves. It should be noted that the waves diminish in amplitude, i.e., each succeeding wave has a smaller amplitude than the preceding one. All the waves from *S* to *F* comprise one wave train. A mechanical analogy will illustrate the production of a damped wave train. Hang a weight on a spring balance, pull the weight down and let it free. It will vibrate up and down and gradually come to rest. The moving weight will set up waves in the air which cannot be heard (sub-sonic), but these waves are of exactly the same character as the motion that produces them. The motion of the weight is gradually decreased due to friction and finally it comes to rest. The waves produced in the air by movement of the weight are exactly as shown in figure 42. They are of decaying amplitude. The radio waves produced by spark transmitters employed in connection with mobile radio telegraphy are also of decaying amplitude and are called damped waves. The production of such waves and their effect on a radio receiving antenna will be shown in a later chapter.

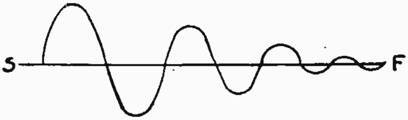


FIG. 42. Damped Waves.

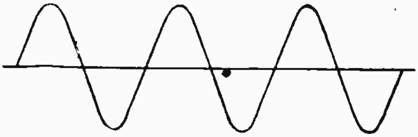


FIG. 43. Undamped Waves.

60. Undamped Waves—Waves in which the amplitude remain constant are called undamped or continuous waves (C.W.).

The following experiment will illustrate how a wave train of constant amplitude can be produced. The same spring balance and weight is used for this experiment. Pull the weight down and let it free. When it has gone up to its highest part and is starting downward again, tap it just hard enough for it to go down to the first, lowest position. Do this each time it starts downward. Its motion and hence the waves set up by it can be represented by figure 43. The amplitudes of all waves are the same. It is an undamped wave. In order to make it undamped or continuous it was necessary to add energy by tapping it at the proper time. Undamped waves have certain advantages over damped waves.

The production of undamped or continuous radio waves by the vacuum tube will be taken up in succeeding chapters.

CHAPTER 2

MOTORS AND GENERATORS

1. **The Alternating Current Generator**—The magneto such as is used for producing current for operating polarized telephone ringers is the simplest form of an alternating current generator.

Referring to figure 44, the following takes place: Magnetic lines of force are flowing across the field from the N. to the S. pole of the permanent magnet. To induce an e.m.f. in the rotary coil it must move through the lines of force, and in *A*, the maximum number of lines is passing through the coil. The number of lines does not change until the armature has passed beyond this position as shown in *B* and the voltage is zero. As the armature rotates a little beyond *B* the lines begin to change and voltage builds up until *C* is reached, when the remaining lines of force are shortened

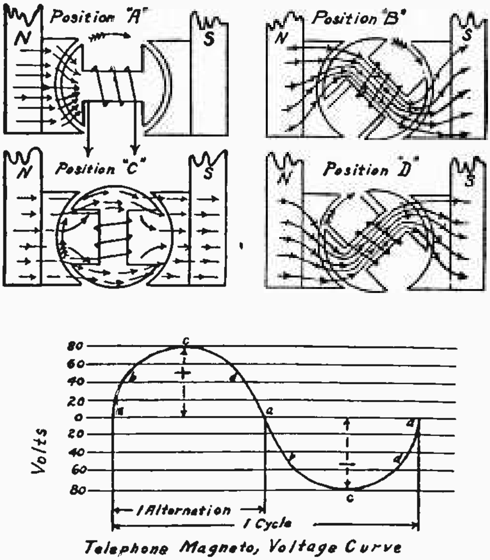


FIG. 44. Generation of Alternating Current by Telephone Magneto.

out of the coil and the rate of change of the lines is the greatest and the voltage will be at a maximum.

When the *D* position is reached the lines of force pass through the coil in the opposite direction and the voltage drops to zero. The induced e.m.f. in the rotating armature produces an alternating current, for while the armature is passing from the position *A* to the position *C*, a plus or positive current is generated if the North pole is on that side and from *C* to *A* a minus or negative current is generated because the wire there is subject to the influence of the South pole. The curve shown is a sine curve as explained in a previous paragraph on alternating current. A machine generating a single alternating current is called a " single phase " machine. Generators used exclusively for spark transmitters are generally single phase.

Commercial alternators do not depend on U magnets but have field poles; the poles carry coils on a frame, which are wound alternately in opposite directions so that the current flows about the turns in opposite directions, giving the poles alternately North and South polarity. The field poles are excited by being connected to a source of direct current which is controlled by a variable resistance so as to weaken or strengthen the field depending upon

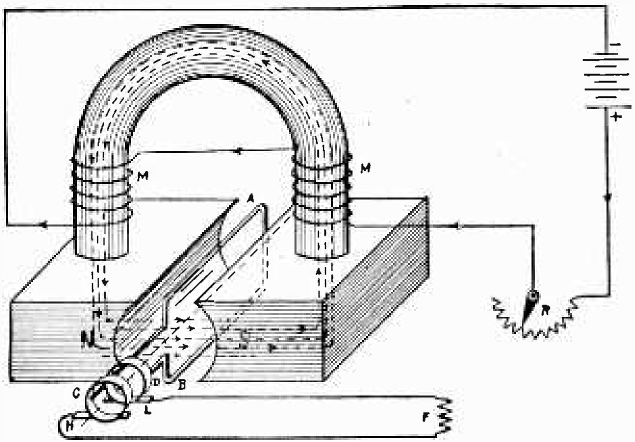


FIG. 45. Fundamental A.C. Generator.

the load on the generator. See figure 45. This variable resistance is called the field rheostat. The armature consists of several coils so connected that the voltage induced in one coil is added on to that of the next coil. In small machines the armature terminals are connected to the collector rings which rotate with the armature. Current is taken from the collector rings by means of carbon brushes which make continuous contact with the collector rings.

On the inductor type of alternator both the armature and field windings are stationary. The rotating element is called the inductor and controls the variable magnetic flux as will be shown later.

Modern generators of large capacity have a rotating field and slip rings. The armature is the stator.

2. Inductor Type of Alternator—The inductor type of alternator is employed considerably in connection with radio telegraphy. As mentioned before its field magnets and armature are both stationary. The rotating element called the inductor is constructed of a mass of iron with many teeth or pole pieces cut in the same. The passage of each tooth or pole piece by a field and armature coil generates a complete cycle of e.m.f. whereas with alternators of either the revolving armature type requires the passage of two poles to cause a cycle.

The principle of operation of an inductor type of alternator is shown in figure 46. A considerable gap separates the stationary field and armature magnet. In this gap is the iron inductor *I*. It is free to revolve in a direction as to pass away from the reader and through the page. When the inductor is in the position shown between *N* and *C*1, and *S* and *C*2, there is a certain magnetic flux due to the direct current excitation furnished externally. When the inductor is not in the position shown there are long air gaps in the magnetic circuit which have a very much smaller permeability than the iron conductors. The flux is therefore considerably less. The increase and decrease of magnetic flux in the coils *AA*.

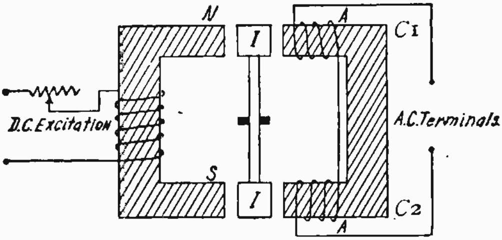


FIG. 46. Production of Alternating Current by Inductor Type of Alternator.

due to the rotation of I sets up an alternating e.m.f. because any change in the flux inclosed by a circuit sets up an e.m.f. in the circuit (see Electro-Magnetic Induction) in the one direction while the flux is increasing, and in the opposite while it is decreasing.

Inductor types of alternators are constructed to generate a frequency as high as 200,000 cycles per second. This high frequency is obtained by having 200,000 inductor teeth pass a given point every second. This result can be obtained only by having a great many teeth on the rotor and driving it at a very high speed. Inductor types of alternators used in spark systems of radio telegraphy are usually designed to generate a frequency of 500 cycles per second.

3. **Determination of Frequency**—The frequency of an alternator may be determined by the formula:

$$F = \frac{N \times S}{120}.$$

F = Frequency in cycles per *second.*
N = Number of field poles.
S = Speed of armature in revolutions per minute.

In commercial practice the frequency of the generator is increased by increasing the speed of the armature as the field poles are fixed.

The voltage of the generator may be increased by increasing the speed of the armature or by increasing the strength of the magnetic field of the field poles as already stated. Generally the latter procedure is employed as increasing the speed of the armature will increase the frequency whereas increasing the field strength makes no change in frequency.

4. **Direct Current Generator**—Since the current in a generator armature is always alternating it is necessary to employ a commutator to convert it into direct current. The function of the commutator is explained as follows: The coil in figure 47 is revolved in a uniform magnetic field producing an e.m.f. in the armature winding, as in the generation of alternating current. But if each end of the coil is connected to a half cylinder of metal on which rests a stationary brush $B+$ or $B-$, then as the loop is rotated the connection to the external circuit is reversed every half revolution, and the pulsations of current are always in the same direction. The brushes are adjusted so that contact is made

to the next metal segment when the current in the armature is zero and about to reverse.

In figure 47 the armature coil *A* — *B* is turning in the direction of the arrow and in the position shown the *A* side of the armature being under the North (+) side of the field magnet generates an e.m.f. in such a direction that the segment *D* has a positive polarity which makes contact with the positive brush *B* +. The current in the external circuit flows from the positive brush *B* + through the load back through the negative brush *B* — to the negative side of the armature coil. As the armature passes a quarter revolution the armature coil will be moving along the flux and not cutting it, so there will be no e.m.f. Each brush will be just in the act of passing from one segment to the other.

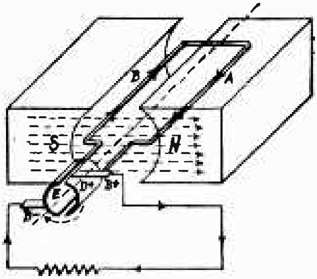


Fig. 47. Fundamental D.C. Generator.

After half a revolution of the *B* side of the armature coil, that *B* side of the armature coil that was under the South (—) pole of the field magnet is now under the North (+) pole and generates an e.m.f. which is opposite from its original direction but in the same direction as the *A* side when under this pole.

Thus the segment *E* is now positive polarity as it is making contact with the brush *B* + and the current again starts to flow from the brush *B* + through the load back to the brush *B* —. In the external circuit the current always flows in the same direction, though in the armature coil the current is alternating.

The voltage curve of such a generator is represented graphically in figure 48. Due to the variation in voltage such a current is said to be pulsating instead of alternating. The current is flowing in one direction all the time but is of an uneven value. In commercial generators enough armature coils are employed so as to

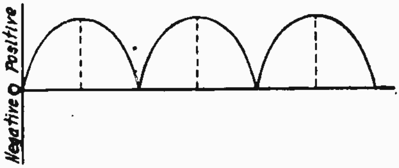


Fig. 48. Voltage Curve of Fundamental D.C. Generator.

deceive one into believing that a maximum e.m.f. is generated all the time. Each coil is connected to its own two segments and the coils are also so connected that the currents in each overlap so that the resultant current is of practically constant value. The commutator of such a machine consists of bars of copper, slightly wedge-shaped, separated by thin insulating sheets of mica, the whole assembled in the form of a cylinder held together by strong end clamp rings. The segments are insulated from the clamps by suitably shaped rings, usually of molded mica insulation. Connections leading to the armature conductors are soldered into slots in the segments, which commonly have lugs or "risers" for the purpose, extending upward at the end toward the armature.

Direct current generators on shipboard are usually driven by an upright steam engine coupled directly to the generator.

Excitation—An alternating current generator requires a source of direct current to excite the field windings. When the current for the field comes from an independent source the machine is said to be *separately excited.*

Direct current generators are so connected that excitation is secured from their own generated armature current.

5. Shunt Wound Generator—The circuit of a shunt wound generator is shown in figure 49, where the terminals of field wind-

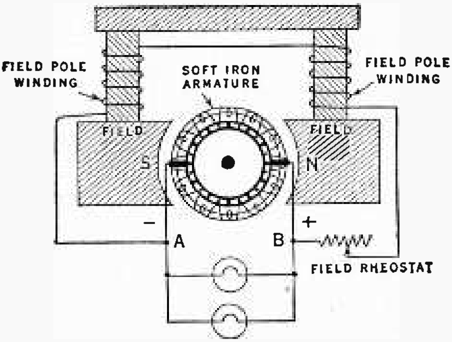


FIG. 49. Circuit of Shunt Wound Generator.

ings are connected across the armature terminals at points *A* and *B*. The shunt field poles are wound with many turns of fine insulated wire. The number of turns is governed by the magnetic flux required for the correct excitation of the machine. Only a small portion of the current generated by the machine flows through the high resistance shunt windings. (The strength of the current flowing through the field windings can be regulated by the resistance called the generator field rheostat.)

When the armature of this type of machine is first rotated it has to depend upon the residual magnetism of the field poles to generate its initial current. Residual magnetism as already explained is the magnetism resulting from the magnetic lines of force retained by soft iron after once being magnetized.

As the armature is rotated the residual lines of force cut the coils of the armature, generating therein a feeble current which flows through the shunt field windings, and increases the number of lines of force cutting the armature coils. This induces a stronger current in the armature conductors which continually adds to the strength of the field until the normal voltage of the generator is established. The complete process usually requires from 10 to 50 seconds. After the generator attains its normal speed, the voltage across its terminals may be raised or lowered by the generator field rheostat. Increasing the resistance of the field rheostat decreases the generator terminal voltage. Decreasing the resistance of the field rheostat allows more current to flow in the field windings and increases the generator terminal voltage.

6. Series Wound Generator—The field windings of a series wound generator are connected in series with the armature. All the current generated by the armature must pass through the field windings; therefore it is necessary to employ large wire in order to handle all the current without heating since the current is large. Thus the necessary ampere turns are secured by virtue of having a large number of amperes and comparatively few turns of wire. The current in passing through the field windings strengthens the weak field due to residual magnetism and the normal voltage of the generator is soon attained. Figure 50 shows the circuit of a series wound generator.

7. Compound Wound Generator—The field magnets of a compound wound generator are wound with two sets of coils, one set being connected in series with the armature and external circuit. The function of the series winding is to strengthen the magnetic field by the current taken through the external circuit, and thus automatically sustain the voltage under variations of a load. Figure 51 shows the circuit of a compound wound generator.

8. Voltage Characteristics of Shunt, Series and Compound Wound Generators—When shunt excitation is used, if the external load is increased, the potential difference at the armature terminals is reduced. The effect of the reduced terminal voltage is to reduce the current of the shunt field windings resulting in a weakened field. With an increased load the armature current increases as the shunt field current decreases; hence the terminal voltage falls off considerably.

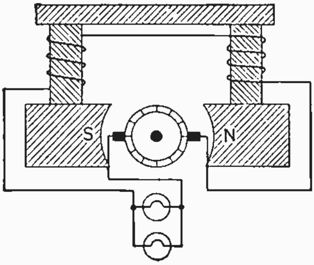


FIG. 50. Circuit of Series Wound Generator.

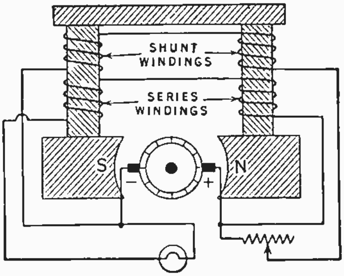


FIG. 51. Circuit of Compound Wound Generator.

With series excitation the condition is very different. When there is no load on the generator, only the weak residual magnetism of the iron pole pieces is available, and the terminal voltage is consequently very small. As the load increases larger values of current flow through the series field windings permitting a greater e.m.f. to be generated. The greater the current taken by the external circuit, the greater will be the voltage.

The compound wound generator gives a more constant voltage on circuits of varying load than is possible with a generator with either shunt or series windings. As the external load of a shunt generator is increased, the potential difference at the armature terminals will fall, but in the case of the compound wound generator, this fall of e.m.f. is counteracted by the series winding, the current which flows in it increasing with load and causing the terminal voltage to rise. The number of turns of each winding and the relative strength of current are proportioned so that a practically constant pressure is maintained under varying load.

Each type of generator has its special uses. For instance, the exciter for an a.c. generator of a radio set can be a shunt generator because the load does not change much. Incandescent lamps require a very steady voltage that is not changed when some of them are turned on or off. A compound generator meets this requirement.

9. **Regulation**—The relation of the voltage on no load to the

voltage on full load of a generator is called *regulation.* It is found by the formula:

$$\text{Regulation} = \left(\frac{V_0 - V_f}{V_f}\right) \times 100 \text{ percent.}$$

Where V_0 = voltage at no load,
V_f = voltage at full load.

A small percentage regulation means that the voltage remains very nearly constant when the load is charged. A high percentage means that the voltage drops considerably on load and the machine therefore has poor regulation. Example: Consider a spark transmitter whose a.c. alternator no load voltage is 300 volts. The key is closed and the voltage drops to 270 volts. Substituting in the above formula

$$\left(\frac{300 - 270}{270}\right) \times 100 = 11 \text{ percent approx.}$$

10. Failure of Generator Field to Build Up—If the initial current generated due to residual magnetism does not excite the field poles in the direction of the residual magnetism, the field will not build up and will be noted by a low or no voltage reading of a voltmeter connected across the output terminals of the generator. The following test will indicate if the magnetism of the field poles is opposite to that of the residual magnetism. Connect a voltmeter across the output terminals and note voltage with *field circuit open.* This reading may be only a volt or two and is the voltage generated due to residual magnetism. Close the field circuit and take another reading of the voltmeter. If the voltage has decreased the connections to the field circuit are wrong and they should be reversed. After reversing field, start generator up again and if the fields are correct the machine should build up to normal voltage. Failure to generate may be due to other causes such as dirty brushes, or commutator, loose connections or loss of residual magnetism. Residual magnetism can sometimes be restored by permitting the current from a battery or other generator to flow through the field circuit for a few hours.

11. Reversal of Polarity of Generator—It sometimes happens especially on ships' generators that while the auxiliary batteries are on charge the generator is stopped by an engineer on duty without first removing the load from the machine. Unless the charging circuit is protected by circuit breakers the battery will start to discharge through the generator resulting in a reversal of the residual magnetism. When the machine is again started the reversed residual magnetism reverses the polarity of the generator brushes, thus reversing the direction of the field current and making it agree with the new direction of the residual magnetism. This will allow the generator to build up, but the polarity will be reversed. The residual magnetism can be again reversed so that the generator will have its normal polarity by sending a current from another generator or a battery through the field in the proper direction. This is accomplished by connecting the positive terminal of the battery to what is now the new positive terminal of the generator and the negative of the battery to the negative of the generator. The brushes should be lifted or removed during this operation. A battery of 6 to 12 volts will sometimes accomplish the correct result. If the reversal does not take place immediately upon first test the battery should remain connected to the fields for an hour or two.

12. **Ground Indicators**—Ground indicators in the form of two lamps in series with the midpoint grounded are sometimes installed on switchboards. Figure 52 shows the connections of such indicators. Normally the two lamps in series will light dimly. Should a ground occur on either leg of the circuit one of the lamps would light to full incandescency. For instance, assume the positive leg of the circuit in figure to become grounded; this will short circuit lamp number 2, and lamp number 1 would then be directly connected across the generator terminals and would be lighted to normal brilliancy.

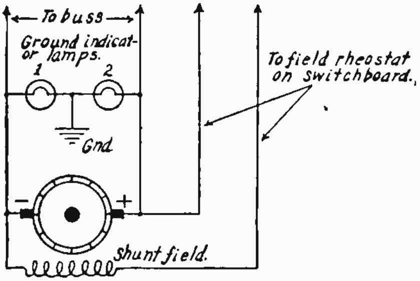


Fig. 52. Circuit of Ground Indicator on D.C. Generator.

13. **Electric Motors**—There is no essential difference between a motor and a generator. The structure of both is identical but the function is reversed. The motor converts electrical power

into mechanical power. Direct current motors are of three types, shunt, series and compound, so called from their winding characteristics. Motors operating from alternating current are of two types, the induction and the synchronous motor. There are special combination motors operating from either d.c. or a.c. This type is known as a universal motor. They are seldom employed in conjunction with radio and for that reason will not be treated here.

14. **D.C. Shunt Motor**—The fundamental operating principle of a motor is as follows: When a current is flowing through a conductor in a magnetic field there is a force that tends to push the conductor across the field. The conductor will move in a direction at right angles both to the direction of the field and to the direction of the current. For example: If the plane of a coil lying between the poles of a magnet is parallel to a magnetic field, and a current is passed through the coil, it will tend to turn or take up a position at a right angle to the magnetic field. If the current is reversed when it has reached this position, the coil will continue to revolve.

The action of the motor can be explained by the diagram in figure 53. The current flowing through the armature windings from the battery *B* is in such a direction that the lower half of the armature coils is magnetized and has a South pole and the upper half a North pole. The upper half will then be attracted by the South field pole and repelled by the North field pole. The lower half will be attracted by the North field pole and repelled by the South field pole.

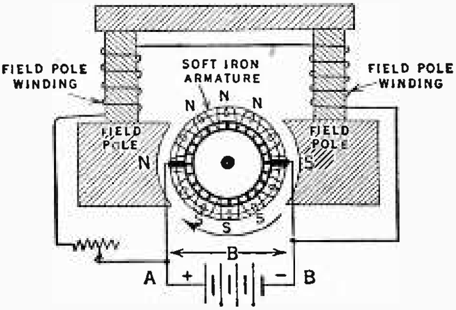


FIG. 53. Circuit of D.C. Shunt Motor.

The action will be continuous, because, as the top of the armature moves toward the South field, the commutator acts to maintain the flow of current in the same direction as before, consequently the upper half of the armature is always a North pole and the bottom a South pole. Thus the armature is made to revolve when supplied with current.

Compare the circuits of the shunt wound generator in figure 49 and shunt wound motor in figure 53. They are fundamentally the same. If the shunt wound generator was charging batteries and the engine was shut off, the generator would continue running providing the battery circuit was large enough and had no circuit breakers. The ammeter in such circuit would show a current in the opposite direction. The battery is discharging and operating the generator as a motor exactly as described in the previous paragraph.

15. **Direction of Rotation**—If the connections from the battery were reversed at points *A* and *B* in figure 53, it would have no effect on the direction of rotation. The armature would still continue to rotate in the direction of the arrow. Reversing the connections from the battery would reverse the polarity of the flux in both the armature and the field poles. The North field pole would become a South field pole and South field pole would become a North field pole. Likewise the armature South pole would become a North pole and the South pole of the armature a North pole. The same power of attraction and repulsion between like and unlike poles would result with no change in direction of rotation. In order to change the direction of rotation the *flow of current must be changed in either the armature or field coils, but not in both.* For example: In figure 53 reverse the field poles only. The North pole is now a South pole and the South pole a North pole. The direction of armature current has not been changed, therefore the upper half is still a North pole and lower half a South pole. The North pole of the armature being attracted by the new South pole, rotation begins opposite to the arrow or counter clockwise, where before, as shown by the arrow, the direction of rotation was clockwise. The same thing would have happened if the armature windings had been reversed instead of the field windings. The general practice is to reverse the current in the armature, rather than in the fields.

16. **Counter Electromotive Force**—As soon as the armature of a motor starts to rotate, an e.m.f. is induced in the armature windings of such polarity as to oppose the e.m.f. that started the motion. The back pressure or voltage is known as counter electromotive force and governs the speed of a motor. The value of counter e.m.f. is proportional to the speed of the armature, the

number of armature wires and strength of the magnetic field. The faster the armature turns the greater the counter e.m.f. becomes. It cannot turn so fast that the counter e.m.f. is as great as the line voltage, because then the two would balance: there would be nothing to make the current flow through the armature, and consequently no pull to keep it turning. If the motor is placed on a load the speed falls off and consequently the value of the counter e.m.f. falls off. The current in the armature is increased as the back e.m.f. falls off and the motor automatically regains speed of sufficient value to drive the load.

The field magnets are always of the same strength, regardless of the load, because the current around them depends only on the line voltage and the resistance of the field coils. It is entirely independent of the current in the armature.

Thus the speed of a motor supplied with direct current at constant voltage varies directly with the counter electromotive force and in any given machine the stronger the field, the slower will be the speed of the armature. The strength of the field can be regulated externally by a variable resistance in series with the field windings. This variable resistance is called a motor field rheostat. If the resistance of the field rheostat is *decreased* more current flows through the field windings, thus increasing the field strength, consequently the *speed of the motor is reduced.* If the resistance of the motor field rheostat is *increased* the magnetic field is weakened resulting in an *increased speed of the motor* up to a *certain point,* or until the increased speed of the armature increases the counter e.m.f. to such an extent as to cut down the armature current. If the motor field rheostat accidently burns out or should any open circuit occur in the shunt field the armature will develop terrific speed. The centrifugal force becomes great enough to burst the windings of the armature, therefore requiring expensive repairs to the machine. If upon starting such a motor the circuit breakers trip, fuses blow or excessive current taken by the motor is noted, the machine should be stopped at once and investigation made to determine if the field circuit is properly connected and not open.

From the above it can be seen that the advantage of a shunt wound motor is that it is self regulating and maintains a fairly constant speed under varying load.

17. **Starting Resistance**—The resistance of a motor armature is small. If the line voltage was applied directly to the armature terminals excessive current would flow which might injure the commutator or burn out the armature windings. The counter

e.m.f. developed by rotation is what keeps the armature current from becoming excessive. When the motor is first connected to the line it is not rotating and there is no counter e.m.f. Some other way must be found to limit the amount of armature current until the machine can attain sufficient speed to generate the required amount of counter e.m.f. This is accomplished by connecting a variable resistance in series with the armature and gradually reducing it as the motor gains speed. A device whereby the resistance is regulated is called a starter. A diagram of a shunt wound motor with hand starter or starting box is shown in figure 54.

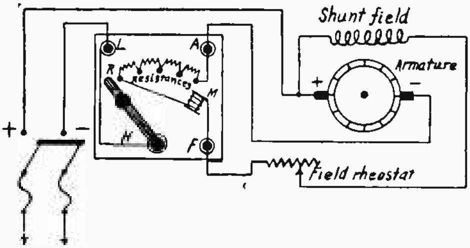


FIG. 54. Cutler-Hammer Hand Starting Box Connected to Shunt Wound Motor.

The action of a typical hand starter is as follows: As the handle *H* makes contact with the stud on the first resistance *R*, the armature circuit is completed with all the starting resistance in series, thus limiting the armature current, and the motor starts slowly. The motor field circuit is completed through the windings of the magnet *M* and the motor field rheostat. As the handle moves toward the full running position, the motor gains speed, likewise the value of counter e.m.f. is increased. When in full running position with all the resistance of the starting box cut out, the motor is generating a counter e.m.f. of such value as to permit the full line voltage to be applied directly to the terminals of the armature. No change has been made in the strength of the field magnets by the operation of the starter. The holding magnet *M* holds the handle in the full running position unless demagnetized by interruption of the d.c. supply or an open in the field circuit. Should the d.c. line be interrupted the handle flies back to the off position requiring the motor to be started in the normal manner. Should the handle fail to fall back excessive armature current would flow when the line voltage is restored, resulting in damage to the machine as explained previously. Should the field circuit develop an open circuit the magnet is again demagnetized, thus releasing the starting handle and preventing the motor from attaining an excessive speed.

If a motor is started too slowly the starting resistances will overheat and burn out. If started too rapidly the fuses in the d.c. line will melt, or excessive armature current will flow, tripping the circuit breakers. It should require about 15 seconds to start motors used in connection with radio transmitting apparatus.

18. Automatic Motor Starters—It is often desirable to install the motor generator of a radio transmitting set at a point remote from the radio room in order that the noise from its operation will

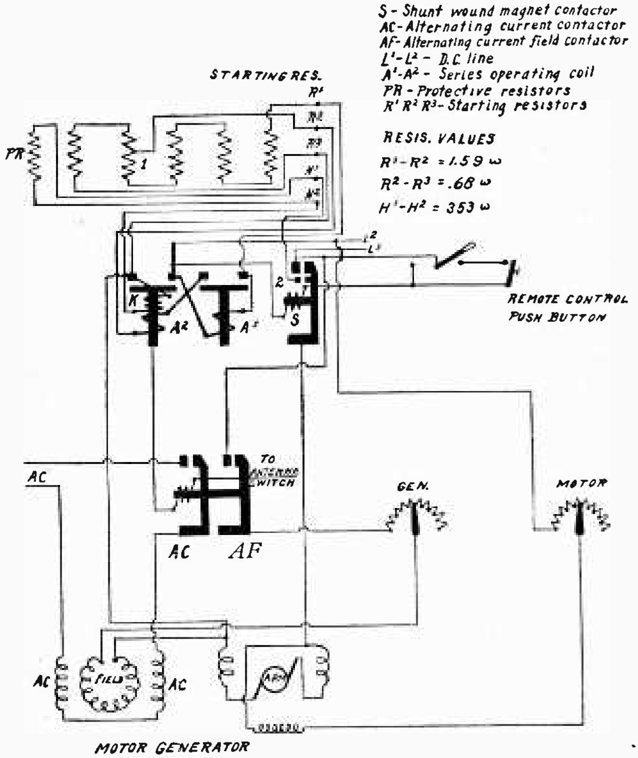


FIG. 55. Circuit of the Electric Controller and Mfg. Co. 2 KW. 120-Volt Automatic Starter.

not interfere with the reception of radio signals. In instances of this kind automatic starters are employed, which are controlled from a distant point by pressing a small button or closing a small switch. The automatic starter solenoid and resistances sometimes are a part of the transmitter panel in the operating room and controlled by a start-stop switch mounted close to the antenna send-receive switch on the operating table. The motor generator is usually mounted in an iron box over the top of the engine room and accessible to the operator for care and maintenance.

The complete circuit of one type of the automatic starter of The Electric Controller and Manufacturing Company is shown in figure 55. This type of starter has been used extensively in connection with Navy Standard 2 K.W. spark transmitters, as installed on vessels of the United States merchant marine.

This push button automatic starter consists of: One type S counter-weighted shunt wound magnetic contactor for closing the main circuit; two type A series wound magnetic contactors for short circuiting the starting resistor; 1 resistor box; and 2 terminals used in wiring the apparatus.

The shunt wound contactor is of standard form, having a shunt wound coil which stands full line voltage continuously without protection and which when energized moves the main contact arm on to stationary contact, thus making circuit to the motor. The contactor has a magnetic blowout to aid in rupturing the arc when opening the circuit. The main arm of the contactor is provided with an auxiliary control circuit contact to make and break the circuit for the shunt holding coil of the last accelerating contactor. The main arm is also counter-weighted to prevent closure of the arm when the contactor is moved out of vertical position.

The series contactors are of the vertical plunger type and are so constructed that an excess of current through the series operating coil will not lift the plunger, in fact will keep the plunger in the open position until the current value has been reduced to such a value that will lift the plunger and contact disk into contact with the contact brushes, thus short circuiting out part of the starting resistance.

19. The Construction of this series contactor is shown in figure 56, in which *A* is the operating coil, connected in series with the motor; *B* is the cast iron case, making the magnetic circuit; *C* is the plunger carrying the contact disk, *D,* at the top, which in the closed position makes contact with the contact brushes *E; F* is the adjusting plug; *G* is the operating air gap; *H* is the lock-out air gap; and *I* is the shunt holding coil.

20. Operation of Series Magnetic Contactor—If current of a higher value than the operating value of the contactor is caused to flow through the series operating coil *A*, an upward pull is exerted on the plunger *C*, due to the flux in the operating air gap *G*, but there is also a downward pull on the plunger due to the flux through the lock-out air gap *H*. This flux in air gap *H* is due to the fact that the steel stem extension on the lower part of the plunger *C* is over-saturated by the flux through air gap *G*. As the current is reduced the flux through air gaps *G* and *H* is reduced until the steel stem of plunger *C* can carry practically all of the flux in air gap *G*; at which time the downward pull at air gap *H* is greatly reduced and the upward pull at air gap *G* is sufficient to overcome the downward pull and the weight of the plunger, thus pulling the

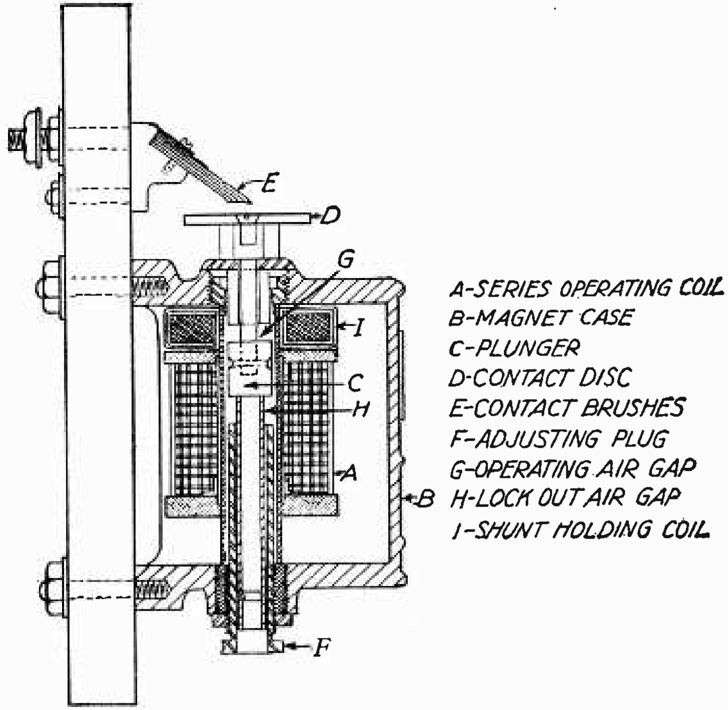


FIG. 56. Type A Series Magnetic Contactor Employed with Automatic Starter.

plunger to its closed position with contact *D* against the contact brushes *E*.

The value of current at which the plunger lifts can be increased by increasing the length of air gap *H*. This is done by screwing the adjusting plug *F* farther out of the case. Or the plunger can be made to lift at a lower value of current by screwing the adjusting plug farther into the case, thus decreasing the air gap *H*.

An increase of current through the series coil after the plunger has lifted only tends to hold the plunger more firmly in the closed position. A reduction of the current through the series coil to about 15 percent of the normal value, or an interruption of the current, will cause the plunger to drop to the open position.

A shunt holding coil *K*, figure 55, is provided on the last accelerating contactor of each starter. This coil is connected in series with a protecting resistor unit *PR*, and they receive full line voltage upon closure of the contactors. At the same instant the series coil is shorted out of circuit and the shunt coil will hold the contactor closed until its circuit is opened.

The resistor box contains the resistor units used for accelerating and the protective resistor unit for the shunt holding coil. The box is of sheet steel with asbestos board cover carrying necessary terminals.

The wiring diagram in figure 55 shows that when the remote control push button is closed the circuit is completed through the shunt wound magnetic contactor *S*, which moves the contactor arm establishing the circuit through the starting resistors R_1, R_2 and R_3, and the operating coil *A*, of the first series contactor. As soon as the current has dropped to a predetermined value this contactor closes, short circuiting the first step of the resistance at point 1 and closing the circuit of coil A_2 of the last accelerating contactor. When the current has again dropped to the proper value this contactor closes, shorting out all of the starting resistance and both series operating coils. The first accelerating contactor drops open but the last accelerating contactor is held closed by the shunt holding coil *K*, which is connected across the armature upon closure of the shunt contactor at point 2 and receives full line voltage upon closure of the last accelerating contactor. The motor continues to run until the shunt contactor is opened by de-energizing its coil. Opening the shunt contactor also opens the circuit to the shunt holding coil of the last accelerating contactor which opens.

The starter is adjusted to accelerate a direct current motor in the shortest possible time and yet keep the current peaks down to

50 percent over normal full load. If the motor is lightly loaded the time of acceleration may be very short, the accelerating contactor closing almost immediately after closure of the main contactor, but if the motor is heavily loaded, several seconds may elapse between closure of the series contactor.

With certain adjustments on the accelerating contactors it might be possible that these contactors will refuse to close if the circuit to the motor has been opened when the motor was running at maximum speed and immediately closed again, thus allowing the motor to continue to run with the starting resistance in circuit. If this is the case, the accelerating contactors will close immediately when the load is thrown on the motor by closing the alternating current circuit.

21. D.C. Series Motor—The field coils of a motor may be wound with thick wire and connected in series with the armature, so that the same current flows through both. It is then called a series motor.

The operating characteristics of a series motor are considerably different from those of a shunt motor. They do not run at a very constant speed, but run very much more slowly when heavily loaded. At the lower speeds they develop a large torque. They are used to advantage on street cars where high turning effort is wanted for starting a load. They are of no use in radio where a constant speed motor is required.

22. Motor with Differential Field Winding—It has been explained how the speed of a motor is increased or decreased by variation of magnetic field and any reduction of the field flux of a given machine will increase the speed of the motor. By the use of a differential field winding, as the external load is increased, the strength of the shunt field is decreased, resulting in restoring the machine to its normal speed. The manner in which this is accomplished is shown in figure 57, where the field winding of the motor is two distinct sets of coils. One is the normal shunt winding connected across the input terminals of the machine and the other a series winding connected in series with armature. The windings of the series coils are so arranged that any flux produced by the series windings is opposite in polarity to that of the shunt winding. A suddenly applied load will tend to slow the armature down, resulting in a reduction of the counter e.m.f., and an increased armature current will flow.

The increased armature current flowing through the series coil produces a magnetic flux opposite to that produced by the shunt field resulting in a differential and therefore weaker field which restores the motor to normal speed.

A field rheostat is connected in series with the shunt field of a differential field winding for variations of speed control.

By the use of a differential field winding, motors may be designed to give very close speed regulation and are, therefore, very desirable to drive a.c. generators for radio telegraphy.

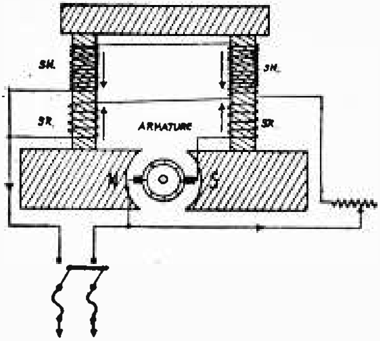


FIG. 57. Motor with Differential Field Winding.

23. Alternating Current Induction Motor—It has been explained how a current flowing through a coil produces a magnetic field. If a set of coils is arranged in the form of a two-phase or three-phase field and connected to an alternating current having two or more phases, it will be noticed that a compass needle placed within the field will start to spin around and will continue to do so as long as the coils are energized. The effect is as if the needle of the compass were under the magnetic influence of a magnet with its poles sliding along the face of the field.

The action of an induction motor can be explained by comparing it to a transformer in which the stator is the primary and the rotor is the secondary. Both have poles and these tend to repel each other. Because the stator field revolves it drives the rotor before it at a speed which is almost the same as the rotating field at no load but which is reduced by any load applied to the motor shaft, or any resistance put into the secondary (rotor circuit).

Speed Control—The speed of the rotor of an induction motor depends upon the construction of the stator and the frequency of the alternating current. In the simplest form there is no connection between rotor and external circuit. However, some types of induction motors have the rotor fitted with slip-rings to provide connection to an external resistance which controls the speed of the machine. This is usually accomplished by providing the rotor with a three-phase Y-connected winding and connecting a variable resistance, in series with each phase, as shown in figure 58. By means of the three-pronged arm, the resistance in series with each phase of the rotor winding can be varied from the full amount to zero, thus varying the speed from minimum to full speed.

The terms "squirrel cage rotor" and "wound rotor" are often used to describe rotors; the first means the simple kind with conductors of plain bars of metal and no slip-rings or other moving contacts, the second means the kind having coils like an armature and fitted with slip-rings.

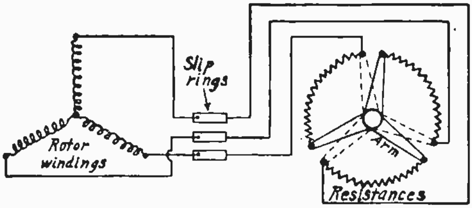


Fig. 58. Speed Control Connections of Three-Phase Induction Motor.

An induction motor cannot be started on single-phase current but will operate on the same if started somehow. One way of starting an induction motor is by the use of a "phase splitter." The armature has two sets of coils, one having more inductance than the other. Due to difference in reactance of the two coils the currents flowing in the two are not in phase. The motor starts then as a sort of two-phase machine. After it gets up to speed the starting winding is disconnected either by a two-way switch having a starting and running position or by an automatic centrifugal cut-out in the motor.

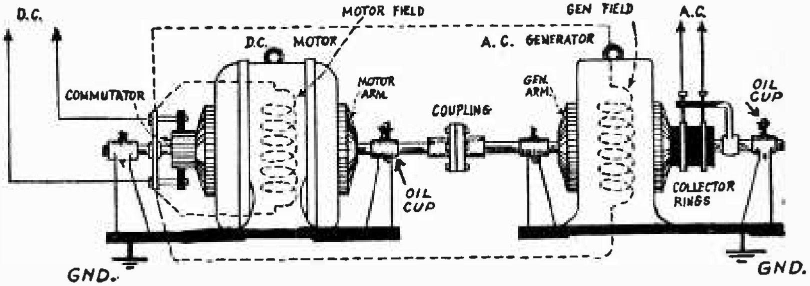


Fig. 59. General Construction of Motor Generator.

24. Motor-Generators—Direct current is the only available power supply on practically all ships. In order to operate the power transformer of a spark transmitter it generally is necessary to use an alternating current. Arc and tube transmitters require direct current voltages considerably higher than those provided by the ship's dynamo. When electric current is to be had, but not in the form needed, the change can be made easily by a motor-generator. This combination, as usually employed on shipboard, consists of a direct current motor and an alternating current generator coupled together on a common iron base. In the case of the arc or vacuum tube transmitter the combination may consist of a direct current motor and a direct current generator which provides d.c. voltages considerably higher than that available from the ship's dynamo. In broadcasting stations the combination may be an a.c. motor coupled to a d.c. generator. Such machines usually have four bearings, two for the motor armature and two for the generator armature. In the case of a shipboard installation the field of the generator is excited from the direct current of the ship's dynamo. Field excitation is controlled by a generator field rheostat. Figure 59 shows the general construction of a motor generator. Motors and generators have been described. Each unit can be thought of by itself, without regard to the other. Some automatic starters employed in connection with motor generators have the wiring so arranged that the field of the alternator is not closed until the motor is in fully running position. This prevents the operator from putting

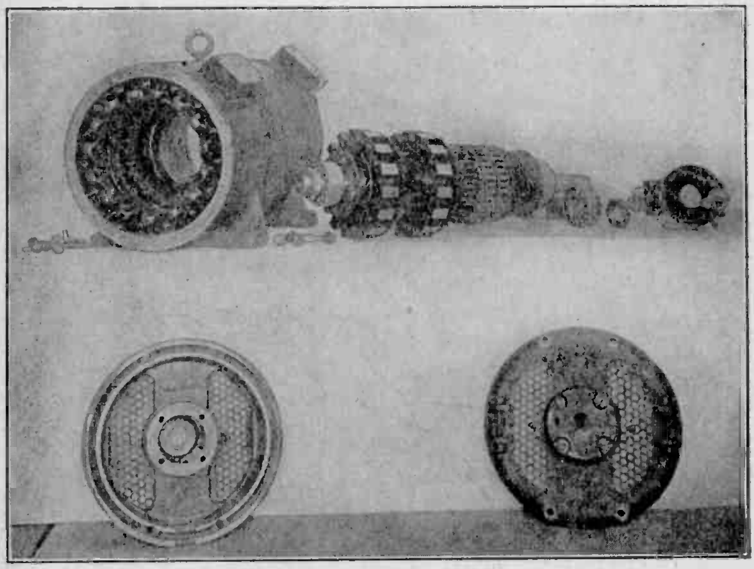


FIG. 60. Exploded View of Crocker-Wheeler 2 KW. Motor Generator with Inductor Type of Alternator.

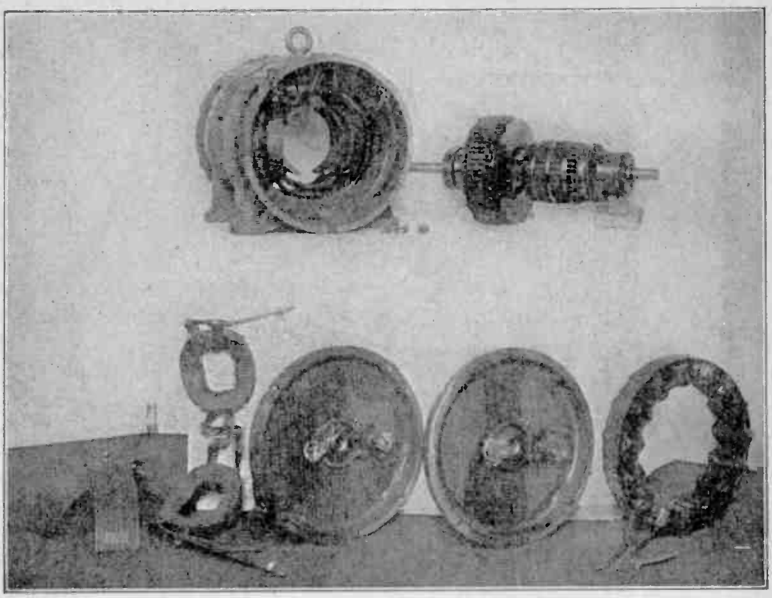


Fig. 61. Exploded View of Crocker-Wheeler 2 KW. Motor Generator with Alternator of "Wound Type."

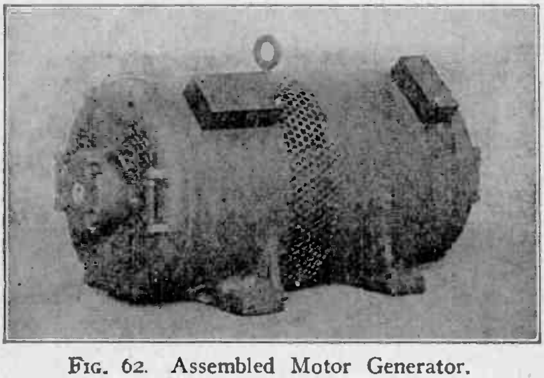


Fig. 62. Assembled Motor Generator.

a load on the machine until the motor gets up to normal speed. Various types of motor generators and their application to a particular transmitter will be described in the succeeding chapters.

25. Rotary Converters—If connections are made to a pair of collector rings from opposite sides of a two-pole d.c. armature, one can take off an alternating current. Since this armature is now able to supply either a.c. or d.c. from the same winding one naturally suspects that it might be possible to *feed in* a.c. at one end and take off d.c. at the other. This is actually possible and such a machine is called a "rotary converter."

The rotary converter shown in figure 63 has a single winding on one armature for both alternating and direct current. Direct current from an external source enters the armature *A* through the brushes *B*1 and *B*2 and also flows through the shunt field *SF*, causing the armature to revolve in the usual way. Taps are taken off the commutator segments directly underneath the brushes and are connected to collector rings *CR* on the opposite ends of the shaft, the circuit continuing through the primary of an a.c. transformer *T*. The voltage of the alternating current will be a maximum when taps to the collector rings are underneath the brushes and minimum when midway between the brushes. As the armature revolves the current taken from the collector rings will flow in the opposite direction and therefore, as the armature revolves, an alternating current can be taken from the armature, the frequency of which varies with the speed. The a.c. voltage of the converter is increased by increasing the speed of the armature, but the frequency of the current increases simultaneously. When such a machine is run as a direct current motor and used to supply alternating current it is spoken of as an "inverted rotary converter."

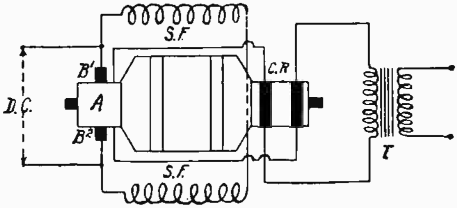


FIG. 63. Fundamental Circuit of Rotary Converter.

26. Dynamotor—A dynamotor is employed to change direct current at one voltage to direct current at another voltage. This is very convenient on small yachts and pleasure craft where from a small battery of low voltage a high voltage from 300 to 1000 volts can be produced to supply the plates of a vacuum tube transmitter. The dynamotor has two separate armature windings placed on a common rotor core. One acts as a motor, the other as a generator. There is but one frame and one set of field magnets. The two windings are connected to commutators at opposite ends of the shaft. The ratio of voltage is fixed when the machine is built, so the output voltage depends on the voltage applied. The field coils receive current from the same source as the motor armature. Fig-

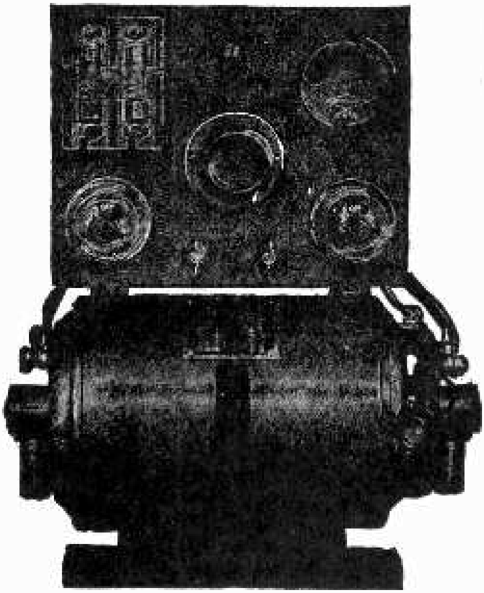


FIG. 64. Esco Dynamotor and Switchboard.

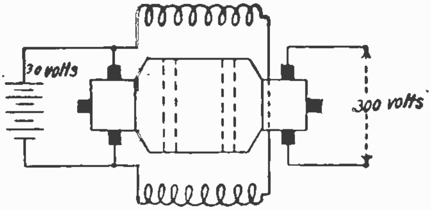


FIG. 64*a*. Fundamental Circuit of Dynamotor.

ure 64 shows the picture of such a machine and figure 64*a* the fundamental circuit.

27. **Protective Devices**—Some means must be provided in a radio transmitter to prevent the radio frequency currents from flowing back into the power leads and thence into the motor and generator windings resulting in damage to the same.

The low voltage wires are usually run in metal conduit and the conduit connected to earth. In some installations lead-covered wires are provided and the lead sheathing of all wires is tied together and then grounded. The high frequency currents are induced in the surface of the conduit or lead-covering and are effectively grounded and thus no harm results to the power machinery.

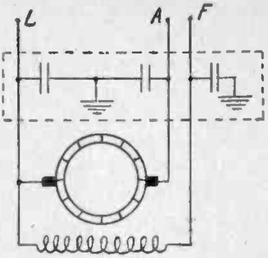


FIG. 65. Protective Condensers Connected across Motor Terminals.

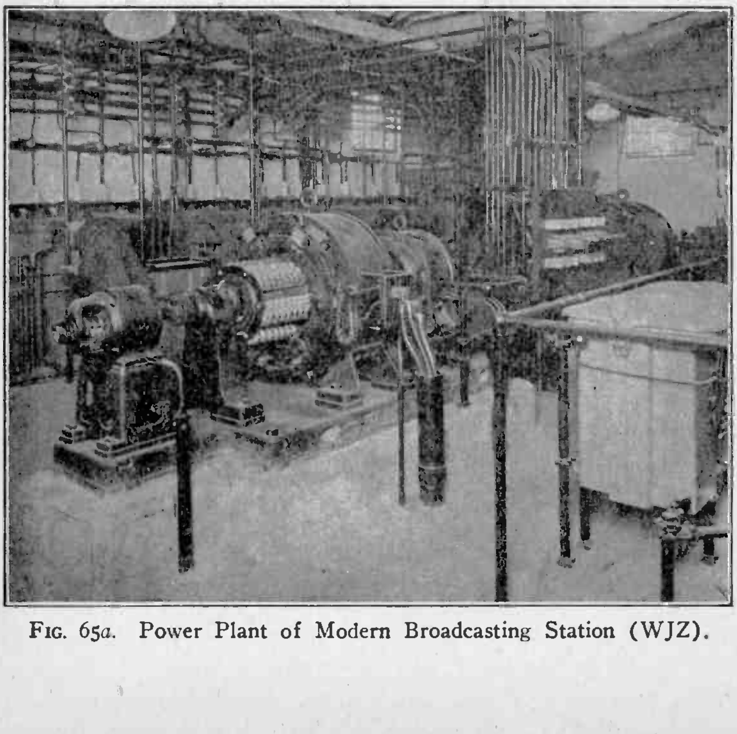


FIG. 65*a*. Power Plant of Modern Broadcasting Station (WJZ).

Protective devices are also used to protect the power machinery in the form of two condensers in series and connected across the power leads with the mid tap of the condensers grounded.

The high capacity condensers offer a path of low impedance to the induced radio frequency currents and they are thus conducted to ground.

These condensers are usually of 1/2 or 1 μ fd. capacity each and are connected in the following circuits:

(1) In shunt to motor armature.
(2) In shunt to motor field windings.
(3) In shunt to generator armature.
(4) In shunt to generator field windings.
(5) In shunt to d.c. feeders entering radio room.

Protective condensers of a motor generator are usually made up as a unit and mounted directly on the frame of the machine. Each terminal of the machine is connected to a condenser and the other terminal of the condenser is connected to the frame of the machine which is grounded by a lead connected to the transmitter ground.

In the succeeding chapters the care necessary for each particular machine supplied with the radio transmitting apparatus is taken up in detail and for that reason the general care and maintenance of motor generators will not be taken up in this chapter.

CHAPTER 3

STORAGE BATTERIES AND CHARGING CIRCUITS

1. Use of Storage Batteries—Storage batteries will be found in practically every ship and aircraft radio installation. On shipboard they are used as an emergency source of power to operate the radio transmitter and receiver, to start gasoline and oil driven emergency generators, routine operation of radio receivers, direction finders and auto-alarm devices, and radio equipped lifeboats. On aircraft installations they are employed to operate dynamotors and to supply power to the filaments of receiving tubes. Therefore, it is essential that the professional operator be thoroughly familiar with the construction, chemical action, operation and maintenance of both the lead acid and alkaline types used in such installations.

The material in this chapter will be found helpful both for study and as a reference on the subject of storage batteries, charging circuits and apparatus.

2. Storage Batteries—Under the heading of Elementary Electricity we have seen how the primary battery created a difference of potential by immersing two dissimilar metals in an acid or alkaline solution. The difference of potential caused a current to flow in a completed metallic circuit. Such a battery will furnish current until all the chemical action possible has taken place. The battery has then become "dead." To produce another flow of current it is necessary to obtain new plates and new electrolyte.

In a secondary or storage battery, neither the plates nor the electrolyte need be renewed. The storage battery differs from the primary battery in that when it has given out all the energy which the chemicals enable it to supply, instead of requiring new elements, the cell can be completely regenerated or brought back to the original condition by passing a current into it in a direction opposite to that in which the flow took place on discharge. The charging current simply reverses the chemical action and restores the plates to the same composition as before the discharge.

A storage battery does not act as a storage place for electricity as its name implies, but the chemical action that takes place when the battery is charged changes the composition of the active materials of the plates so that when they are connected together by a conductor, sufficient difference of potential exists to cause a current to flow. The current flow, or discharge of the battery, reverses the chemical action that took place when the battery was charged until finally the character of the plates is such that no difference of potential exists and the battery is discharged.

3. **The Edison Cell**—The Edison storage battery differs in electrical characteristics, chemical action and mechanical construction from any other battery.

4. **Electrolyte**—The potash electrolyte is composed of pure distilled water combined with a 21 percent solution of *potassium hydrate* mixed with a small portion of *lithium hydrate.* It has a specific gravity of approximately 1.200 at 60 degrees F. after being thoroughly mixed by charging. This reading should be taken one hour after discontinuance of charge to allow for dissipation of gases.

The specific gravity of the cells changes but little with charge and discharge and therefore is of no value in determining the charged or discharged condition of the cell. However, throughout the useful life of the cell the electrolyte gradually weakens and for this reason specific gravity readings are of value to determine when a renewal of solution is necessary. The low limit of specific gravity is 1.160 and is usually accompanied by a temporary loss of capacity and sluggishness.

5. **Plate Construction**—The *positive plate* is made up of many perforated steel tubes into which has been packed, under heavy pressure, alternate layers of nickel hydrate, the positive active material and nickel flake. Each tube is reinforced by eight seamless steel rings. The *negative plate* is composed of a steel grid supporting many perforated nickel-plated steel pockets. Iron oxide, the negative active material, is loaded into these pockets, which in turn are secured to the grids by means of hydraulic pressure of 120 tons.

6. **Chemical Action**—The fundamental principle of the Edison storage battery is the oxidation and reduction of metals in an electrolyte which neither combines with nor dissolves either the metals or their oxides. Although the electrolyte is decomposed by charge and discharge, it is reformed again in equal quantities and therefore its density and conductivity remain the same over a long period of time. The active materials of the plates are insoluble in the electrolyte, therefore, no chemical decomposition takes place therein.

The chemical reactions in charging are (1) the oxidation from a

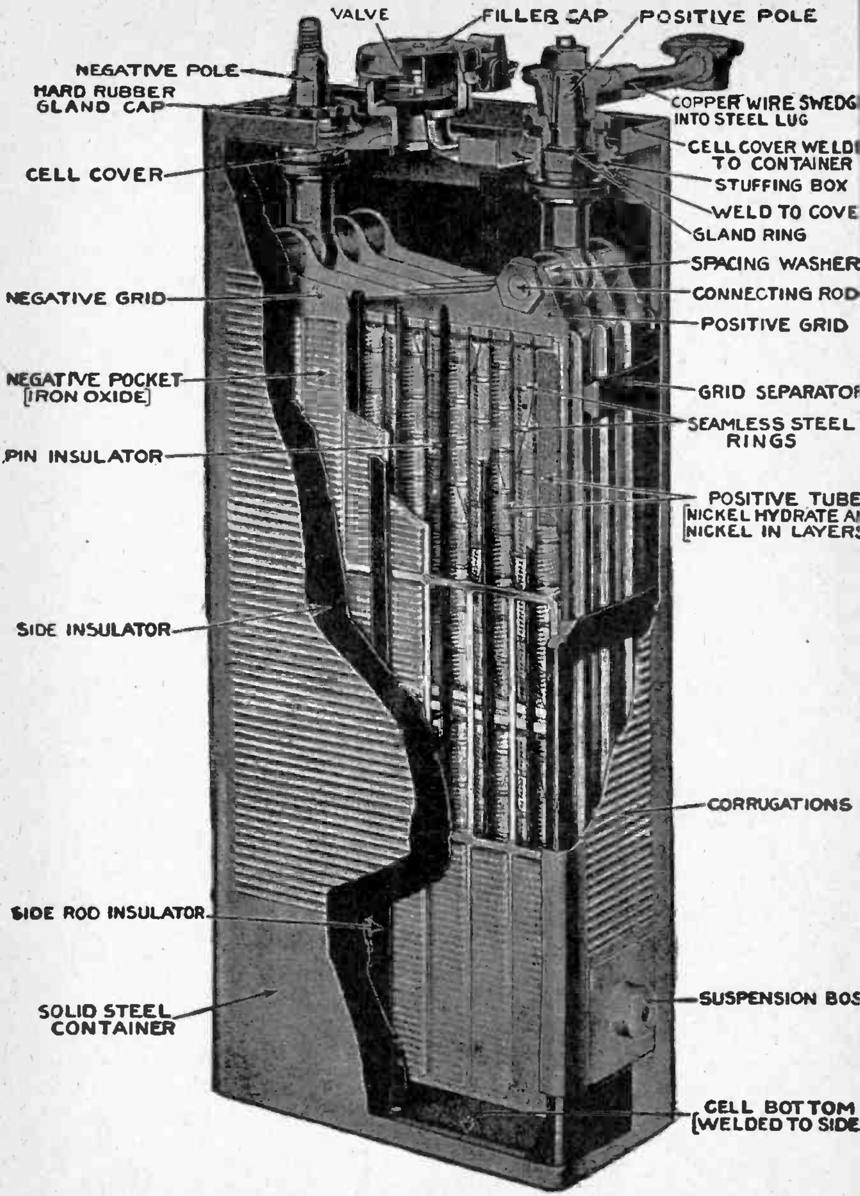


Fig. 66. Sectional View of Edison Storage Battery.

lower to a higher oxide of nickel in the positive plate and (2) the reduction from iron oxide to metallic iron in the negative plate. The oxidation and reduction are performed by the oxygen and hydrogen set free at the respective poles by the electrolytic decomposition of water during the charge.

The discharge of the cell is simply the reversal of the above reactions, the hydrogen reducing the higher oxide of nickel to a lower oxide, and the oxygen oxidizing the iron to iron oxide.

7. **Container**—The container is made of high grade steel which is oxy-acetylene welded. Each battery consists of two or more cells connected together by nickel-plated copper connectors fitted with a tapered steel lug which fits the terminal post of each cell. Each lug is held in place by a hexagonal nut. Each cell fits into a specially constructed wooden tray so arranged that the containers which are conductors will not short-circuit the battery.

The Polarity of the Positive Terminal of an Edison battery is designated by a red bushing and a plus sign (+), stamped on top of the container. The negative terminal is indicated by a black bushing with no sign on the container.

A *filler cap* of special construction is provided in the center of the cell to enable watering and to allow for the escape of gas. It is of such construction that the cell can be tipped to an angle of 45 degrees without spilling the electrolyte.

8. **Voltage**—The fully charged voltage of an Edison cell when discharging at the 5-hour rate is approximately 1.4 volts per cell.

The average discharge voltage at the 5-hour rate is 1.2 volts per cell.

The discharged voltage at the 5-hour rate is 1.0 volt per cell.

9. **Installation**—The Edison battery may be installed in any part of the vessel; however, in most marine installations the battery is located either in a special room adjoining the radio operating room or in a well-ventilated box placed on the boat deck. In several installations the battery has been placed in one corner of the operating room and carefully housed in with screens for ventilation.

The Edison battery requires no lead-lined compartment and gives off no noxious fumes during charge. A dry location is preferable; if too warm, excessive evaporation of electrolyte may result. The battery box need not be lined but should be absolutely water proof to prevent salt spray and other impurities from striking the cells.

Edison batteries are generally shipped fully charged. This is indicated by a red label accompanying the battery and indicates they are ready for immediate use.

A green label indicates that the cells are not charged and that they require an overcharge at the normal rate before being placed in service.

10. **Height of Solution**—Upon receipt of the battery the height of the solution should be tested by use of the glass tube shipped for that purpose.

One half inch is the proper height of the solution above the top of the plates for all types of Edison batteries in marine use except the high type cells. The proper height of the solution in the high type cells is 3 inches above the top of the plates for the A type and 2 1/4 inches for the B type.

11. **Testing Height of Solution**—Insert tube until the tops of the plates are touched, close the upper end with the finger and withdraw the tube. The height of the liquid in the tube indicates the height of the solution above the top of the plates.

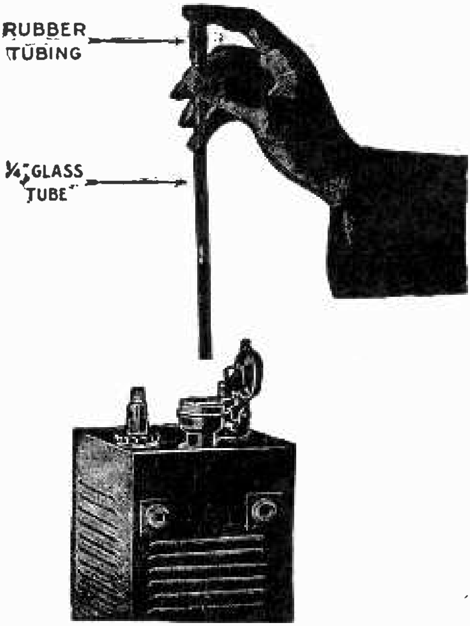


Fig. 67. Testing Height of Solution.

A glass tube reasonably walled, about 8 inches long and not less than 3/16 inch inside diameter with ends cut straight and smooth, may be used for this test in event none is supplied. A short length of rubber tube forced over one end and projecting about 1/8 inch will prove a good finger grip.

12. **Refilling Battery**—If the plates are visible above the top of the solution or if the packing case or surrounding materials show a rusty stain, it is an indication of spilled electrolyte and thus loss must be replaced preferably with Edison storage battery "Standard Refill Solution" or lacking this, with "Standard Renewal Solution." Lacking either of these, pure distilled water should be added until the solution is brought to the proper height.

When the level of the solution is only a small amount below the proper height, fill with pure distilled water.

13. **Maintenance of Edison Battery**—The Edison battery requires a minimum of attention; however, by observing a few simple precautions the operator can be assured of maximum capacity from the battery in time of emergency or disaster.

1. To charge, the positive of the charging source should be connected to the positive terminal of the battery. No great damage will result to an Edison battery if it is left discharged or if charging polarity is reversed, except to temporarily reduce the capacity of the battery.

2. If battery is in compartment or box, open cover of same before charging.

3. Make sure solution is at the proper level.

4. The correct charging voltage should be 1.85 times the number of cells in series.

5. It is well to remember that a marine battery of 90 or more cells is broken up into parallel banks of 45 cells or more for charging. This is accomplished by a 3- or 4-pole double throw switch on the charging panel.

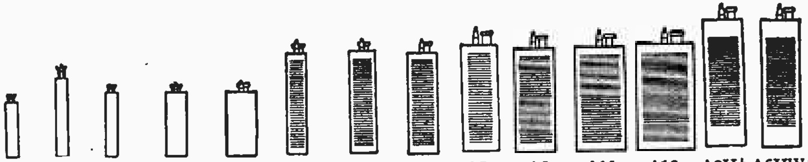
Do not exceed charging rate as specified under electrical data, for the type of battery in use. Where discharge is less than 80% of normal discharge rate, charging may be done at a rate of 125% times the discharge rate employed. 80 to 90 degrees is the normal temperature for maximum efficiency.

Frothing indicates too rapid charging or too high level of solution.

6. Never put lead battery acid into an Edison battery or use utensils that have been used with acid.

Operators on vessels using both Edison and lead cells should

General Data and Tray Dimensions of Edison Storage Batteries. (¼-in. Positive Tubes.)



Type (Letters denote size of Plates, Figures number of Positive Plates)	N2	B1H†	B2	B4	B6	A4	A5	A6	A7	A8	A10	A12	A8H†	A6HW‡
Prices on Application														
Rated Capacity, Ampere-Hours	11.25	18.75	37.5	75	112.5	150	187.5	225	262.5	300	375	450	300	225
Discharge Rate (8-hour) Amperes	1.41	2.34	4.69	9.38	14.06	18.75	23.44	28.13	32.81	37.5	46.88	56.25	37.5	28.13
" " (5-hour) "	2.25	3.75	7.5	15.	22.5	30.	37.5	45.	52.5	60.	75.	90.	60.	45.
Average Discharge Voltage (8-hrs.)	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
" " " (5-hrs.)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Normal Charge Rate (7-hours)	2.25	3.75	7.5	15.	22.5	30.	37.5	45.	52.5	60.	75.	90.	60.	45.
Weight of Cell, Complete, pounds	1.67	5.2	4.5	7.8	11.3	13.8	16.7	19.4	22.6	26.8	33.3	40.6	30.4	28.4
" per Cell, in Trays, pounds	1.94	5.6	5.1	8.5	12.1	14.9	17.5	20.8	24.6	29.0	36.2	43.9	32.1	32.2
Amount Renewal Solution per cell (lbs.)	.34	2.0	1.1	1.9	2.7	3.2	3.8	4.3	5.22	6.4	8.1	9.9	8.7	10.13
Over-all Tray Dimensions, in Inches														
Width of Standard Tray	3½	6⅛	6⅛	6⅛	6⅛	6⅛	6⅛	6⅛	6⅛	6⅛	7¾	9	6⅛	6⅛
*Height over-all (Filler Cap closed)	7½	11⅜	9⅝	9⅝	9⅝	14⅜	14⅜	14⅜	14⅜	14¾	14¾	15½	17½	17½
*Height over-all (Filler Cap open)	8½	12⅜	10⅝	10⅝	10⅞	16	16	16	16	16⅜	16⅜	17	19⅛	19⅛
Lenght of Trays: 1-cell Tray	2¾	3⅛	3⅛	4¼	5⅜	4⅝	5¼	5¾	6¼	7¼	7½	7½	7¼	7¼
2-cell Tray	4½	5	5	7⅜	9⅝	7¾	9	10	11	12⅞	13½	13½	12⅞	12⅞
3-cell Tray	6¼	6⅞	6⅞	10½	13⅞	10⅞	12¾	14¼	15¾	18⅜	19½	19½	18⅜	18⅜
4-cell Tray	8	8⅞	8⅞	13⅝	18⅛	14	16⅜	18½	20⅞	24⅛	25⅞	25⅞	24⅛	24⅛
5-cell Tray	9¾	10¾	10¾	16¾	22⅜	17⅛	20	22¾	25⅝	29¾	32¼	32¼	29¾	29¾
6-cell Tray	11⅞	12¾	12¾	19⅞	26⅝	20¼	23⅝	27¾	30⅜	36	....	....	36	36
7-cell Tray	13⅝	14⅝	14⅝	23	31¼	23¼	28½	32	35½	41⅝	....	....	41⅝	41⅝
8-cell Tray	15⅜	16½	16½	26	35⅝	27¼	32¼	36¼	40¼	47⅛	....	....	47⅛	47⅛
9-cell Tray	17⅛	18½	18½	29¾	39⅞	30⅜	36	41⅛	45	53⅝	....	....	53⅝	53⅝
10-cell Tray	18⅞	20⅜	20⅜	32⅞	44⅛	33¼	40⅛	45⅛	50⅛	....	....	....	....	....
11-cell Tray	21	22¼	22¼	36	....	36⅜	43⅞	....	....	....	....	....	....	....
12-cell Tray	22¾	24⅜	24⅜	39	....	40⅛	....	....	....	....	....	....	....	....

†The "H" Type has an extra high container allowing for an excess of electrolyte (about 50 or 60 per cent) and permitting longer intervals between "filling." All above types can be furnished with the extra high container if desired. They are designated respectively as B2H, B4H, etc., and have the same electrical characteristics as B2, B4, etc. The difference in height is about 2¾ inches on the Type "A" and 1¾ inches on the Type "B"—the other dimensions remain identical.

‡The "HW" type has an extra high and an extra wide container, allowing for a still greater excess of electrolyte and permitting still longer intervals between filling. Practically all of the above "A" type cells can be furnished with the extra high and extra wide container if desired. They are designated respectively as A-4HW, A-6HW, etc., and have the same electrical characteristics as A-4, A-6, etc. The height of the container is the same as that of the "H" type and the width is the same as that of the next larger type, e.g., the container of the A-4HW and the A-6H is identical in size as is the container of the A-6HW and the A-8H. The other dimensions remain identical.

*Over-all heights are given for bottomless trays. Add ¾-inch to height and ¼-inch to length for trays with bottoms.

FIG. 68. Data and Tray Dimensions of Edison Battery.

take special precautions not to use the hydrometer syringe of the lead batteries to fill Edison batteries.

7. Never add anything to the electrolyte of battery to prevent freezing. It is nearly impossible to freeze the alkaline solution and no permanent injury is caused by the severest cold.

8. Keep cells clean and vent caps free from crystals or potash salts which are liable to accumulate on cells.

9. Cell tops of marine batteries have a coating of brownish wax (rosin vaseline compound). If this is removed it should be replaced either with rosin vaseline or liquid vaseline.

10. Batteries should be removed from box or compartment from time to time and inspection of cells and compartment made. Make sure no water has accumulated in box or compartment. Remove all dirt and other foreign substances that may have accumulated which may in time short-circuit and damage battery.

11. It is very seldom that a battery is totally discharged in marine service and may become sluggish due to lack of work. If this condition is noted the battery should be completely discharged to zero at normal rate and then short-circuited for one or two hours. Follow this by an overcharge. If the condition is pronounced, this procedure should be repeated; 15 hours at the normal rate is considered an overcharge for the marine batteries, providing they have been discharged and short-circuited to zero voltage.

12. *On charge, and immediately following charge, all storage batteries give off hydrogen gas. Inasmuch as this gas is explosive in the presence of a spark or open flame, extreme care should be taken:*

(*a*) *that no spark or open flame be permitted near the battery or its compartment.*

(*b*) *that if battery be put in any other container or cabinet, such container or cabinet be adequately ventilated to allow a rapid dissipation of gas.*

(*c*) *that all connections be kept tight to eliminate the chance of sparking due to loose connections.*

14. **Charging a Storage Battery**—In order to charge a storage battery it is necessary to connect the positive terminal of the battery to the positive terminal of the charging source, and the negative terminal of the battery to the negative terminal of the charging source.

The voltage of the charging source must always exceed the maximum voltage of the storage battery because the voltage of the battery exerts a back e.m.f. on the charging voltage. If the back e.m.f. of the battery is greater than the charging voltage, no charging current will flow.

A variable resistance is usually connected in series with the charging circuit to regulate the amount of current flowing into the battery. The correct resistance to be inserted in such a charging circuit can be computed from Ohm's law. Assume it is desired to charge a 5-cell A-8 Edison battery by the constant current method from a d.c. line whose voltage is 110. The charging rate as specified by the electrical data accompanying the battery is 60 amperes. Inasmuch as a voltage of 1.85 per cell is required to maintain normal rate at the end of charge the 5 cells in series will require 5 × 1.85 volts or 9.25 volts at the end of charge. Inasmuch as a voltage of approximately 1.5 per cell is required to obtain normal rate at the beginning of charge the 5 cells in series will require 5 × 1.5 or 7.50 volts at the beginning of charge.

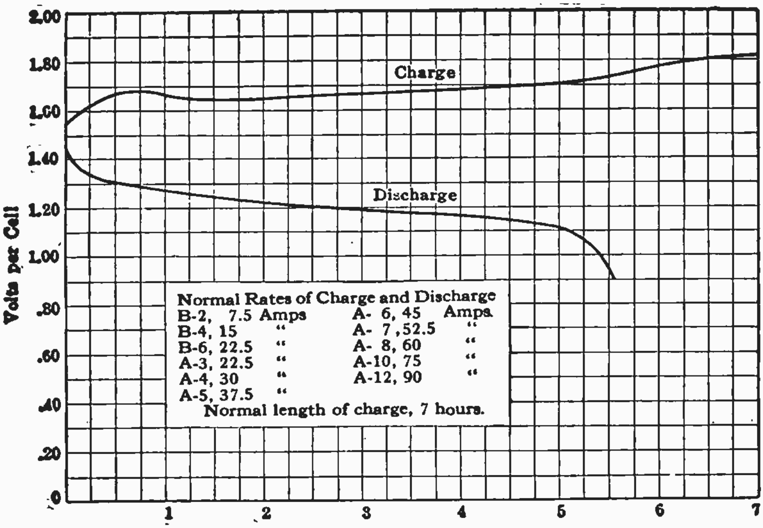


FIG. 69. Characteristic Curve of Charge and Discharge of Edison Battery.

Ohm's law is modified to read:

$$R = \frac{E - e}{I},$$

E = supply voltage,

e = battery voltage,
I = normal charging rate,

$R_1 = \frac{110 - 7.50}{60}$—resistance in ohms to obtain normal rate at beginning of charge.

$R_2 = \frac{110 - 9.25}{60}$—resistance in ohms to obtain normal rate at end of charge.

It will, therefore, be seen that in order to maintain normal rate throughout the entire charging period a resistance will be required which will be variable between the limits of R_1 and R_2. A lamp bank provides a convenient method of adjusting the correct charging rate to a battery. A bank of this type is shown in figure 70. In order to increase the charging rate it would be necessary to increase the number of lamps connected in parallel. To decrease the charging rate the number of lamps in parallel should also be decreased. If lamps of high or low voltage are employed the charging rate would increase or decrease respectively. More recently there are procurable resistance coils which can be conveniently screwed into a lamp socket. This type of resistance has sufficient current carrying capacity to replace several lamps which would otherwise be necessary in order to secure the same charging rate.

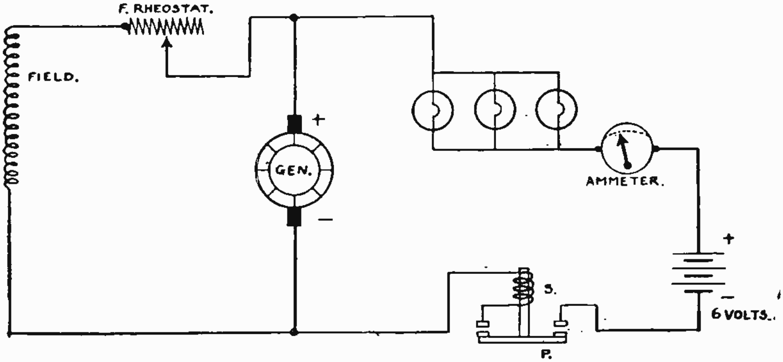


Fig. 70. Charging Circuit with Lamp Bank Resistance and Underload Circuit Breaker.

A protective device in the form of an underload current breaker is usually employed in charging circuits. In event the charging voltage is cut off or drops below that of the battery, the circuit is interrupted, preventing the battery from discharging through the generator, which usually results in a reversal of the residual magnetism of the field poles, and consequently the output of the generator.

Referring to figure 70 the solenoid *S* is connected in series with the charging current. The magnetic flux created by this current holds the plunger *P* in position to complete the circuit. Should the generator be shut down while charging, the solenoid *S* would be immediately demagnetized and the plunger would drop out, thus interrupting the battery charging circuit.

15. Determination of Polarity—The polarity of the charging voltage may be determined by four different ways:

1. By a direct current voltmeter of the movable coil type.
2. By an electrochemical polarity indicator.
3. By the use of a raw potato.
4. By dipping the terminals of the charging mains in a glass of plain or salt water.

Direct current voltmeters of the movable coil type have the correct polarity marked on the binding posts.

If connected properly to a source of direct current the needle will move in the correct direction on the scale indicating the voltage of the mains but if connected improperly the needle will move off the scale in a direction to the left of the zero position. The wire connected to the positive terminal of the voltmeter is the positive terminal of the mains and the other, of course, the negative terminal.

Chemical polarity indicators are composed of a chemical composition within a glass tube provided with terminals; when connected to a source of direct current the positive terminal turns blue.

Sticking the wires momentarily into a raw potato with about an inch or two separation, provides a path for a small current to flow which decomposes the starch of the potato causing that portion of it surrounding the positive terminal to turn blue.

When the terminals are dipped in a glass of plain or salt water, bubbles will appear at the negative terminal.

16. Charging a Battery when the Voltage Exceeds that of the Generator—It has already been stated that in order to charge a battery the charging voltage must exceed that of the battery. Occasionally batteries employed aboard ships as an auxiliary power supply have a total voltage of 120 volts or more. Usually the Edison batteries in such installations have 90 or more cells, whereas the lead plate batteries have 60 cells. In order to charge such batteries from the ship's dynamo, which usually generates 110 volts, the battery is split into two banks and the two banks are charged in parallel. When placed on discharge they are connected in series. This is accomplished by either a three-pole or four-pole double-throw switch. On vessels of the U. S. the emergency power supply frequently consists of two six volt batteries connected in series to provide 12 volts and of sufficient ampere-hour capacity to operate the emergency motor generator and tube filaments for six hours. See figs. 75 and 76.

17. Lead Plate-Sulphuric Acid Battery—In general, the lead plate-sulphuric acid cell consists of lead plates immersed in a dilute sulphuric acid solution. If two plates were immersed in a dilute acid and then connected to a charging current it would soon be noted that the character of the plates had changed. The plate through which the current entered the solution, called the positive plate, would be brown in color due to the formation of the chemical peroxide of lead on its surface. The other plate or the one by which the current left the solution would become light gray by the formation of pure lead on its surface. Now if the charging current be disconnected and a voltmeter be connected in the external circuit, it will be found that the cell will have become a

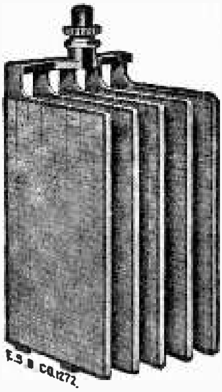


FIG. 71. Negative Plates of Lead Battery.

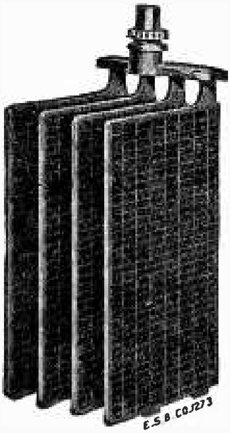


FIG. 72. Positive Plates of Lead Battery.

source of voltage and current, and that this current will flow in the reverse direction from the charging current.

18. Cell Construction—The average commercial cell is made by "pasting" the active elements into lead grids. After the grids are cast, they are pasted with oxides of lead made into a paste of special composition which sets, in drying, like cement. The plates then go through an electrochemical process which converts the material of the positive plate into brown peroxide of lead and that of the negative plate into gray, spongy lead.

Both the positive and negative plates are provided with an extension or "lug" and they are so assembled that all the positive lugs come at one side of the container and all the negative lugs at the other, thus enabling each set to be burned together with a connecting strap, giving one positive and one negative pole. The burning is done by a hydrogen flame, which melts the metal of both lugs and strap into an integral union. There is always one more negative plate than positive, the outside plates of the grids being negative. The straps are made of hard lead alloy and are provided with posts to which the cell connections are made.

19. Separators—To prevent contact between adjacent plates, separators made of light pieces of wood, vulcanite or other material are placed between them. The wood separators used in one type of battery are grooved on the side which goes against the positive plate to allow for circulation of the electrolyte and the escape of the gas generated when charging. To prevent the highly oxidized positive plate from charring the wood, and also to check the washing away of the positive material, due to vibration and the gassing on charge, a thin sheet of perforated hard rubber is placed between the positive plate and the wood separator.

20. Electrolyte—The electrolyte for the cell is a dilute sulphuric acid. Sulphuric acid is usually sold and shipped in the concentrated form. It is an oily, syrupy liquid, and much heavier than water. In purchasing the acid for this purpose care must be taken to specify that it be free from iron and other impurities. To prepare this acid for use in one of the cells, one part of acid is added to about four parts of water. *Never add water to the acid,* since the chemical action of this combination is quite violent and there is danger of the steam from the water throwing acid on the hands or clothes of the operator. The acid must be slowly added to the water while constantly stirring the mixture. This process must be carried on in a clean glass, earthenware or lead container. If placed in an ordinary metal container, chemical action will start at once between the acid and the metal and the electrolyte will become contaminated.

21. **Use of Pure Water**—Only approved water should be used to mix with the acid and to replace that lost by evaporation. Distilled (but not merely boiled) water is approved. Water taken from wells, springs or rivers is often satisfactory, but should not be used unless approved. Never transport or store water in any metallic vessel (lead excepted) and keep receptacle clean and covered, to keep out impurities. Glass, earthenware, rubber or wooden receptacles that have not been used for any other purpose are satisfactory. If water is drawn from a tap, it should be allowed to run a few minutes before using it.

22. **Containers**—The jar or container for portable batteries is usually of a hard-rubber compound; but larger batteries, which are used in a fixed position, are generally contained in glass or lead-lined tanks. The plates rest on stiff ribs or ridges in the bottom of the jar or container, allowing space for the accumulation of sediment.

23. **Hydrometer**—In mixing the electrolyte the correct proportion of water and acid can be exactly determined by test with the hydrometer. The hydrometer is a small glass tube closed at both ends and weighted at one of them. The hydrometer floats in the fluid and displaces the fluid more or less as the fluid is more or less dense. Thus, the density of the fluid can be read at the point where the "water line" of the fluid meets the graduated scale of the tube. The density of pure distilled water in terms of specific gravity scale is 1.000 at 70 degrees Fahrenheit. The specific gravity of the concentrated sulphuric acid is far above this and the water and the acid must be properly combined until the specific gravity of the combination is of the correct value for the particular type of battery. Since the temperature of the electrolyte has its effect upon the density of the electrolyte, the readings must be taken at approximately 70 degrees Fahrenheit, or else corrections for temperature must be applied. The general rule is to add .001 to the hydrometer reading for each 3 degrees above 70 degrees F., and to subtract .001 for each 3 degrees below 70.

24. **Baume Hydrometer**—Some foreign countries do not use the specific gravity hydrometer in taking the density of the electrolyte. The Baume hydrometer is the same as the specific gravity hydrometer except that the scale readings are calculated from different constants.

For liquids heavier than water:

$$\text{Sp. Gravity} = \frac{145}{145 - \text{Baume degrees}},$$

$$\text{Baume degrees} = 145 - \frac{145}{\text{Sp. Gr.}}.$$

Example: What is the Sp. Gr. of the electrolyte of a cell that shows a Baume reading of 29 degrees?

$$\text{Sp. Gr.} = \frac{145}{145 - 29} = \text{Sp. Gr.} = 1.250.$$

The specific gravity of a lead plate sulphuric acid cell increases with charge and decreases with discharge; therefore, the gravity readings are of considerable value in determining the charged or discharged condition of the cell.

25. Voltage Characteristics—The voltage of a lead cell is dependent upon the amount of dissimilarity in chemical action between the two plates. It is therefore dependent on the state of the solution and the active material of the plates. It is also dependent on state of charge and whether battery is on charge, or open circuit or on discharge. It is independent of the size of the plates or their number connected in parallel and of the distance between the plates in the liquid. The open-circuit voltage of a lead-acid cell is approximately 2 volts. The open-circuit voltage, however, does not indicate the state of charge. When the lead cell is being discharged at its normal rate, usually given by the manufacturer on the name plate, the voltage at its terminals gradually falls from approximately the open-circuit value to about 1.7 volts, at which point practically the complete capacity of the battery has been delivered. It is not desirable to continue the discharge beyond this point, except when the cell is delivering current at much more than the normal rate; for example, at 10 times the normal rate of discharge it is permissible to continue the discharge until the voltage of the cell has fallen to about 1.4 volts per cell. The average voltage which the cell can maintain during discharge varies with the rate of discharge and the construction of the cell. The average voltage will be about 1.95 volts when discharging at the normal rate. As the cell discharges the specific gravity of the electrolyte decreases. For many types of portable batteries the cell is considered discharged when the specific gravity has fallen to 1.140.

26. Unit of Capacity—The capacity of a storage battery is rated in ampere-hours. The ampere-hour is the unit employed to express the equivalent quantity of current represented by current of one ampere flowing through a given circuit for an hour of time. The ampere-hour capacity of a cell depends for the most part upon the amount of active surface of the plates exposed to the solution. It is therefore proportional to the area and the number of plates.

27. **Ratings**—The normal discharge rate of a battery is usually obtained by dividing the total ampere-hour capacity of the battery by the normal continuous discharge rate. If the battery is discharged at the normal discharge rate it will give its normal ampere-hour capacity by the time it reaches its discharge voltage limit. If discharged at less than its normal discharge rate it will give more ampere-hour capacity and if discharged at more than its normal discharge rate it will give less ampere-hour capacity. A battery of 210 ampere-hour capacity with a normal discharge rate of 21 amperes can be expected to last for 10 hours if discharged at its normal rate. If discharged at only 7 amperes it will last more than 30 hours, whereas if it were discharged at 30 amperes it would reach its discharge voltage limit within less than 7 hours.

28. **The Ampere-Hour Meter**—This instrument is of particular advantage in denoting the state of charge or discharge of a battery. It is in the form of a small motor connected in series with the charge and discharge of the battery and operates a pointer which moves over a dial calibrated in ampere-hours. The speed at which the motor operates depends upon the amount of current entering or leaving the battery. It is so constructed that a revolution counter connected to the motor records directly in ampere-hours the quantity of electricity passing through the meter. When the battery is fully charged the pointer on the dial reads zero. As the battery is discharged the pointer moves in a clockwise direction toward the full scale reading. A red pointer on the meter is usually placed at the number corresponding to the capacity of the battery with which the meter is employed. When the rotating pointer reaches this point it is an indication that the full ampere-hour capacity of the battery has been utilized and it should be placed on charge. As the battery charges the pointer moves in a counter-clockwise position and just before reaching the zero or fully charged position the pointer makes contact with a projection that operates a set of contacts which causes the underload circuit breaker to trip, disconnecting the battery from the charging source. This type of meter runs slower on charge than on discharge so as to allow some necessary overcharge.

29. Discharge Voltage Limits—The discharge of a battery must be stopped when it has reached the discharge voltage limit which depends—upon the type of cell, the concentration of the acid, and the rate of discharge. The discharge voltage limit when given on the battery name plate is for the normal discharge rate.

A battery discharged at a high rate can be carried to a lower voltage limit than a battery discharged at a long low rate. During high rates of discharge the chemical reactions in the cell are very rapid, forming sulphate in the outer layers of the active material of the plates, making it difficult for the acid to reach the interior portions of the plates and increasing the internal resistance of the cell, causing the voltage to drop quickly. It may be allowed to drop lower than during either a long low or an intermittent rate discharge, since at a low rate the acid reaches the interior portions of the plates, reduces them to sulphate, and when the voltage limit is reached there is very little capacity left in the plates. In a short or high discharge to the voltage limit only a fraction of the capacity of the cell is withdrawn, although the voltage is carried lower than during a long low discharge, when the cell is more nearly exhausted.

30. Chemical Action During Charge and Discharge—When a cell is fully charged the negative plate is lead sponge, Pb, and the positive plate is lead peroxide, PbO_2, the specific gravity of the electrolyte (sulphuric acid, H_2SO_4, and water, H_2O) is at its maximum between 1.210 and 1.220 (marine radio batteries, Sp. Gr. higher for some other types), temperature 70 or 80 degrees F. Chemical energy is stored in the cell in this condition.

If the cell is put on discharge the H_2SO_4 of the acid is divided into H_2 and SO_4. The H_2 passes in the direction of the current to the positive plate, and combines with some of the oxygen of the lead peroxide and forms H_2O; the SO_4 combining with the liberated Pb of the positive plate to form lead sulphate. The SO_4 also forms lead sulphate, as the negative or lead sponge, Pb, plate. As the discharge progresses both plates are finally reduced so that they contain considerable lead sulphate, $PbSO_4$. The water formed has diluted the acid lowering the specific gravity of the electrolyte; when the plates are entirely sulphated current will cease, since the plates are identical, and any electric cell requires two dissimilar plates in the electrolyte. In common practice, however, the discharge is always stopped before the plates have become entirely reduced to lead sulphate. The lead sulphate that has formed by the acid in contact with the plates is more bulky than the lead sponge or lead peroxide just as copper sulphate on copper, or iron rust on iron, is more bulky than the amount of copper or iron eaten away. The lead sulphate, on account of its increased volume, fills the pores of the active material until finally near the end of discharge, the circulation of acid in the pores of the plates is retarded due to the increased bulk of the lead sulphate. Since the acid cannot get into the plates to maintain the normal action, the cell becomes less active, as indicated by the drop in voltage.

To charge the cells direct current is passed through the cells in a direction opposite to that of discharge. This current passing through the cells in the reverse direction will reverse the action which took place in the cells during discharge. It will be remembered that during discharge the acid of the electrolyte went into and combined with the active material, filling its pores with sulphate and causing the electrolyte to become weaker. Reversing the current through this sulphate in the plates restores the active material to its original condition and returns the acid to the electrolyte. Thus, during charge the lead sulphate, $PbSO_4$, on the positive plate is converted into lead peroxide, PbO_2, while the lead sulphate on the negative plate is converted into sponge lead, Pb, and the electrolyte gradually becomes stronger as the SO_4 from the plates combines with hydrogen to form acid, H_2SO_4, until no more sulphate remains and all the acid has been returned to the electrolyte. It will then be of the same strength as before the discharge and the same acid will be ready to be used over again during the next discharge.

Since there is no loss of acid, none should be added to the electrolyte.

31. Object of Charging—The acid absorbed by the plates during discharge is, during charge, driven from the plates by the charging current and restored to the electrolyte, thereby making the battery available for another discharge cycle.

32. Charging Methods and Gassing—A battery can be charged at as high a rate as desired until it starts gassing. When fully discharged, but not overdischarged, it can absorb current at the highest rate. As the charge progresses, the plates can no longer absorb current at the same rate and the excess current goes to form gas. In a battery which is charged or nearly charged, the plates can absorb current without excessive gassing only at a low rate, and a high charge rate will be almost entirely used in forming gas, resulting in high temperature and wear on the plates.

33. Overcharge—Persistent overcharging not only tends to wash out the positive active material, but also acts on the positive grids, sometimes giving them a scaly appearance.

34. Injurious Effects of Local Action—There is another chemical action which takes place in any battery, termed "local action." This is going on all the time whether or not the battery is in use, and during all states of the charge. The lower the state of charge, the more injurious are the effects of local action, and the higher the density of the electrolyte used the more vigorous its action. The temperature of the electrolyte also has an effect on the local action—the higher the temperature the greater the effect. In addition to causing a battery to lose its charge, local action produces a lead sulphate of a different composition from that produced by electro-chemical action. The lead sulphate produced by local action is of a much harder texture than that produced by normal electro-chemical action and has a whitish crystalline appearance. It also has a high resistance and is insoluble in sulphuric acid. On account of the nature of this material, if allowed to accumulate on the active material to any appreciable extent, it will cause an increase in the internal resistance of the battery and a reduction in its capacity. This sulphate also tends to cause the plates to bend and buckle if allowed to go unchecked, because it continues to increase in volume as long as there is any sulphuric acid in the electrolyte. This is more noticeable where the sulphate has once gained foothold. In such cases the ordinary amount of charging will not bring the density of the electrolyte up to the proper specific gravity, and as the natural tendency of the repair personnel will be to add electrolyte, a trouble which has already gained headway will be aggravated.

35. Treatment to Remove Sulphate Produced by Local Action—If this injurious sulphate is not allowed to get too great a headway, it may be removed by long low-rate chargings. This method requires considerable time and is expensive, but is the only practicable one that can be employed without removing the elements and scraping them. Scraping the plates is objectionable, because in so doing a quantity of the active material is unavoidably removed with the sulphate, which naturally reduces the capacity of the battery. This sulphate forms not only on the surface of the plates, but also in the active material beneath the surface. The only proper course to follow is to take the necessary precautions to prevent as far as possible the formation of this sulphate to any appreciable extent. This can be done by remembering that local action is dependent upon the state of charge, the density, and the temperature of the electrolyte, the lower the state of charge and the higher the density and temperature the more injurious the effects. The local action thus far discussed is a natural consequence under the conditions mentioned, even though the electrolyte is pure, but if impurities are introduced, a multiplicity of chemical actions will be set up which will have a disastrous effect on the plates.

36. Buckled Plates—Buckled plates are plates which have been bent and warped out of shape. Lead, like most all material, will expand under the action of heat, but it has a very low elastic limit, and once expanded, it will remain in that condition. If the temperature is kept below 110 degrees F. there will be no trouble from this source. Most buckled plates are caused by continued overdischarge or lack of charge.

37. Height of Electrolyte—The height of the electrolyte should be kept at the correct height above the tops of plates at all times. This height varies with different makes and types of batteries, but in general it should be kept as high as will allow the battery to be charged without overflowing; that is, without causing the electrolyte to run out at the filling tubes while charging.

38. Maximum Gravity and Equalizing Charge—By maximum gravity charge is meant, as the term implies, charging the battery until the density of the electrolyte reaches its maximum specific gravity. The object of the maximum gravity charge is to offset the effects of local action and to bring all the cells into step with each other in regard to state of charge. Instructions for carrying out maximum gravity and equalizing charge are usually given by the manufacturer.

39. Trickle or Floating Charge—A method of charging a battery held ready for emergency work or a battery out of service is what is known as a "trickle or floating charge." With this method a small charging current is passed *continually* through the battery. This low rate of charge will keep batteries in good condition with minimum attention. The only precautions to be observed are that reasonably good ventilation is provided and that water is added at sufficiently frequent intervals to prevent the plates from becoming uncovered. If the system is designed to keep the battery fully charged automatically, its operation should be checked periodically until it is certain that the system is not giving too much nor too little charge. If the cells gas continually, the battery is receiving too much charge. If the gravity continues to drop, the battery is not receiving enough charge.

For a battery which is on trickle charge 24 hours every day, if the adjustment is correct the voltage directly at the battery terminals will be between 2.10 and 2.30 volts per cell and should average very close to 2.20 volts per cell. If it is continually below

2.10, the charging is insufficient. If continually above 2.20 it is excessive. (These values are correct for batteries whose full charge gravity is 1.200–1.22—but not for other batteries.)

There is a wide-spread impression that a lead and acid battery held ready for emergency should be given periodical cycles of discharge and charge in order to maintain its normal capacity. If such a battery is kept on a trickle or floating charge, at the required rate, when not in use, it will be fully charged and capable of delivering its maximum capacity at the normal discharge rate during an emergency.

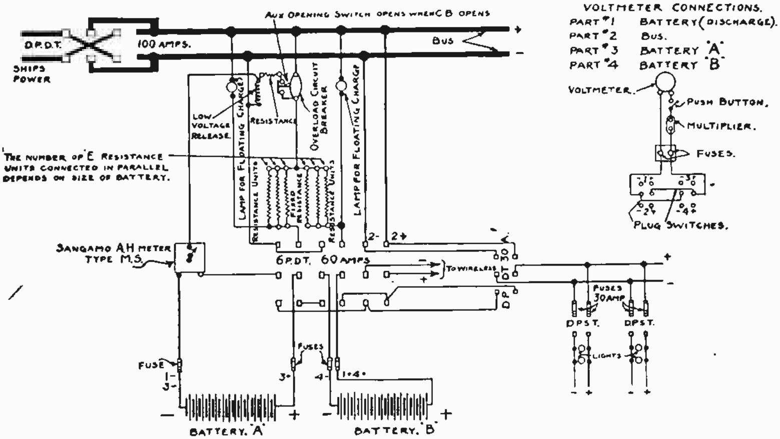


FIG. 73. Diagram of Exide Storage Battery Company's Switchboard.

40. Exide Storage Battery Switchboard—The ship's power circuit is connected through the large upper double-pole double-throw switch which is so connected that in case of the reversal of the polarity of the ship's power the same relation between the power bus and the battery can be obtained by reversing the switch. The circuit breaker is equipped with overload, low-voltage release, and automatic trip operated by the ampere-hour meter.

41. Operation—First determine that the power bus switch is closed in the proper direction by observing whether the voltmeter reads when the plug switch is in the lower left-hand receptacle. If it does not read, reverse the power bus switch, then ascertain that the two halves of the battery are also properly connected by taking readings in the upper and lower right-hand receptacle. The voltmeter circuit is normally open and a push button switch is provided on the switchboard for closing the circuit when it is desired to take a voltage reading. This precaution is taken to prevent inductive effects incidental to the operation of the radio outfit damaging the meter.

42. **To Charge the Battery**—Close the circuit breakers at the time, holding up the plunger of the low voltage release coil, and then close the 6-P.D.T. switch to the left. This will place the respective halves of the battery on charge through the charging resistances on the back of the board. The red pointer on the ampere-hour meter should be set at the numbering corresponding to the capacity of the battery in use. The black hand of the ampere-hour meter indicates the state of discharge of the battery at any time. As soon as the charge is started the black hand will begin to move towards zero and the charge should be completed when it reaches zero. When the black hand reaches zero it makes a contact which opens the circuit breaker by means of the automatic trip, thus automatically cutting off the charge. For the equalizing charge; or if for some other reason the battery requires an overcharge, it is necessary to remove the cover from the ampere-hour meter, or, by the use of a key furnished with the same, and turn the black hand to the proper point. (As determined by reference to the battery instructions.)

If when the battery is charging the ship's power circuit fails, the low voltage release will open the circuit breaker, preventing the battery from discharging back into the bus. The battery can be used for supplying current in such an emergency as described under "Discharging the Battery."

43. **To Float the Battery**—With the 6-P.D.T. switch closed to the left and the circuit breaker open, the charging circuit through the resistance units will be open, but the battery will be receiving a floating charge through the two lamps mounted in the upper corners of the switchboard. This is intended to be the normal condition of operation; i.e., battery fully charged and floating, with circuit breaker open, and 6-P.D.T. switch closed to the left, the radio circuit is connected direct to the bus. When the battery is floating or charging, the lights cannot be operated from it, and the lower double-pole double-throw switch should then be closed to the left. The feeder switches for the various light circuits can be opened or closed, as desired.

44. **To Discharge the Battery**—With the circuit breaker open, close the 6-P.D.T. switch to the right. With the battery discharging the lights can be operated from either the bus or the bat-

tery by closing the small lower double-pole double-throw switch to the left or right, respectively.

Whenever the ship's dynamo is shut down care should be taken to open the radio circuit switch on the ship's switchboard.

45. Operating Exide Batteries in Emergency Radio Service on Ships—Keep the battery and surrounding parts dry and clean. If electrolyte is spilled or if wood trays (or compartments) are damp with acid, apply a solution of cooking soda and water, then rinse with water and dry; do not allow soda solution to get into cells. Soda solution or ammonia will neutralize the effect of acid on clothing, cement, etc.

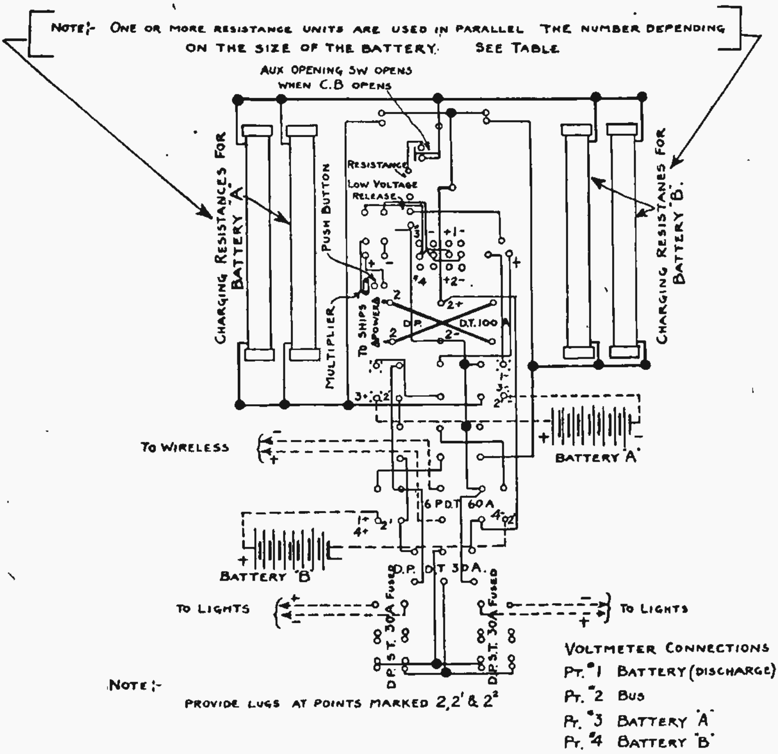


FIG. 74. Back View of Wiring of Exide Storage Battery Switchboard.

46. Replacing Evaporation—Do not allow the surface of the electrolyte to get below the top of the separators; keep it above by adding sufficient suitable water to each cell as often as necessary. Do not fill higher than 1/2 inch above the top of the plates. In cold weather the time to add water is at the beginning of a charge, so that gassing will insure thorough mixing and any danger of the water freezing be avoided. It will never be necessary to add new electrolyte, unless some should be spilled. Never transport or store water in any metallic vessel (lead excepted) and keep receptacle clean and covered, to keep out impurities. Glass, earthenware, rubber or wooden receptacles that have not been used for any other purpose are satisfactory. Only suitable water should be used for replacing evaporation. Distilled water is suitable. Rain water is usually satisfactory, if obtained on a clean roof in a clear atmosphere, but care should be taken to allow the rain to flush the roof before catching the water.

47. **Pilot Cell**—The specific gravity of all cells in series on discharge and charge falls and rises together, so that the gravity reading of the electrolyte of one cell, known as the "pilot cell," will indicate the state of discharge or charge of the series as a whole. As the battery is divided into two parallel series for charge, a pilot cell in each half is necessary.

48. **Discharging**—The system is laid out with the idea that the battery is to be discharged only in emergencies.

49. **Discharge Limits**—In emergency, little if any permanent harm will result if the battery is discharged to the full amount that it will give (provided that it is immediately recharged) but overdischarging *as a constant practice will soon result in permanent damage.*

50. **Floating**—The battery is to be floated at all times, except when charging or discharging. When floating, both lamps on battery, switchboard will burn dimly. If either lamp goes out, immediately replace it with another of proper rating.

In order to check the generator polarity and to guard against the battery becoming accidentally discharged through the reversal of the generator, read the voltmeter frequently with the voltmeter plug in opening marked "Bus." If the polarity has changed, throw over the switch marked "Reversing Switch."

The system is designed to keep the battery fully charged and its operation should be checked every week or so until it is certain that the system gives neither too much nor too little charge. With proper adjustment, the specific gravity of the pilot cell will remain practically constant (within 5 to 10 points if level of electrolyte is kept the same height) and the cells will not be gassing. If the cells gas continually, the battery is receiving too much charge. If the gravity continues to drop, the battery is not receiving enough charge. Adjust the charging current if necessary by changing the floating lamps, using higher wattage to increase rate or lower wattage to decrease. Make another check after a week or so, repeating until it is certain that the system gives neither too much nor too little charge. The adjustment can then be considered correct and will only require occasional checking.

51. **Charging**—After discharges of any kind totaling one-tenth capacity or more, immediately put the battery on charge and continue the charging until the black hand of the ampere-hour meter has returned to zero. Once each month, preferably during fair weather, charge the battery. Move the black hand of the ampere-hour meter back, halfway to the red hand, and charge until the " pilot cell gravity " and the voltage of each side have remained constant for one hour and all cells have been gassing or bubbling freely for the same length of time. This means that, under normal conditions, the charge will be of about two hours' duration. When charging, keep the bus voltage at 110 volts as, if it is low, the charging rate will be reduced and the time required to charge correspondingly increased. For example, a bus voltage of 100 volts reduces the charge rate one-third and therefore increases the time 50 percent; a 90-volt reduces the rate two-thirds and triples the time.

Raise the covers of the battery box during this charge and *never bring a lighted match or other exposed flame near the battery as this might cause an explosion.* Keep the vent plugs in the cells. Do not remove them during charge except to take specific gravity or temperature readings. After the charge, reset the black hand of the ampere-hour meter to zero.

52. **Specific Gravity of Electrolyte**—The normal specific gravity of the electrolyte should, with the cells fully charged, be between 1.260 and 1.295 for all marine types with the exception of type MVS, for which it should be between 1.200 and 1.220.

It will never be necessary to add new electrolyte, except in connection with replacing actual loss of electrolyte due to spillage or similar causes. Before adjusting low gravity by adding acid, first make sure charging will not raise the gravity. To do this, continue charge until specific gravity shows no rise, and then for five more hours. Never make a gravity adjustment on a cell which does not gas on charge. To adjust low gravity, add new electrolyte of 1.300 specific gravity instead of water when replacing evaporation until the gravity at the end of an equalizing charge is up to 1.260 (1.200 for type MVS). Then stop adding electrolyte and replace all further loss from evaporation with suitable water. Do not adjust higher than 1.260 (1.200 for type MVS) and do not add electrolyte of higher gravity than 1.300 directly to the cells.

53. **Impurities**—Impurities in the electrolyte will cause a cell to work irregularly. Should it be known that any impurity has gotten into a cell, it should be removed at once. In case removal is delayed and any considerable amount of foreign matter becomes dissolved in the electrolyte, this solution should be replaced with new immediately, thoroughly flushing the cell with water before putting in the new electrolyte.

54. **Broken Jar**—If a jar should become broken, do not allow the plates to dry. If there is no extra jar on hand, remove the cell (either with or without its jar) from the circuit, immerse it in a wooden bucket filled with water and keep it covered with water until ready to reinstall it.

55. **Indications of Trouble**—The chief indications of trouble in a cell are:

(*a*) Falling off in gravity or voltage relative to rest of the cells.
(*b*) Lack of gassing on charge.

If a battery seems to be in trouble, the first thing to do is to give it a charge. Then take a gravity reading of each cell. If all the cells gas evenly on the charge and the gravity of them goes above 1.225 (1.180 for type MVS), most likely all the battery needed was the charge; otherwise, record all gravities less than this, resume charge and continue until three consecutive half-hourly readings of the gravity of all these cells show no increase for any of them. Then make gravity adjustment on those which are still below this and which are gassing. Before making an adjustment, determine whether the jar is cracked by adding water to the proper height and allowing cell or jar to stand several hours, noting whether level falls. If a jar is changed, charge it. If a cell will not gas on above charging, investigate for impurities.

If in doubt as to whether the electrolyte contains impurities, a half pint sample should be submitted for test. The Electric Storage Battery Company will analyze and report on, free of charge, samples received at its works (Allegheny Ave. and 19th St., Philadelphia, Pa.) with transportation charges prepaid; provided the battery in question is an Exide.

Battery Charging Panel—A small battery Charge-Discharge panel is shown in figure 75. This is a typical small panel as furnished with the radio equipment of a vessel fitted with a low power emergency transmitter. The two storage batteries connected in series, as illustrated in figure 76, furnish power to operate a motor generator. The generator develops AC voltage for the plate transformer of the vacuum tubes.

FIG. 75. Battery Charge-Discharge Control Panel.

Referring to figure 75 the double pole double throw switch when thrown to the left places the batteries on charge directly from the ship's power. The charging current is regulated by fixed resistors on back of the panel. The switch is thrown to the right to discharge the batteries. The ammeter on the front of the panel indicates to the operator whether or not the battery has the correct charging polarity and the rate of charge and discharge. When not on charge or discharge the ammeter needle reads zero on the center of the scale. On the left side of zero the scale is marked "Charge" and on the right side of zero it is marked "Discharge." When the batteries are placed on charge and the charging polarity is correct the needle will move to the "Charge" side of the scale. If the polarity is reversed, it will move to the "Discharge" side and the switch should be immediately opened.

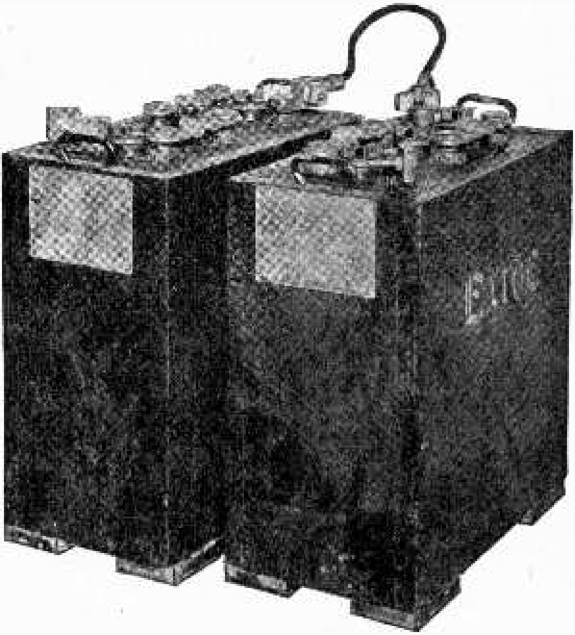


FIG. 76. Lead Plate Batteries Used for Auxiliary Power Supply.

On small charging panels of this type no protective circuit breakers are provided and the operator is required to take the batteries off charge whenever the ship's dynamo is shut down. If this is not done, the batteries will discharge through the windings of the dynamo, possibly resulting in reversal of the polarity of the machine when it is again started. This is discussed in detail in paragraph II on page 63.

CHAPTER 4

THE ELECTRON TUBE

It is no longer possible to call all radio tubes "vacuum tubes," since we constantly employ rectifier and control tubes which do not contain a vacuum but have had their losses greatly reduced by the introduction of a metallic vapor, or else have their sensitivity raised by the introduction of a gas. In some types both a gas and a metallic vapor are present for these or other purposes. The pure vacuum types are still fundamental, and hence discussed first.

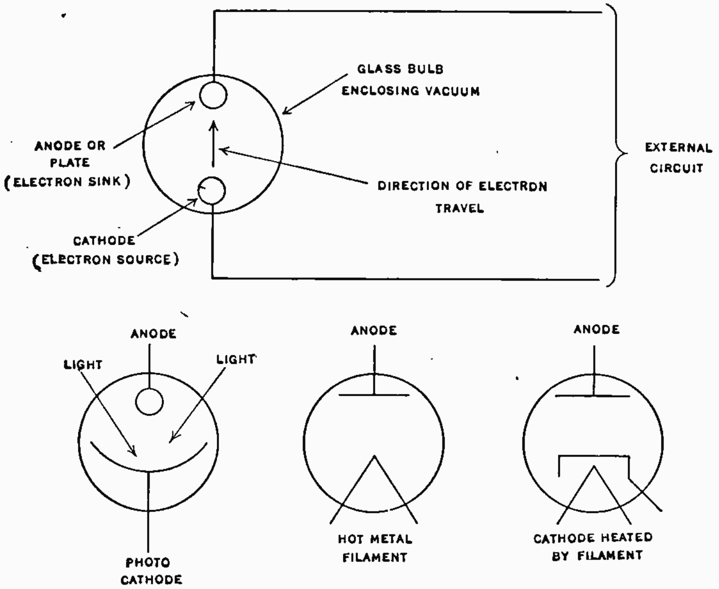


FIG. 77. The Fundamental Electron Tube. The High-Vacuum Diode, in Several Forms.

Fortunately the tubes commonly used in radio reception and transmission have one thing in common, and this one thing provides a good starting point for understanding all of them. Whether the tube is built in a glass bottle, or in a metal can with a glass cork, it is almost sure to contain a birthplace of "free" electrons and a burial-place of free electrons. This entire chapter, and much of the rest of this book, has to do with the lightning-fast journey of free electrons from their birthplace (the "Cathode") in one part of the tube to their burial-place (the "Anode") only a few millimeters distant in the same tube. The usefulness of the tube depends on our ability to create this rain of electrons from cathode to anode, and then to change its intensity, or its speed or its direction. In order to do that the cathode and anode are given many forms, and in the space between them there may be placed numerous varieties of metallic devices for controlling the electronic rain. As already stated, the proceedings inside the tube may likewise be greatly altered by introducing a gas or a metallic vapor—remembering that this does not replace the original electronic requirement of an electron "source" and an electron "sink." If this general picture is kept in mind, the following pages will not be confusing, as the effects in tubes are briefly outlined.

PART A—TUBES AND TUBE APPLICATIONS

1. The Cathode (Emission of Electrons Due to Light or Heat and the Space Charge)—It will be recalled from Chapter 1, that all substances are considered to be composed of very tiny bits of electricity, called electrons, but at present we are concerned only with metals and their compounds (oxides etc.) since these are the materials from which are made the electron-sources or "cathodes" of our tubes. This class of materials can be made to give off a cloud of "free" electrons, but it depends on the metal, alloy or compound how fast this proceeds, and how it may be caused.

The giving-off or "emission" of electrons from the cathode may (for some materials) be caused by so small a thing as light shining on the cathode. The emission is very small, but is used in so-called "electric eyes." Depending on the materials used, a photo-electric tube may be sensitive to ultra-violet light, to visible light, or to infra-red light. Since the last is the same as heat, it may be generated inside the cathode-metal electrically, instead of sending it in as a beam. Then, instead of a photo-electric tube we have the common hot-emitting cathode used in most tubes. For tubes subject to very rough use or very high voltage the cathode is a simple and extremely rugged tungsten wire (filament) running at white heat. If the use is to be more moderate the filament is run at an orange heat, or even a red heat, and since tungsten fails to emit electrons at such temperatures it is activated by an alloy of thorium (or caesium), or a surface coating of an oxide mixture of metals such as barium, calcium and strontium. Much less heating-power is required, materially more emission is secured, and adjacent tube-parts are heated less, but the thoriated and oxide-coated filaments lack the great ruggedness of plain tungsten and are readily damaged by excessive space-current, especially if the cathode is too cool at the time—one of the commonest causes of tube failure in both receivers and transmitters. "Indirectly heated" cathodes (also called equipotential cathodes) serve the same purpose, but have some special advantages. They keep the cathode-heating current out of the cathode by surrounding the heater-filament with an insulating sleeve which in its turn is surrounded by the actual cathode in the form of a metal sleeve coated with such oxides as mentioned above. Indirectly-heated cathodes are slower to start, and require more heating power, but permit the use of a.c. heating current without appreciable hum, are very sturdy, and greatly facilitate the design of circuits in which the cathodes are to be at different voltages but heated by one transformer or battery. (Receivers for example.) Their use is being extended to larger tubes.

2. The Vacuum—If the hot-emitting cathode of the usual tube be exposed to air it will burn up with almost the promptness of a Mazda lamp whose bulb is cracked. However, burnout-protection could be given by a "soft" vacuum whereas radio tubes actually use a "hard" or high vacuum for another reason. This reason is that any gas left in the tube will obstruct the electrons leaving the cathode. As they collide with the gas, the tube almost instantly becomes filled with a conducting mass of "ionized" gas, stopping the normal electron procedure in a manner similar to the effect of pouring an electric motor full of salt water; a large current will flow immediately unless there is some safety device, and it will continue to flow until the supply is shut off. This "trigger" action of gassy tubes is sometimes useful, but usually is avoided by removing the gas which makes it possible. Most of the gas is pumped out, and the bulk of the rest is trapped by a chemical "getter" whose work leaves a colored smear on the glass of the tube. Thereafter the tube must be worked cooler than at the time of pumping.

Tubes containing a metallic vapor (usually mercury-vapor) give effects resembling the above in some ways, but are more certain,

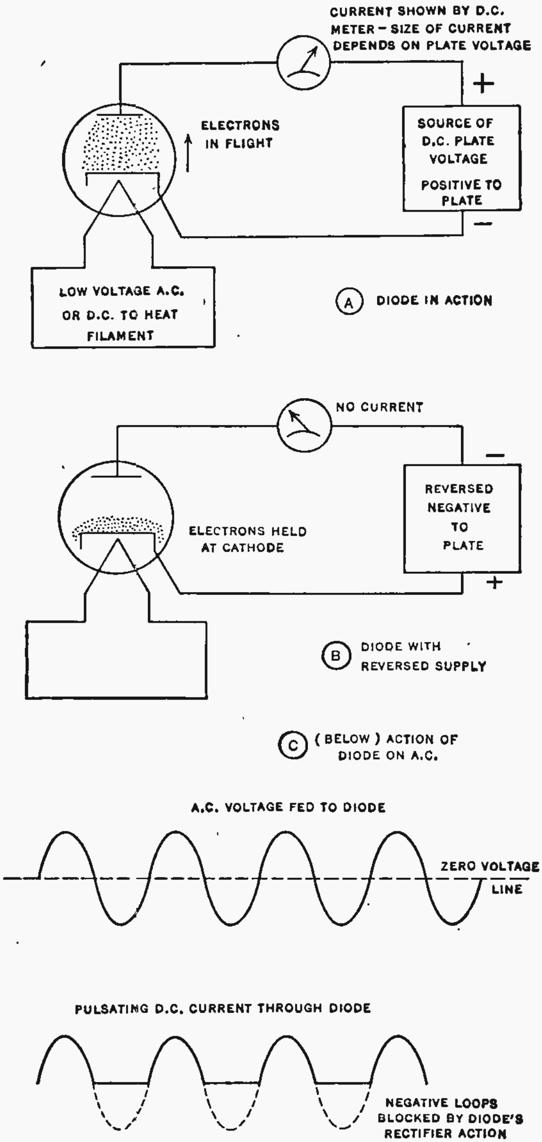


FIG. 78. Effect of Plate Supply on Diode Action.

more used in radio, and worth separate discussion later. We turn now to the non-gassy, non-vapor tubes, that is the true "vacuum tubes." These make up the bulk of all radio tubes.

3. The Vacuum Diode—The simplest of the vacuum tubes is the "Diode" (which means a 2-part device), so named because it contains only the cathode, and the anode, or plate. Having generated an electron-cloud at the cathode and having cleared the tube of gas, it is found that a few electrons stray to the anode and form on it a negative charge which with the "space charge" prevents further electrons from leaving the cathode, somewhat as a fog over a puddle will prevent evaporation. The electron-fog may be pulled away from the cathode by making the anode positive by the means shown in figure 78*A*. More electrons immediately emerge from the cathode and rush toward the anode as a "space current" whose electrons on striking the plate enter it and continue through the wire outside as an ordinary "plate current." Increasing the plate-supply voltage can increase the plate current until it represents all the electrons emitted by the cathode but so high a current is ruinous to the cathode, and often to the anode.

If the plate (anode) supply voltage is reversed as in figure 78*B* the electrons are driven back to the cathode, and unless the anode is accidentally very hot (hot enough to emit electrons), the current stops. Therefore the diode is an electrical 1-way or non-return valve or "rectifier," and if alternating current is connected to it as in figure 78*C* only ½ of each cycle will pass through, so that the output is a pulsating current instead of an alternating current.

4. The Vacuum Diode Detector or Demodulator—Such a vacuum diode rectifier is the most commonly used detector (demodulator) in present radio receivers. In this case the alternating current to the rectifier is of radio frequency and very small power, so that a very small diode suffices. The output of this diode is a pulsating radio-frequency current, consisting of the positive half-cycles, and these are passed through a *small* smoothing filter from which there comes out smooth d.c. which represents no sound at all. Now if the transmitting station "modulates" (varies) its output by means of voice, music, or tone, we shall no longer have a smooth d.c. output from the detector diode, but rather one consisting of varying d.c., that is d.c. which carries the variations of voice, music or tone. These variations can be heard by placing a headset in the diode output circuit, or they can be fed to an audio amplifier, which is described later. The diode is a high-fidelity (very faithful reproducer) detector, even for strong signals, but it is not an amplifier in any way. Note that the smoothing filter in its output may not be large or it will also smooth out the sound-frequency output and destroy all usefulness.

5. The Vacuum Diode Rectifier—The diode detector itself is an example of a vacuum diode rectifier. Larger diodes are used for rectifying alternating currents, where it is inconvenient to use a d.c. generator because the required power is small (plate supply of receivers and small transmitters), or because the voltage is so high that a d.c. generator is costly or impractical (large radio transmitters). The principle is simple, but the design of the a.c. power source and of the smoothing filter must follow certain rules which are outlined in section 36 of this chapter under the heading of "Power supply systems employing tube rectifiers." If those rules are not followed there results the common experience of unsatisfactory diode-life.

In power-supply work a single diode is seldom used, since better efficiency in both power and the use of material results from "full wave" rectification, in which two diodes work alternately to pass alternate half-cycles of the supply-current into a circuit so arranged that they may add into a smoother pulsating current which may accordingly be smoothed (filtered) more cheaply. This idea may be carried further, with the use of additional diodes, as explained in the section above referred to.

Note—The mercury-vapor type of rectifier diode is intentionally deferred until later in this chapter. See sections 34 and 36.

6. The Vacuum Triode. Grid Control. (The Basis of All Amplifiers.)—A triode is a 3-part device, due to Dr. Lee DeForest and differing from the diode in that it *can amplify and oscillate while still able to rectify.*

It has been seen that a change in plate (anode) supply voltage will change the plate current of a diode. DeForest found that this same change could be produced much more easily by keeping the plate voltage unchanged and instead changing the voltage of a third metal part which he called the "grid" (Fig. 79) because it originally was a small wire gridiron placed between the cathode and the anode. Figure 80 is a pair of so-called "characteristic curves" showing how such a triode-system works. First consider the curve "*B*" which shows the plate current for different grid voltages while the plate voltage remains at 180. For zero grid voltage (where *B* crosses the vertical zero line) it is seen that the plate current is about 40 milliamperes. To change this we must either change the plate voltage or the grid voltage. Suppose we

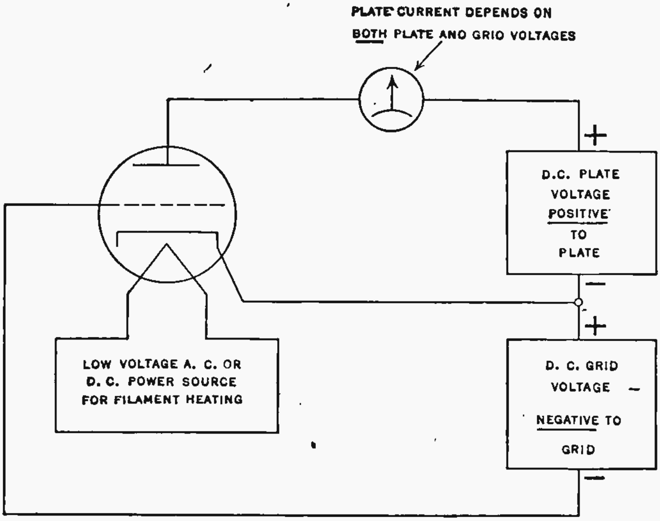


FIG. 79. Basic Vacuum Triode.

wish to drop to 20 milliamperes. By following "*B*" to the left it is seen that this can be done by making the grid about 4 volts "minus" (negative). On the other hand if we had left the grid voltage at zero and instead dropped the plate voltage to 90 (curve "*A*") the plate current would likewise drop to 20 milliamperes.

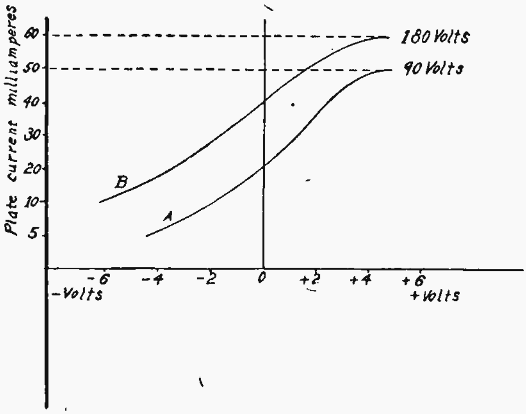


FIG. 80. Characteristic Curves of a Vacuum Tube.

Thus the same effect is produced *in this tube* by changing the plate voltage by 90 volts, or changing the grid voltage by only 4 volts—1/22 as much (22 is roughly the amplification constant or "mu"). The grid is evidently a much more effective control, or if you please the control has been "amplified" by use of the grid. On this are based the amplifiers discussed later. It should be noted that as long as the grid is kept negative it repels electrons, hence none alight on it, and there is no grid current—therefore no *power* is required to change the grid voltage, though actual power is controlled in the plate circuit.

Had the grid been coarser, or further from the cathode, the same size of tube would pass a larger anode current, but with a lower degree of control, that is with a smaller "mu" or "Amplification constant." The d.c. voltage fed to a grid is called the "Grid Bias," while a.c. voltages fed to the grid are known as "grid input" or "Grid Excitation." **IT IS ALWAYS POSSIBLE TO REDUCE THE OUTPUT BY (1) DECREASING THE EXCITATION OR (2) INCREASING THE BIAS.**

This grid control is at the bottom of all amplifiers such as are described later, but the difference between high-mu and low-mu tubes is important principally in "class A" amplifiers, also described later. It also accounts for all ordinary methods of controlling gain manually or automatically.

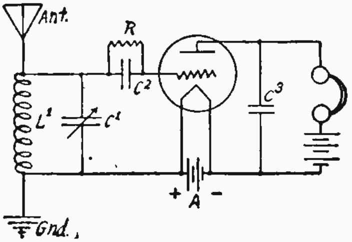


FIG. 81. Vacuum Tube Circuit Employing Grid Leak and Condenser.

7. The Vacuum Triode as a Gridleak Detector—Two quite distinct sorts of triode detectors are in common use, though the diode is replacing both.

The Gridleak Detector—The older, more sensitive, but more easily overloaded and more given to distortion, is the gridleak detector which constitutes the extremely simple 1-tube battery-operated receiver shown in figure 81. Whether the gridleak detector uses the plain filament-type of tube shown, or an indirectly heated cathode, is not significant. In either case there is no grid-bias until a signal arrives, hence the plate current must be kept down by using a tube with a fine grid mesh (high mu) or by using only 45 to 100 volts of plate supply.

The action of this type of detector depends on the presence of the small grid-blocking condenser C_2, and the high-resistance (several million ohms) gridleak resistor R. The latter may be connected either as shown or directly from grid to cathode—the positive end where the cathode is the filament iself, as shown here. In either case the function of the combination is to permit trapping electrons on the grid to the right of the condenser C_2, and the subsequent slow "leaking off" of these electrons via R to the cathode. The action is as follows:

When a radio "carrier" (unmodulated) signal is received, the alternating (high frequency) voltage generated by it in the tuned circuit L_1 C_1 is applied to the grid through the grid condenser C_2, which does not obstruct the passage of such high frequencies. Thus the grid swings at radio-frequency, and at each swing in the positive direction a few electrons are attracted from the passing space-current, but they are not cast off during the negative swing since the grid is not hot and therefore unable to act as an electron source. Within a very few swings (certainly less than 1/100,000 of a second) enough electrons are stuck on the grid so as to charge it negatively to the same voltage as that of the incoming carrier alternations, after which electrons are accumulated by the grid only as fast as the old ones contrive to escape cathode-ward

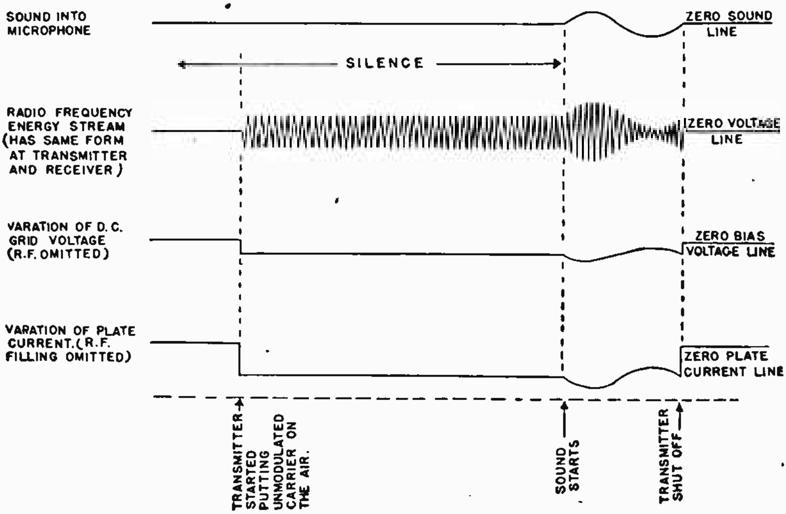


Fig. 82. Grid Leak Detector Action (Compare with Fig. 84).

through the gridleak. For the moment this means a fixed (d.c.) grid bias whose size depends on the strength of the incoming carrier, and which reduced the detector plate current in accord with the strength of that carrier.

Now if modulation (variation) of the carrier begins, it follows that whenever the carrier becomes larger (higher voltage) the grid will swing more widely and at once (within perhaps 1/100,000 second again) will charge itself up to this new level and thus still further depress the plate current. Similarly when the carrier is modulated downward (has its voltage lowered) the grid will swing less widely, therefore fail to pick up electrons, and presently *R* will "leak it down" to this new carrier voltage, and allow the plate current to rise. Thus the average plate current wanders up and down (but in reverse direction) with the sounds made into the transmitting station's microphone, and these sounds may be heard by a headset in the detector plate circuit, or fed to an audio amplifier. For reasons which shall not be gone into here this type of detection is subject to more difficulties than the diode type of section 4, or the biased triode type of section 8, hence is used where sensitivity excuses other shortcomings.

Satisfactory gridleak detection requires that C_2 be large enough to pass the radio-frequency readily, but not to bypass the grid for high audio, that *R* leak off the grid-charge fast enough to permit following high-audio variations, but not so fast as to reduce sensitivity, and that C_3 (often supplemented by an r.f. choke coil of small distributed capacitance) at the right of the condenser be of a size small enough to prevent bypassing the high-audio output but still adequate to return to the cathode such amplified r.f. as appears in the plate circuit—that is the plate system is supposed to short-circuit the r.f. but pass the audio along to the amplifier. In practice this results in a 2 to 5 megohm (million ohm) gridleak *R*, a plate circuit bypass of about .0001 microfarad for good high-note response and about 2 1/2 times that if music is not to be received, and also a grid condenser of about the same proportions. For wavelengths under 100 meters both condensers may be smaller. **THE GREAT SENSITIVITY DEPENDS ON THE AMPLIFIER ACTION—SEE SECTION 6 AGAIN.**

This type of detector is more sensitive if the tube is of the "soft" or "gassy" type such as the type 200A, but as suggested in the introductory paragraph and in section 2 of this chapter, such tubes are less stable, being affected by room temperature, critical as to plate voltage, and subject to "spilling" from strong signals or noises, whereupon the plate supply must be cut off momentarily to restore normal operation.

8. The "Bias" or "Plate" Type of Vacuum Triode Detector—The bias type of triode detector, shown in figure 83, is in direct contrast to the gridleak type in several ways.

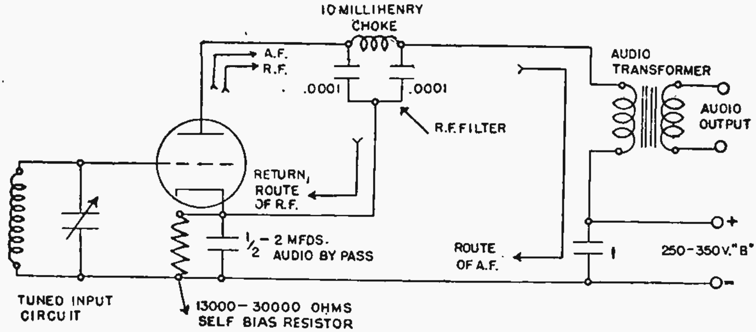


Fig. 83. Biased Triode Detector. (Increase Filter Constants if Carrier Frequency Is Less than 500 kc.)

It is less sensitive (though still far above the diode), less easily overloaded, and under proper conditions distorts less. It does not operate with a low signal-made bias but with a fixed bias of so high a value that the plate current is about 1/5 of 1 milliampere (1/5000 ampere) until a signal arrives. Thus when an alternating voltage, such as a received radio signal, is fed to the grid, the negative grid-swings have no effect as it is impossible to cut off a tube which is already cut off. This supplies the rectifier action. On the other hand the positive swings, though not large enough to make the grid "go plus," do swing it in that direction and each let through a pulse of plate current, hence the average plate current rises in approximate proportion to the strength of the incoming signal, and follows any variations therein. The slow variations due to signal-fading may then be used to operate an automatic volume control system (see last three sentences of section 6 for basis of all A.V.C. systems), while the fast variations—which are of course the desired audio output—are passed through a coupling capacity of moderate size to the grid of an audio amplifier tube.

9. "Cutoff Bias" and "Variable mu"—Cutoff bias is simply the grid voltage required to stop the flow of plate current. If we have a tube working with a plate voltage of 1000 and having a coarse grid so that the "mu" (amplification constant) is only 5 the cutoff bias is ordinarily taken as being 1000/5 = 200, though as a strict fact this voltage does not completely stop the electrons because of changes in their paths. If the tube had a fine grid, placed near the cathode, and giving a "mu" of 25, the cutoff bias would be 1000/25 = 40 volts. Thus the high-mu tube is more easily biased and more easily "swung" by the a.c. grid input. Thus the high-mu tube is of advantage in amplifying very small voltages such as weak radio signals or the small voltages from a high-quality microphone, but is also over-swung by larger voltages. In radio receivers the received signals are of widely different strengths and the first few tubes must be able to tolerate strong signals (which suggests low-mu tubes) without being insensitive to weak signals (which require high-mu tubes). A combined type called "variable mu" or "super control" was devised by H. A. Snow and Stuart Ballantine. These tubes have a grid of which one part is coarse and the other fine, or with different spacing from the cathode so that one part of the tube is sensitive while the other is proof against blocking by strong signals. The com-

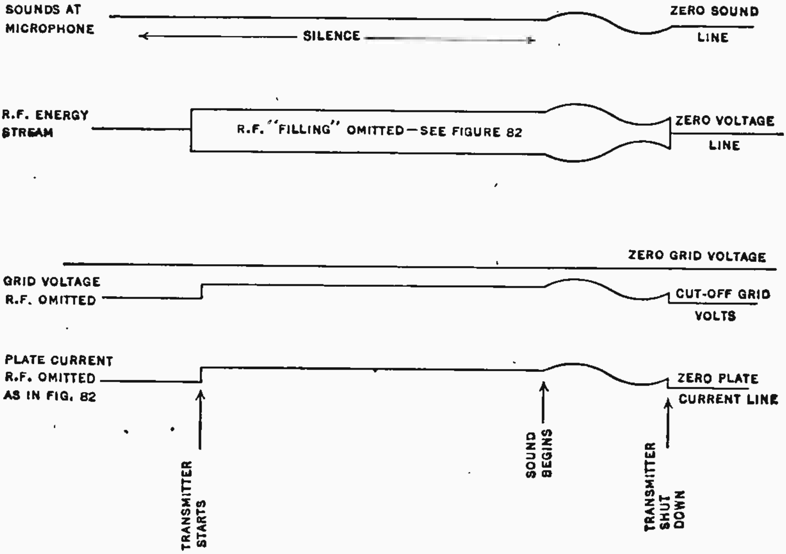


FIG. 84. Bias Detector Action (Compare with Fig. 82).

bination works as in figure 85. Such tubes are necessary only in the first few sockets; after that the automatic volume control has had opportunity to act and the later tubes receive a proper signal level. Variable mu tubes are also especially well suited to automatic volume control because of the difficulty of blocking them through high bias, as explained in the next paragraph.

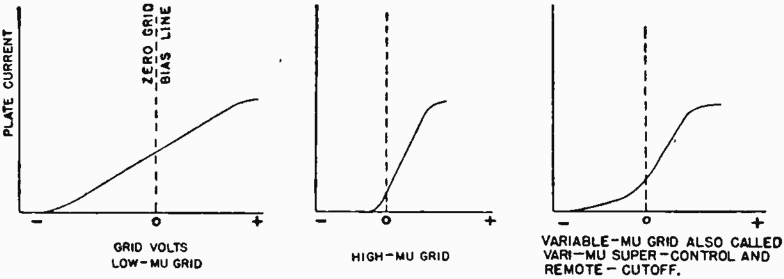


Fig. 85. Comparison of Grids.

10. Automatic Volume Control or "AVC." Also Noise Limiters—It has already been pointed out that both the diode detector (section 4) and the biased triode type of detector (section 8) produce not only audio output but also a d.c. output (equivalent to rectified carrier). Since the d.c. component varies with the strength of the incoming "carrier" it may be used as an added bias on the first tubes of the set if first suitably filtered, and will then have the very useful effect that if the signal becomes stronger (fading upward) the d.c. detector output also goes up, thus increasing the bias-voltage on the first tubes and pulling down their sensitivity (as explained by the last three sentences of section 6) and preventing any large rise in loudspeaker output. This is called automatic volume control or more commonly "AVC." A more exact name is automatic gain control or agc, but this is not yet common.

The methods of applying AVC are very numerous but in effect all consist of passing the detector output through a load-resistor as in figure 86, and at a suitable point tapping it for an audio-output condenser, while at lower points it is tapped for the d.c. gain-control or AVC voltage which is filtered by a resistor of about 1 megohm in series with a wire which then goes back to a condenser of about 1/10 to 1 microfarad capacitance (depending on the speed of action needed), thence through branch wires to the grids to be controlled, the exact circuit depending on a variety of things, but illustrated by any modern receiver circuit. The tubes so controlled should be of variable-mu type to avoid blocking. A good AVC system gives almost uniform output for signal-changes of far more than 1000 to 1 in strength. To avoid loud noises due to the automatically excessive sensitivity when signals fade far down, or when no station is tuned in, the AVC system is often supplemented by another system which blocks the output of the receiver whenever the signals become too weak. The combination is called "Quiet AVC" or "QAVC."

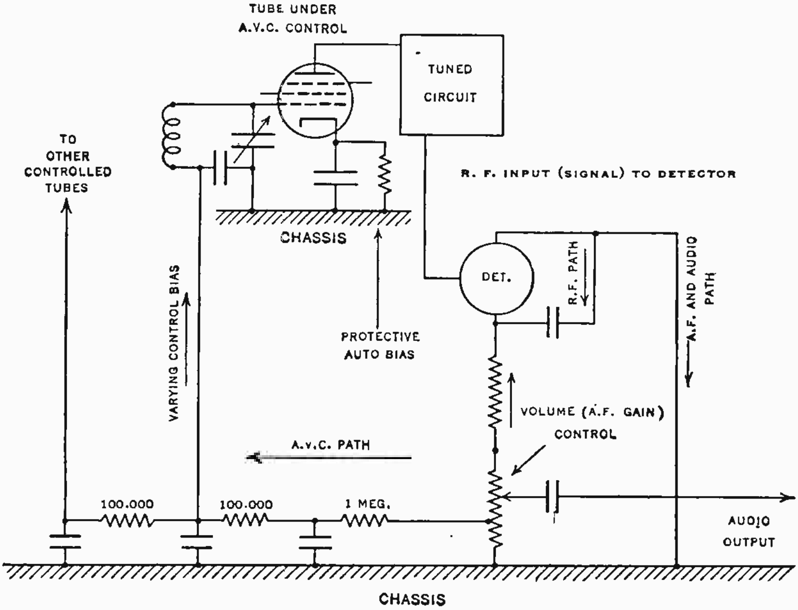


FIG. 86. Principle of A.V.C. or A.G.C. ("DET" is the detector-diode.)

A special case of automatic volume control is that of the noise-reducer circuit, encountered in receivers. The oldest of these was used certainly 25 years ago and was simply a miniature lightning arrester—a gassy diode intended to break down on strong static crashes and by short-circuit replace a "bang" with a silence—or at least with a lesser bang. To do this same thing more perfectly is the objective of noise limiters in general, though the later forms act on noises much nearer the signal level, and accomplish their intentions more completely. Some of them take the form of an actual automatic volume control system, but the action and the principle are as successfully produced and illustrated by the very simple expedient of shunting a portion of a diode detector circuit with a second diode in series with a condenser and a source of bias voltage. The second diode is reversed and tends to short-circuit the detector system whenever a signal or noise produces a detector voltage superior to the bias voltage of the noise-dumping diode. This rudimentary system has been improved in various ways, in general by the addition of more circuit elements which have the purpose of varying the preventive bias automatically with changes in signal level so that only abrupt noise-voltages are dumped through the second diode.

11. Volume Expanders and Compressors—An automatic volume control applied to an audio amplifier is useful in preventing overloadings. In this case it is not operated by a detector's d.c. output, for there is no detector. Instead it is worked by a tube which may—after all—be thought of as a detector, for it works with a high bias and therefore has an output variable with signal level, and therefore capable of being filtered and used as control bias. This is only one of the possible methods. Such devices are used to prevent over-modulation in radiophone transmitters, sometimes with a limited effect for ordinary modulation, and sometimes with an exaggerated effect which makes the speech nearly unintelligible until it has again been "expanded" by another device at the receiver whose nature is to be thought of as the reverse of the compressor. The merit of such operation is that even weak speech-sounds can be made to over-ride noise and static without overloading the transmitter on the sounds which are (before compression) strong.

12. The Classes of Amplifiers. Quick rules for recognizing classes A, B, C and the intermediate classes AB1, AB2, and BC—Amplifiers (whose common basis is explained in section 6) are commonly divided into classes whose engineering definitions appear in the discussions of the following chapter, but which are more easily understood by the student when defined by their more obvious actions and their appearance.

It is first necessary to distinguish between:

Single-sided amplifier stages
Push-pull amplifier stages
Push-push amplifier stages.

A single-tube amplifier is the simplest form of the single-sided amplifier. If more power output is wanted another tube may be connected in parallel with the first, that is plate-to-plate, grid-to-grid and cathode-to-cathode, thus in effect making a tube of double size. For audio work this is satisfactory if small resistors are placed in the plate leads to prevent "parasitic" oscillations between the two tubes, as these heat the tubes and contribute nothing to the output but a "mushy" quality. At radio frequencies this tendency is increased and the need of matching tubes increases. Such stages (single or parallel) may be of class A only for audio, of any class for r.f.

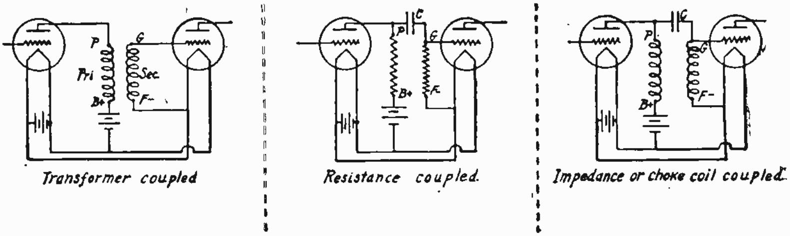


FIG. 87. Methods Used to Couple Vacuum Tubes in an Amplifier.

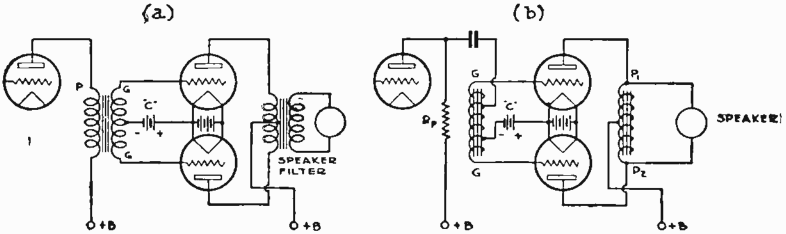


FIG. 88. Push-Pull Amplifier.

Another way of using more than 1 tube is the "push-pull" amplifier in which two tubes are connected as in figure 88. The cathodes are tied together, but the plates are at opposite a.c. voltage though at the same d.c. voltage, similarly the grids. Such a stage produces about double the power of a single tube, but has the very great merit that the a.c: output of the stage has small tendency to escape into the plate-supply-system and thence to enter other amplifier stages. Furthermore any distortion appearing *IN THIS STAGE* at double-frequency is largely cancelled out in the output-transformer. Push-pull stages may be of any class in either audio or radio work.

Still another type is the "push-push" stage (one definition) which is connected as in figure 89. Here it is seen that the grids are as in a push-pull stage but the plates are in parallel for both d.c. and a.c. Such a stage doubles the input-frequency, and is used for that purpose in transmitters.

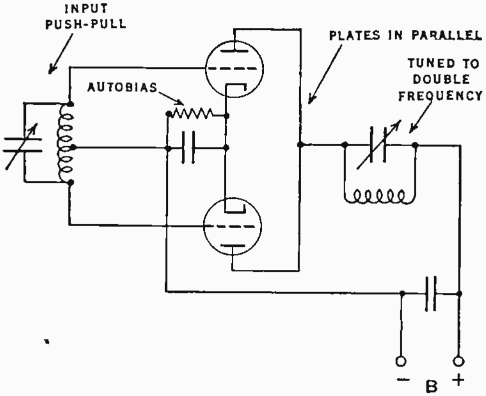


FIG. 89. Push-Push Frequency Doubler.

It is furthermore necessary to recall that in audio work we are always concerned about distortion, while in r.f. amplification we can and do tolerate extreme distortion in the tube habitually for the double reason that the distortion cannot be heard, and that the additional frequencies created by the distortion are readily sifted out by tuned circuits. Hence in general an audio amplifier must be a better amplifier than the r.f. amplifier, and not all classes will pass the requirements.

A pure class A amplifier may use 1 or 2 tubes in a single-sided arrangement or in push-pull, and may employ a wide variety of "interstage couplings," that is the devices which feed the a.c. output of one stage to the next stage. The one sure mark of this type is that a meter placed in the d.c. plate supply lead shows little or no movement even in going from full volume to no input at all. This steady plate current unfortunately heats the tubes to no profit, and the efficiency at full volume is seldom 20 percent.

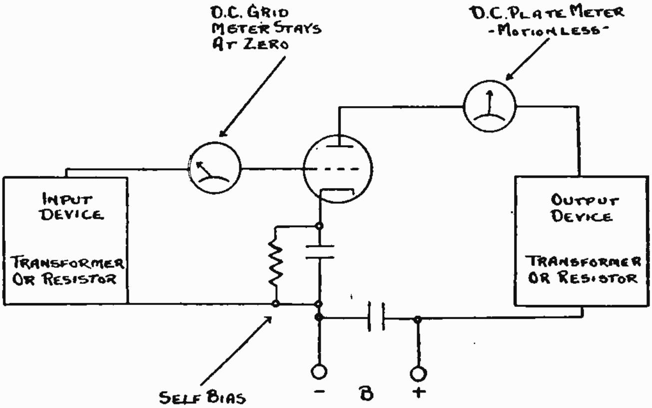


FIG. 90. Class "A" Audio Amplifier in Action (May also be Push-Pull).

Good fidelity is possible with good materials and design, *if low-mu triodes are used when working into variable loads* such as loudspeakers—that is in the stage feeding this type of load. Fixed loads are less exacting. No. d.c. grid current can be found.

A class AB amplifier differs from the foregoing in degree rather than by sharp division. The plate current varies with signal-level, but the extent of the variation differs very widely with the tube-type. The bias used is larger and the "resting" plate current smaller than for class A for the same tubes (consult manufacturer's tube table), hence the heating is less, efficiency greater and output 150 to 200 percent that of class *A*. The stage is always push-pull for audio, and seldom used for radio. The fidelity, with proper design, is not materially below class *A*. In the lower part of the range no grid current appears (d.c. meter in bias lead). This is the "*AB*1" region. For larger signal-swings (*AB*2) small grid currents appear and actual power must be supplied by the preceding stage which accordingly feeds this stage through a transformer without step-up and usually with a step-down—that is with secondary turns equal to or fewer than the primary.

A class B stage is difficult to distinguish from *AB* since the plate-current swings may be either less than or more than those of class *AB2*, depending altogether on the type of tubes used. Class *B* operation is clearly intended if the tube tables and the voltmeter show that the bias used is near the "cutoff" value. Likewise class *B* operation is intended if the tubes are of a very-high-mu type operating with no bias whatever. Ordinary meters do not permit noting the *REAL* difference between this type of operation and the preceding classes, namely that the class *B* tube works on only 1/2 of each a.c. grid-input cycle, so that the output of one class *B* tube is an amplified *AND RECTIFIED* copy of the input. For r.f. amplification this does not matter as the tuned plate circuit acts as a pendulum and supplies the other half-swing, but for audio it is necessary to use two class *B* tubes back-to-back, which is to say push-pull, supplying alternate half-cycles. They must be *MUCH* better matched than in either *A* or *AB* in order to give good fidelity. A class *B* audio push-pull pair will deliver about 5 times the output of the same tubes in class *A*, or 2 1/2 times the class *AB* output. When used in r.f. such a stage generally follows a modulated tube and as will be seen in the next chapter, the output is then somewhat less, usually about 80 percent of that just stated, the values being at full audio level for the transmitter in question.

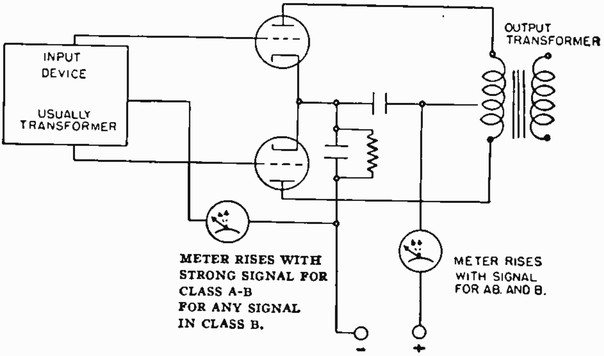


FIG. 91. Class A-B and Class B Audio-Amplifier in Action.

The class C stage appears in r.f. work only, and differs from all the preceding in the use of an extremely high bias, equal to at least *TWICE* the cutoff value, and furthermore in the use of a *STEADY GRID INPUT* or excitation, also made very high. Offhand this appears to leave no possibility of anything but a steady r.f. output, and in fact class *C* stages are used just so for telegraphy, by merely cutting off the grid input when the key is "up," whereupon the high bias stops all tube action.

13. **Modulation**—Class *C* stages have another use. With the grid input both fixed and high, it is obviously still possible to vary the output by raising or lowering the d.c. voltage of either the grid or plate (for a triode). This can be done by connecting an audio amplifier to a transformer whose secondary winding is in such a d.c. supply lead. Thus the d.c. passing through the transformer secondary will have the audio voltage alternately added to it and subtracted from it, varying the tube-elements voltage and hence the tube output, the variations being "in a voice-frequency manner" (figure 92). This operation of "modula-

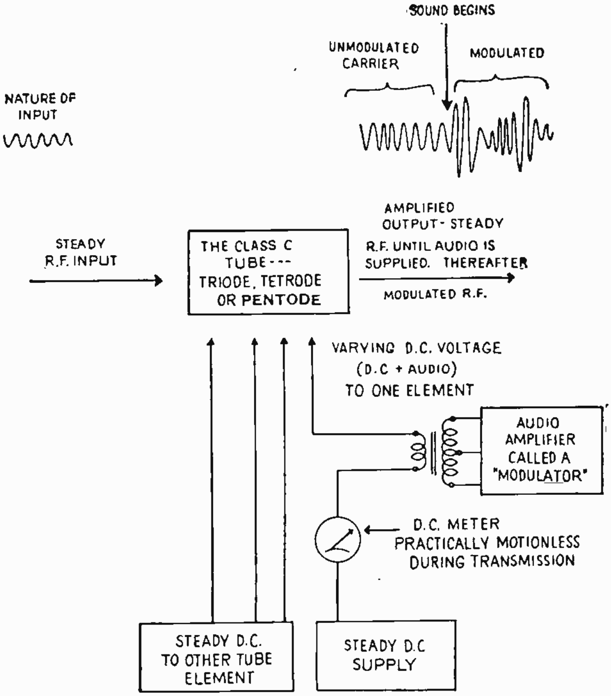


FIG. 92. The Principle of Modulation by Variation of the Voltage of a Tube Element. (Depending on the element the result is plate modulation, plate-screen modulation, screen modulation, input grid modulation or suppressor grid modulation. The output is of the same nature for all methods.)

tion" can be applied not only to the grid or plate of a triode, but also to the screens, suppressors and other elements of the more complex tubes mentioned later. Plate modulation requires the most audio power, but it also produces the most output from the transmitter. Suppressor-grid-modulation and input-grid-modulation are at the other end of the list in both regards.

14. Regeneration and Degeneration—Since the output of an amplifier stage is greater than the input it is of course possible to return a portion of the output to the grid for further amplification, thereby increasing the "gain" accomplished by the stage. The return of output voltage to the input grid is called "feedback" or "regeneration." Since it is possible to reverse the direction of the feedback voltage, we may also use this device to oppose the grid-voltage and thus reduce the stage-gain, which process is called "reversed feedback" or "degeneration." The several very important uses of both regenerative and degenerative feedback are now to be taken up.

15. The Regenerative Detector—It will be recalled that in the detector discussions of sections 7 and 8, the amplified r.f. appearing in the plate circuit was intentionally wasted by returning it to the cathode. Where unusual detector sensitivity is essential, as for example in the case of a 1-tube or 2-tube receiver, this r.f. in the plate circuit may be utilized regeneratively by means

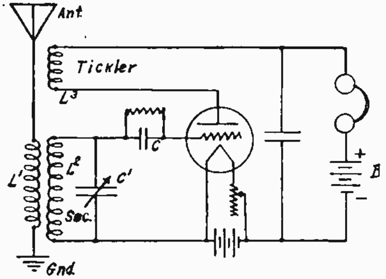


FIG. 93. Regenerative Detector Circuit.

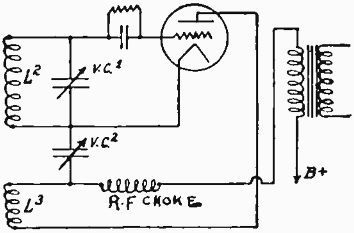


FIG. 94. Capacitive Control of Regeneration.

of such circuits as are shown in figures 93 and 94. The coil L_3 in the plate circuit, known as a "tickler," carries the complete plate current, that is d.c., r.f. and audio, but has only a few turns so that its audio effect is negligible, and its d.c. effect practically zero. It is however large enough to act as the primary of a radio-frequency transformer when brought near the coil L_2, which then acts as the transformer secondary and returns a portion of the plate-power to the grid. Control of the regeneration is accomplished by moving L_3 to and from L_2 or by varying the condenser in the plate circuit so as to change the impedance which it offers to the r.f., and thus control the size of the r.f. current in the plate circuit. The two circuits shown are only apparently different.

This is an excellent example of regeneration at one frequency (the r.f. carrier frequency), without regeneration at other frequencies. Nearly all of our regenerative and degenerative effects are greater at one frequency than at others—either intentionally or accidentally.

The regenerative detector may be easily made 50 to 100 times as sensitive as the non-regenerative detector, but is correspondingly easily overloaded and critical in action.

16. Regeneration by Plate-loading—An altogether different way of securing regeneration is possible, and is unintentionally the cause of most circuit instability in both receivers and transmitters. If any amplifier tube be given a plate-circuit load of large impedance at the working frequency—that is a circuit tuned near (not exactly to) the working frequency, or a coil having a great number of turns so as to present great inductive reactance at the working frequency, then the tube is able to create a considerable voltage across this load at the working frequency. Looking at figure 95 one will see that there is connected across this load-voltage two things in series, namely the grid-input circuit and the small condenser which consists of the grid and the plate. The action can be illustrated by an intentionally exaggerated case. Let us suppose that the frequency is 1,000,000 cycles per second, that the tuned grid circuit has an impedance of 250,000 ohms at the working frequency, and that the plate-to-grid capacity (com-

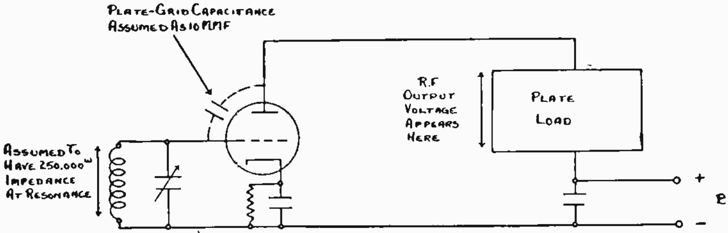


Fig. 95. Exaggerated Case of Feedback.

monly written C_{pg}) is 10 micro-microfarads, which capacity at 1,000,000 cycles presents a reactance of about 16,000 ohms whereupon the r.f. plate voltage "feeds back" through the plate-grid reactance of 16,000 ohms and the portion appearing across the tuned grid circuit is evidently:

$$\frac{250{,}000}{250{,}000 + 16{,}000} = 94\%.$$

As first stated, this is a greatly exaggerated case, to stress the point, which is that feedback through the plate-to-grid takes place *whenever the plate load is high enough* and of the proper sort, *the second requirement being quite as important as the first.* Unfortunately this is just the condition under which the highest amplification is secured in a tuned r.f. amplifier, so that high gain and a tendency toward regenerative instability are always walking the same trail, the effect increasing with frequency because the reactance of the plate-to-grid capacity is falling, and making feedback easier.

Furthermore no plate load remains the same at all frequencies, hence irregular variations of regeneration are the rule. Thus transformer-coupled amplifiers commonly have a "bump" in the amplification gain in the vicinity of 7,000 to 12,000 cycles, where the transformer falls into tune with the frequency and thus becomes a higher load, productive of feedback on this account and also because it is now productive of the proper phase of feedback.

17. Effect of Phase-shift on Regeneration—It has already been stated that if the feedback-voltage be reversed the effect is degenerative, rather than regenerative. In departure from in-phase (that is in step or additive) feedback is therefore a departure from the strongest regeneration so that feedback due to the plate

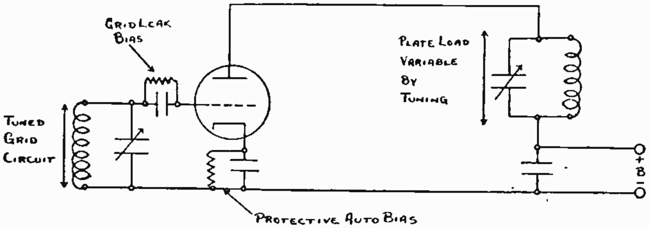


Fig. 96. Armstrong Circuit. By Tuning Plate Circuit Near Resonance Large Regenerative Amplifier Gain or Steady Oscillation May Be Produced at Will.

load depends not only on the size of the plate load, but also on the nature of its reactance. This is readily illustrated by the Armstrong-circuit of figure 96. Here the plate load is a pure (and very high) resistance when the plate circuit is tuned to exact resonance, and may be made either capacitive (reactance) or inductive (reactance) by detuning to one side of resonance, or the other. The result will be found to be a wide variation in efficiency. A variant of the system is the ingenious arrangement of figure 97, due to K. E. Hassel. In this case the tuned circuit loading the plate is the tuned-grid of a following amplifier stage, but it is related to the plate only magnetically, that is by transformer action. As the receiver is tuned toward higher frequencies the regenerative tendency normally increases as already stated, but this is counteracted by connecting the movable plate coil mechanically to the tuning condenser, so that it at the same time retreats from the tuned circuit, thus lessening the plate load and limiting the regenerative tendency, both by changing the nature of the plate load and by changing its size.

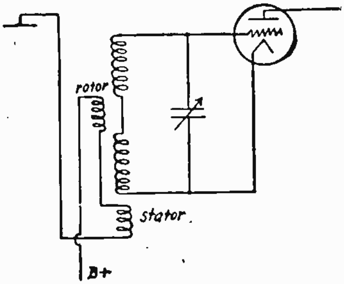


FIG. 97. Hassel's Method of Variable Coupling.

A more deliberate attempt to shift regenerative feedback into degenerative feedback is that shown in figure 98, this form of the reversed-tickler idea being due to Mr. Robert Miner, and the operation being apparent from what has gone before. In both this and the Hassel arrangement the thought is to design the amplifier load so as to produce a strong regenerative tendency,

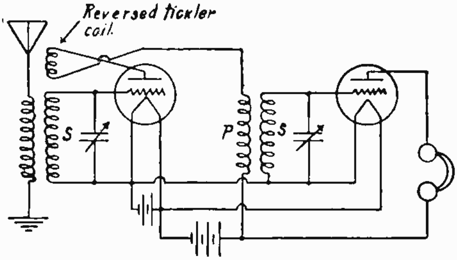


FIG. 98. Tuska's Reversed Feed-Back Circuit.

and then to use the control to limit this action. The decreased cost of tubes and parts has minimized the use of such devices.

18. Regeneration in Transmitters—In the r.f. amplifier chain of a transmitter most of the tubes have plate loads consisting of tuned circuits set for the maximum output, which is also the favorable condition for maximum regeneration and instability. In most of the stages this regeneration is not wanted, hence transmitters commonly have anti-regenerative devices applied to most of their r.f. stages.

19. Anti-regenerative Devices for r.f. Amplifiers—Except for the Miner and Hassel circuits of section 17, anti-regeneration systems depend on providing an additional feedback path external to the tube but of reverse nature, so that the regenerative feedback through the tube shall be met at the grid by an equal and opposite degenerative feedback. To accomplish this there have been devised a considerable number of "neutralizing" or "balancing" circuits, differing in their complexity, ease of adjustment and ability to stay in balance with changes of frequency, or temperature. A number of such circuits have the common nature of becoming less well balanced when the operating frequency is changed, as in tuning a receiver—either because the circuit is inherently incapable of remaining balanced except at one frequency, or because it is not possible in practice to attain theoretical conditions. Depending on the circuit and the adjustment it is possible to cause regeneration to rise with rising frequency, or to fall with rising frequency, the latter being preferable as it compensates for the slope of the gain-curve due to a changing L/C ratio—that is the tendency of an r.f. tuned amplifier to amplify less at that end of the range where more capacity (but the same coil) is operative. It is also quite practical to use different neutralizing circuits in different stages of an amplifier system, such as that of a receiver, though this is mainly of historical interest as the need of receiver-tube neutralizing is essentially historical since the arrival of the tetrode and pentode tubes. Our interest here, accordingly, is confined to the neutralization circuits which are of use in the r.f. amplifiers of transmitters where triodes still prevail to some extent for cost reasons.

20. Neutralization Circuits Used in Transmitting r.f. Amplifiers—Figure 99 shows the Rice neutralization circuit as used in two successive stages. Let us consider the first, or left-hand, stage alone. The coil T_1 has received r.f. energy from an outside source at a frequency to which it is tuned by the variable condenser across its terminals. The upper half of the coil feeds the a.c. voltage to the grid and cathode and amplification proceeds in the usual way, producing an amplified a.c. voltage across the coil T_2. A portion of this voltage now returns to the grid through the plate-grid capacity, which has been drawn in as a "real" condenser C_1. If that were all, the stage would be highly regenerative and unstable. However, at the same time some of the voltage from the upper end of T_2 is being returned through the "neutralizing condenser" C_n to the end of T_1 which is *opposite* the grid, thus opposing the voltage which returned to the grid via C_1. Another simple way of explaining the opposition and cancellation between the feedback voltage via C_1 and that via C_n is that the tuned coil T_1 acts as a species of electrical see-saw, pivoted on its center-tap. Like any see-saw it tends to come to rest if both ends are pushed down at the same time. Thus the undesired grid voltage is cancelled and only that arriving legitimately from the previous stage (not shown) operates on the grid.

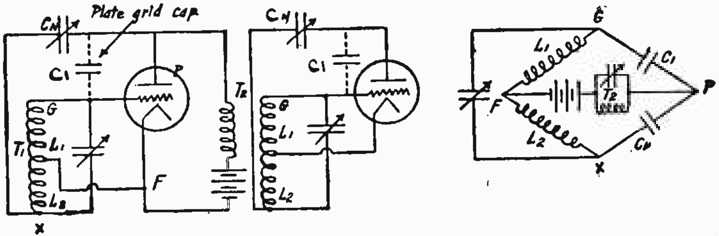


FIG. 99. Rice Circuit Employing Wheatstone Bridge Circuit for Stabilizing a Radio Frequency Amplifier.

At the right of the figure the Rice circuit is shown re-drawn as a Wheatstone bridge for the benefit of those familiar with that device.

If the tap on the coil T_1 is at its center, and the coil as well as the tuning-condenser have been placed symmetrically with respect to the cathode circuit and other near-ground-voltage devices, it is seen that the capacity of C_n will be equal to that of C_1. Since these conditions are not quite true in practice, and since C_1 varies between tubes of the same type, the condenser C_n is commonly made adjustable. Its proper adjustment is found by cutting off the plate-supply voltage (which must have a bypass condenser so the circuit remains closed for r.f.), feeding a strong signal into the stage and adjusting C_n so that this signal does not appear in the plate circuit, as tested by a low-range r.f. meter connected to a single turn of wire held near T_2. The stage must be in tune. For very strong signals the test-device may be a lamp connected to the single turn of wire, and for very weak signals it may be some sort of a receiving device, whereupon the signal preferably is tone-modulated for ease of hearing. If the adjustment is properly made the plate-supply voltage may be restored (after displacing the delicate indicator), and the plate current will then show no sudden changes as the stage is tuned.

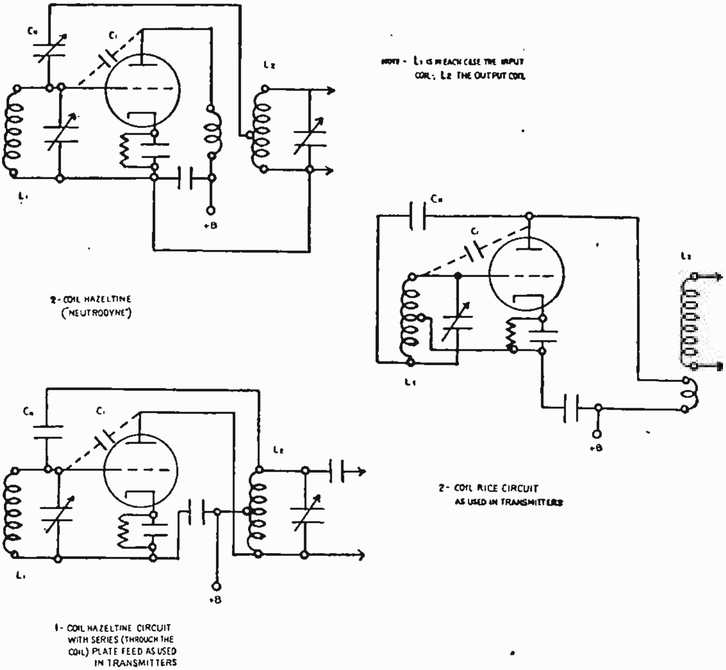


FIG. 100. Neutralizing Circuits Used in R.F. Transmitting Amplifiers.

Figure 100 shows the comparison between the Rice and Hazeltine neutralizing circuits. The latter is in effect the Rice circuit transported to the plate side of the tube. Here the action is that from one end of the plate-load (the tuned circuit is also called a "tank" in an r.f. amplifier) an r.f. voltage returns through C_1, while from the opposite end of the plate load an opposite voltage returns to the same grid, cancelling the original feedback. Again the feedback condenser C_n has the same capacity as that of the tube if the conditions mentioned in the preceding paragraph are met with. The adjustment method is similar.

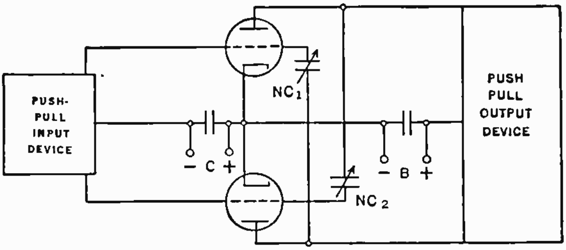


FIG. 101. Ballantine Cross-Neutralization of a Push-Pull Stage. (The grids are normal, being shown double-ended solely to simplify the diagram.)

Figure 101 shows the Ballantine method of cross-neutralizing a push-pull r.f. amplifier stage. Study of this circuit will show that if one of the neutralizing condensers be removed both tubes will still be capable of neutralization by readjusting the remaining neutralizing condenser. In this condition one of the tubes is Rice-neutralized and the other is Hazeltine-neutralized, but the adjustment is rather delicate and tends to go out of balance with changes of voltage as in modulation or with small changes of tuning. The complete Ballantine circuit is superior in these regards. For tubes which are fairly well matched it is quite possible to tie the two neutralizing condensers together mechanically (but not electrically) so as to give 1-control neutralization.

Numerous other neutralization circuits are possible and some have been used extensively, especially the R.F.L. circuit, which was probably employed in more receivers than any other. An unusual facility in adjusting the frequency-versus-regeneration curve was provided by the Phelps circuit.

21. Regenerative Oscillators, Using Vacuum Triodes—From what has been said in foregoing sections the student will see with some readiness that the normal tendency of a triode amplifier is to regenerate when provided with a load of adequate size and of such nature as to permit high amplification. If no brake is applied, the regeneration tends to feed back enough voltage so that the grid swings rise rapidly in amplitude, with a consequent rise in the a.c. plate voltage, as in figure 102, until the swings are as wide as permitted by the plate-supply voltage and the cathode emission. The tube is now "oscillating."

Figure 103 shows various circuits capable of providing dependable regenerative oscillation. Other oscillators using triodes, tetrodes and pentodes are shown in figures 107, 114 and 115. They are all seen to depend on one of two basic ideas, already touched on in previous discussion:

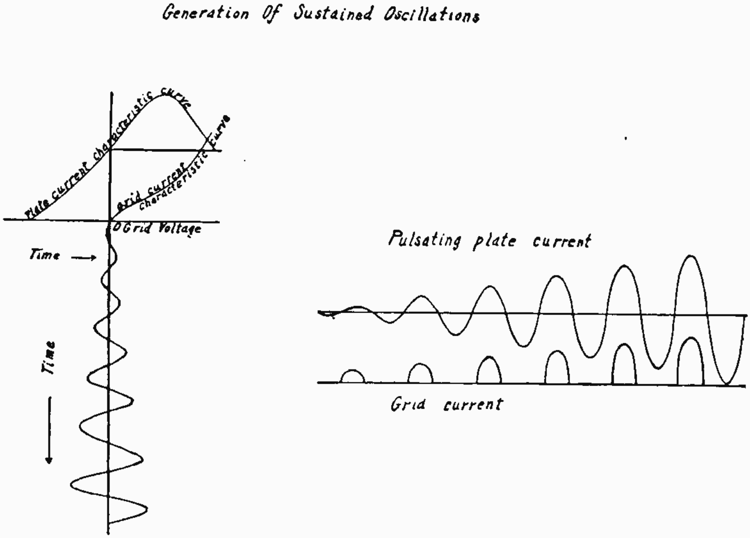


FIG. 102. Characteristic Curve of Vacuum Tube Employed as a Generator of Sustained Oscillations.

(*a*) A tuned circuit is provided with the grid and plate connected to opposite ends thereof so as to maintain them at opposite a.c. voltages, while the tube swings or oscillates. The feedback is via the tuned circuit.

(*b*) A tuned circuit is placed in one branch (grid or plate) and the other one is provided with either a high impedance or another tuned circuit adjustable as to resonance-frequency (tunable) so that it may be made to have a high inductive reactance. The feedback is via plate-grid capacity.

(*c*) A tuned circuit is placed in one branch but the other is coupled to it magnetically to give action equivalent to (*a*) above.

(*d*) A tuned circuit is replaced by a quartz crystal plate.

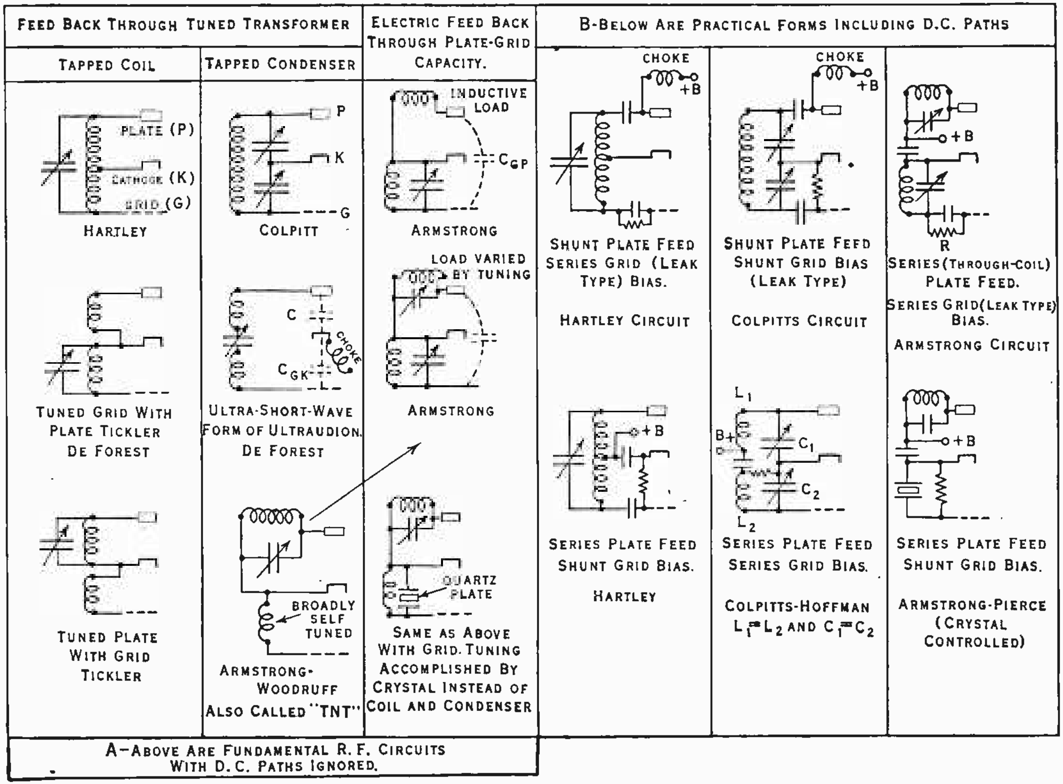


FIG. 103. Regenerative Triode Oscillators for Tetrodes and Pentodes (See Fig. 107).

In modern transmitters these oscillators appear mainly as mere drivers of a 2, 3 or 4 stage amplifier system, and do not generate much power on their own account. This permits the use of a small oscillator tube, protected from temperature changes by a suitable enclosure, and from voltage-changes by a small independent plate supply. It is thus able to provide exceptional frequency stability, keeping the station well within the authorized frequency tolerance. The crystal-controlled oscillators offer especial advantages in this regard. It is quite possible for a tube to oscillate at two frequencies at the same time. See figure 114. Attention is also drawn to the more complete oscillator discussion in the following chapter.

22. Frequency and Power Limits of Vacuum Triodes—In most tube applications the limit as to power-output is set by heating of the tube, though it is also possible to encounter difficulty with the tube's insulation, or to injure the filament, while heating does not appear excessive. These latter difficulties are usually met when working the tube with small plate current, high plate voltage and grid bias, and very strong excitation (very large a.c. grid input). Under these conditions the plate current consists of very brief pulses, much less than 1/2 cycle in duration, but of very great momentary amplitude. These pulses are quite capable of damaging the filament and quickly reducing its emission. Caution is therefore necessary when attempting to operate triodes in the manner indicated, whether for the purpose of frequency-multiplying, or for the purpose of securing exceptional r.f. output. The advice of the tube maker is very valuable in this connection.

As the frequency is increased there arrives a point at which the tube must be worked at lesser voltage to avoid gradual or immediate damage. This is due to the fact that the tube does have internal capacities, and that as the frequency rises, more and more r.f. current is sure to flow through any condenser, tending to heat the same if it is not massive, and of exceedingly low losses. Thus as the frequency rises a larger and larger share of the entire r.f. current flows through the tube capacities until a number of amperes may be flowing through the grid, though its d.c. grid current is perhaps 1/10 of an ampere. As the heat-dissipation permissible in the grid is limited, the voltage must be lowered gradually, with lesser output as a consequence. Follow the maker's recommendations.

Another effect enters here. Not only does the tube-capacity-current flow through the vacuous space; it also flows through any insulation material lying between two tube-elements—even via por-

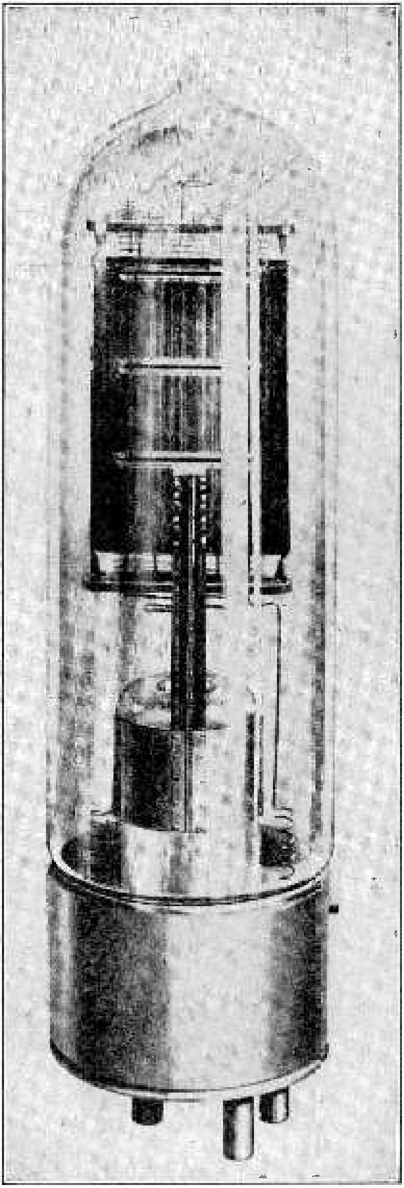


FIG. 104. Western Electric 250-Watt Power Tube.

tions of the glass envelope, or the tube-base. Older tubes were frequently destroyed by the resultant local heating when used at higher frequencies but recent tubes are designed to avoid such losses.

Finally there is a frequency limitation due to the length of the wires passing from the tube elements to the outside of the tube. Illustrative of the importance of this limitation are the two tubes known as type 800 and type 834, both of a high-frequency type, but of different design-date. The grid-plate and grid-filament capacitances of these two types differ very little, but the 834 has its grid and plate placed near the top of the bulb and "brought out" through thick and short wires as opposed to the long and thin wires of the 800 type. The 800 works at maximum rating for frequencies as high as 100 megacycles (millions of cycles) but the 834 continues to 170 megacycles—nearly another octave—before requiring reduced operation. The highest possible frequency for the two tubes is 300 and 500 megacycles respectively.

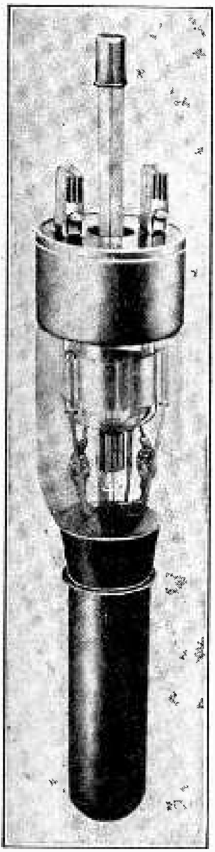


FIG. 105. Western Electric 5-K.W. Water-Cooled Power Tube.

23. Water-cooled Tubes—Water-cooled tubes do not differ as much from air-cooled tubes as their appearance, figure 105, suggests. One end of the tubular plate has been closed by a metal head, and the opposite end by a sort of glass cork through which the grid and cathode leads enter, the actual cathode and grid occupying the usual positions inside the plate. As opposed to a complete glass enclosure this construction has the advantage that the plate is exposed and can be cooled by water flowing around it through a metallic water-jacket in which the tube rests on a flange provided for that purpose and made tight by a rubber gasket. The much more rapid removal of heat makes possible much larger outputs for the same size of tube (though the filament must be larger) and also makes possible much larger vacuum tubes.

Water-cooled tubes are at a disadvantage for very high frequencies, partially because of the mass of metal which forms the water-jacket, but recent forms will operate at quite high frequencies.

Water-cooled tubes are in many cases provided with airblast cooling of the glass portions, and there have been designs in which water is led into hollow grid and plate structures to cool them. Such devices are due to the necessity of disposing of the heat liberated by the filaments, which amounts to a number of kilowatts in the larger tubes.

24. Safe Dissipation Limits—The "plate dissipation" is that power which is left on the plate as heat, and must be removed by the cooling water, or in the case of an aircooled tube must be removed by radiation through the glass envelope, possibly with the aid of an airblast directed on the glass to wipe away that share of the heat which fails to penetrate the glass in radiant form. The power originally fed into the plate is:

Watts plate input = Plate supply voltage × plate input amperes. Neither the voltage nor the current should exceed the manufacturer's rating for the type of service intended. The widespread impression that it is economical to over-run tubes is true only if one is making a definitely temporary use of the equipment; it cannot be substantiated for long-time operation.

The "Plate circuit efficiency" or "conversion efficiency" is the fraction of the input power which emerges as output, and is usually stated in percent efficiency.

This leaves the portion of the input which has not been converted into output, hence stays in the tube as heat and constitutes the main limitation of tube operation. *If this dissipation cannot be kept below the limit recommended by the manufacturer the input must be reduced for best life.*

Excessive heating of the plate (in particular) may result in damage to the tube, either by the release of gas and destruction of the vacuum, or by reducing the insulation of the tube and leading to early failure by internal short circuit, or by cracking of a seal and the admission of air with the consequent oxidation of the filament—giving the familiar milky white smoke and burnout. Indirect damage may be done to the filament without actual cracking and leaking.

Excessive heating of other elements is also quite possible, hence both the d.c. *and the r.f.* currents to all grids must be kept below recommended limits.

GRAPHITE PLATES DO NOT SHOW COLOR UNTIL THE LOSSES FAR EXCEED SAFE LIMITS. EVEN A FEW MINUTES OF DULL-RED OPERATION SHORTEN THE TUBE LIFE GREATLY.

25. Reactivation of Damaged Filaments—The oxide-coated type of filaments, once damaged, is incapable of repair unless the tube is sent to a repair shop, opened and re-worked. The active coating has been stripped from the surface of the filament.

However the alloy type of filament (see section 1) known as "thoriated" may have suffered no damage save to have the thorium stripped from the surface layer at a rate too great to permit replacement by diffusion from inside the filament. In this case "reactivation" may be attempted as follows:

(*a*) Remove all voltages from the tube elements except the filament.
(*b*) Operate the filament at normal voltage for 20 minutes.

If this does not effect a remedy "flashing" and "seasoning" may be tried:

(*c*) Operate the filament at 300 percent normal voltage for 30–60 seconds. (This is flashing.)
(*d*) Season at 150 percent normal voltage for 10 minutes.
(*e*) Restore to normal operation. If still low—discard. Some burnouts will take place during treatment.

Warning: Oxide-coated or indirectly-heated cathodes are injured severely by this treatment—be sure of the type. Pure tungsten cathodes will *certainly* be burned out, and cannot possibly be benefitted by treatment. If they fail to produce emission at normal voltage the tube is defective in some other regard, and must be repaired or discarded.

26. Other Types of Vacuum Tubes—Tetrodes, pentodes, hexodes, etc.

In addition to triodes there are other tubes having more internal elements to facilitate certain actions—though it is a rather good rule that a triode can do anything done by other tubes, though not necessarily as well.

In section 16 it was shown that feedback (regeneration) is a limitation on radio-frequency amplification and that regeneration takes place because there is capacity between the grid and plate of any triode. If this capacity can be destroyed, or kept from acting, regeneration ceases and more amplification becomes possible. A very old device for stopping capacity effects is to interpose a sheet of metal—but this would also stop the electron-stream or plate current. Hence there is used instead a perforated sheet of metal—that is a screen instead of a shield. The electrons are to some extent able to proceed by flying through the holes of the screen, but tend to stick to the screen, charge it negatively and thus "block" the tube. To prevent this they are led away by a wire returning to the cathode. However this alone does not suffice to give free electron-flight, which is accordingly encouraged by cutting the plate wire and placing in it a "screen voltage supply" feeding d.c. to the screen at a voltage from 1/3 to 2/3 the plate voltage. This causes the screen to catch more electrons, which is a pure power-waste, but also increases the plate current to a value more nearly approaching that of a triode, in fact materially exceeding that of a triode of the same high-mu as the tube which has just been described. This tube, with the "screen grid" added, is seen to have 4 elements (cathode, grid, screen and plate), hence is called a "tetrode" (figure 106). Its main utility is in r.f. amplification, where it permits very high gain without neutralization. However, see sections 27 and 28.

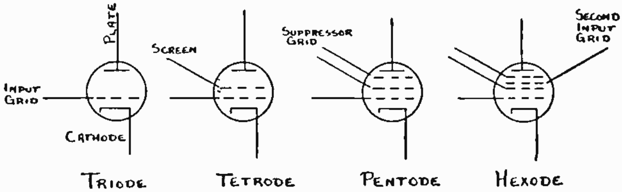


Fig. 106. Various Tube Types.

The "pentode," also shown in figure 106, has one more element, which is placed between the screen and the plate. This also is a screen and is *usually* connected back to cathode without d.c. voltage. It is called the "suppressor grid" because it suppresses certain bad effects in the tetrode, and rather beyond this book. In general a pentode will give about twice the r.f. or audio gain obtained from a similar tetrode. In receivers it is largely used in place of tetrodes.

27. Special Tetrodes and Pentodes—Audio-frequency tetrodes and pentodes differ materially from the types just outlined, since they are required to deliver power instead of merely working as voltage amplifiers. They must accordingly be constructed to draw materially large plate-current inputs which usually (and in this case also) implies a somewhat lower "mu."

"Beam power" tubes are tetrodes of a special type.

28. Audio Tetrode and Pentode Loads and Distortions. Correction by Intentional Reversed Feedback—It was suggested in section 12 that among the triodes the low-mu variety is most tolerant of varying loads, that is able to work into a variety of loads without great changes in output or in the percentage of distortion. High-mu triodes do not have that facility, and neither do audio tetrodes and pentodes, all of which rise rapidly in distortion when the load is incorrect. When working into a " dead resistance " load such as the modulated stage of a radio transmitter, this is not very serious—but it becomes extremely serious when the load consists of loud-speakers whose impedance not only rises at higher pitches, but dips and falls at intermediate frequencies. Two remedies are commonly used:

(*a*) The irregular load is "swamped" by connecting across it a " dead resistance " load or a load which rises when the other load falls.

(*b*) The circuit is given an intentional feedback, going back 1, 2 or 3 stages. Any frequency receiving excessive amplification then feeds back exceptionally strongly also and reduces the damage. The feedback circuit may of course be designed to suppress or favor certain frequencies. The gain of the amplifier is thus reduced and another stage or so must be provided with proper care that the benefit is not thereby destroyed.

29. Composite Vacuum Tubes. Hexodes, Pentagrids, Diode-pentodes, etc.—An essentially endless variety of tubes is possible by combining several tubes in one envelope. In most cases this provides mere mechanical compactness and does nothing which could not be done by connecting ordinary diodes, triodes, tetrodes and pentodes. Of this classification are such tubes as:

Plate-supply rectifier and power audio tube in one envelope.
Detector diode in same envelope with amplifier triode, tetrode or pentode working at r.f. (ahead) or audio (after) the detector.
The same with a double diode (duo diode).
Two triodes in same envelope for use as push-pull stage or for resistance-coupling as 2-stage amplifier.
Two triodes of different type in same envelope permanently connected as voltage stage driving power stage.

and various others here and abroad.

There are, however, some types which accomplish results not equally well attained by independent tubes. A notable example of this is the "pentagrid converter" outlined in section 30.

30. The Dow Electron-coupled Oscillator. Also Pentagrid Tubes—Consider a triode whose plate is made of wire mesh. Some electrons will penetrate this mesh, and if the triode is made to oscillate it is clear that the electron-stream coming through the mesh will be pulsating. This pulsating electron-stream may be caught upon a plate placed beyond the mesh-plate. This second

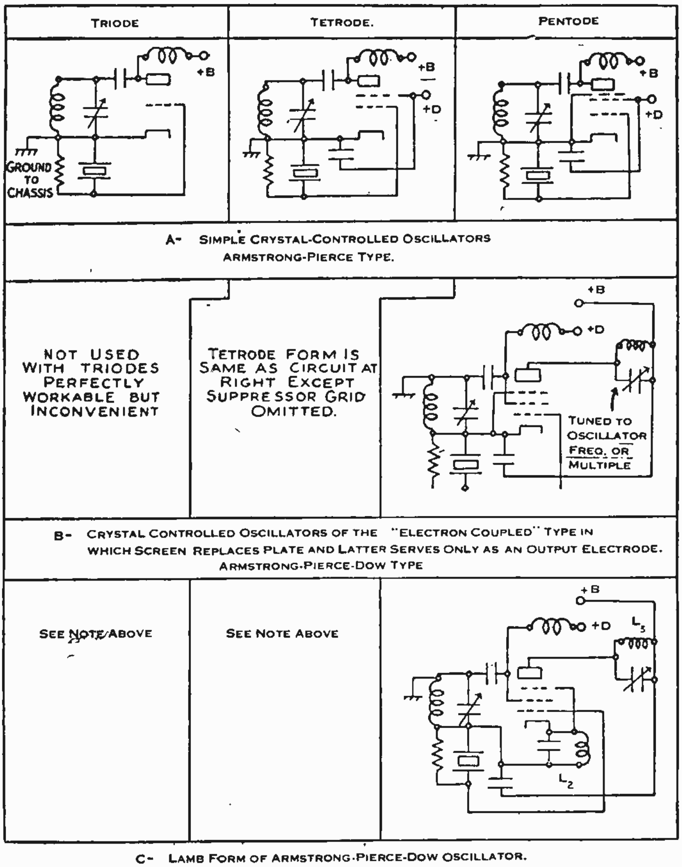


FIG. 107. Pentode and Tetrode Oscillator as Illustrated by Crystal-Controlled Variants of the Armstrong Circuit.

plate is kept at a higher voltage than the first and now receives a pulsating electron-stream which of course emerges from the second-plate connecting lead as a pulsating plate-current, the pulsations of course being at the frequency at which the triode is oscillating. The combination of a triode with a mesh-plate, backed by another plate, is nothing but an ordinary tetrode, the mesh-plate being the screen. The circuit can be modified in a great many ways without losing the fundamental advantage that the output element (plate) is connected to the oscillator only by "electron coupling," hence the oscillator is relatively well protected against outside influences such as changes of load. Figure 107 shows some circuit forms, all rather manifest descendants of the oscillators of figure 103, section 21, with the "ground" moved to the screen to give the best protection against unwanted screen-to-plate coupling other than the desired electron coupling.

Dow oscillators, like others, produce a highly distorted wave form when oscillating strongly, hence numerous additional "harmonic" frequencies (multiples of the original frequency) are present and can be derived by merely equipping the plate (output) circuit with a circuit tuned to the desired harmonic. Further strengthening of the harmonic is possible by the means suggested in figure 107*C*. The coil L_2 is tuned so as to present reactance at the grid-circuit frequency (not to resonance), while the coil L_3 is tuned for maximum output on the desired 2nd harmonic frequency, i.e. double the oscillator frequency. The matter may be carried further by adjusting for the 4th harmonic (quadruple frequency) and output may be secured on other frequencies also. The peculiar fitness of the Dow type of oscillator lies in the relative independence of the oscillator from these other adjustments.

The Dow oscillator has at times been explained as consisting of a triode oscillator plus a tetrode amplifier and some forms have been given names intended to describe this rather fanciful concept. Such terms are "pen-tet" and "tri-tet," may be excused as a part of a radio-industry fashion for giving each circuit-variants a name for purposes of publication or sale.

31. Other Types of Vacuum Triode Oscillators. Barkhausen-Kurtz, Magnetron and Other Non-regenerative Types—The oscillators so far described all depend upon regeneration, that is they are amplifiers in which a portion of the output is returned to the grid to secure continued swinging. In addition to these we have another class of oscillators using vacuum tubes. These are the types in which we do not merely vary the size of the electron-stream as it passes from cathode to anode, but rather stop the electron in its progress anode-ward and cause it to zig-zag in the vacuous space. These zig-zags may be made very short, hence the oscillation-frequency may be made very high.

One form of such oscillation is that of the Barkhausen-Kurtz oscillator of figure 108. This is a triode oscillator but the grid is positive and eventually captures all the emitted electrons, which is normally a plate function. Therefore the grid current is large, the grid heats strongly, and the tube must be worked at very small power. The plate is negative and serves to drive back the electrons which fly through the meshes of the grid, whereupon it is presumed that the electrons zig-zag their way back to the grid. The frequency of the zig-zag is determined mainly by the tube dimensions and voltages, but is influenced by any circuit connected to the tube and tuned near the oscillation-rate or some multiple of it. With proper tuning this output circuit materially strengthens the effect, but only a few watts at best are obtained at the "centimeter waves" for which this oscillator is employed. Fortunately such wavelengths are useful only for beam transmission to distances not much beyond the horizon, hence a small power suffices. Amplification being not very practical with present tubes, it is customary to modulate one of the oscillator voltages and to endure the consequent frequency wabbles. Reception is with a tube working similarly and used as a detector feeding an audio system. These statements will probably be partially obsolete very shortly.

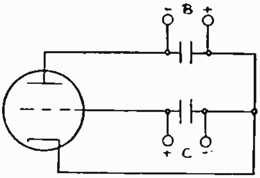


FIG. 108. Barkhausen-Kurtz Type of Non-Regenerative Oscillator. (Note reversed polarities of d.c. grid and plate supplies.)

Another type of wandering-electron oscillator is that based on the magnetron which in its simplest form is a diode consisting of a straight filament running down the center of a tubular plate, the whole tube being surrounded by a large coil of wire carrying adjustable d.c. current so as to produce a strong magnetic field parallel to the filament—i.e. lengthwise of the tube. If the magnetic field be made strong enough the plate current of such a tube ceases until the plate voltage is raised, whereupon it can again be shut off by increasing the magnetic field. It is assumed that the magnetic field causes the electrons from the filament to spiral about it instead of going out radially, and with a strong field to flatten out into a circle, like moons going around a planet. Now if the plate be split lengthwise and the two halves "brought out" through separate connections it is found that a.c. voltages can be made to appear between the two half-plates by correct adjustment of plate voltage, filament heat and magnetic field, which things also determine the frequency, though as in the case of the B–K oscillator this frequency can be modified and reinforced by a tuned circuit, in this case connected from plate-half to plate-half.

Another form of magnetron oscillator has the magnetic field at right angles, or an intermediate angle, and produces a somewhat different type of effect.

There are other such oscillators also.

Other sorts of non-regenerative oscillators, oscillators using gassy or vaporous tubes, are taken up in the following section.

32. Gassy Diodes. (Non-vacuum Tubes)—Diodes in which the vacuum has been replaced by a small amount of some gas harmless to the cathode and plate are useful as rectifiers, voltage-controls (ballasts) and to some extent as oscillators, for the last of which purposes the vacuum diode does not serve. In all these uses the important point is that mentioned in the opening paragraph of the chapter and in section 6, namely that if a high-speed electron travels for any considerable distance in a gassy tube, there is sure to be a collision with the gas followed by ionization and an enormous reduction of the tube's resistance, which continues until the current is shut off long enough to permit the gas to " de-ionize " which will take place in a few milli-seconds if the tube is not very hot.

33. Gassy Diodes as Rectifiers, Voltage Controls and Oscillators—The diode rectifiers accordingly are so constructed that the average electron-path in one direction is much greater than in the reverse direction, whereupon there is an increased probability of gas-collision and high conduction. In the reverse direction the short path, which would appear to be most conductive, is less so since there is less chance of a collision in a short distance. The effect is secured by making one electrode of small area and sunk in a sort of insulating nozzle. A hot cathode is not essential.

There is also the type of diode rectifier typified by the familiar "tungar" battery charging diode which does use a hot cathode, and employs a gas (argon) to increase the plate current greatly by the gas-collision ionization method, but operates at such low plate voltage as to avoid a runaway effect. In this and the foregoing case it is necessary that reverse-conduction or "arc back" be prevented by keeping the one electrode relatively cool and non-emitting.

A gassy diode with one or both electrodes cool may be used as an oscillator in a circuit such as shown in figure 109 provided the desired frequency is not above perhaps 10,000 cycles per second. Since such a diode has a fairly definite breakdown voltage below which it does not conduct, but after breakdown it continues to conduct until a lower voltage is reached, the action can be made as follows:

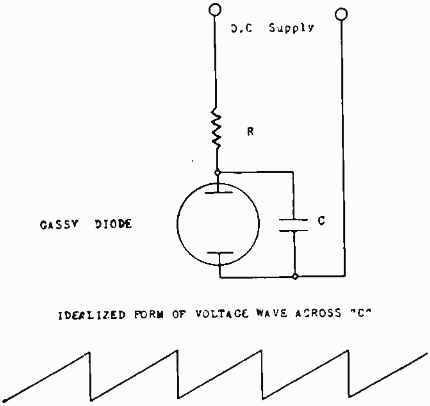


FIG. 109. Gassy Diode as a Non-Regenerative Oscillator.

The condenser *C* is charged gradually through the series resistor which may be the plate-circuit of a vacuum tube if desired. When the condenser voltage reaches the tube's breakdown value the condenser discharges through the tube abruptly and continues to discharge to quite a low voltage. The tube then goes out since the resistor does not pass enough current to keep it alive. The process then begins over. The rate of pulsation is determined by the size of the condenser, the voltage and the value of the resistor and the wave-form may be made to resemble that shown in the figure, which happens to be useful for some cathode-ray-tube work. A gassy triode may be similarly used, the grid merely serving to set the breakdown point.

Gassy triodes may be used as detectors as was explained in section 7. They may also be used in discharge-oscillators similar to those just mentioned but with a better wave-form due to the presence of the grid which is given a bias applied through a grid resistor (but no condenser) of several thousand ohms.

The gassy diode (without hot cathode) has another use. If one electrode is cylindrical and the other central and rod-shaped, the tube being filled with low-pressure neon, argon, or the like, it will be found that the tube starts to glow at—for instance—125 volts and instantly drops to about 90 volts, not rising above this voltage until the current through the tube has been so increased as to cover the whole cylindrical electrode with a glow inside and out. Thus such a tube connected across a low-voltage supply (or portion thereof) will draw more or less current as the voltage rises and falls, thereby steadying the voltage or acting as a "ballast." This is a d.c. device.

(A similar effect may be obtained with a vacuum triode of low plate resistance, whose bias is altered by the voltage variations.)

A complete list of uses is impractical here, of course.

34. **Vaporous Diodes, Triodes and Tetrodes. (Mercury-vapor Non-vacuum)**—A family of non-vacuum tubes giving much more pronounced effects, and capable of additional new effects, consists of the tubes containing metallic vapors, commonly that of mercury. Here the action is not exactly that of the gassy tube though ionization of the mercury does take place after the mercury has been heated by the cathode-heating. The mercury ion is important in these tubes because it is a metallic ion, physically and electrically probably quite enormous as compared to the electron. It is thus possible for a mercury ion to transport electrons in quantity and to accomplish the essential elimination of the obstructing space-charge, which reduces the voltage-drop through the tube to perhaps 1/20 the former value and makes it nearly constant, though much larger currents are being passed. Thus the 217C vacuum diodes are of the same size as the 872A mercury-vapor diodes, indicating about the same heat-dissipating ability, yet a pair of the former have a maximum rated output under 1 kilowatt while the 872A mercury tubes deliver 8 kilowatts at materially better efficiency, without requiring materially more filament power to create the original emission. Mercury-vapor diodes are used principally in power-supply rectifiers, and are further discussed under "Power supplies" in sections 36–40, part B of this chapter.

The mercury-vapor triode is not met as much in radio work as in power-control and distribution devices where it is extremely active under such names as "*thyratron*" which happens to be the General Electric trade name but very aptly explains the tube since it means "a gate device." The mercury triode with hot cathode does not pass large forward currents as does the diode just mentioned—for this time the gate has a latch, called the grid. If the plate voltage is increased the latch will be pushed open unless we cause it to latch more tightly by raising the grid bias at the same time. In either case we have a blocked or "cut off" triode until the latch does slip, but from that instant the tube acts quite differently from a vacuum triode—for the grid loses control completely and the gate swings wide open, letting current flow through with only about a 12–14 volt drop as compared to anything from 40 to 10,000 volts in a vacuum triode. This current

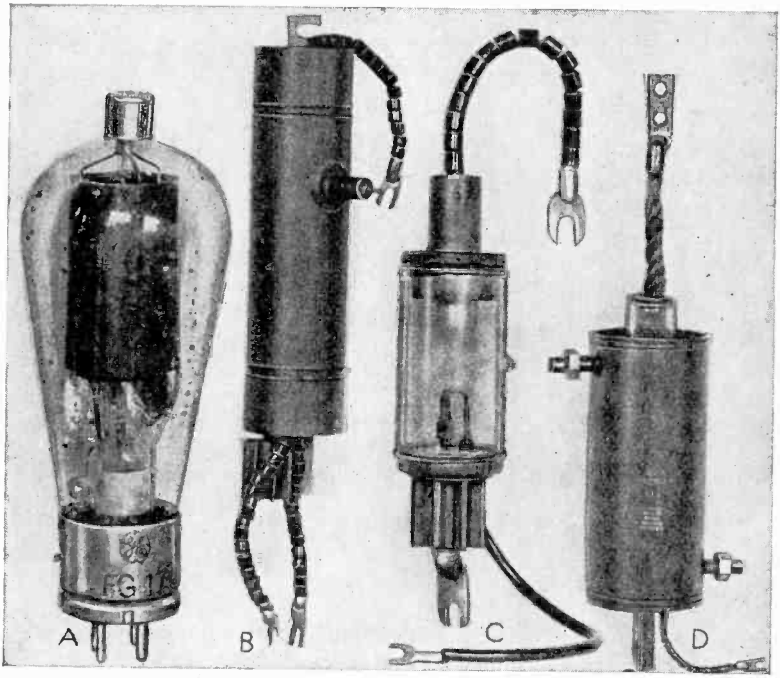


FIG. 110. Typical Thyratrons and Ignitrons.

A—Small triode thyratron, type FG–17. Height 6 3/8″, starting voltage 0–1000 depending on grid bias, ionization time 10 microseconds, current rating 1/2 ampere.

B—Metal-shell tetrode thyratron type FG–172. Body length 8 1/4″, current rating 6.4 amperes, others as for FG–17.

C—Small glass-body ignitron, showing construction. Type FG–253, body length 6 inches, current rating 2.4–4 amps. average, 600 peak. Igniter current required 15 amps.

D—Metal-shell water-cooled ignitron FG–235A. Body length 8″, current rating 50–100 amperes for short times, 6000 amperes peak under proper conditions. Igniter current 40 amperes.

Courtesy General Electric Company.

continues to flow until the plate voltage is removed long enough to permit the mercury vapor to de-ionize, the time varying greatly with tube-design and temperature. If the plate supply be a.c. it is clear that the grid can recover control at each negative half-cycle, so that a large a.c. current may be interrupted *NOISELESSLY AND INSTANTLY* by a few volts applied to a grid. Furthermore the amount of a.c. flowing can be controlled by setting the grid voltage so that only a part of each positive half-cycle passes. If the grid bias is d.c. less than 1/4 cycle cannot be passed except by cutting off completely, but with a.c. grid voltages it is possible to use phase-shifts so as to pass practically any desired portion. Two "thyratrons" thus constitute a full-wave switch of remarkable capabilities, which have barely been grazed on here but are daily being expanded.

There are also mercury-vapor tetrodes but their abilities may be inferred from previous discussion.

One special sort of vaporous tube, called the *ignitron,* is exceptional as compared to all which goes before. This is a triode but of a curious and unconvincing structure. It consists of a plate suspended over a mercury-pool into which dips the third element. This third element fulfills the function of the grid in the thyratron, but in a wholly different manner. As there is no hot cathode the tube has little initial tendency to conduct, and instead of being in need of restraint from a negative grid it must rather be kicked into action. This kick is provided by the third or "igniter" electrode which has a carborundum point dipping slightly into the mercury pool. If a sufficient voltage is applied to this electrode current passes between it and the mercury, producing a small amount of ionized mercury vapor and triggering off the main discharge to the plate in a manner similar to the striking of any mercury arc, but this arc goes out on each negative half-cycle and stays out if the igniter has meantime been deprived of its ignition voltage. Thus the tube functions as the thyratron, but with a simpler and very rugged structure with a long life-expectancy. The momentary currents which such tubes can pass for control and welding purposes are extremely high. Their radio application is as yet limited.

35. **Cathode-ray Tubes**—The cathode-ray tube is ordinarily of vacuum type and should perhaps have been discussed sooner except for the fact that its action is more easily understood after some of the special types already mentioned. A typical construction appears in figure 111 and consists of an "electron gun" which fires a stream of electrons at high speed toward the other end

of the tube where they strike the center of a round "screen" which is a layer of a material such as zinc silicate or calcium tungstate, capable of glowing when struck by electrons.

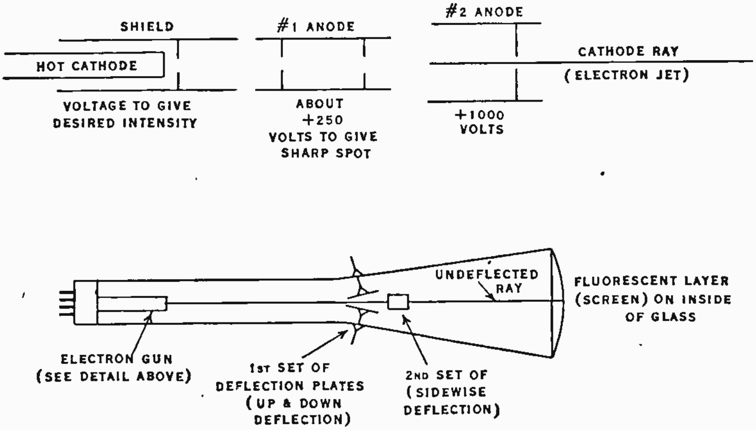


Fig. 111. Cathode Ray Tube.

The electron-gun of the cathode-ray tube consists of a hot electron-emitter (cathode), of a grid to control the current-flow, and of several anodes to direct this flow into a thin stream. The second and more positive anode usually has a small opening from which this stream emerges as from a nozzle, striking the center of the screen unless deflected. The deflection is possible with the aid of either magnetism or by electrical field, since both these things affect electrons. Some cathode ray tubes have no internal deflecting devices, and are to be used with coils laid alongside the electron-path, while others have small plates sealed into the tube in pairs, the ray passing between them and hence being bent by any voltage applied to the pair. Two pairs are common to permit moving the ray in two directions.

Primarily the cathode-ray tube is a voltmeter (the beam bending proportionally to the strength of the electric or magnetic field), whose response is instantaneous, and which draws virtually no current, hence will work at high frequencies at and with small power. In addition it is nearly fool-proof, enduring violent over-voltage uninjured. The ability to move in several directions makes possible the drawing of curves and such special applications as television. For the radiotelephone station their greatest interest is in the ability to draw a moving picture of the modulation far more informative than many meters, and constantly up-to-date.

PART B—POWER SUPPLY DESIGN OUTLINE

36. Power Supply Rectifiers and Filters—In sections 5, 32 and 34 the use of tube rectifiers has been touched on lightly, but this subject demands a few added comments because of its importance.

The commonest of the small-power sources of plate-voltage, for receivers and small transmitters, employs the circuit of figure 112 though the two diodes may be either in a single tube or in two tubes, with their cathodes tied together. The action is apparently explained by the figure, but various important considerations cannot be seen there.

(I) The transformer supplying a rectifier is loaded with half-wave surges of abnormal wave-form, hence its most economical design departs somewhat from straightforward a.c. practice and purchase from a maker specializing in transformers for this particular use is advisable.

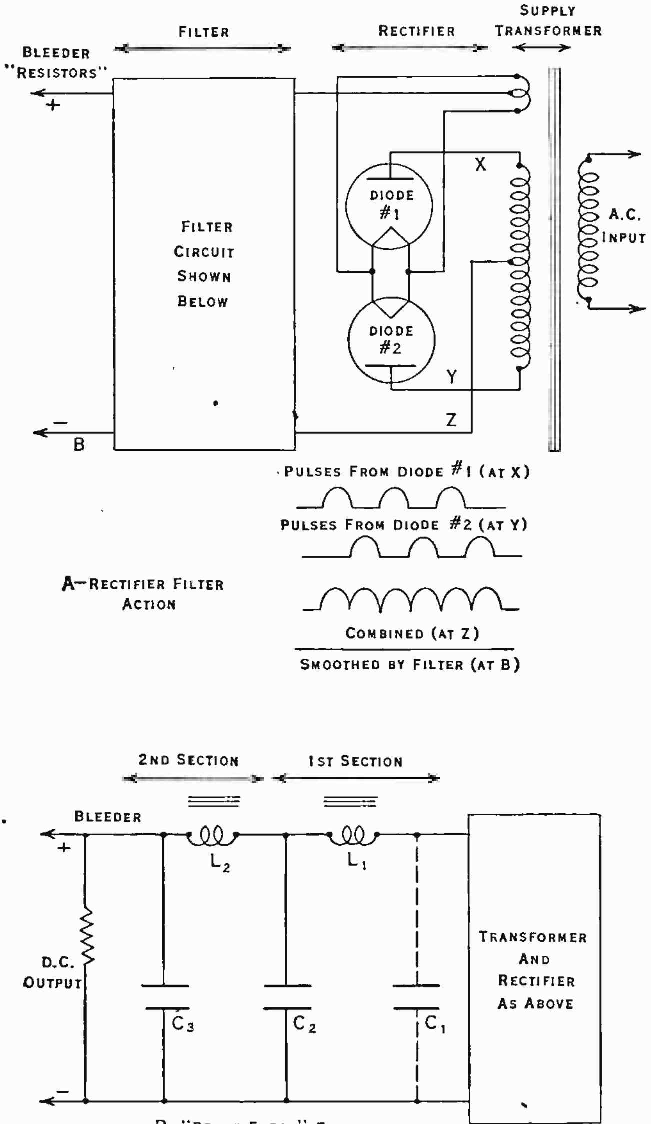
(II) The goodness of the smoothing (filtering) and the voltage stability are both very strongly affected by the design of the filter, for which simple rules are suggested.

(III) The tube-life, especially for the mercury-vapor type of rectifier, depends on unequivocal adherence to certain rules of filter-design and loading.

Before proceeding to the filters we must recall briefly the nature of the three types of diode rectifiers.

The gassy diode (section 32) is in moderate use for small power supplies and has the merit (where power is limited) of requiring no filament-power as there is no filament. The tendency toward slight irregularities productive of noises in associated or adjacent receivers may require the supply-transformer to have its two half-secondaries shunted by small "buffer" condensers of not over .1 microfarad, and preferably materially smaller—the smallest which do the work as they use power. The tube may need to be covered with a metal shield also.

The vacuum diode (section 5) is free from the objections just cited but requires a filament source. It is practical in a wide range of sizes, may be made efficient as compared to the gassy type (low voltage drop), but suffers quick and permanent filament-injury in the event of a serious overload as from a short-circuit in the



A—RECTIFIER FILTER ACTION

B—"BRUTE-FORCE" FILTER

FIG. 112. Typical Power Supply Rectifier-Filter Circuit and Its Action.

filter or load, or even from a moderate and maintained overload. It is possible for ruinous momentary overloads to exist though the meter in the d.c. filter-output indicates a safe load. This will be touched on in (III) following. Vacuum diodes are often paired in the same tube.

The mercury vapor diode, as stated in section 34, is capable of handling large currents without excessive heating, hence is attractive in the larger applications. Its use in receivers has been attempted most unsuccessfully because of the noises created by the abrupt surge at the first part of each "forward" half-cycle. It is necessary to guard against this in transmitters also, and to screen nearby low-power stages well. The mercury diode, because of the surge-tendency and also because of its very low resistance, is even more easily injured by wholly unsuspected short-time current peaks due to incorrect filters, and not detectable on a d.c. meter, nor any other ordinary meter save the cathode-ray tube when connected to inspect the wave-form of the current flowing through the tubes into the filter. Since the mercury-vapor tube depends on ionization of the mercury, any failure of this process results in concentrating the whole plate voltage (almost) at the filament surface which may lose all its active surface in a few seconds, minutes or hours depending on the degree and persistence of the too-low filament temperature.

37. Filters as Affecting Smoothing and Regulation—The common power-supply filter does not attempt to use tuned circuits but simply shunts large bypass condensers across the output circuit and large iron-core choke coils in series with the "+" lead, as shown in figure 112*B*, a method aptly called "brute force" by Ballantine, but generally accepted as best for the problem of smoothing an output obtained by rectifying a.c. which output contains a wide variety of ripple-frequencies, even if the a.c. was of good sine-wave form, which is not always true. The essential requirements of such a filter are:

It must contain enough capacitance and inductance to reduce the ripples to the desired extent, and must avoid resonance with the supply-frequency.

It must not use too little inductance and too much condenser (except at very low voltage) or tube-surges will result in the damage already mentioned, particularly in the case of mercury-vapor tubes.

Filter-troubles ordinarily begin in the first filter section (figure 112*B*), especially with mercury-vapor diodes. Of course this may be the only filter section used, particularly in a radio-telegraph transmitter. Resonance with the supply frequency is easily avoided if the first section has a "henrys times microfarads" product of 14 for a 60 cycle supply, or 20 for a 50 cycle supply, but this must not consist predominantly of capacity unless the voltage and the load current are quite low—even for a vacuum rectifier. If the filter has a "first" condenser (C_1) then the first choke L_1 should have a value of 20 henrys or better, with the first condenser not exceeding 4 microfarads greatly, and the second condenser of about the same value in the case of a mercury-vapor rectifier, or as large as desired for a vacuum rectifier under normal conditions. With such a condenser-input filter the vacuum rectifier tubes may be worked at the same load current as with a filter of the inductance-input sort—that is one lacking C_1. However the a.c. voltage supplied to the tubes should not be very greatly over 75 percent of the voltage permissible with an inductance-input filter. Or, on the other hand, if the input voltage is kept the same, then the load current must be reduced 25 percent from that considered proper at maximum voltage with the inductance-input filter. In other words *the vacuum rectifier cannot work at maximum current and maximum voltage simultaneously when using a capacity-input filter.*

Typical Ratings of ½ Wave Vacuum Diode Rectifier

	Permissible Load Current in Milliamperes	
	Filter with Capacity Input	Filter with Inductance Input
Plate volts (a.c.) 600	180	180
Plate volts (a.c.) 650	135	180
Plate volts (a.c.) 700	135	180
Plate volts (a.c.) 750	—	180

The "regulation," that is to say the voltage-drop under load, is greater with the capacity-input filter, but also this type of filter produces a higher no-load output voltage for the same a.c. input voltage. Thus it depends on the load whether a certain a.c. supply voltage will produce a higher output voltage through a capacity-input filter or an inductance-input filter. Where the load is light and steady the condenser-input has an advantage. Where the load is heavy (30 percent or more of tube rating), and especially where it is variable, the inductance-input is to be preferred.

37B. Filters for Mercury-vapor Tubes.

These considerations are much more powerful for the mercury-vapor type of tube which may be used with a condenser-input filter

ONLY IF RUN AT REDUCED LOAD CURRENT AND MODERATE VOLTAGE. The anti-resonance rule already given must be observed, and if a condenser-input filter (strongly advised against) be used it must also observe the rules already set down, but with a *50 percent reduction* in load current.

TYPICAL MAXIMUM PERFORMANCE OF MERCURY-DIODE RECTIFIERS

	Relative Volts	D.c. Load Amps.	Filter Recommendations	
			Minimum L_1 (henrys)	Maximum C_2* (microfarads)
2 tubes, fullwave, 1 ph. cap. input filter	1.25	0.5	See previous paragraphs on capacity-input filter	
2 tubes, fullwave, inductance-input filter	1.00	1.0	10	1
4 tubes "bridge" fullwave, same filter	2.00	1.0	20	0.5
6 tubes, 3 phase fullwave	3.0	1.5	2	0.5

* May be increased in the same proportion as L_1 is increased.

Perhaps the most striking thing about this tabulation is the much smaller safe value of the first choke when using 3-phase rectification. The secret is that such a rectifier produces overlapping pulses, hence no tube looks into a current-less circuit, and cannot be subjected to a starting-surge as severe as that in a 1-phase rectifier with an equally small first choke. For high-power rectifiers such polyphase rectifiers are invariably used because of the increased ease of filtering, decreased danger to tubes, and higher output voltage for the same tube-strain.

37B. Filters as Affecting Regulation with Mercury-vapor Tubes, and Filters for High-resistance Loads—The regulation effect of the filter on a vacuum diode has been mentioned. This effect is also present with the mercury diode, and the low resistance of the latter permits a filter-action productive of superior regulation. To accomplish this the first-choke is made larger than required by the rules so far set down, for those cases where the load is of high resistance. Such loads, incidentally, *may* cause surging in tubes with the first-chokes previously mentioned.

TABLE OF FIRST INDUCTANCES (L_1) TO PROTECT MERCURY-VAPOR DIODES AGAINST SURGES AND POOR REGULATION UNDER CONDITIONS OF HIGH-RESISTANCE LOAD. (Load resistance defined as d.c. output voltage/d.c. output current.)

Load Ohms	Recommended First-Choke (L_1)
100,000	200 hy
10,000	20 hy
5,000	10 hy

Note—Tabulation applies to 1-phase full-wave (2 tubes) only.

The great cost of a choke with such high inductance at light load, but large enough to carry full-load current, has led to the "swinging choke" popularized by F. S. Dellenbaugh. This is a choke so designed as to have high inductance at light load, but to undergo magnetic saturation under heavy load current, with consequent decrease in inductance. If the swing-ratio is high the choke MUST be designed for the load-current, but if the swing is only 2/1 or 3/1 it may be used with some carelessness while providing improved results and lower cost, and permitting the power-supply to work with either large or small load currents.

HOWEVER NO MERCURY-VAPOR RECTIFIER SYSTEM SHOULD BE OPERATED ENTIRELY WITHOUT LOAD IF AVOIDABLE. IN ALL CASES PROVIDE A DRAIN EQUAL TO 5–10 PERCENT OF FULL LOAD, THROUGH A "BLEEDER" RESISTANCE IF NECESSARY, OR PROVIDE A NO-CURRENT RELEASE TO CUT OFF THE POWER SUPPLY WHENEVER THE LOAD DROPS BELOW SUCH A VALUE.

38. **Noises Due to Mercury-vapor Rectifiers**—Mercury-vapor rectifiers produce severe radio noises in nearby receivers, and often in audio amplifiers apart from receivers, unless they are prevented from surging. Capacity-input filters are always troublesome, and can seldom be quieted altogether. The best cure is an adequate input choke, L_1, supplemented by shielding of the tubes and the whole supply, and sometimes r.f. chokes of a few millihenries connected close to each plate. "Buffer" condensers connected across each tube may be helpful. They must be of excellent r.f. type, suited to high d.c. voltage, and of a capacity around .001 microfarad.

39. **Goodness of Filtering for 1 and 2 Section Filters**—While the first filter-section has the foregoing requirements for the sake of tube-safety (except at reduced voltages and currents), the final filtering effect is due to the total amount of capacitance and inductance employed. The theory need not be gone into here, and the following tabulation is a fair guide for most work.

TABULATION OF FILTERS FOR 1-PHASE FULL-WAVE POWER SUPPLIES
(Either Vacuum or Mercury Rectifier Tubes)

Class of Load and Theoretical Percentage Ripple	1-section Filter Constant, ($L \times C$)	2-section Filter Constant, $(L_1L_2)(C_1 + C_2)^2$
Push-pull class A audio stages—5%	20	130
Radio-telegraph transmitters—1%	100	650
Radio-telephone transmitters—1/4 of 1% and audio stages	400	2520
High-grade audio systems—under 1/10 of 1%	Impractical	6500

The actual ripple is customarily higher, but may be made lower by suitable back-couplings in the filters, especially in the following.

Low-level audio stages and bias supplies—1/20 of 1%	Above filters inadequate and 3 stages of filtering recommended.	

40. Devices for Effecting Filter-economy—In many cases it is quite needless to filter the entire power-supply output to the same degree of goodness. Thus in a radio receiver the output stage may be a push-pull class A system working at 300 volts, while the other tubes work at 250 volts and draw small currents, and the screens of these tubes work at 100 volts and draw still smaller currents. It is then economical to employ a cut-down form of the 2-stage filter of figure 112B, taking off the output-stage supply just beyond L_1, which is made of small inductance. The first filter-stage smooths to only a limited extent, as the push-pull output transformer will "buck out" hum if the two tubes are reasonably alike. The effect is not completely attained in most receivers because of the nearly universal practice of using the field-coil of the loudspeaker as the first filter choke L_1, thereby introducing an objectionable hum unless the speaker is very poor at low notes. In good receivers the speaker field is either used as a second choke L_2 or is connected across the plate-supply system after some filtering has been accomplished. The other tubes demand only small currents, hence L_2 may be small and cheap, or may be replaced by a number of small resistors, one in each supply-line, and each followed by a condenser of moderate voltage rating, in place of a single C_3. The various branch-line resistors are proportioned to produce the proper voltage-drop in the d.c.

supply, besides action as ripple-filters. A danger of such filter systems is that if they are operated with the tubes removed full voltage will be delivered to all the condensers, and as those beyond the resistors are not intended to stand this strain, damage ensues.

PART C—THE ELECTRON TUBE IN TUNED CIRCUITS. RADIO RECEIVER SYSTEMS. RADIO TRANSMITTERS

Many electron-tube effects depend upon tuned circuits, which have thus far in this "Manual" been assumed rather than explained. Nor is it necessary now to have in mind more than a very few points concerning tuned circuits:

(*a*) A mechanical tuned system (piano string, tuning fork etc.) has inertia due to weight and elasticity due to the "springiness" of the material. Similarly an electrical tuned circuit has *electrical* inertia (called "inductance"), and electrical elasticity which is due to the "capacitance" of the circuit. In its simplest form an electrical tuned circuit consists of a coil (inductance) across which is connected a condenser (capacitance).

(*b*) Both mechanical and electrical tuned circuits can be made to oscillate (vibrate) by single impact as in a piano, or they can be made to vibrate by a series of small impulses recurring at their own natural frequency, as a piano string responds to a singing tone. Other tones will cause response only if near to the natural frequency of the tuned piano string, or if very loud, but the string's response may be made less discriminating (less sharp) if its free vibration is somewhat obstructed. Similarly an electrical tuned circuit becomes less discriminating if electrical resistance is increased. We then say that it tunes broadly, or that it is less *selective,* and must use additional tuned circuits to restore the lost selectivity.

(*c*) Since the frequency of a tuned circuit depends on the size of the inductance and capacitance we have the ability to change this frequency by changing either the inductance or capacity, consequently to change the frequency of an associated tube's operation, whether it be amplifying or oscillating. This is called "tuning."

(*d*) The frequency of a tuned-circuit-device also depends to some extent on the coil resistance and *any* associated devices, which are called "loads." Even the associated tubes are themselves loads on the tuned circuits and may greatly modify the tuning.

Of most immediate interest is use of tuned circuits in radio receivers and transmitters.

RADIO RECEIVER SYSTEMS

If the foregoing pages have been scanned, the present types of radio receivers will not appear strange, for they consist of devices already mentioned, that is to say class *A* radio-frequency amplifier stages to strengthen the signal (sections 6, 12, 16, 26), a detector or demodulator to make the signal audible (sections 4, 7 and 9), and an audio amplifier to make the sounds louder (sections 6, 12, 27), together with an automatic volume control to limit the changes in output as the signal " fades " and an anti-noise circuit (sections 6 and 10). In nearly all cases the receiver is tunable so as to respond to signals of different frequency at will as just explained and there are commonly provided manual controls of tuning-sharpness, audio fidelity (" tone control "), sensitivity, and occasionally a sort of gearshift to change the mechanical ratio between the tuning handle and the actual tuning device, which is usually a variable condenser. There may also be a device for electrically or electro-mechanically completing the tuning when the receiver is set approximately on a station's frequency, as in section 45.

The tube types have all been outlined, the diodes in sections 3, 4 and 5—and as power devices in sections 36–38, the other types in sections 6, 7, 8, 9, 26, 27, 28 and 29.

Despite the obvious variety possible, there are only a few fundamental types in present use, and of these the Barkhausen-Kurtz type is not sufficiently commercial to justify discussion here. Thus we are left with the types popularly called " tuned radio frequency receiver," " superheterodyne receiver " and " super-regenerative receiver," not one of which is a distinct class as combinations are possible and customary. However the discussion shall follow popular classification.

41. The " Tuned Radio Frequency " Receiver—This system consists of the detector necessary in any receiver, preceded by 1 to 4 stages of tunable r.f. amplifier to strengthen the signal before delivering it to the detector (figure 113) from which it customarily, though not necessarily, goes through a stage or two of audio amplifier before being delivered to the loudspeaker or headset. The radio-frequency stages are invariably based on tetrode or pentode tubes, and the gain per stage varies widely with the wavelength, from well over 100 times (voltage amplification) at long waves to almost nothing at the frequency-limit of the tubes. In any case it is affected by the *L/C* ratio of the tuned circuits and rises with this ratio. Both the gain and the selectivity of the successive stages are multiplied together for the final result, except as the system departs from "true cascade" amplification through undesired interstage couplings and stray pickup of the original signal. These effects are minimized by shielding of the tubes, coils and connecting wires and by resistance-capacity filters in the leads feeding them—which sentence represents many days of painstaking work in any really good receiver design.

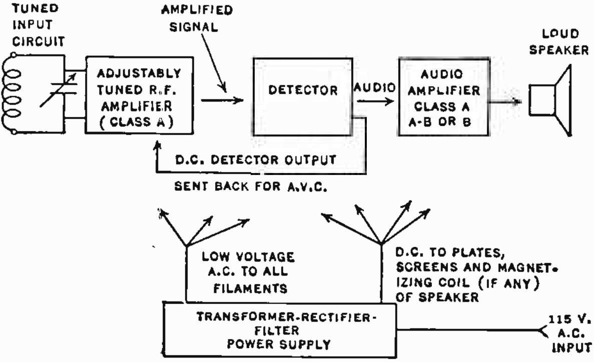


FIG. 113. Typical Tuned Radio Frequency (T.R.F.) Receiver.

When made for high gains (see figure 119) and high selectivity (see figure 117) the "TRF" receiver is costly because of the necessity of causing 5 or more variable condenser sections to operate very exactly together, and continuing to do so despite age, weather and mechanical shock. It is this element of high cost which causes the super-heterodyne type to be preferred where high gain is desired, or high selectivity imperative, and at least one of these two requirements applies to most present-day reception. Where interference is small and fidelity of reproduction is desired the TRF type must be taken seriously.

The "Detector audio" type. A somewhat antiquated receiver is the foregoing minus the r.f. amplifier. Its one merit is economy of both material and weight. See figure 117 as to its selectivity, figure 119 as to its sensitivity—or lack thereof.

42. **The Super-regenerative Receiver**—As an attempt to increase the sensitivity of the type just mentioned there was devised

by Major E. H. Armstrong the so-called "super-regenerative" receiver which is a device for greatly increasing the modulated signal gain due to the regenerative detector mentioned in section 15. The ordinary limitation of such detectors is that just as the gain is becoming worth-while the regeneration "runs away" and the tube oscillates, whereupon it is worthless as a detector of *MODULATED* signals. However during the instant of going into oscillation the gain is enormous and much work has been done to capture and maintain that condition. Failing this, an alternative scheme is to allow the detector to run through the transient high-gain condition, then bring it back and let it start over again—repeating the performance so rapidly that the resulting flutter is above audibility—or at least so high as to be unobjectionable. This is the super-regenerative idea. It may be carried out by modulating the tube at a super-audible rate—for instance by adjusting the tube to oscillate strongly at the signal frequency —we shall say that is 1,000,000 cycles, and then feeding into its grid a rather strong 30,000 cycle a.c. voltage which shall have the effect of 30,000 times per second blocking up the oscillations, and compelling the tube to start over, thus traversing the high-gain regenerative region again. In this case the 30,000 supply would be known as the "variation frequency" or "quenching frequency." While 30,000 cycles is inaudible and thus unobjectionable, it unfortunately does not provide the best gain except at quite short waves—the tube does not have enough time to "work up." A lower pitch gives much higher gain, but unfortunately lower pitches are audible and to filter them out damages the audio output proper. Thus the present use of the super-regenerative detector is largely in very short wave work (1 to 10 meters) where there are a great many oscillations per quenching even if the variation frequency is made inaudible. Even there the receiver is used mainly for speech, not music, as it is characterized by a strong noise-background whenever signals are weak.

The super-regenerative detector has a rather pronounced "threshold value" as ordinarily constructed, that is signals below a certain strength are simply dropped as by a "QAVC" system (section 10). In fact the super-regenerative detector acts as a very effective QAVC system in itself, so that a signal which is gradually strengthened pops into hearing rather abruptly, gains slightly in strength and thereafter holds steady even though increased hundreds of times. This has strengthened a general feeling that "power does not matter" at the ultra-short waves.

Both the variation frequency and the signal-frequency oscillation may be generated by the tube itself, since it may be made to oscillate at two frequencies simultaneously by use of a circuit such as that shown in figure 114.

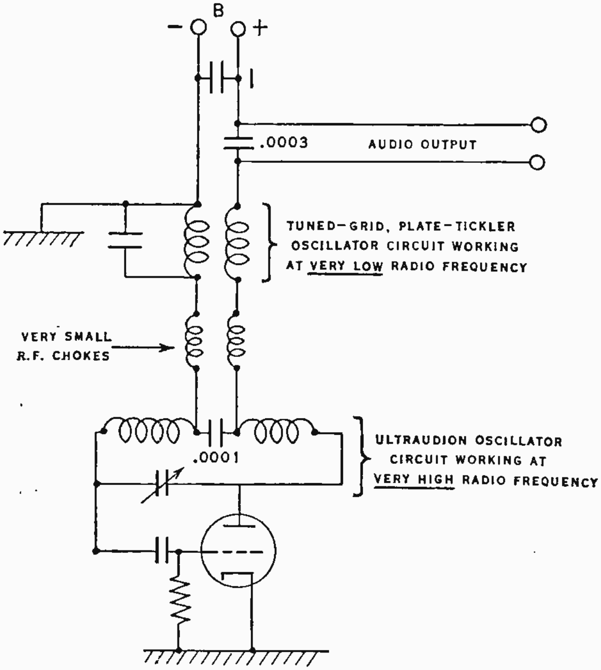


FIG. 114. Super-Regenerative Detector Oscillating at Two Widely Different Frequencies.

One of the pronounced demerits of the super-regenerative detector is that it tends to radiate a rather wide frequency-band because of its strong oscillation and the frequency-wabbles due to the quench-frequency modulation. To minimize this effect such detectors may be preceded by tuned r.f. amplifiers. Every effort must be made to secure some gain in this r.f. system else the noise-to-signal ratio is increased. This is possible with present tubes at very short wavelengths.

43. The Super-heterodyne Receiver—In section 41 it was stated that the amplification gain of an r.f. stage decreases with wavelength, or if one please the gain falls as the frequency rises.

Thus there is no difficulty whatever in attaining large amplification in each stage at a frequency of—for example—500,000 cycles (wavelength 600 meters), but at a frequency of 30,000,000 cycles (wavelength 10 meters) the stage-gain is discouragingly small. This gain can be raised by regeneration in the r.f. stage, but the result is extreme instability if more than one stage be used—and that probably does not provide the desired gain. It would therefore be a great advantage if *ALL* signals could be fed through a long-wave amplifier before going to the detector and audio system. This necessarily involves translating signals of all short wavelengths into long-wave signals, and while there are several possible schemes, the most tractable of them consists of translating the signals all to the *SAME* long wavelength so that the long-wave amplifier may be of fixed tuning. The merit of fixed tuning is a double one:

(*a*) The mechanical complexity is vastly reduced.
(*b*) Since the tuning capacity is not to cover a wide tuning range it may be very small, permitting the use of a large coil, that is a higher *L/C* ratio and better stage, gain. The entire system may then be put in a metal can, preventing inter-stage couplings to a considerable extent.

Such a system is called a "super-heterodyne" or a "supersonic heterodyne" and was originally devised by Major E. H. Armstrong, already mentioned. The essential portions are shown in figure 115. The "intermediate frequency amplifier" (or i.f. amplifier) is the long-wave amplifier already mentioned. It commonly works at a fixed frequency in the region of 100,000–500,000 cycles (100 to 500 kilocycles). The number of stages in this amplifier ordinarily ranges from 1 to 4, 2 being usually adequate and easily stabilized. The interstage coupling devices are transformers, commonly made with iron-dust cores, which gives improved coils at these relatively low r.f. values.

The detector and audio system following are orthodox and in accord with the descriptions of sections 4, 8 and 12. Because of the high gain ahead of the detector it is normally of the diode type (section 4) or the biased triode type (section 8).

It remains to describe the translator or converter which consists of an oscillator and a rectifier-amplifier sometimes unfortunately called a "first detector." The function of the translator is to translate the incoming signal into a long-wave signal suited to the i.f. amplifier. This is done as follows:

If two frequencies, x and y, are mixed and then passed through

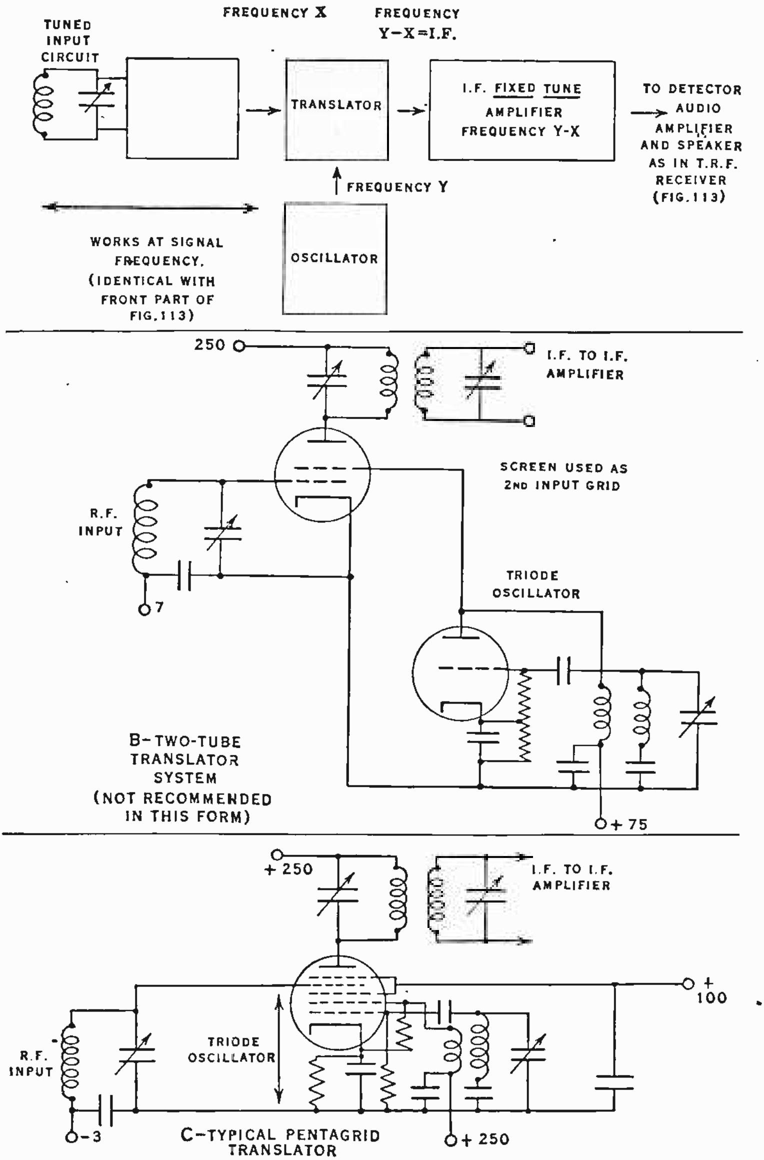


Fig. 115. The Superheterodyne Receiver.

a rectifier, there will be found in the rectifier output all of the following frequencies:

(*a*) The original frequency x.
(*b*) The original frequency y.
(*c*) A new frequency equal to $y+x$.
(*d*) A new frequency equal to $y-x$.

In the superheterodyne the incoming radio signal is the x frequency, while the y frequency is supplied by a tunable oscillator in the receiver. No use is made of the $y+x$ frequency which is discarded through a shunting condenser, as are both the original frequencies after passing through the translator. This leaves the $y-x$ frequency, which is quite evidently a lower frequency as desired. It is evident that by adjusting the oscillator frequency we can make $y-x$ be anything desired—for instance the i.f. amplifier tuned frequency. Let us say for instance that the i.f. amplifier works at 465 kilocycles. Then if y is 465 kilocycles greater than the incoming signal, there will come from the rectifying amplifier a frequency equal to 465, hence this frequency will enter the i.f. amplifier, thence the detector and audio system, and the desired translation has been concluded satisfactorily.

The important point is that such a translation can be accomplished without damage to the modulation, which is to say the original modulation can in effect be transplanted to a new carrier. The complete tuning process consists of adjusting the oscillator to translate the desired signal to the intermediate frequency, and adjusting the tuned input circuit to accept this signal. These interlocking operations are facilitated by connecting the two tuning condensers to the same control knob. It is quite beyond the scope of this discussion to explain the design of the circuits which permit the oscillator circuit to maintain the desired difference in tuning as the control knob is turned.

The actual oscillator and rectifier-amplifier may take a widely assorted combination of forms, of which the representative forms in figure 115 differ principally in that the second one utilizes Dow electron coupling between the triode oscillator section and the tetrode amplifier-rectifier section. Incidentally there are here actually present enough elements so that this may be denominated a triode-tetrode or "tri-tet," a descriptive name not fitting the device ordinarily so named (section 30, figure 107*C*).

44. The Superheterodyne Pre-selector—The performance of a superheterodyne is vastly improved by placing 1 or 2 stages of tuned r.f. amplifier ahead of the translator. This is not for lack of gain in the i.f. amplifier, which may be made extremely large. Rather it is because of two effects not so far mentioned. One of these is that a translator tends to contribute a considerable amount of a distressing type of noise sometimes described as "superheterodyne shush" unless the signal is moderately strong to begin with. (This is not the entire story of "shush" by any means as it is strongly dependent on the design of the translator and the use of a proper oscillator voltage.) The other effect is that a translator protected by merely a single tuned circuit is unable to refuse strong signals near to the "wanted" signal, and while these will subsequently be wiped out by the high selectivity of the i.f. system, there will remain permanent injury in the form of "cross modulation" which is modulation grafted onto the i.f. from the undesired signal. Thus improved "front end" selectivity is indicated, and while this can be provided by merely adding more front-end tuned circuits, such a procedure wastes some of the wanted signal, and hence damages the signal/noise ratio, which effect may be avoided by using not merely an additional tuned circuit but also an amplifier tube—which is to say a stage of tuned r.f. amplification (figure 113). Thus the superheterodyne in its better forms has at least 3 tuning condenser sections.

Two other types of interference can also be reduced by the increase of front-end selectivity which a pre-selector affords. The first is interference by a transmitter (usually telegraphic) operating near the intermediate frequency of the receiver, that is near 465 kc. for the common entertainment receiver. This type of interference is heard at almost the same intensity "all over the dial" though it may be suppressed when a strong station is tuned in. The experience of two makers of entertainment receivers is that this difficulty rarely arises more than 100 miles from the interfering station, and that a single such station can be eliminated satisfactorily by a wavetrap. However a pre-selector has the advantage of requiring no adjustment for local stations, of rejecting several stations as well as one, and of contributing the other advantages mentioned in this section.

The tuned pre-selector is of considerable effectiveness in eliminating another variety of interference which is due to the inherent tendency of a superheterodyre to respond to two widely separated frequencies, the "unwanted frequency" or "image frequency" being separated from the "wanted signal" by the amount 2 × intermediate frequency. Thus if the intermediate frequency is 500 kc. and the oscillator is set at 2500 kc. it is clear that we intend to receive a signal at 2000 kc. $(2500 - 2000 = 500)$

but if it chances that there is a fairly strong station at 3000 kc. it will also be heard unless there is enough selectivity ahead of the translator input grid to prevent the 3000 kc. signal from reaching that grid. (Note that 3000 — 2500 = 500 also that 3000 — 2000 = 2 i.f.) At medium waves any fairly good pre-selector practically eliminates this effect, but at short waves excellent design is necessary unless the i.f. is higher than 500 kc. The image response is generally weaker than when the receiver is tuned to the assigned frequency of the station and appears when the receiver is tuned a frequency lower than the assigned frequency, since in most superheterodynes the oscillator tracks or is aligned higher in frequency by an amount equal to the value of the "intermediate frequency."

In all these uses of the pre-selector the expected protection is realized in full only if the shielding of tubes AND LEADS is very thorough and if the pre-selector produces true amplification gain.

45. **Automatic Frequency Control or AFC**—In the superheterodyne type of receiver it becomes practical to use a form of semi-automatic tuning which corrects manual inexactness in tuning, provided the device is well maintained and further provided that the "wanted" signal is fairly well above interfering signals on adjacent frequencies, or has manually been tuned in well enough to create a similar effect upon the receiver. These devices appear in various forms in trans-oceanic communication receivers, and in more commonplace receivers also, but all alike depend on the possibility of altering the frequency of the translation oscillator slightly by changing its load or one of its d.c. voltages in such a manner as to cause the oscillator to shift in the direction required to shift the signal into the i.f. channel. One of the numerous ways of deriving the required control from the received signal is shown on figure 116. Here a "discriminator" circuit, tuned to the intermediate frequency, is fed by both magnetic and capacity coupling. If a signal is tuned correctly the two ends of the circuit are equally affected and the associated rectifiers give forth equal and opposite direct-current voltages, which oppose each other and nullify. If the signal is mistuned one end of the circuit picks off more of it and the output of the associated diode predominates. Thus the amount and direction of the d.c. output voltage from the diodes is related to the direction and amount of mistuning *AND THE SIGNAL STRENGTH,* but the last factor confuses the system, hence must be minimized by a preceding limiter tube, that is a tube unable to respond to more than a

fixed amount. In any case the d.c. from the diodes is now fed to the grid of a "control tube," additional to (or in opposition to) the fixed bias of that tube. The control tube is enabled to govern the oscillator frequency by virtue of the fact that the control tube

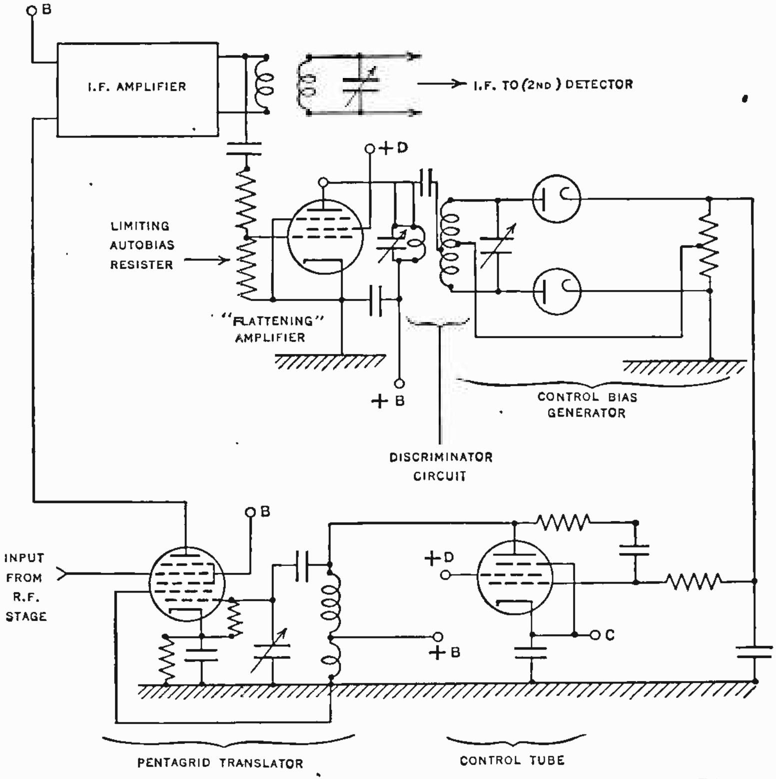


Fig. 116. Principle of Automatic Frequency Control (A. F. C.).

plate is connected to the tuned circuit of the oscillator. The exact manner in which the control becomes effective depends on the designer and his choice of either a single control tube or a pair placed back to back, but in general the control tube plate circuit either acts as a varying load or else as a source of a varying R.F. voltage originally derived from the oscillator but changed in phase and amplitude by the control tube before being returned to the oscillator. Either action changes the oscillator frequency but it is a fine design task to obtain changes of the proper magnitude.

46. Receiver Selectivity—The selectivity of a receiver, i.e. its ability to reject unwanted signals, depends on both the number and the goodness of the tuned circuits used (see figure 117). In the tuned r.f. system this number is equivalent to the number of tuning-condenser sections and the goodness of the circuits (reactance/resistance) is limited by the fact that the *C/L* ratio changes with tuning. In such systems, if more than 1 r.f. stage be used, it is accordingly worth while to use a number of tuning ranges (sets of coils) and a small tuning capacity, and to look carefully to sources of stray capacitance and losses—i.e. solid dielectrics not essential to the structure. Where high performance is wanted this leads to the elimination of coil-switching schemes

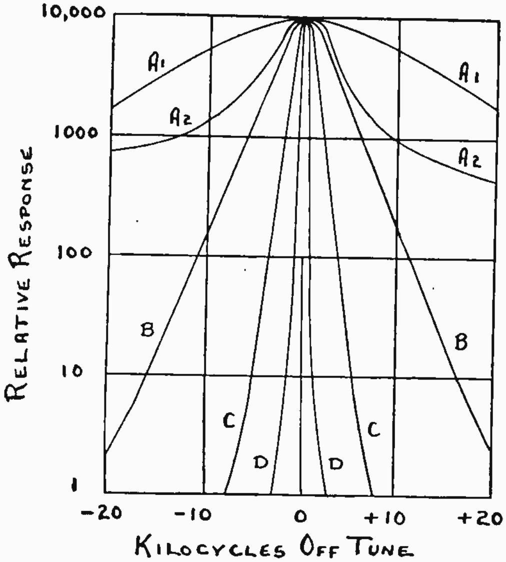


FIG. 117. Typical Selectivity Curves.

A_1—T.R.F.—2 Tuned Circuits.
A_2—Same with Regeneration—Note Assymmetry.
B—I.F. Amplifier Transformer—Iron Core.
C—Entire I.F. System—6 Tuned Circuits.
D—Same Plus Quartz Crystal Filter.

in favor of plug-in coils or a movable coil-tray sliding under fixed contacts, rather than fixed coils with a gang-switch.

In the superheterodyne receiver the selectivity problem is far easier for two distinct reasons. The first is that the receiver may easily employ many tuned circuits, most of which have no moving parts (being in the i.f. system) and may thus be designed for high selectivity. The second is that there is a sort of unearned selectivity-increase due to the fact that the i.f. is lower than the signal frequency, hence a given mistuning is a larger percentage and is more energetically refused. Thus if the signal is at 2,000,000 cycles (150 meters) and is interfered with by a station on 2,010,000 a TRF receiver will find difficulty in separating the stations as this is but 1/2 of 1 percent difference. However if the signals are both translated to 500,000 cycles this same difference is 2 per cent. It is very easily possible to make a superheterodyne too selective to pass the higher frequencies of music, and many household receivers are provided with a control of i.f. selectivity to permit wide-band reception on those occasions when interference permits it. These schemes may operate by changing coupling in the i.f. transformers, by variable resistors or by auxiliary circuits —in some cases even by discarding the superheterodyne system and feeding from the r.f. pre-amplifier directly into the (so-called second) detector.

47. Crystal Filters in Superheterodynes—Since a quartz crystal plate is suitable for oscillator control simply because it is the equivalent of a very sharply tuned circuit, it may also be used as a tuning-circuit—in fact the original use of such plates (due to Dr. W. G. Cady) was just that, the oscillator-control by quartz plates (section 21) being a later invention by Dr. G. W. Pierce.

Where extreme selectivity in a superheterodyne is desired it may be supplied by using a quartz plate as one tuned element in the i.f. amplifier, the plate having the proper thickness to resonate at the i.f. It is necessary to place the quartz between two metal plates in order to make it operative, and as this comprises a condenser (which is NOT selective) the system is vitiated unless the capacity effect can be balanced out. The balancing may be done by extending the circuit to form a small balanced wheatstone bridge as in figure 118. This is the Robinson " stenode " receiver, which is quite capable of being so designed and adjusted as to pass very little beyond a band 50 cycles wide—a selectivity too large for voice or music reception, but at times advantageous for telegraphic reception through noise—though at the expense of some signal distortion occasioned by the inertia of the crystal. Robinson used such a system for music reception by employing an audio correction amplifier designed to give abnormal high-note response. He also observed that by slightly unbalancing the crystal-net it was possible

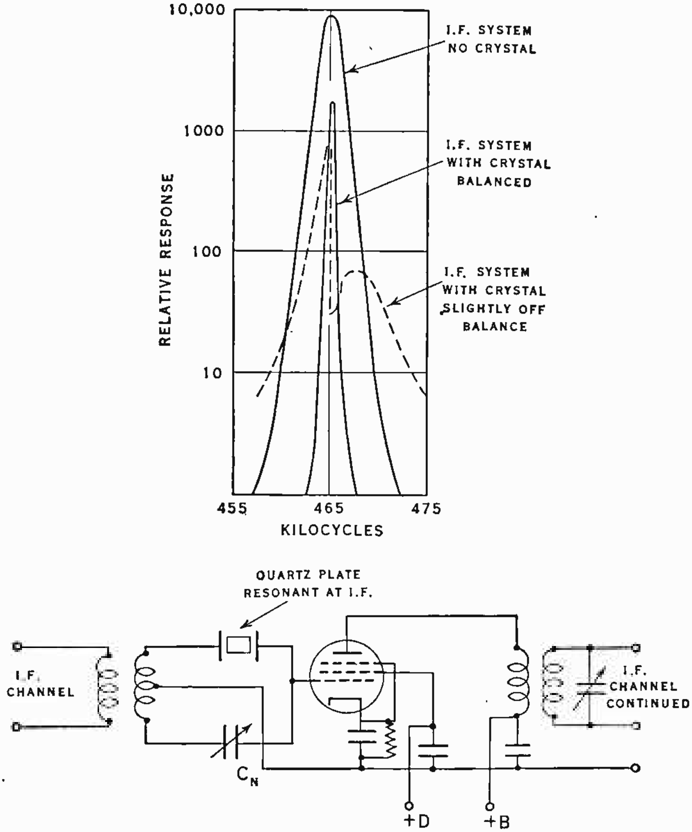


FIG. 118. Robinson "Stenode". Principle.

to eliminate one sideband of a modulated signal, the mathematical explanation of which effect has been provided by R. R. Batcher. Similar asymmetrical adjustments of the crystal-bridge (see figures 118 and 121) are at times used to reduce an unwanted telegraphic signal near a wanted one, this effect, additional to the high selectivity already mentioned, having suggested the name " single signal receiver" for this application of the stenode. Under conditions of extreme interference voice-signals are occasionally intelligible with the stenode when not intelligible otherwise, and so-called "communication" receivers may be used with the crystal switched in on voice signals, the lack of an audio correction system being partly made good by the accident that such receivers usually have midget loudspeakers which respond more strongly at higher pitches —one case where such a speaker may be of advantage.

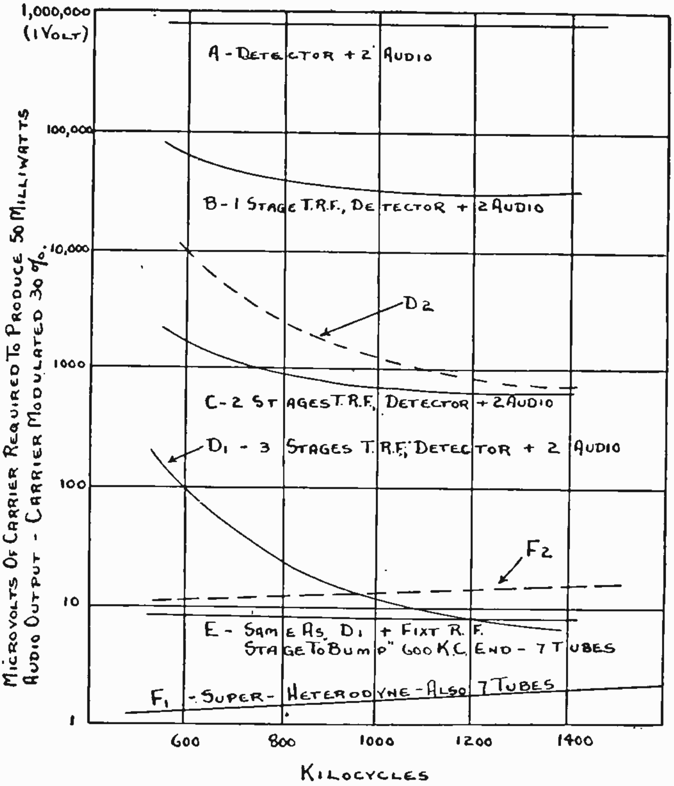


FIG. 119. Sensitivity of Typical Receivers in the 600–1600 kc. Tuning Range. Performance at Higher Frequencies (Shorter Waves) Is Always Poorer, Curves D_2 and F_2 Correspond to D_1 and F_1 but Are for the Range of 6000 and 14,000 kc.—i.e. Ten Times the Frequency.

48. Useful Receiver Sensitivity—While it is not within the subject of this chapter, one may detour sufficiently to point out that receiver sensitivity is useful only insofar as it is attained without inclusion of noise, whether received from the antenna, from the power supply, or generated in the tubes of the receiver. The prime source of tube-noise is lack of amplification early in the receiver—i.e. before tube and other noises have opportunity to contaminate the signal. Thus the importance of a tuned r.f. stage ahead of all other tubes assumes added importance. This effect of keeping the signal above the noise is at the very base of all successful amplification, whether in receivers, in transmitters, in public address systems, or at the low levels of a high-quality microphone. The user of the electron tube must at all times be on the watch lest in addition to the desired result there are obtained other and bad results which vitiate the benefit striven for. One may well keep in mind the definition of a vacuum tube as "A bottle containing very little, from which you can get a lot of things you don't want."

49. Receivers for Unmodulated Signals—Radio telegraphic signals are usually unmodulated, hence do not represent any sound when passed through the receiver systems so far described. However the unmodulated "carrier" does of course amount to a stream of energy arriving at the detector (in the case of a superheterodyne receiver it is the second detector) whenever the sending key is closed. If now the receiver is equipped with an adjustable low-power r.f. oscillator tuned to (for instance) 1000 cycles above the frequency at which the signal reaches the detector, there will result an action like that described in the superheterodyne translator (section 43), and from the detector there will emerge a 1000 cycle note sustained as long as the sending-station key is held closed. When the incoming signal ceases the local oscillator continues—but it also represents no sound when working alone. Such an arrangement is known as a "beatnote oscillator" or as a "heterodyne." The translation here is from radio to audio instead of a high radio frequency to a low radio frequency, but after all this is merely a difference in the size of the jump—not in its nature. Since the output is in this case audible, the effect of oscillator changes can be heard. Reference back to figure 115 is suggested.

The heterodyne oscillator of a tuned radio frequency receiver system must be tunable as it must keep the proper distance from the desired signal, as must the oscillator of a detector-audio system which lacks an r.f. amplifier. For this reason it is convenient to make the detector itself oscillate, and then to provide either its tuned circuit or that of the r.f. system with a small "trimming" condenser to effect the desired 1000 cycles staggering, or difference in tuning. Frequently this is omitted as the trf system is commonly broad enough so that it may be mistuned by that amount

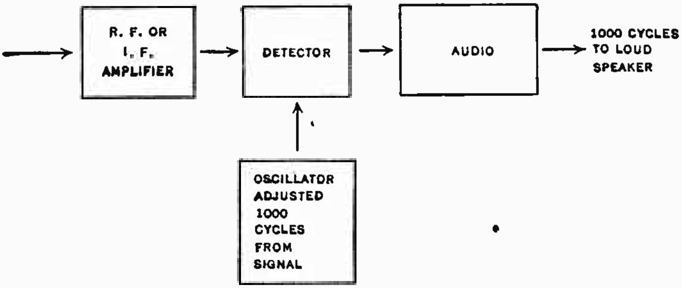


FIG. 120. Heterodyne Method of Beatnote Reception.

(thus tuning the oscillating detector to give the desired beatnote) without material loss of signal.

The oscillating detector is also called an "autodyne" detector, and is provided with control of the intensity of oscillation by the means already mentioned in section 15, in order to obtain best sensitivity.

In the case of a superheterodyne the beatnote oscillator is of course additional to the translation oscillator, but does NOT need to be tunable since it works against the supposedly fixed intermediate frequency and requires adjustment only to compensate for heating and aging drifts or to suit the fancy of the user as to beatnote pitch. It is accordingly given a frequency near the i.f. and a limited range control accessible at the receiver panel or by opening the receiver case.

50. "Tone" Selectivity in Telegraphic Receivers—If interference is moderate, successful telegraphic radio reception may be accomplished with receivers having 2 or even 1 tuned circuit, i.e. 1 or no r.f. stages, by taking advantage of the "tone selectivity" or "pseudo-selectivity" of figure 121 due to the fact that detuning changes the beatnote and drives it out of audibility at a rate far in excess of the 1 or 2 tuned circuits to reject an off-tune signal. For instance we may say that a beatnote has become essentially inaudible at 15,000 cycles, which is but 1/10 of 1 percent of the 15,000,000 cycles represented by a 20 meter signal—a difference against which a single tuned circuit working on "legitimate selectivity" is ineffective. To obtain the same selectivity by pure tuning would require a good superheterodyne with perhaps 9 tuned circuits and a minimum of 7 tubes. This receiver would, to be sure, have a sensitivity above that of the autodyne-plus-audio receiver, and would also be much more selective against STRONG signals, for the "tone selectivity" *is no defense against detector overload, nor yet against modulated signals, whereas tuned-circuit selectivity wards these off also.*

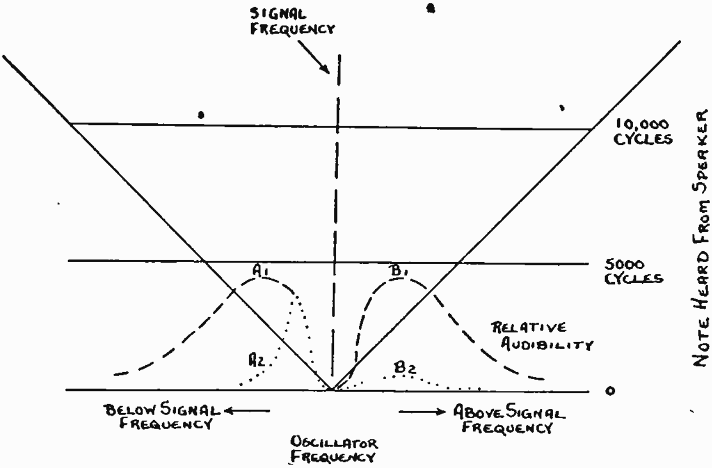


FIG. 121. Beatnote or Pseudo Selectivity.

In the simple receiver just discussed, the signal would be heard at two adjustments (A_1 and B_1, figure 121) with equal intensity. In a good gang-tuned superheterodyne, especially one with crystal filter (section 47), this would *NOT* take place since only one of two peaks can take place when the signal is tuned exactly "into" the highly selective I.F. system. The effect may be further exaggerated by unbalancing the crystal, giving curve A_2 B_2.

The use of crystal-filter i.f. systems is fairly common in radiotelegraphy, and has been discussed in section 47.

51. Other Features of Telegraphic Receivers—Telegraphic receivers are seldom required to produce high audio outputs, hence may have a relatively small audio system without "power" audio tubes. Their automatic volume control systems also differ from those of receivers intended for modulated signals, because telegraphy consists of cutting off the carrier entirely, which would cause an ordinary AVC system to go to maximum sensitivity and thus to inject bursts of noise between the dots and dashes, also to start each dash very loudly and then to depress the latter part. To avoid these effects the AVC system may be made slower in action by using larger capacitances. QAVC, as described in section 10, is helpful.

The telegraphic receiver ordinarily is benefited by a deficient audio response for low and high notes, thus depressing noise and interfering signals, while favoring tones in the region of 1000 cycles. Where receivers are used for telegraphy and voice in turn, a "peaked" audio filter is occasionally provided with switch for disconnecting it when receiving voice or music.

In commercial services it is especially essential that the signal be always found near the same place on the tuning scale and great care is taken to design the tuned circuits (especially the translation oscillator circuit) for permanence by the use of "non ageing" materials, mechanical construction far stouter than that of household receivers, and by so proportioning and placing the parts as to minimize frequency shifts of the heating-drift class, whether due to the heat of the tubes, or external sources such as weather and nearby electrical equipment. No detail need be given on this point, for only the manufacturer of the receiver has any control of the matter and it does not fall within the range of reasonable receiver adjustments, and alterations, such as the reader of this Manual may be expected to make. Neither is it proper to give adjustment instructions for receivers as these differ with the particular design, and are better obtained from the same source as the receiver itself. The intent of this section is merely to suggest what may be found desirable in a telegraphic receiver.

52. Television Receivers—The television receiver is at this moment difficult to describe for that art is in rapid flux and no standards exist as yet. At the moment such a receiver consists of two superheterodynes of which one is conventional except for the secondary fact that it works on a signal-frequency in the vicinity of 40 megacycles. The other receiver is the picture-receiver and is so organized as to derive from the incoming signal all of the following—or at least a control of some of them and the actual values for the rest:

The picture intensity modulation which controls the brightness at each point as the picture is rapidly painted on the receiver screen by a cathode-ray (see section 35).

The frequency which provides right-to-left swings of the ray.
The frequency which provides up-and-down swings of the ray.
The frequency which starts each picture at the right instant so as to frame the picture correctly.

This involves no function other than those already touched upon.

53. **Transmitter Systems**—Transmitters also depend on the actions set forth in the preceding brief outlines. Thus in figure 122 we find that the modern transmitter consists of an oscillator (sections 21 and 30) followed by a chain of r.f. amplifiers (sections 6 and 26), one stage of which chain is modulated (section

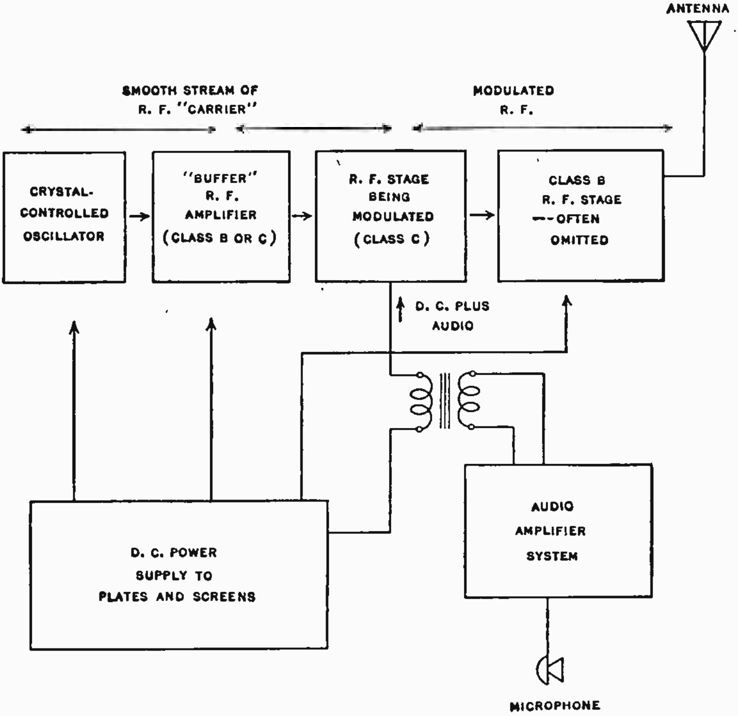


Fig. 122. Radiophone Transmitter. (Telegraphic transmitters usually omit final Class B.R.F. stage, operate Class C stage at higher carrier level and omit audio system but add a keying system for interrupting the carrier altogether in the spaces between dots and dashes.)

13) by the last of a chain of audio amplifier stages (sections 6, 12, 27), while the whole thing takes the necessary power from a power-supply system as outlined in sections 36–38. The methods of stabilizing the r.f. part of the system have been touched on in sections 18, 19 and 20, and some of the tube limitations in sections 22, 23, 24 and 25. It will be seen that the transmitter to a considerable extent makes use of the same devices as does the receiver, though in a different sequence and at quite a different power level. The following chapter goes into this more fully.

CHAPTER SUMMARY

There will be encountered electron-tube circuits not here mentioned, and at first mysterious in their nature. In attempting to analyze them it is well to suspect unexplained tubes of being special amplifiers, as for example limiter tubes working with low voltage to render them incapable of more than a small response, phase-reversers working at small gain for the sole purpose of reversing the a.c. voltage fed to them, "d.c." amplifiers whose input and output lack any a.c. in the ordinary sense but merely rise and fall slowly, or perhaps frequency changers working with abnormal bias to induce distortion. Often the function may be deduced if the tube is ignored while the rest of the circuit is analyzed. Habitual analysis of this sort develops skill in circuit-inspection, which is very useful to those who employ the electron tube.

CHAPTER 5

VACUUM TUBE AMPLIFIERS AND OSCILLATORS

1. Fundamentals—In any vacuum tube amplifier, whether triodes, tetrodes or pentodes be used, the control grid input voltage (sometimes called the "signal" or "excitation") is applied between the control grid and the cathode. It is almost always an a.c. voltage. This voltage usually acts in series with a direct (d.c.) voltage called the "grid bias."[1] Variations in the total grid voltage are produced by the input voltage, and these changes cause corresponding changes in the plate current. These fluctuations of current develop alternating power in the load circuit, or output circuit, which acts in series with the (d.c.) plate voltage supply. The general disposition of these essential elements is shown by figure 123.

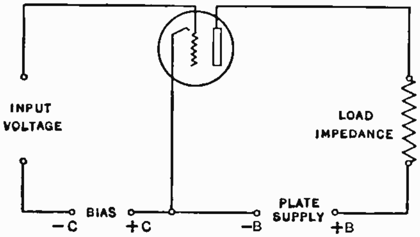


FIG. 123. Essential Elements of an Amplifier.

As the input voltage and the output fluctuations are alternating voltages and alternating currents, and the bias and plate voltages are direct, "blocking" condensers and "choke" coils are commonly employed to separate the direct and the alternating components. This permits important simplifications in design. Figure 124 shows one of the many circuits in which blocking condensers and choke coils separate the input and the output a.c. circuits from the bias and plate-supply d.c. circuits. It is essential that the choke coils possess high impedance to the frequencies to

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[1] That is to say the d.c. source and a.c. source are connected in series; adding at some moments, subtracting at others.

be amplified. For radio-frequency amplifiers, inductances of from 1 to 100 MH. (a millihenry = 1/1000 henry) are needed, and air core coils are employed. For "intermediate" radio frequencies, somewhat higher values may be desired, and special iron core construction is occasionally used, although air cores are common.

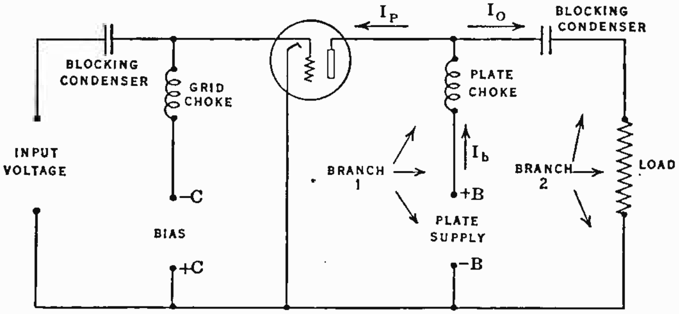

FIG. 124. Amplifier Circuit Showing Use of Chokes and Blocking Condenser.

For audio frequencies, iron cores (or cores of high permeability alloy steel such as "permalloy") are considered essential to obtain the necessary inductance without requiring excessively large coils. Values of from 1 to 500 henries are necessary. The design of such chokes is very important because low inductance will result in poor amplification at low frequencies, while high hysteresis losses or excessive distributed capacity will reduce amplification at the higher frequencies.

The capacity of *blocking* or bypass condensers must be large enough to keep the reactance low [2] at the lowest frequency to be amplified. At the same time it is frequently (but not invariably) necessary that the capacity from either set of plates to ground be kept low or a loss of amplification may be experienced. Radio-frequency amplifiers use values ranging from 0.00001 to 0.002 mfds. depending on the frequency and the impedance of the other circuit elements—i.e. resistors and inductors. Audio amplifiers use larger values, 0.01 mfds. up to as much as 50 mfds.

[2] This means low *as compared to the other circuit elements.* Thus in an audio amplifier a plate-to-grid coupling condenser is of "low" impedance as compared to a 100,000 ohm plate resistor and a 500,000 ohm grid leak if it be of 0.1 mfd. capacity but the same amplifier may require a 25 mfd. condenser to by-pass a 200 ohm cathode resistor.

2. Triodes, Tetrodes and Pentodes—Figures 123 and 124 have been drawn to show a triode tube. Tetrodes and pentodes operate in exactly the same manner. *The fixed voltages on the screen grid and (in a pentode) the suppressor grid are applied for the sole purpose of obtaining the desired relations between grid voltage and plate current.* All the discussions, equations, and diagrams to follow apply equally to triodes, tetrodes, and pentodes, except where specifically mentioned. Figure 125 shows a pentode amplifier. Note that the most active elements (grid, cathode and plate) are connected exactly the same as in a triode amplifier. Both screen and suppressor grids are given d.c. voltages, but since these elements are to be kept free of a.c. voltages they are by-passed to ground, through condensers. The screen current (and to a lesser extent the suppressor current)[3] is affected by the input signal, and without the by-pass condenser this would produce an a.c. screen voltage since the screen-supply lead contains a resistance, used to lower the d.c. voltage to a value proper for the screen. In radio-frequency applications, the inductance of the screen supply lead may be great enough to cause an a.c. voltage drop, and for this reason it is advisable to place the by-pass condenser as close to the tube socket as possible.

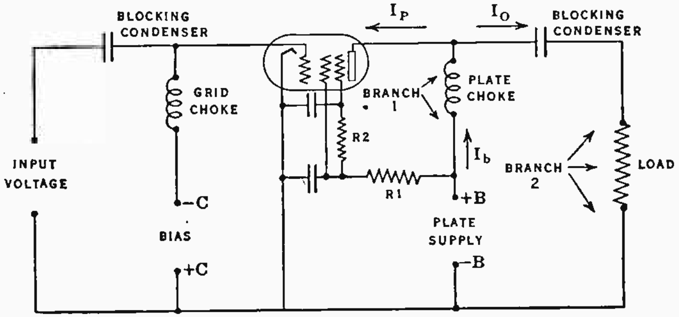

FIG. 125. Pentode Amplifier Circuit.

In the circuit of figures 124 and 125, the *average* d.c. plate current flows steadily through the "parallel feed" branch 1. When the a.c. input voltage is applied to the grid, only a very slight fluctuation of this current is produced, because the choke coil

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[3] The use of R_2 and a suppressor blocking condenser is not as common as the simpler practice of connecting the suppressor grid directly to the cathode, whose d.c. (and a.c. if any) voltage it then assumes.

resists changes. Due to the high impedance, this slight fluctuation builds up a voltage across the choke coil. This changes the voltage across the load circuit, and current will flow to or from the load circuit depending upon the polarity. In a properly designed amplifier the current flow to or from the load circuit is much larger than the current fluctuation through the choke coil.[4] For most practical purposes we may state that the current through the choke is constant, and all the variations in the *tube* plate current will be duplicated in the load circuit.

During instants that the tube is drawing average plate current (average of the signal-frequency cycle), no current will flow in branch 2 (the load circuit). When the tube is drawing less than the average current, the excess of the supply current is delivered into the load circuit. When the tube draws more than average current in another portion of the cycle the difference between the supply current and the momentary plate current is made up by a current flowing *back* from the load circuit (branch 2) to the tube. The effective voltage across the load changes direction at the same time the current does, so power is delivered into the load regardless of the direction of current flow. *ALL THIS POWER COMES FROM THE PLATE SUPPLY.* Every time the tube plate current is disturbed by a change in grid voltage, a pulse of power from the plate supply is delivered into the load. These pulses[5] in output power correspond approximately to the voltage applied to the grid, so the net effect is that "the grid voltage is amplified and impressed across the load circuit." From this effect comes the name "amplifier." If one wishes to be more precise, one may say that the tube is a power converter, changing d.c. power from the plate supply into alternating power to an output circuit. The input grid is only the control device. None of the grid power is delivered to the output.

Much simpler than the "parallel feed" circuits of figures 124 and 125 are the equally common "series feed" circuits in which the plate choke disappears and is replaced by the load.

Even parallel feed circuits frequently dispense with chokes, using resistors instead—see almost any receiver for examples. Nor need the load be a resistor, it may be any power-consuming device or a transformer feeding such a device.

Amplifier Classes—Amplifiers may be operated with various combinations of grid bias, input voltage, and plate voltage, each combination especially suited for certain purposes. The

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[4] If this is not true, the choke impedance is too low.

[5] Usually not disconnected, but joined, and therefore constituting a.c.

alphabetical designations *A, B,* and *C* have been applied to the three most important combinations and are widely recognized. The identification of these classes and the intermediate types *A–B* and *B–C* was touched on in section 12, Chapter 4. Further characteristics will be discussed in the following pages.

3. Class "A" Amplifiers—The "Pure Class *A*" amplifier claims first attention because it is the simplest, oldest and enormously most numerous. Class *A* operation of tubes is found in all but a very few stages of the audio systems of radiophone stations, telephone systems, public address systems and "talkie" theatres, besides many less common devices. Class *A* is used in all the r.f. stages, i.f. stages and some audio stages of millions of radio receivers.

The class *A* amplifier has been described briefly in section 12 of Chapter 4. It will be recalled that the plate-circuit efficiency of a class *A* tube is 20 percent or less, hence the tube must be large if much power is to be handled without overheating. Fortunately most of the amplifier stages in the world handle much less than 1 watt of power, so that they may work in class *A* which has advantages possessed by no other class of operation. These are now to be considered.

It will be recalled from section 12, Chapter 4 that in class *A* the grid bias is low, so that plate current flows even when there is no a.c. grid input. The best value of class *A* bias is not too readily stated and it is well to accept the results of the tube-maker's experiments. In figure 126 is outlined the proper operation of a class *A* tube. The conventional sine wave tone shown is merely

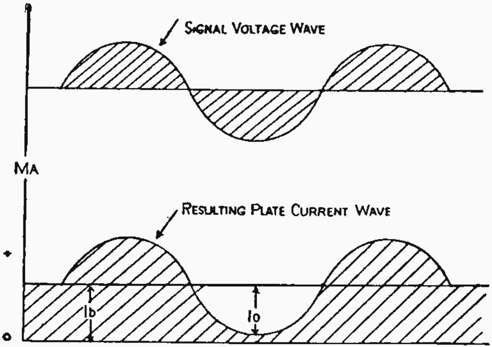

FIG. 126. Class "A."

for illustration. Though the plate current contains both d.c. and a.c. it (as shown) never goes to zero and (what is not shown so clearly) the *average* plate current is very nearly the same as before the a.c. input began. (It is assumed that I_0 is not more than about 90 percent of I_b.) Thus a d.c. plate-supply meter remains stationary, as was stated in section 12 just referred to. It is essential that the meter be of d.c. type—not a.c. or "universal"—i.e. it must be of the usual d'Arsonval type, not the iron-vane type. If the a.c. grid input voltage is made too high the plate current no longer remains fixed nor is the reproduction faithful; the amplifier is "overloaded." An extreme case (conventionalized) is shown in figure 127. The plate-input meter would have risen considerably before this. As long as proper class *A* operation continues the invariable d.c. plate supply current permits us to use a plate supply of cheap construction, with little attention to regulation.

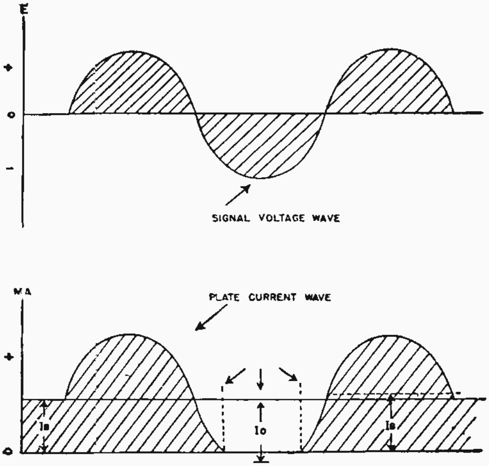

FIG. 127. Severe Overload in Class "A." When "Io" Exceeds "Ib," the Plate Current Cannot Reproduce the Signal Wave Shape Throughout the Entire Cycle. Distortion Is Introduced, and the Amplifier Is Said to Be "Overloaded."

4. Grid Current—In a pure class *A* amplifier the grid input voltage is *invariably* less than the negative grid bias voltage. As long as this is the case, the grid is at all times negative (with respect to the cathode) and therefore no d.c. grid current will flow. There are no pulses of grid current to produce irregular voltage drops and corresponding distortion. Then too, the grid bias (if fed in parallel to the input circuit as in figure 128) may be supplied through a high resistance rather than a choke coil. This tends to make the amplification more uniform since the impedance of any choke varies with the frequency whereas the impedance of the resistance is nearly constant. None of these remarks apply to *A–B, B, B–C,* or *C* amplifiers.

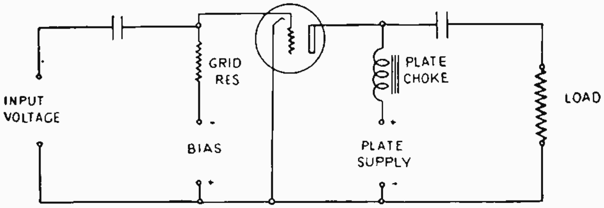

FIG. 128.

The effect of these limits is shown by figure 129 which shows the plate current, output current, plate voltage, output voltage and signal voltage for a class *A* amplifier. Each quantity is shown progressively for no output (1–2), half output (2–3), full output (3–4) and finally overloaded (4–5). For clarity this figure shows a pointed and straight sided (triangular) input wave form, not met commonly.

5. Load Resistance—The load resistance presented to the tube determines the relation between the plate current fluctuations and the plate voltage fluctuations (when the input voltage is applied). When the load resistance is low, the plate voltage variations will be small. The power output will also be small. On the other extreme, if the load resistance is very high, the plate current changes will be so small (i.e. the a.c. plate current is small) that the power output will be low, even if the plate voltage changes are quite large. It is evident that some intermediate value of load resistance will allow moderate variations of *both* plate current and plate voltage, and consequently will permit the maximum power output. This value may be determined mathematically by a process which is of little interest to the operator. However, the result is interesting. *WHEN THE GRID INPUT VOLTAGE IS LIMITED TO THE VALUE OF THE GRID BIAS, MAXIMUM UNDISTORTED OUTPUT WILL (FOR TRIODES ONLY) BE OBTAINED WHEN THE LOAD RESISTANCE IS EQUAL TO TWICE THE INTERNAL*

PLATE RESISTANCE OF THE TUBE. NOTE ESPECIALLY THAT THIS RULE APPLIES ONLY TO TRIODES, ALSO THAT IT IS NOT THE RULE FOR THE GREATEST POSSIBLE OUTPUT. If low distortion is no object a greater output may be obtained by using a load only equal to the tube's internal plate resistance, i.e. one half as much as stated above. Only in class *A audio* amplifiers is the "twice plate resistance" rule of consequence. For maximum *voltage* output quite another rule obtains—see section 10.

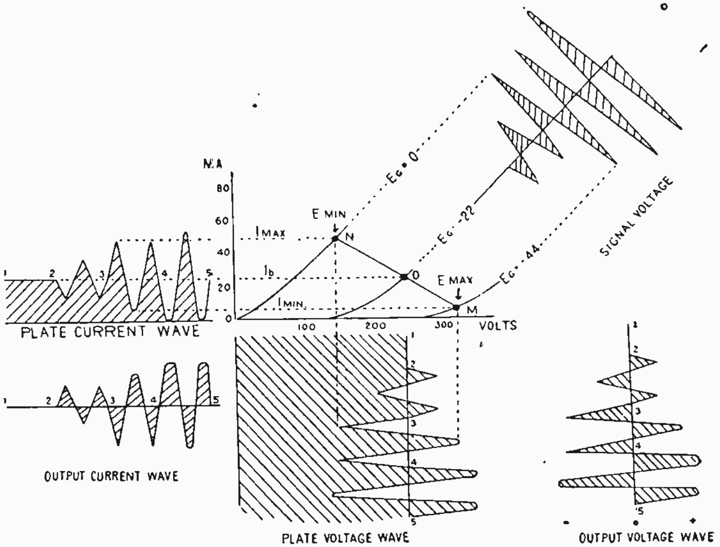

FIG. 129. Class "A" Operation Showing the Relations Between Signal Voltage, Plate Current, Plate Voltage, and Load Resistance at Various Output Levels.

These simple relations have led to the suggestion that the load resistance must "match" the impedance of the tube which is an incorrect statement. Impedance matching is the process whereby reflection losses are eliminated when a circuit having *distributed constants* (such as telephone or transmission lines) is joined to another circuit or a load.

6. Class "A" Triode Power Output Computations—The application of the rule just discussed provides a simple graphical solution for triodes operated in class *A* at audio frequency.[6] The values are worked out directly on the tube's characteristic curves. (See section 6, Chapter 4 as to meaning of such curves.)

Example:

Compute the audio power output of a type 6F6 pentode tube connected as a triode (i.e. grid No. 2 (that is the screens) tied to the plate). The characteristic curves are given on figure 130 and the maximum safe plate voltage is specified by the manufacturer as 250 volts.

A happier choice of tubes might have been made. A pentode is not a pure triode, even when the screen is tied to the plate. There is still the suppressor or "No. 3" grid, welded to the cathode though lying between screen and plate. However, it does not prevent operation of a sort sufficiently like that of true triodes to permit use of the same methods, as follows.

1. Extend the zero grid voltage line until it intersects the applied plate voltage (250 volts). The plate current at the point of intersection is seen to be 96 Ma. The operating plate current should be exactly 1/4 of this current, or 24 Ma.

2. The desired operating plate current of 24 Ma. may be obtained by using a negative bias of 22 volts, as may be seen by examining the curves. The intersection of the grid bias voltage, the operating plate current, and the applied plate voltage is indicated as point "*O*" on figure 130.

3. The upper end of the "load line" may now be "picked off," by locating the point where the zero grid voltage line crosses a plate current of exactly twice the operating (d.c.) plate current, in this case 48 Ma. The plate voltage at this point (indicated as "*N*" on figure 130) is seen to be 148 volts.

4. The "load line" is now drawn in, a straight line starting at point "*N*," passing through point "*O*," and ending where the grid voltage reaches twice the bias voltage or —44 volts. This end is indicated as "*M*" on figure 130, and at this point the plate current is seen to be 6 Ma., and the plate voltage is 326.5 volts.

5. The a.c. output current is found by averaging the upward and downward swings of the plate current, or:

$$\text{peak } I_b \text{ a.c.} = \tfrac{1}{2}(I_b \text{ max.} - I_b \text{ min.}) = \tfrac{1}{2}(48 - 6) = 21 \text{ Ma.,}$$

where I_b a.c. is the a.c. component of the plate current, i.e. the output current, I_b max. is the current at *N*, I_b min. is the current at *M*.

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[6] At radio frequencies additional factors enter which go beyond the proper scope of this book, and are not important because r.f. amplifiers are usually of the "voltage" type discussed in section 9 of this chapter.

In speaking of alternating currents, it is common practice to specify the "RMS" values rather than the peak values. "R.M.S." stands for "root of the mean square" which is a mathematical way of stating the *effective* value of a.c.—*which is shown by any a.c. meter.* (See section 38, Chapter 1.) Dividing the peak output current by the square-root of 2, we obtain the r.m.s. output current:

$$I_b \text{ a.c.} = 21/1.414 = 14.8 \text{ Ma.}$$

6. The peak output voltage is found in similar manner by averaging the upward and downward swings of the plate voltage:

$$\begin{aligned} \text{peak } E_b \text{ a.c.} &= \tfrac{1}{2}(e_b \text{ max.} - e_b \text{ min.}) \\ &= \tfrac{1}{2}(326.5 - 148) = 89.2 \text{ volts.} \end{aligned}$$

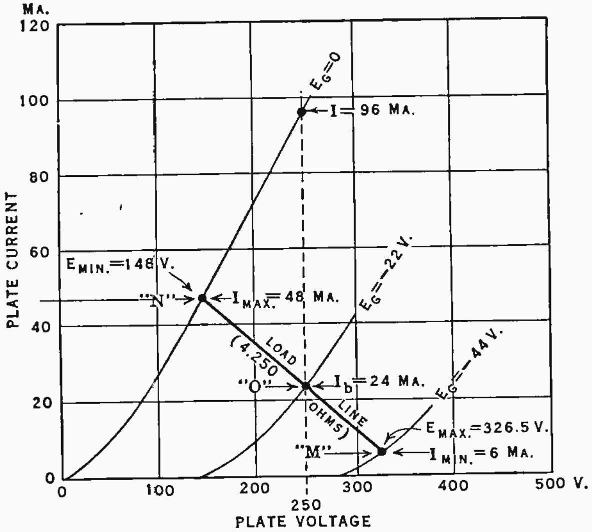


FIG. 130. 6F6 (Triode Connected) Operated at Full Output.

Converting this figure to the more common expression of r.m.s. volts:

$$E_b \text{ a.c.} = 89.2/1.414 = 63 \text{ volts.}$$

7. The optimum values of output current and output voltage just found will be obtained only if the load resistance R_p is correct; that is:

$$R_p = E_b \text{ a.c.}/I_b \text{ a.c.} = 63/0.0148 = 4250 \text{ ohms.}$$

In applying this equation, either peak or r.m.s. values may be used, but *both* figures must be expressed in the *same* units. Note also that the current is expressed in *amperes* instead of in Ma. If Ma. are used, the answer must be multiplied by 1000.

8. The power output may be found by multiplying the output current and output voltage:

$$\text{P.O.} = E \text{ a.c.} \times I \text{ a.c.} = 63 \times 0.0148 = 0.93 \text{ watt.}$$

Here, again, the current must be expressed in amperes.

In solving for power output, steps 5, 6, and 8 may be combined to form the familiar equation:

$$\begin{aligned}\text{P.O.} &= (e_b \text{ max.} - e_b \text{ min.})(I_b \text{ max.} - I_b \text{ min.})/8 \\ &= (326.5 - 148)(0.048 - 0.006)/8 = 0.93 \text{ watt.}\end{aligned}$$

The current is, of course, expressed in amperes.

7. **Distortion**—In the example just worked out, it will be noticed that the output current and voltage were not symmetrical That is, the upward swing of the plate current was from 24 to 48 Ma., or 24 Ma., while the downward swing was from 24 to 6, or only 18 Ma. Likewise, the upward swing of the plate voltage was 250 to 326.5, or 76.5 volts, while the downward swing was 250 to 148, or 102 volts. These discrepancies are caused by the curvature of the tube's characteristics.

If the unsymmetrical output wave is analyzed, it will be found to contain harmonic components which were not present in the input voltage wave. The arithmetical sum of these harmonics, expressed as a percentage of the main frequency, is the usual measure of the amount of distortion introduced. In a single tube class *A* amplifier, such as the one just discussed, the distortion consists of a reduction, or flattening out, of every other half cycle, i.e. the positive plate current swings are normal, but the negative plate current swings are all reduced. This type of distortion consists principally (not entirely) of *even* harmonics, of which the second harmonic (*twice* the input frequency) is the most important. The amount of this type of distortion may be estimated from the values already computed, thus:

$$\%\ \text{distortion} = 100\frac{(2I_b - I_b \text{ max.} - I_b \text{ min.})}{2(I_b \text{ max.} - I_b \text{ min.})}$$

which for our example becomes:

$$100\frac{(2 \times 24) - 48 - 6}{2(48 - 6)} = 100\frac{-6}{84} = 7.15\%.$$

The minus sign has no significance.

The most important feature regarding this distortion is that it can be reduced materially by a small reduction in the grid input voltage, i.e. by operating somewhat below the maximum capacity. Conversely any further increase in output will be attended by a rapid increase in distortion. The performance of a typical class *A* amplifier is shown in figure 131. Note that the operating level, selected for extremely low distortion, is considerably below the rated output which would be computed in the manner just described.

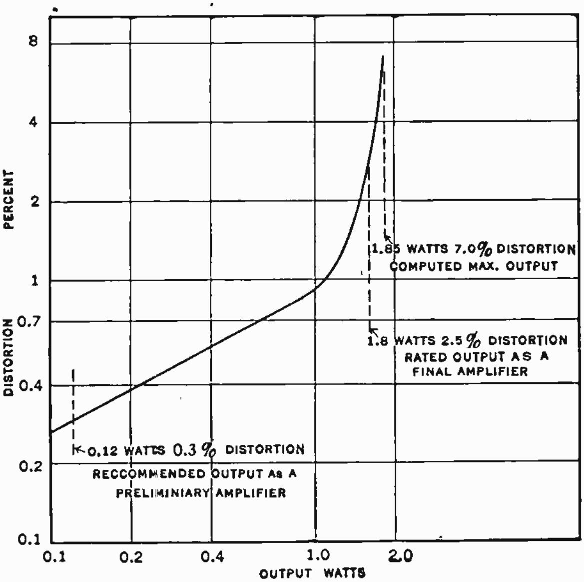


FIG. 131. Typical Class "A" Performance Curve.

As it is obviously undesirable to operate high power amplifiers far below their full output, good engineering practice is to allow about 2.5 percent distortion in the final amplifier. (The term "final amplifier" means only the modulator, in the case of a transmitter, or the stage that supplies the loud speakers, in the case of a receiver or public address system.) As 80 percent or so of the maximum output can be secured without exceeding this distortion limit, this limit is not unreasonable, especially as only the occasional loud sounds reach into this region, most sounds being at a much lower level. *All preliminary amplifiers should be, however, operated considerably below their full capacity in order to keep the over-all distortion low.* It is apparent that a series of, let us say, 8 stages, each operating so near its maximum capacity as to generate 2.5 percent distortion, would show a combined distortion of an intolerable amount. Figure 131 shows the general relation between the computed output, the rated output as a high-grade modulator, and the recommended output as a preliminary amplifier.

8. Push-Pull Class "A" Audio Amplifiers—The example just shown indicated that the performance of a single tube class *A* amplifier is limited to a certain extent by the generation of even harmonics. These may be removed from the output by using two tubes in a "push-pull" circuit one form of which is shown in figure 132. The even harmonics of the individual tubes are in phase, whereas the fundamental output currents are "out of phase." By connecting through a properly designed output transformer, the even harmonics will not be transferred to the load. The principal distortion remaining is then the third harmonic (three times the input frequency). Unfortunately, tests have shown that a given percentage of third harmonic distortion is more objectionable to a listener (the reason is not clearly understood) than an equal percentage of second harmonic distortion. For this reason, a push-pull amplifier will not deliver appreciably more power than twice the single tube rating.

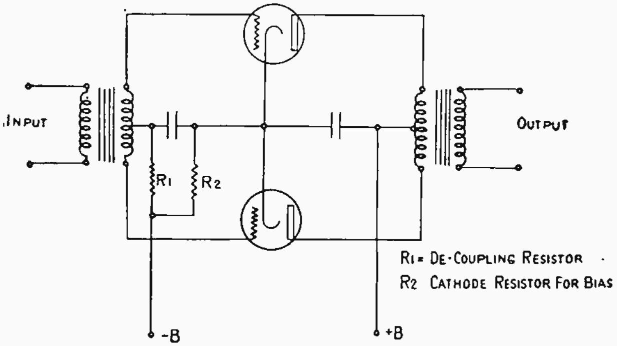


FIG. 132. Push-Pull Class "A" Amplifier.

Push-pull class *A* audio circuits do possess three very important advantages:

1. The steady (d.c.) plate currents of the two tubes flow through the output transformer windings in opposite directions, thereby producing no steady magnetization of the transformer core. This is important since the core need be only large enough to handle the magnetic flux caused by the a.c. (output) current. This makes the unit more compact, cheaper, and more efficient.

2. There is no tendency for the output current to flow through the power supply unless the tubes are unlike. This greatly simplifies the by-passing and isolating necessary for stable operation. (A small degree of by-passing is usually provided to allow for the probable lack of perfect balance between the two tubes.)

3. When the filaments are operated from a.c., the resulting hum is reduced by the push-pull action.

The student is cautioned not to confuse push-pull class *A* amplifiers with classes *A–B* and *B*. Although the circuits are essentially the same, the voltages and operation are different. In practice it is easy to distinguish because the class *A* shows steady plate current at all times, whereas the classes *A–B* and *B* plate current meters will swing with the signal.

9. Class A "Voltage" Amplifiers—Class *A* voltage amplification busies most of the world's vacuum tubes.

When an audio amplifier stage supplies a loud speaker, modulates an r.f. stage, or feeds into a telephone line, the power output is an important consideration. However, if the amplifier load is of extremely high impedance, notably if the load is a succeeding class *A* stage (not *AB, B* or *C*), then the tube's power output is so small that the a.c. voltage alone is of interest and we call the stage the "voltage amplifier." Most receiving tubes also work as class *A* "voltage" amplifiers, for the r.f. and i.f. stages of receivers (also some preliminary audio stages of some receivers) are required to do no more than swing the currentless grid of a following class *A* stage.

10. Factors Governing Voltage Amplification (Audio and Radio)—The voltage amplification of a single tube (triode, tetrode, pentode or other type) is always something less than its "mu" (amplification constant, see section 6, Chapter 4). Thus if a 6C5 "general purpose" triode tube with an amplification constant of 20 is used we shall never actually secure a voltage gain of 20 times. A near approach is possible only if the frequency is *not* too high and the load-resistance *is* high as compared to the internal plate resistance of the tube. This is not so easy as it sounds. The plate resistances of the general-purpose triodes such as 201A, 27, 37, 56, 76 and 6C5 are all around 10,000 ohms for rated plate current at a plate voltage of 250, hence it seems as if we need merely to obey the rule of section 5, supplying a load of $2 \times 10{,}000 = 20{,}000$ ohms. This would in fact permit the greatest *undistorted power* output, which is perhaps 1/4 watt for these small tubes, but the *voltage* amplification is not 20 by any means. It is:

$$\text{voltage gain} = \text{amplification constant}\left(\frac{\text{Load ohms}}{\text{plate ohms} + \text{load ohms}}\right)$$

which for our 6C5 example is

$$20\left(\frac{20{,}000}{10{,}000 + 20{,}000}\right) = 14.6.$$

In the operation of the amplifiers this would mean that 4.8 volts of a.c. applied to the input (grid) would produce about $14.6(4.8) = 70$ output a.c. volts for driving the grid of the next stage. (Were it possible to make good the full mu of 20 we would need only $70/20 = 3.5$ a.c. input volts.) For a 3-stage amplifier this means that we need:

$$70/14.6/14.6/14.6 = .022 \text{ input volt.}$$

It is now clear that for small-power class *A* amplification it is very much worth while to use tubes with a high mu *provided* it is possible to provide loads of extremely high impedance, for a high mu tube has higher plate impedance than the general purpose triode tubes just discussed, hence the high mu will not be made good unless the loads are rather extreme. As an alternative to high-mu tubes one may use the general-purpose tube already discussed and place between them devices which are themselves capable of providing a voltage step-up. Such devices are invariably transformers with more turns of wire on the secondary than on the primary. These transformers always deliver less power than they receive (especially at intermediate and radio frequencies). Consequently they are not to be used without tubes for any really considerable amount of gain; a cascaded system of three transformers would (especially at high radio frequencies) be a dismally effective de-amplifier. Even with tubes the transformers have limitations, giving less and less voltage-gain as they are improved from a fidelity standpoint. Thus in a superheterodyne the broad-tuned intermediate-frequency transformers necessary for high-fidelity reception give materially less gain than would be possible. Similarly in audio work a transformer with 5 times as many secondary turns as primary may give nearly a 5/1 voltage step-up at 1000 or 2000 cycles, but falls off rapidly at higher and lower frequencies so that speech is mangled and music destroyed. It is good for telegraphy only—if at all. On the other hand high-fidelity transformers are invariably relatively costly and have perhaps a 2/1 step-up. However this must not be ridiculed for if our 6C5 amplifier used only two such high-quality transformers between the tubes the required input would be dropped:

$$2 \times 2 = 4 \text{ times}$$

and the necessary input voltage would become:

$$70/14.6/14.6/14.6/2/2 = .0055 \text{ volt} = 5.5 \text{ millivolt.}$$

Just such combinations of general-purpose triodes and inter-stage transformers have been used very extensively. The main objection to them in *audio work* is the cost and (for portable work) the weight of the transformers, and the tendency of the transformer core to "pick up" hums from power lines or nearby plate-supply and transmitting equipment. The cost objection will probably remain but recent transformer designs have greatly reduced the other two difficulties. It must be understood that the reference here has been purely to audio frequency inter-stage step-up transformers. The kind of transformers intended to associate an amplifier output with a telephone line or with control equipment is not intended to provide a step-up, but rather to adjust impedances or to permit the use of a "balanced to ground" line with equipment which has one side grounded actually or in effect. On the other hand microphones of low-impedance type are commonly connected to transformers with a high step-up so as to get the signal above the noise-level. In class *A* radio-frequency amplifiers (almost exclusively of receiver type) the transformer step-up is often small, especially at the higher radio frequencies. In the case of tuned r.f. stages the transformer gain for any one tuning range goes down as the condenser capacity increases with tuning, so that the gain curve for any one range is not level but sloping. In another tuning range (that is with a different set of r.f. transformers switched in) there is met another sloping curve, either higher or lower than the first, depending on the relative wavelength of the two ranges. Higher gain is possible at the longer waves (lower frequencies). As the wavelength becomes shorter (frequency higher) the transformers become less effective and presently are acting as step-down devices of poorer and poorer performance. Since the tubes themselves are also decreasing in effectiveness with rise of frequency the entire amplifier soon ceases amplifying. At 100 megacycles (3 meters) ordinary tubes and transformers have little effectiveness, while at 300 megacycles little gain is attained even with miniature tubes and special transformers. In either case a per-stage gain of 3 would be considered good, whereas at 100 kilocycles (3000 meters) a per-stage gain of several hundred is quite possible for a normal r.f. pentode. The mention of pentodes in the midst of a triode discussion may seem out of order, but in class *A* r.f. and i.f. amplification triodes are very seldom used, for reasons given in Chapter 4, sections 14, 16, 19 and 26. To discuss the r.f. inter-tube transformer further than this is to go far beyond the proper scope of this book, which has nothing to do with receiver design. This is information to be found in standard text books, and also in the last few years of the "Proceedings of the Institute of Radio Engineers," which likewise provide extensive further references.

11. Voltage Amplification (a.f. and r.f.) with High-mu Tubes—When the voltage-gain is to be increased by the use of high-mu tubes it is first necessary to consider the available tubes. These consist of triodes with a "mu" around 75–100, tetrodes with mu in the region of 500 and pentodes with mu in the region of 1000 or more. All of these types could be made with still higher mu, but it has already been said in section 10 of this chapter that the mu of a tube cannot be "made good" unless the load impedance is large as compared to the plate-resistance of the tube. Thus it is quite profitless to double mu unless one can increase the load impedance. Triodes, tetrodes and pentodes all are limited by this consideration.

In the case of the triode of receiving size a "mu" of 100 produces a plate resistance in the neighborhood of 100,000, thus lowering the effective or "made good" mu to:

$$100\left(\frac{20{,}000}{100{,}000 + 20{,}000}\right) = 16.6$$

if the same 20,000 ohm load impedance be used as for the general purpose triodes of section 10. This is not an impressive improvement over the 14.6 obtained with the general-purpose tube having a mu of only 20. The difficulty is obviously that the transformer has not a sufficient primary impedance to work effectively out of the high-mu tube, and it will further be found that the transformer fidelity has suffered by the change for reasons not important here. It is possible to make a transformer of more than 20,000 ohms primary impedance, even at low audio frequencies, but it is difficult to maintain good high-note response at the same time, hence it is common to allow high-mu audio triodes to work into a resistance load instead of a transformer, for high resistances are very cheap and they do not favor any particular audio frequency. The circuit then resembles figure 124 except that the "Plate choke" has been replaced by a plate resistor which is the real load, while the "load" of figure 124 is now a gridleak of 1/2 to 2 megohms, the upper end of which connects to the grid of the next tube. The output voltage available across the plate-load resistor now depends on the same rule which has been used in this section and section 10, but not all of that output voltage reaches the next grid, for the resistance-condenser combination (unlike a transformer) is always a step-down device and the available voltage is divided between (*a*) the blocking condenser and (*b*) the gridleak-and-tube following. It is therefore customary to make the blocking condenser large (0.1 microfarad or more for low audio frequencies), and to make the gridleak as large as possible without grid-blocking, say 1,000,000 ohms or more. This cannot be carried too far; a common disease of resistance-coupled amplifiers is severe distortion on loud signals through reduction of the grid bias on account of leakage of plate voltage through the blocking condenser, whose leakage is larger as the condenser is larger. However, a reasonable and practical "made good" gain of 50 is possible for such a tube, with a plate-load resistor of 100,000 ohms and a plate-supply voltage of 250, as before.

There is an unwarranted tendency to claim that resistance coupling should replace audio transformers where audio fidelity is wanted. This is not sound. Resistance-coupled stages all "droop" at higher audio frequencies because of the shunting effect of the tube's capacitances. The customary remedy is to use some transformer-coupled stages which may be given a high-frequency "bump" by resonating them with their own and the tube and circuit capacitances at perhaps 8000 cycles, or else to provide excessive amplification and then to waste some low-note gain through a suitable device shunted across the system and known as an equalizer. Thus the gain of three high-mu resistance-coupled stages after equalization is not as high as might be expected by comparing a "made good" gain of 50 with that of $14.6 \times 2 = 29 +$ obtained from the 6C5-and-transformer stage of section 10. The outstanding merit of resistance-coupling for audio work is not so much high per-stage gain as cheapness and relative freedom from hum-pickup. Its main shortcomings are those already mentioned and the tendency of resistors to become noisy with use.

Intermediate between the transformer-coupled stage and the resistance-coupled stage is the type using a plate choke coil just as shown in figure 124, and commonly called "impedance coupled." If the gridleak is also replaced by a choke the combination is "double impedance coupled." The performance is fairly obvious from what has been said. For audio work the chokes, of course, have iron cores to attain sufficient inductance at low frequencies, while at radio frequencies at least one of them is commonly condenser-tuned as the only handy way of obtaining a high impedance, and also some selectivity. The selectivity is generally less than for an r.f. transformer because of the closer coupling.

In class *A* r.f. voltage amplifiers the triode is undesirable because of its tendency to regenerate and oscillate whenever the frequency is high enough to permit appreciable energy to return to the grid through the small plate-to-grid capacity. (See Chapter 4.) In fact the tube goes into oscillation long before the load has been made large enough to secure gains such as have just been discussed, and reasonable r.f. voltage gain can be obtained from triodes only if they are neutralized as was explained in Chapter 4, sections 19 and 20. In class *A* work this is now commonly avoided by using the tetrode or pentode. The tetrode is not usually made with mu exceeding 500, for its plate resistance then becomes so high that a proper load cannot be provided. The pentode's plate resistance is lower for the same mu, hence a higher mu is possible without running away from the load, and in practice r.f. voltage gains (class *A*) about twice as great as for the tetrode are obtained. What the actual gain is depends not only on the load, but on the frequency as already stated. The drooping tendency of resistance-coupled stages which is encountered in the upper audio range continues as the frequency is raised and in the r.f. region resistance coupling becomes ineffective, therefore is used only of necessity.

12. Notes on Transformers in Class A Amplifiers—As already suggested, transformers have other uses than mere voltage step-up. Telephone or microphone lines pick up hum, noise, and cross-talk from nearby circuits by reason of mutual capacity and inductance between the circuits. Although shielding will reduce this, it is not always practical, nor is the shielding action ever perfect. The disturbing currents are induced in the same direction (polarity) in both of the two wires composing the telephone or microphone line. The desired currents, on the other hand, are (at any given instant) traveling in *opposite* directions on the two wires. This is illustrated by figure 133. If either of the wires is grounded, the disturbing current in the opposite wire will induce a voltage into the amplifier. If no ground is provided, the currents return to earth through whatever capacities exist between the windings and ground. Note that if no transformer is provided, one side of the line will by necessity be grounded through the amplifier.

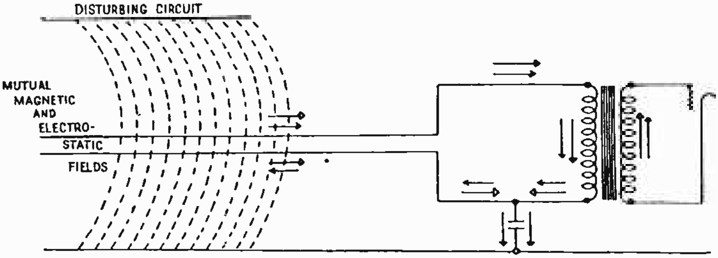


FIG. 133. Disturbing Currents from Other Circuits Are Passed into the Amplifier if Either Side of the Line Is Grounded.

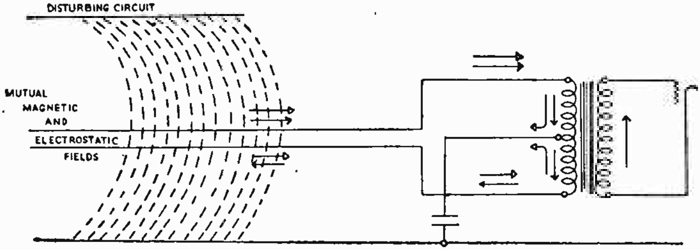


FIG. 134. Disturbing Currents from Other Circuits Can Be Balanced Out if an Input Transformer Mid-Tap Is Grounded.

In figure 134, the center-tap of the primary (line) winding is shown grounded. The disturbing currents can pass freely to ground over this path, and being opposite through the two sections of the primary, do not induce any voltage into the amplifier.

Two precautions are necessary. The transformer should have a grounded electrostatic shield between the windings, else the disturbing current can pass over to the secondary (into the amplifier) through the inter-winding capacity. Such a shield may consist of a " dead " layer of wire or preferably of a layer of thin sheet metal forming one turn but with the overlap insulated so that it is not short-circuited. Also, the ground should be made through a condenser to avoid a path for direct currents. In some localities, electric railway or street-car earth return currents may flow through such a path and possibly damage the equipment. (This assumed that the line is grounded at another location, as is usually the case.)

Transformers may be used to advantage when a single tube is to be coupled to a push-pull stage. The purpose here is to obtain the required phase difference, and not amplification.

Transformers must be used between the plate of a tube and the actual load terminals, unless the load happens to have exactly the right impedance. This is very seldom the case, as usual tube loads should be between 2,000 and 10,000 ohms (depending upon the tube and the operating conditions as previously explained) while telephone lines generally present an impedance of 500 ohms, speaker voice coils are frequently as low as 3 ohms and other types of loads also have incorrect values. In order to obtain maximum output, the impedance connected to the tube must be obtained by means of a transformer having the proper turns ratio. The relation between turns ratio and impedance changing is given by the expression:

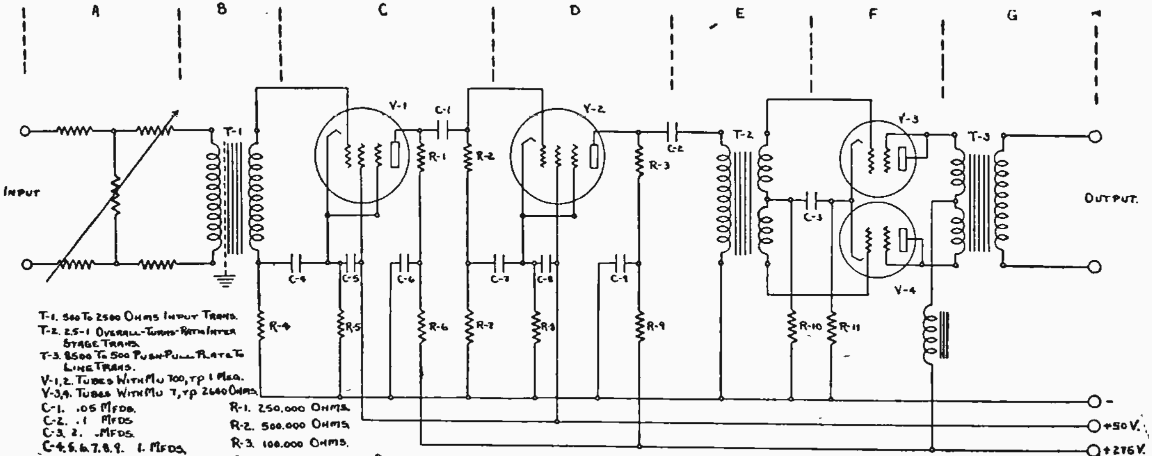
$$R_L = R(N_p/N_s)^2,$$

or

$$R_L/R = (N_p/N_s)^2,$$

where R_L is the load presented to the tube, N_p is the number of turns in the output transformer primary (the plate winding), N_s is the number of turns in the secondary (load winding), and R is the load connected to the secondary. The expression here determines the *actual* value. When limited by commercial apparatus, there is frequently a discrepancy between the *desired* value and the *actual* values obtainable from the transformer ratios available. In this case, the actual value should be *larger,* rather than smaller.

13. Calculation of Audio-frequency Class A Voltage Gain—Voltage amplification, or " gain," is the ratio between the amplifier input voltage and the amplifier output voltage. The amplification is usually stated in terms of decibels which is abbreviated as "db." This unit is equal to twenty times the common logarithm



T-1. 500 To 2500 Ohms Input Trans.
T-2. 2.5-1 Overall-Turns-Ratio Inter Stage Trans.
T-3. 8500 To 500 Push-Pull Plate To Line Trans.
V-1, 2. Tubes With Mu 700, rp 1 Meg.
V-3, 4. Tubes With Mu 7, rp 2640 Ohms.
C-1. .05 Mfds.
C-2. .1 Mfds.
C-3. 2. Mfds.
C-4.5.6.7.8.9. 1. Mfds.

R-1. 250.000 Ohms.
R-2. 500.000 Ohms.
R-3. 100.000 Ohms.
R-4.6.7.9.10. 100.000 Ohms.
R_5. 300 Ohms.
R_8. 300 Ohms.
R_{11}. 500 Ohms.

FIG. 135. Audio Frequency Amplifier.

of the voltage amplication ratio. The use of this unit is preferred to the actual voltage ratio because (1) large confusing numbers are avoided, (2) the "gain" or "loss" of two or more pieces of equipment connected together may be simply added to find the overall amplification or loss, (3) power output may be expressed in the same units, and the "gain" or "loss" simply added to find the new power output. In addition, the unit is roughly equal to the loss of one mile of standard telephone cable, thus giving a quick idea of the amount of amplification necessary on any particular job using such circuits. For a person of average hearing, one db is the smallest change in sound intensity that is perceptible so the unit has a rational basis as well as a mathematical one. The student is urged to become thoroughly familiar with the use of this unit by studying section 1 of Chapter 7.

The gain of an amplifier, such as the one depicted in figure 135, is found by solving for the voltage amplification for each part indicated. This will be done to illustrate the process.

Part *A*. This part is a variable network of resistances used as a "gain control." In computing amplifier gain, this control is set in the maximum position.

Part *B*. The voltage step-up ratio of the input transformer may be computed either from the turns ratio, or from the impedance ratio, depending upon which of these happens to be known. In this case the transformer is described as "tube to line, primary 500 ohms, secondary 25,000 ohms."

The figures 500 and 25,000 refer to the appropriate load impedances, thus they indicate an "impedance transformation ratio" of 500/25,000, i.e. a 500 ohm primary load is transformed into a 25,000 ohm load at the secondary. The voltage ratio is the square root of this:

$$E_s/E_p = \sqrt{Z_s/Z_p} = \sqrt{25{,}000/500} = 7.07;$$

to convert this into decibels we write

$$\text{Gain} = 20 \log 7.07 = 17 \text{ db},$$

but for the non-mathematician it is more convenient to convert the voltage ratio of 7.07 into the db value of 17 by reference to a graph or chart of db versus voltage ratios.

Part *C*. The gain contributed by the tube in class *A* is given by the formula:

$$\text{V.A.} = \mu R_p/(R_p + r_p),$$

where V.A. is the voltage amplication, μ is the amplification constant (here 700), R_p is the load resistance and r_p is the internal plate resistance, here 1,000,000 ohms.

In this case R_p consists not only of R_1 but also the grid leak. The two are practically in parallel, since C_1 has (in this case) a resultant large capacitance. Thus R_p is not 250,000 ohms, but 250,000 in parallel with 500,000, that is 166,666 ohms.

$$\text{V.A.} = \frac{700 \times 166{,}666}{1{,}000{,}000 + 166{,}666} = 100.$$

Converting into db,

$$\text{Gain} = 20 \log 100 = 40 \text{ db.}$$

Part *D*. Neglecting the shunting effect of the transformer, the plate load is equal to the resistance of *R*–3, or 100,000 ohms. Using the same tube constants as for the stage above, we find:

$$\text{V.A.} = \frac{700 \times 100{,}000}{1{,}000{,}000 + 100{,}000} = 63.6.$$

Converting into db,

$$\text{Gain} = 20 \log 63.6 = 36 \text{ db.}$$

Part *E*. This transformer has an over-all turns ratio of 2.5 : 1. The ratio is a step-up, that is, there are slightly more turns in either grid winding than there are in the plate winding. The voltage step-up is the same as the turns ratio, so:

$$E_s/E_p = N_s/N_p = 1.25/1 = 1.25.$$

Converting to db units,

$$\text{Gain} = 20 \log 1.25 = 2 \text{ db.}$$

Part *F*. The gain in the final stage is computed using the tube constants ($\mu 7$ and r_p 2600 ohms) and the load resistance found in the solution (for a single tube) in the early part of this Chapter. The effect of the *two* tubes is accounted for when the output transformer ratio is evaluated. The load for one tube was found to be 4250 ohms. (Of course, if the transformer ratio available produces a somewhat higher value, that figure should be used instead.) Then:

$$\text{V.A.} = \frac{7 \times 4{,}250}{2{,}600 + 4{,}250} = 4.35 \text{ times.}$$

Converting to db,

$$\text{Gain} = 20 \log 4.35 = 12.8 \text{ db.}$$

Part *G*. The output transformer primary (plate to plate) impedance should be twice the desired load impedance for either tube, or 8500 ohms (twice 4250 ohms). The secondary is wound for 500 ohms. (Presumably to feed a line.) The voltage ratio is step-down, and is found from the impedance ratio:

$$E_s/E_p = \sqrt{Z_s/Z_p},$$

$$E_s/E_p = \sqrt{500/8{,}500} = 0.243.$$

However, only half of the primary is used by either tube. The voltage ratio of half-primary to secondary is twice as great, that is 0.486. Converting this latter ratio into db, we find the gain:

$$\text{Gain} = 20 \log 0.486 = -6.3 \text{ db.}$$

Note that the "gain" is negative, indicating a reduction in voltage in this device.

The overall amplifier gain is now found by adding the figures for each section:

A. Gain control section	0
B. Input transformer	17.0
C. First tube	40.0
D. Second tube	36.0
E. Inter-stage transformer	2.0
F. Push-pull stage	12.8
G. Output transformer	— 6.3
Over-all gain	101.5 db

14. Input and Output Impedances—In stating the gain of an amplifier, it is assumed that the input and output impedances are equal unless otherwise stated. A little consideration will show that any difference in the impedances will change the gain, and unless so stated, may be misleading. For example, the amplifier just discussed showed a gain of 101.5 db measured from a 500 ohm input to a 500 ohm output. Now if the input source had been a mixer with a 50 ohm output, a 22:1 input transformer could have been used in place of the 7:1. This higher ratio would produce 10 db more voltage gain, and the amplifier would show 111.5 db. This is misleading unless the difference in impedance is mentioned.

In the same fashion, if the amplifier was to be fed from a crystal pick-up (a high impedance source), the input transformer would be omitted and the computed gain would only be 84.5 db.

Note—Class *A* output circuits are discussed in section 26.

15. **Class B Amplifiers**—In section 12, Chapter 4 was given a general outline of the differences between amplifiers of the classes *A*, $A–B_1$, $A–B_2$ and *B*. It is necessary only to recall that the *A–B* types are intermediates and will be understood if the *B* class is discussed as the *A* class has been in the early part of the present chapter.

Recalling that the class *A* amplifier is extremely easy to " drive " and that it is capable of excellent fidelity of reproduction, it is natural that the class *B* amplifier is used only when that is made necessary by a higher power level. Since class *B* operation will enable an audio push-pull stage (for example) to deliver about 5 times the output watts which could be obtained from the same size of tubes in class *A*, it follows that class *B* operation becomes interesting whenever the power level is such that the tube-cost has risen uncomfortably. Likewise the higher plate-circuit efficiency of the class *B* stage effects a power saving which may in itself be a consideration if the output is to be anything above perhaps 100 watts. Finally it is clear that a change from class *A* to smaller tubes in class *B* may sometimes permit a lower plate voltage supply system. *It is not necessarily true that class B is always cheaper than class A.* In transmitters and also in receivers cases are common where no saving in the plate supply system result since the rest of the system must be supplied as before. It is even possible to find cases where the class *A* system operates satisfactorily from a certain source, while a class *B* system, because of its unsteady plate-input current, disturbs that supply and requires additional filtering or an independent supply. An additional " driver " audio stage may be necessary to provide the grid-input a.c. power demanded by the class *B* stage. General statements are unwise and each case should be studied. That is not within the limits of this book, and we now turn to the operation of the class *B* stage.

The increased efficiency of the class *B* stage, as compared to class *A* is due in part to the elimination of (most of) the plate input when the tube is " resting," which is accomplished by a high negative grid bias of " cut-off " value (see section 9, Chapter 4), or by the use of a fine-mesh grid which is without bias able to cut off the plate current approximately (same reference). Thus plate current input takes place only as the grid is swung by a.c. input, and in more or less direct proportion to such grid input, whereupon it becomes possible to convert a considerable proportion of the plate input into a.c. power output. The output of the tube cannot be of the same form as the grid input, but as stated in Chapter 4 is an amplified *and rectified,* or half-wave copy of the a.c. grid input, because the tube can produce output on the positive grid swings, but on the negative swings it can do nothing for it is already cut off, and a further negative swing produces no effect. Thus one definition of a class *B* stage is:

" An amplifier in which the grid bias is approximately equal to the cut-off value so that the plate current is approximately zero when no exciting (a.c.) grid voltage is applied, and the plate current . . . flows during approximately 1/2 of each cycle when an exciting (a.c.) grid voltage *is* applied."

IT IS NOT ESSENTIAL THAT TWO TUBES BE USED UNLESS FIDELITY OF REPRODUCTION IS NECESSARY. A single class *B* tube is quite capable of driving a tuned circuit, delivering power to a variety of a.c. devices including loudspeakers (where only a tone is desired), or delivering power to resistance devices, and these things may be done at either audio or radio frequencies. The radio-frequency use of single-tube class *B* is the commoner as it is possible to use the fly-wheel effect of the tuned circuit to fill in the missing half-cycles and thus produce an alternating or full-wave current. *In audio class B work it is true that two tubes (in push-pull) are necessary.* We now turn to such a push-pull audio-frequency class *B* stage.

16. Audio-frequency Class B Push-pull Amplifier—Figure 136 shows the wave forms (but not relative amplitudes) of the grid and plate circuits in a very highly idealized class *B* amplifier, and attempts to explain how the two half-wave outputs are combined by an output transformer into a fullwave output. In an actual class *B* stage the conditions are not so ideal, for the two half-wave outputs do not join so precisely end-to-end, even when the best value of grid bias is used. The discontinuity is minimized by proper transformers. Another departure from ideal conditions arises from the fact that the class *B* grid draws a varying grid current as it swings more or less deeply into the positive-grid region, thus the grid becomes a varying load upon the previous ("driver") stage and serious distortion at this place is possible unless the driver stage is one capable of tolerating such varying loads, which is a requirement most simply met by a large class *A* driver stage of low amplification constant, coupled into the class *B* grids by means of a step-down transformer. (An exception to this method has been suggested which involves neutralization of the tubes.) If the driver is not adequate there will be rapidly increasing distortion as the point of increasing class *B* grid current is reached. A good design would be one in which the driver over-loaded at the point which also represented the heating-limit of the class *B* plates.

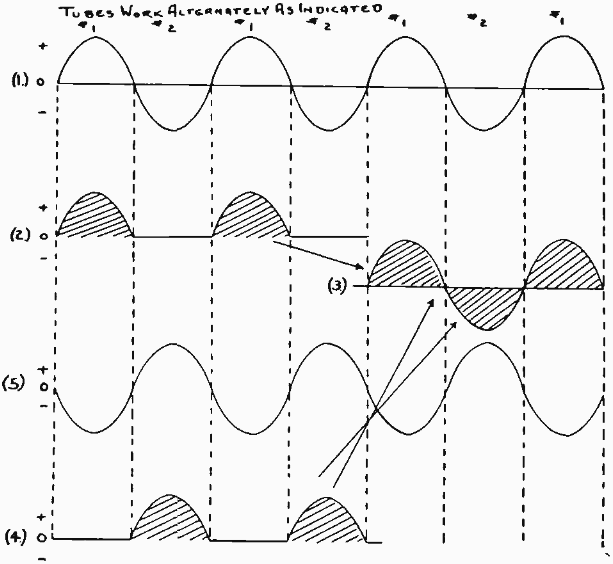


FIG. 136. Class "B" Audio. (Does Not Apply to Class "B."R.F. as Usually Used.)

1. Signal Voltage on Grid of Tube No. 1.
2. Plate Current of Tube No. 1.
3. Output Current, Tubes Nos. 1 and 2 Combined by Output Transformer.
4. Plate Current of Tube No. 2.
5. Signal Voltage on Grid of Tube No. 2.

17. **Class B Audio Amplifier Plate Efficiency**—It is quite outside the proper scope of this book to present the mathematics of class *B* audio design in full, but an outline may be useful. It will be recalled that class *A* amplifiers draw a large steady plate current when idle, and that as the input (a.c. to the grid) begins and is increased, a larger and larger part of this input is converted into output, so that the plate efficiency gradually rises from 0 to about 20 percent. In class *B* a similar rise of efficiency with

grid-input takes place, but the absence of a large "resting" plate current (except for the zero-bias type of class *B* tube) makes it appear reasonable that there be larger efficiency, especially as the class *B* tube operates with larger a.c. grid voltages, made possible by a driver adequate for swinging the grid into the positive region. Thus the full-load efficiency is in the region of 60–66 percent in familiar tubes. The equation showing the mathematics of class *B* plate-circuit efficiency does not contain the factor "mu," that is the amplification constant, which is to say the class *B* power output possible from a tube does not depend on its "mu" as was the case for class *A*. Thus it will be found that in a family of tubes differing only in their "mu," the class *B* output and also the full-load plate current is very nearly the same for all members of the family. This does *NOT* mean that they may be used in mis-mated pairs for the bias required is not the same, the "resting" plate current is not the same, and the load presented to the driver is not the same unless the tubes are not merely alleged to be alike, but are actually very closely alike—that is more closely than is common in tubes having the same type number. Thus it is advisable to pick tubes.

A limitation to class *B* operation which is not readily apparent to the user not equipped with a cathode-ray oscilloscope or its equivalent, is that if the tube is of a type which is reluctant to show distress by visible plate-heating, one may be misled into thinking that increased operating-level is justified when actually the peaks of the plate-current wave are being clipped off through one of two possible effects. One of these is swinging the grid so highly positive that it robs the plate of its proper current at the peaks, thus overheating the grid and distorting the plate-current wave-form. Further distortion is introduced by the abrupt change in driver-load due to the sudden rise in class *B* grid current, also by the probability of dynatron oscillations in the class *B* tubes. These limitations are more severe in larger water-cooled tubes where grid-heating more surely results in disaster. The manufacturer's ratings should be observed in all class *B* work unless the full effect of changes is clearly understood. There is one exception to this warning:

> In uses where the tube-life will ordinarily terminate by leakage or accident, rather than through filament wear, it is economically justifiable to hasten the filament-wear by over-running a tube for the purpose of securing larger output and thus avoiding the purchase of a larger tube. A notable advantage is gained if speech only (not music) is to be handled, since speech peaks

> are momentary and thus the overloading is also momentary. Thus a radio amateur may find it economical to over-run a pair of tubes with a class *B* audio rating of 45 watts and a cost of \$7, rather than to under-run a pair rated at 110 watts and costing \$20—simply because he intends to use the equipment perhaps 200 hours per year. The same practice applied to commercial service, 12 hours per day, 365 days per year would be costly even if the increased frequency of service-failures is not accounted.

Nevertheless the fact remains that the peak values of plate current are in class *B* stages higher than any reading of the direct-current meter in the plate-supply line by a factor in the vicinity of 1.56/1 and the possibility of swinging into the saturation region is an actual one when maker's ratings are exceeded. In fact as the emission decreases with tube aging this eventually takes place at normal rating and unsatisfactory or unbalanced operation of a class *B* stage may be due to an emission failure of an aging tube.

18. "Driver" Stages for Class B Audio Amplifiers—As already indicated, the d.c. grid current of a class *B* stage depends upon the characteristics of the tube, and upon the instantaneous grid and plate voltages. During each cycle, as the grid swings toward the positive the plate-voltage naturally falls because of the a.c. voltage drop in the tube's load. The grid current does not rise uniformly, but slowly at first and then more rapidly. At about the point where the grid voltage has risen to 1/2 of the (instantaneous) plate voltage the grid current begins to rise rapidly. At this point the (a.c.) grid driving power is about 5 percent of the output power. As this is not an unreasonable power it is frequently used for design.

The fact that there is d.c. grid current in the class *B* stage necessarily compels the preceding or driver stage to supply actual power rather than mere voltage as in the class *A* stage. In consequence the performance of the class *B* stage is so closely associated with the driving stage that the two must be designed together. The driver is ordinarily a class *A* "power amplifier" stage, that is a stage using low-mu tubes, but unlike some other cases this stage must work into a load which varies during the cycles (see previous 2 sections). It will be recalled that the gain of a class *A* stage is equal to the product of load resistance and amplification constant, divided by the sum of the load resistance and internal plate resistance (section 10), so that the "gain" may almost equal "mu" for a very high-impedance load. However as the load-resistance becomes smaller the amplification drops away. The reasonableness of this is apparent when one considers that this process would end in a short circuit, which naturally permits no amplification. If the load resistance is merely reduced to the point where it equals twice the class *A* tube's plate resistance the equation just stated in words will show the amplification to be equal to mu (2/3). Thus for a swing from an extremely high-resistance load to a load equalling twice the class *A* tube's plate resistance there would be a 33 percent change in voltage gain and a serious distortion of the signals. While the range of loads stated is not intended to represent any practical case, it illustrates the desirability of preventing load-excursions, and explains why tube-data commonly recommend that a class *A* tube be given a high-resistance load when driving class *B* grids, this being accomplished by means of a transformer whose primary turns are more numerous (usually) than their secondary turns. A proper loading condition is arrived at somewhat automatically if the driver tubes have a normal class *A* rating of at least 4 times the required driving power (which is stated by the better tube maker's in their commercial data), and if (furthermore) the input transformer of the class *B* stage is so designed that the class *B* grids will just receive their full voltage swing (again see tube data) when the driver's are operating at full output. If this is to be done from voltage-ratio considerations the peak a.c. voltage in the class *A* plate circuits, and the required peak grid-swing of the class *B* circuits provide the starting point, while the wattage to be handled, the lowest frequency wanted, and the need of keeping the secondary resistance down to perhaps 1000 ohms for a small class *B* tube, indicate the size of the transformer. The actual design is work for the transformer maker if economy is desired.

19. Class B Amplifier Performance—Figure 137 shows the performance of a typical low-grade class *B* amplifier stage. At low grid swings the grid operates in a region where it is just beginning to collect grid current, therefore the tube's characteristics are changing rapidly and the distortion is high. This tendency is characteristic of all class *B* amplifiers. In this case the curve starts off at 3 percent and almost immediately rises to 5 percent. However as the grid-swing is extended it reaches into the more linear region and the better performance in that region begins to average down the bad distortion in the lower part of the swing so that a minimum of 2 percent is eventually reached. However as the grid current continues to rise, and presently enters the region of increasingly rapid rise, the load on the driver changes and with it the distortion, which once more goes up to 5 percent.

The difficulty in this case is not altogether in the class *B* stage, but resides partly in the use of a driver not adequate for the work in hand, and therefore too much influenced by the changing load. Thus it has already begun to give bad performance at the time the useful power limit is reached. Figure 138 shows the performance of a high-grade class *B* audio stage with a proper driver stage, and with tubes specifically designed for class *B* use.

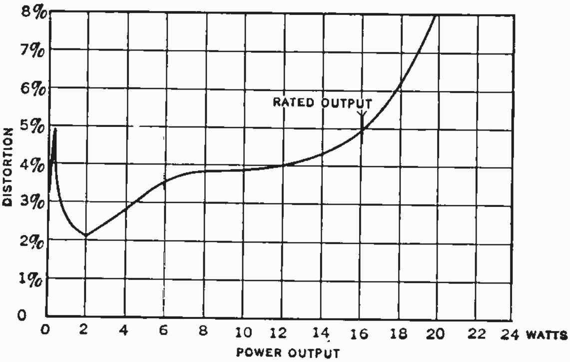


FIG. 137.

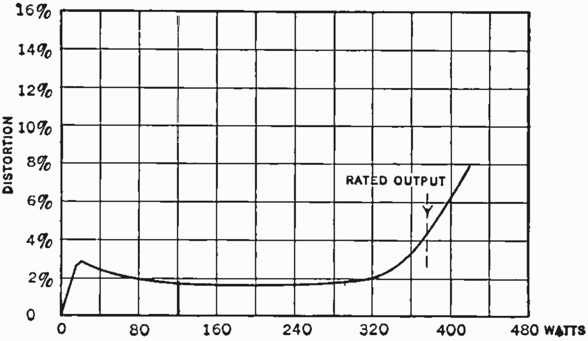


FIG. 138.

20. Special Class B Tubes—Several varieties of tubes have been introduced particularly for class *B* audio service, though most of them are useful in other ways also. One of these varieties consists of two small high-mu triodes built into a single envelope for use in the audio output stage of receivers and the like. This has the merit of compactness. These dual tubes may be, and often are, of the very high-mu varieties which are nearly self-cut-off and require no bias voltage. Such "zero bias" tubes are also available single and in that case are made in all sizes including the "100 kilowatt" water cooled variety. There are also 2-grid tubes which become high-mu zero-bias class *B* tubes when the grids are tied together, but become moderate-mu class *A* driver tubes when one grid is instead tied to the plate. Finally there is the variable-mu type of triode, more or less overlapping with some of the varieties already mentioned, and possessing advantages as regards ease of drive improved performance. The curve of figure 138 was obtained from such a pair of tubes.

21. Maintenance of Class B Amplifiers—The problem of maintaining a class *B* amplifier is mainly one of keeping the tubes balanced. Operators report that tubes now on the market differ in their characteristics to such an extent that it is advisable to select a pair of tubes by trial. The choice *should* be made on the basis of minimum measured distortion. Occasionally it will be found that tubes apparently vary from week to week. The solution is, of course, to measure distortion at frequent intervals and investigate any increase. Balancing the static or resting (no-signal) plate currents by means of separate bias controls is desirable. Lacking apparatus for measuring distortion, a crude check may be made if separate plate current meters are provided for the two tubes. Balance the no-signal plate currents (if means are provided) and then check the plate currents at full output. If there is a difference between the two tubes, switch the tubes in the sockets. If the *same tube* again shows the higher plate current, the tubes are not matched. They should balance within 5 percent for satisfactory performance. If the tube in the *same socket* (i.e. now the other tube) always draws the higher plate current, there is a lack of balance in a preceding amplifier, or perhaps the class *C* modulated amplifier is not working properly.

The present practice of installing audio amplifiers and modulators in close proximity to radio-frequency stages is to be deplored. It is very difficult to keep traces of radio-frequency out of the audio circuits. This causes undesired feed-back, produces noise in resistors and connections (electrical noise) and increases the distortion. If grid current meters are provided, they should be checked frequently. Grid current present during no modulation is a sure indication of radio-frequency current where it does not belong. An exception is the case of class *B* modulators operating with zero bias. Such stages *may* show no-signal grid current but it should be verified by shutting down the R.F. portions to make sure the grid current still flows. If it does not, the inference is obvious.

22. Power Limit of Class B Audio Tubes—In designing class *B* audio amplifiers, there are four factors that limit the possible power obtainable from a given pair of tubes:

1. The safe plate voltage must not be exceeded.
2. The dynamic peak plate current must not exceed the emission capability of the filament.
3. The power dissipated at the plate must not be excessive.
4. The driving power requirement must not be excessive.

The first item depends upon the internal construction of the tube, particularly upon the spacing of the supports and leads in the "press" where the wires pass through the glass. The plate voltage limit must be specified by the manufacturer because it cannot be determined by test without risking destruction of the tube.

In small tubes, such as are designed for receiving sets, the filament emission is limited (to save filament power) and item 2 is an important limit. For this reason, a plate current limit is often specified by the manufacturer. Exceeding this current will result in loss of emission. On the other hand, the size of the plate and the envelope are generous so that (except at unusually high plate voltages) the plate dissipation is not a limit. With larger tubes, the reverse is true. Filament economy is of minor importance so an abundance of emission is available, especially if the tube is also intended for R.F. service. For such tubes the size of the plate and envelope are the principal limit. The power that can be safely dissipated is always stated by the manufacturer.

The fourth item has been discussed previously, and is here covered by the arbitrary rule that the minimum instantaneous plate voltage shall be at least twice as great as the maximum positive grid voltage. With these limits in mind, the power output and other data will be computed for typical class "*B*" operation.

23. Class B Audio Computations—Given two tubes with the characteristics shown by figure 139 safe plate voltage 400, and dynamic peak plate current limit 200 Ma. per tube, solve for:

1. Grid bias.
2. Signal voltage.
3. Output voltage.

4. Output current.
5. Power output.
6. Plate input.
7. Plate efficiency and plate dissipation.

Solution—First Method—1. Examination of the characteristic curves shows that at the operating plate voltage, the plate current is nearly cut-off with zero grid voltage. Negative bias is, therefore, unnecessary.

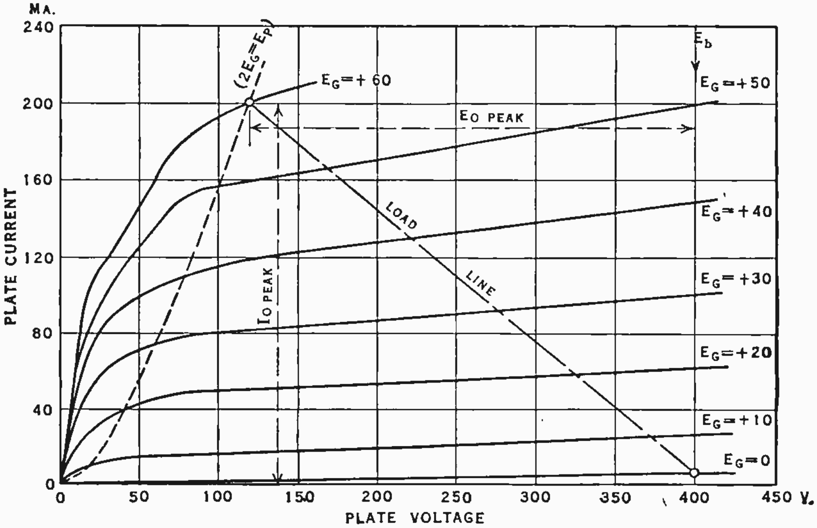


FIG. 139. Type 46 in Class "B" Audio Frequency.

2. On the characteristic curve, mark off each point where the plate voltage is just twice the grid voltage. Draw a line through these points. This is the nearly vertical dashed line marked $2E_G = E_P$. Any point on this line, or to the right of the line, satisfies the arbitrary requirement given in section 18 for reasonable driving power. This line crosses the plate current limit (200 Ma.) specified at a grid voltage of 60 and a plate voltage of 120. These are, respectively, the maximum positive grid voltage, and the minimum instantaneous plate voltage. With zero bias, it is evident that the signal voltage for full output must be 60 volts to attain the required maximum positive grid voltage. This is a peak value, the rms being 0.707 × 60 or 42 volts.

3. The peak output voltage is merely the difference between the applied plate voltage (400) and the minimum instantaneous plate voltage (120), or 280 volts. The rms voltage is 0.707 × 280 = 198 volts.

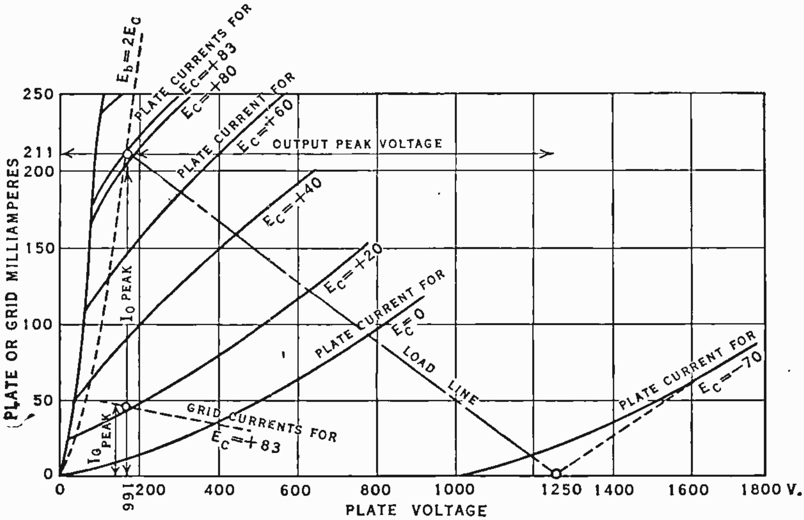


FIG. 140.

4. The peak output current is just equal to the dynamic peak plate current already specified as 200 Ma. The rms current is .707 × 200 Ma. = 141 Ma. = 0.141 ampere.

5. The product of rms output voltage and current is the power output, or: P.O. = 198 × 0.141 = 29 watts.

Note—*This is the tube output. From it must be deducted the losses in the output transformer to obtain the actual power at the secondary. For such low powers, transformer efficiencies run about 75 percent, making the net output power only 21.6 watts. This agrees quite closely with the manufacturer's rating.*

6. The average plate current of either tube is 0.318 times the dynamic peak plate current. This factor is an inherent characteristic of the class *B* plate current wave shape. In this case, the average plate current is 0.318 × 200 Ma., or 63 Ma., per tube, or 2 × 63 = 126 Ma. for both tubes. This is, of course, obtained only at full output.

7. The plate input is the product of average plate current and

plate voltage; that is: P. in = 400 × 0.126 = 50.4 watts. Deducting the tube output of 29 watts, we obtain: the plate dissipation; that is, 50.4 — 29 = 21.4 watts loss. This is, of course, shared between two tubes, so that either tube must dissipate half this amount, or, 10.7 watts loss per tube. The plate efficiency is the *tube* output, divided by the input, which is: 29/50.4 = 0.576 = 57.6 percent plate efficiency.

In the solution just given, the plate dissipation of either tube was shown to be 10.7 watts. The manufacturer's limit is 10 watts. If adequate ventilation is provided, this slight excess will do no harm. However, if conditions are unfavorable, it may be desirable to operate at a reduced audio level, or if the computed dissipation is appreciably higher than the allowable value, it is advisable to make a new solution using method (2nd) given below.

Solution—Second Method—Experience with typical tubes has shown that a plate efficiency of about 60 percent is obtained at full output. That is, the full load output (60 percent of the input) is just 1.5 times as large as the plate dissipation (the remaining 40 percent of the input). Thus the power output of any two tubes in class *B* audio could be quickly estimated by multiplying the rated plate dissipation (for both tubes together) by the factor 1.5. However this would leave no margin at the maximum-loss level which is slightly below the full output point and a more correct value is 1.44. It must be definitely understood that this factor is an estimate, based upon a probable plate efficiency of 60 percent at full output. The actual output may differ somewhat. It is, however, useful in making a solution when the plate dissipation (rather than the plate current) is the limiting factor. This will be illustrated by an example.

Example—Given a pair of tubes with safe plate dissipation limit of 35 watts each, plate voltage 1250, and characteristic curves as on figure 140. (**Note**—For simplicity most of the usual "family" of curves has been omitted from this illustration.) Operated as class *B* audio, solve for:

1. Grid bias.
2. Plate input for full output.
3. Signal voltage for full output.
4. Computed power output.
5. Plate efficiency, and plate dissipation at full output.

Solution—From inspection of the curves of figure 140 it may be seen that if we neglect the curvature at its lower end the plate-current curve for a grid voltage of — 70 reaches zero current at

1250 volts, which is to say 70 volts is the cut-off bias for this tube at a plate voltage of 1250. This is the required bias for class *B*. Using the factor of 1.44 already mentioned the estimated power output for a plate dissipation of 70 watts (35 per tube) is $1.44 \times 70 = 101$ watts. It might now be reasoned that the full-load input is to be 70 loss-watts + 101 output watts = 171 watts, but this is not altogether correct for the full-load loss is less than the loss at a slightly lower level. At full load we again assume 60 per cent efficiency and the required input is seen to be $\frac{144 \times 70}{.6} = 168$ watts plate input to both tubes at full load. At 1250 volts 168 watts is represented by $168/1250 = 0.134$ ampere. This of course is for both tubes. For either tube it is half that, or 0.067 ampere. With the shape of current-wave met in class *B* plate circuits the peak plate current is related to the average by the factor 3.14, that is the peak current is $3.14 \times 0.067 = 0.211$ ampere. This is the "dynamic peak plate current" of one tube at full output.

Turning again to figure 140 and the line labeled $e_b = 2e_c$. This line at the point of maximum dynamic plate current just found, that is 211 Ma., is slightly above the plate-current curve for a grid voltage of +80—say at about +83 volts. Accordingly a curve for +83 volts has been "guessed in" and the point where it crosses the $e_b = 2e_c$ line is labeled "*O*" for convenient reference. Ignoring all curves for a moment it is seen that "*O*" is at a height of 211 Ma. (vertical scale at left of figure), while it is 166 volts to the right of zero (horizontal scale at the bottom of the figure). These values are respectively the maximum peak plate current and the simultaneous minimum peak plate voltage, while the +83 line through *O* represents the grid voltage at that same peak instant. The synchronous occurrence of +83 at the grid and +166 at the plate is as it should be for it was originally determined that the plate voltage at this peak was to be twice the grid voltage and $166 = 2 \times 83$.

To proceed: Since the grid is to be swung to +83 despite a d.c. bias of —70 volts it is clear that the audio a.c. grid input peak voltage must be $70 + 83 = 153$ audio peak volts. This corresponds to an rms value of $0.707 \times 153 = 108$ rms grid input volts. In the plate circuit it is clear that the minimum voltage of 166 is due to the a.c. peak which must accordingly be within 166 volts of the plate-supply voltage, that is $1250 - 166 = 1084$ peak a.c. plate volts or $0.707 \times 1084 = 766$ rms a.c. plate volts.

The peak plate current has already been found, being 211 Ma.

which is 0.707 × 211 = 0.149 rms ampere = 149 rms Ma. Thus the power output is 0.149 ampere × 766 volts = 114 tube-output watts, but not all of this reaches the actual load as some is wasted in the transformer. Assuming the transformer to have an efficiency of 90 percent we find the useful output to be 114 × 0.9 = 102.5 watts useful output from the transformer secondary.

Class B Output Transformer Efficiency—There is no inherent connection between power rating and efficiency, but economic factors, including the cost of labor, material and power, control the actual goodness of commercial transformers roughly as follows: The figures relating to class *B* output transformers only:

Up to 25 watts	75 percent
25–100 watts	85 percent
100–500 watts	90 percent
500–5000 watts	95 percent
over 5000 watts	98 percent

Returning to the class *B* stage proper, the plate efficiency is determined by dividing the tube output by the plate input as in the previous cases, that is 114 watts tube output divided by 168 watts input = 0.679 = 67.9 percent plate efficiency. The plate loss is clearly the difference between input and output, that is 168 — 114 = 54 plate-loss watts or 27 watts per tube.

It has been stated that the maximum loss does not take place at full load. In this case it takes place when the signal input voltage is 79.5 (rms volts) and amounts to 30.8 watts, nearly 4 watts per tube more than at full output.

The load resistance required to obtain the conditions just solved for is obviously equal to the output voltage divided by the output current, that is 766 output volts/0.149 output ampere = 5140 load ohms.

AS ONLY ONE TUBE IS ACTIVE AT ANY INSTANT, THIS IS THE EFFECTIVE RESISTANCE THAT MUST BE PRESENTED BY EITHER HALF OF THE OUTPUT TRANSFORMER PRIMARY. The "plate-to-plate" resistance (offered by the whole primary winding) will be four times this value, or 20,560 ohms. This value is convenient when computing transformer ratios which are normally specified in terms of entire primary to secondary.

24. Predicting Driving Power—The grid driving power of the class *B* stage is equal to one-half the product of the peak grid current and the peak signal voltage. In the above example the peak grid current is 0.045 ampere (from the curves for a grid voltage of +83 and a plate voltage of 166) and the peak signal voltage is 153 volts (sum of grid bias, 70 volts, and peak positive grid voltage, 83 volts). This makes the required driving power 3.44 watts. The driver should be rated four times this power or 13.7 watts. This can be conveniently obtained from push-pull low-mu triodes, preferably with fixed bias.

25. Class A–B_1 and A–B_2 Audio Amplifiers. (Also Called A Prime)—As the designation indicates, the *A–B* class lies between class *B* and class *A*. It may be regarded as an over-biased and over-swung class *A* stage, for at low levels the plate current (d.c. input) flows throughout the cycle, and even the highest operating level does not reduce it to mere half-cycle pulses. On the other hand it may be regarded as an under-biased class *B* stage, and like the proper class *B* stage it requires actual power input to the grid, except at low audio levels, hence the driver conditions resemble those of class *B* for a part of the cycle.

The merit of class *A–B* is that it avoids the low-level distortion of class *B* by operating in approximate class *A* for this region. At high levels the operation is substantially class *B*, with consequent high efficiency and output. It might be thought that in the region between severe distortion would be encountered but in practice very satisfactory results are possible. It is well not to be hasty in assuming that a stage is operating in class *B* simply because it has a plate current varying with audio level—see section 12, Chapter 4.

Sometimes class *A–B* is divided into class $A\text{–}B_1$ (no grid current at any time) and class $A\text{–}B_2$ (drawing grid current at the upper part of its range) but this is a distinction of degree rather than basic difference.

26. Audio-frequency Class A Output Circuits—Certain devices, such as headphones, and magnetic speakers, are designed to present the correct resistance to an audio amplifier. Such devices may be connected directly to the plate circuit of a tube. In figure 141*A* the device is connected between the plate supply and the plate of the tube. This simple connection has two objectionable features: (1) the plate current of the tube flows through the device and may (if the polarity is incorrect) destroy the permanent magnetism, and (2) a shock may be received if the output device is not thoroughly insulated as all parts of the circuit are above ground potential by the amount of the *B* voltage. For these reasons, this connection is advisable only when the *B* voltage is 90 volts or less, and the plate current is not over 10 Ma.

In figure 141*B*, the direct plate current goes through the plate choke. This presents a high impedance to the audio output currents. The output current therefore flows through the condenser C_o into the speaker (or phones etc.). With this connection, one terminal of the speaker may be grounded, thereby eliminating the shock hazard. This circuit should be used in preference to the one shown in figure 141A whenever possible.

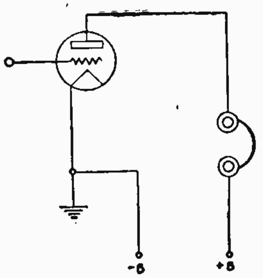


FIG. 141A.

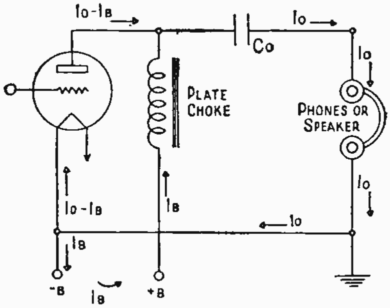
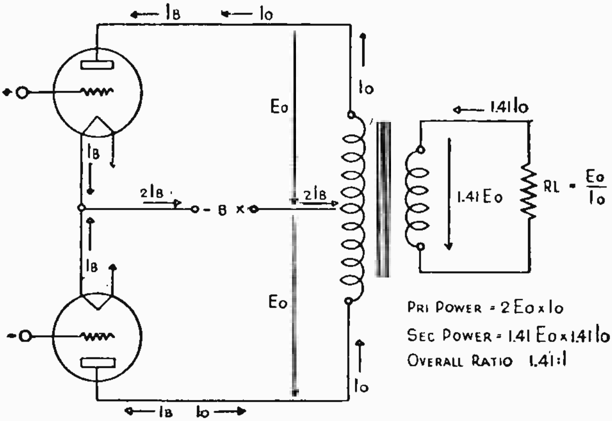


FIG. 141B. Showing How a Choke and Condenser May Be Used to Prevent Shock Hazard.



PRI POWER = 2Eo x Io

SEC POWER = 1.41 Eo x 1.41 Io

OVERALL RATIO 1.41:1

FIG. 142. A Transformer Is Necessary to Combine Properly the Power Output of Two Tubes in Class "A" Push-Pull. Arrows Show Current and Voltage Directions When Excitation of Upper Tube Is Positive.

These simple circuits are not applicable to push-pull amplifiers. A transformer is always necessary to connect the two tubes properly. This is shown on figure 142. If the resistance of the load is proper for one tube, then for a push-pull stage the transformer must have a ratio of 1.41 to 1 from the entire primary to the secondary.

For each half of the primary to the secondary, the ratio will be 0.707 to 1. With two tubes, the total primary voltage can be seen to be double that computed for either tube. The primary current is as for one tube because the output current of each tube only flows through half of the winding. This makes the power delivered to the primary $2\ E_0\ I_0$, which is obviously correct. With a transformer ratio of 1.414′ to 1, the secondary voltage will be $2\ E_0/1.414'$ or $1.414\ E_0$; and the secondary current will be $1.414'\ I_0$. Dividing secondary voltage by secondary current, we find E_0/I_0 as the required resistance. As this is the speaker resistance we assumed, the transformer ratio is correct.

(NOTE: To avoid the confusion which results from the similarity of the numbers, the figure 1.414 marked with a prime (′) represents the transformer ratio. Where the figure 1.414 is written without a prime, it is the result of an arithmetical operation.)

LOW IMPEDANCE OUTPUT DEVICES—When audio amplifiers deliver power to low impedance devices such as dynamic speaker voice coils or telephone lines, proper output can be secured only by the use of a step-down transformer. The ratios required can be found by simple computations.

Example 1—A single-ended audio amplifier requires a load resistance of 4250 ohms. What transformer ratio is necessary if the amplifier is to feed into a 500 ohm line?

Solution—The transformer ratio is equal to the square-root of the resistance ratio or:

$$\text{Primary turns/secondary turns}$$
$$= \sqrt{\text{ohms wanted at tube/load ohms}} = \sqrt{4250/500} = 2.91.$$

This formula for class *A* single-ended only.

Note—*The fact that a telephone line does not present a pure resistance does not introduce any considerable error, nor is it necessary to consider the fact that different lines vary somewhat from the exact figure of 500 ohms. Such refinements are beyond the scope of this book.*

The required turns ratio is 2.91 to 1, the primary having the greater number of turns.

Example 2—Two tubes operated in class *A* push-pull are to feed a 15 ohm voice coil. The proper load resistance for either tube has been found to be 4250 ohms.

Solution—In the case of push-pull class *A* the plate-to-plate load resistance should be twice the required load for either tube. This figure may be used to obtain the ratio of entire primary to secondary. Thus:

$$\text{Primary turns/secondary turns} = \sqrt{2 \times 4250/15} = 23.8.$$

This formula for class *A* push-pull only.

The required ratio is 23.8 to 1 for the entire primary to the secondary.

27. Audio-frequency Class B Output Circuits—Class *B* push-pull differs from class *A* push-pull in that only half of the output transformer primary is active at any instant because the two tubes work on alternate half-cycles. The ratio is figured on the basis of half of the primary and the load resistance of one tube.

Example 3—A certain tube in class *B* audio requires a load resistance of 5140 ohms. What output transformer ratio is necessary if the actual load is a class *C* amplifier operating at 1000 volts and 0.1 ampere?

Solution—The resistance which the class *C* stage will present to the secondary of the output transformer is found by dividing the class *C* plate voltage by its plate current, i.e. 1000/0.1 = 10,000 ohms.

The transformer ratio between either half of the primary and the secondary can now be found:

$$\text{Turns } \tfrac{1}{2} \text{ primary/turns secondary}$$
$$= \sqrt{\text{resistance wanted at tube/load resistance}}$$
$$= \sqrt{5140/10{,}000} = 0.716.$$

This formula for class *B* output only.

The required ratio is 0.716 to 1, for half the primary to the secondary. In this case, the secondary has the greater number of turns. However, the ratio of the entire primary to the secondary is twice this ratio, or 1.43 to 1. Thus the entire primary has more turns than the secondary.

28. Audio Transformer Efficiency and Frequency Response

—Since transformers, especially small ones, are not 100 percent efficient, the voltage ratio will be slightly less than the turns ratio. The reduced secondary voltage reduces the power output in just about the right proportion to make up for the transformer loss. Thus the resistance-conversion calculated is after all nearly correct and no alteration need be made in the figures of the examples to allow for transformer efficiency. This of course assumes that no highly unreasonable transformer is used.

The turns-ratios calculated do not tell how many turns there are to be, nor how large the transformer is to be. A considerable amount of material on those points was contained in the original manuscript of this chapter but reconsideration seemed to show that it would not be of use to the reader who necessarily must depend upon a manufacturer of transformers and work with stock items, or if a special need develops he will still be better off by explaining the need to the manufacturer and allowing him to use his own methods of design in accord with his own means, materials and stock of experience. In no item of commerce is it more true than of the audio transformer that—"you get what you pay for." Really good audio transformers come from really good manufacturers, and they bear a price proportionate to the effort required in manufacture and testing. No manufacturer of sound judgment may promise that an amplifier shall have a certain over-all flatness if his transformers are used; but if he knows just what is aimed at he can recommend transformers which will give a reasonable approach to that result with proper care in other matters. Therefore while it is proper enough to wish for adequate primary turns and core to hold up the low-frequency response, with low capacitances to hold up the high-frequency response, it may be quite as well to put these wishes into the more practical form of looking for a transformer whose frequency-response curve has the desired form *under conditions like those to be met in the amplifier.* There are two ways in which manufacturers may quite innocently mislead the purchaser by merely giving insufficient information. One of these is to show a curve which has been measured in a circuit which does not provide the same loading as met in normal amplifier service, without realizing that this mistake has been made . . . an error which classifies the manufacturer, of course. Another is to make measurements which are proper enough, but do not indicate what ensues if a different d.c. flows through the primary. On the other hand there is the type of manufacturer who does give proper and adequate information, an example of which might read about like this:

PERFORMANCE OF INTERSTAGE (PLATE TO GRID) TRANSFORMER TYPE X5

Primary d.c. Ma.	Source ohms	Primary *L*	Frequency range (Flat within 2 db)
2	15,000	80	28 to 12,000 cycles
6	8,000	60	33 to 12,000 cycles
9	4,000	25	27 to 12,000 cycles

Note—Maximum permissible primary d.c. is 18 Ma. but values above 10 are not recommended for continuous service or good fidelity. The steel cases are compound filled to prevent entrance of moisture. The dimensions are those shown for type X1. Weight 56 ounces. Finish is black enamel over cadmium plating.

This is not a complete story, but at least it permits a preliminary decision to be made and allows intelligent questioning to begin. A presentation of this sort is a good initial recommendation for the product.

The importance of an adequate primary inductance arises from the loss in low-frequency gain which results from an inadequate primary, which may be explained well enough here by considering the primary inductance as acting in the manner of a shunt connected across the load. At low frequencies an inductance has a low reactance unless it is of large inductance, therefore a low-frequency shunting-loss is to be expected. At medium and high frequencies the effect is unimportant for the reactance of an inductance rises with frequency. However at high frequencies another effect enters, which is the bypassing of the high-frequencies by the inter-turn winding-capacitances, which may either depress the high-end, or produce a "hump" by resonance effects with some of the inductance of the device. As already indicated this effect is constantly used to bring up the otherwise gradually drooping high-frequency end. Not yet mentioned are the effect of the resistance of the two windings, the core-loss (heating of the iron core), and the effect due to magnetic leakage, though the latter enters into the resonances just alluded to. Thus there results a picture somewhat too complex for quick guesswork, and intimately tied up with details of manufacture. The recommendation is repeated that the matter is one proper to be placed in the hands of an honest and capable maker of transformers.

The transformer must not be charged with all the responsibility, in any case. The design of an amplifier must be made with care to see that the audio currents go where wanted, and not elsewhere. Thus an insufficient bypass around the cathode-resistor of a tube (especially a pentode) may easily "knock down the low end" more than the difference between good and bad transformer could ever do. A thoughtless placing or insufficient checking of the amplifier may leave it exposed to noise-pickup not due to any faulty shielding of the transformers, while innumerable things can happen during construction to cause curious kinks in the frequency-response curve of the finished job. The only safety lies in making a frequency-response curve of the finished amplifier —a job for which any voice station should have the equipment. See Chapter 7 for procedure.

29. Differences between A.F. and R.F. Class B Operation— In radio frequency amplification there are two quite distinct and separate fields. One is the extremely low-power-level amplification of received signals, which can be done most satisfactorily by the pure class *A* r.f. amplifier as discussed in section 3 this chapter, even with the smallest of our tubes. The other field is that of the transmitter in which the power to be handled is not measured in microwatts and milliwatts, but in watts and kilowatts, so that tube efficiency becomes of importance and class *A* amplification loses its attractiveness, at least to some extent, and classes *B, C* and *B–C* become attractive as the power level rises. *Most of the amplifiers in radio transmitters operate in class C.* The reason for this is that a class *C* stage provides higher efficiency than a class *B* stage, and consequently higher output, or a cooler tube, or a smaller tube, or perhaps operation at a lower voltage. Thus in the usual transmitter the oscillator, the "buffer" amplifiers, the frequency doublers (if any) and the modulated amplifier (if any), are all in class *C*. Frequently this includes all the r.f. tubes in the set—there are no more. However in radiotelephone transmitters it is sometimes desired to modulate a relatively small tube, and to amplify the *modulated* output of that tube. For such "post modulator" amplification the class *C* condition is not suitable, and the class *B* r.f. tube is used; occasionally a second class *B* stage follows. *Though the plate voltage and grid bias are the same as in audio-frequency work, there are some notable differences between audio and r.f. class B operation.*

1. The audio-frequency class *B* tube has no grid input when there is no sound into the microphone, therefore any "resting" plate current is entirely converted into heat. On the other hand the radio-frequency class *B* tube is never without grid input in the ordinary radiophone transmitter, for during silences the radio-frequency "carrier stream" of unmodulated r.f. power is still being sent to the antenna as explained under "Modulation" later

in this book, so that the tube is working at all times, though the level changes with modulation. (The statement does not hold for class *B* r.f. stages of carrier-elimination transmitters, and holds only partially for those using controlled carrier.) Thus a typical pair of recently designed "quarter kilowatt" tubes when used in push-pull class *B* audio deliver 500 watts at full signal and none during a silence, but if used in class *B* r.f. they deliver 560 watts of r.f. power during modulation peaks, while during a silence they maintain a carrier output of 140 watts—just 1/4 the peak output. This 4-to-1 relation is essential in the operation of a post-modulated-stage r.f. amplifier, employing ordinary modulation.

2. In class *B* audio a complete output-wave form is secured by combining the halfwave output of two tubes working on alternate halves of the cycle as was discussed in connection with figure 136. In r.f. class *B* amplifiers the audio wave form exists only as variations of an r.f. power-stream, hence is not exposed to distortion as long as these variations are maintained in proper time and form even though the *radio frequency* wave form is distorted considerably in the tube. Thus, although push-pull r.f. class *B* was mentioned in the foregoing paragraph it is not essential for the prevention of distortion—though commonly used because of the superiority of a push-pull r.f. stage as regards ease of feeding the d.c. power to the plates, and the automatic reduction of the second r.f. harmonic (double frequency or 1/2 wavelength) which may be a source of interference to other radio services. If a single tube be used in a class *B* r.f. stage it is necessary that the tube work into a tuned plate circuit ("plate tank" capable of converting the very distorted 1/2 cycle plate-current pulses into a wave form not too greatly different from a sine-wave. Such a tank must not have too small a ratio of C/L.

3. In an audio class *B* amplifier, proper loading of the driver (to improve the regulation) is secured by using transformer input coupling with a definite ratio. In radio-frequency circuits, a definite ratio is difficult to obtain. The problem is solved by loading the driver with a fixed resistance. This load is proportioned to absorb at least 4 times as much power as the actual peak driving power.

4. In audio class *B* amplifiers, the maximum plate dissipation occurs near full output. During no modulation the plate dissipation is very small. In radio-frequency amplifiers, the greatest dissipation occurs at carrier output (i.e. at no modulation) because here substantial power is delivered at fairly low plate efficiency.

Under full modulation, full output is alternated with very low output so the average dissipation is actually less than at carrier output. (Does not hold if carrier is controlled or eliminated.)

30. Computation of Class B r.f. Performance—Keeping the foregoing factors in mind, we shall proceed with the computation of class *B* r.f. amplifier performance.

Example 1—A tube is operated in class *B* r.f. with a plate input of 0.75 ampere and 4000 volts. Find the carrier power if modulation capability is to be 100 percent. The characteristics are given on figure 143.

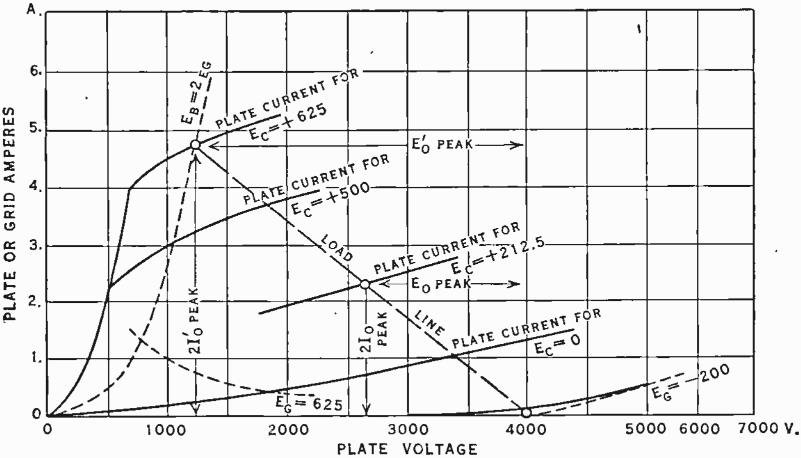


FIG. 143. Tube in Class "B" Radio Frequency.

Solution—The problem is solved for the conditions obtained at a positive modulation peak. This is done briefly since the procedure resembles that of section 23. At that point, the plate input will be twice as great or 1.5 amperes at 4000 volts. Thus:

$$I_b \text{ max.} = 1.5 \text{ amperes.}$$

The instantaneous peak plate current is found from: i max. $= 1.5/0.318 = 4.71$ amperes. A line is drawn on the characteristic of figure 143 through all points where the plate voltage is equal to twice the positive grid voltage. (See section 23 for details.) Where this line crosses the maximum peak plate current we find:

$$e_c = 625 \text{ volts,}$$
$$e_b = 1250 \text{ volts.}$$

Subtracting this minimum instantaneous plate voltage from the applied plate voltage we find the peak output voltage 4000 — 1250 = 2750 volts. The peak output current is equal to 0.5 times the peak plate current of the tube, or: 0.5 × 4.71 = 2.35 amperes.

The power output is now found: ½ peak voltage × peak current = ½(2750)(2.35) = 3235 peak output watts. This is the peak output power attained under a positive modulation peak. The carrier power is, for ordinary modulation, one quarter of this amount, or 809 watts carrier, but is much less for a controlled carrier and entirely absent in carrier elimination. The required load resistance is found by dividing the output voltage by output current = 2750/2.35 = 1170 load ohms. The plate efficiency at carrier output is: output/input 809/3000 = .268 = 26.8 percent efficiency. This value is somewhat low and could be improved by operating at a higher plate voltage. The manufacturer recommends 6000 volts for 1000 watts carrier. The value 4000 was chosen for the example because many transmitters are in operation attempting to obtain 1000 watts carrier with similar tubes at that voltage.

The required grid bias for a plate voltage of 4000 is found by inspection of the characteristic curves. Neglecting the curvature at low plate currents, a bias of —200 volts will cut-off. With this bias, a peak signal voltage of 825 volts is required to attain the maximum positive grid voltage of 625 volts. At carrier output, the signal voltage will be just half this amount, or 412 volts peak. This would be, of course, 292 volts rms.

31. Driving Power and Driver Loading—Examination of the characteristic curves shows that for a plate voltage of 1250 and a positive grid voltage of 625, the grid current will be 0.785 amperes. As the grid current is peaked rather than sinusoidal, and flows only during half the cycle, the fundamental component peak value will be somewhat less than 0.5 times the peak current. The decimal 0.4 is estimated as a probable value. This makes the peak value of the fundamental component 0.4 × 0.785 or 0.314 ampere. The required grid driving power is evidently ½ the product of this current and the peak signal voltage = ½(0.314 × 825) = 129 watts. This is the actual grid driving power required to produce a 100 percent positive modulation peak (at which point the output from the class *B* amplifier is 3235 watts). To obtain good regulation from the driver, and consequently low distortion, the driver should be loaded with resistances to four times this power; i.e. 516 watts. The 387 difference between 516 watts and the actual driving power of 129 watts is dissipated in the resistance load. At carrier output, the power dissipated in this resistor will be one quarter of this amount, that is, 387/4 = 96 + watts. The resistor should be capable of dissipating about 1 1/2 times this wattage continuously.

32. Bias Supply for Class B r.f. Amplifiers—A point frequently overlooked in the design of class *B* r.f. amplifiers is the regulation of the grid bias supply. The peak grid current computed above was 0.785 ampere. If adequate a.f. by-passing is provided, only the d.c. component will flow through the bias supply. This component is estimated to be about 25 percent of the peak grid current, or 0.196 ampere. However, this value is reached only during positive modulation peaks. In normal modulation positive peaks alternate with negative peaks during which the grid current is low. Thus if adequate audio frequency by-passing is provided only the average d.c. will flow through the bias supply. However this increases during modulation, hence for low distortion the grid-bias supply should possess sufficiently good regulation so that the grid-bias voltage does not vary greatly in consequence of the changed current—say 5 percent voltage change as a maximum. Such regulation is easily obtained with a generator. Storage batteries are not without objection for though they do not vary in voltage with momentary current changes, they do gradually become charged and go to a higher steady voltage, thus shifting the operating point. Vacuum tube rectifiers and filters may be used as grid-bias supplies but the regulation is seldom within the 5 percent limit unless the supply is made very large and stabilized by wasting much power in a "bleeder" resistance, or else is equipped with a regulating device with a very short time-lag. Mercury-vapor rectifiers, because of their lower internal resistance, provide inherently better regulation if an adequate first filter choke be used (see section 37, Chapter 4 for size), but in any rectifier system it is necessary to use a fairly heavy bleeder-current and satisfactory regulation should not be assumed without check.

33. Plate Supply for Class B r.f. Amplifiers—Good regulation of the plate supply of a class *B* r.f. system is as necessary as for class *B* audio, about 10 percent regulation being the maximum which should be tolerated from carrier-only to full-modulation. This regulation is perfectly possible with mercury-vapor rectifiers and filters of fairly good design in accord with the general rules set down in section 37, Chapter 4.

A fruitful source of trouble is the operation of a class B stage, either audio or r.f. from a plate supply which also serves other *stages.* If this cannot be conveniently avoided there should be interposed an additional filter stage using a large condenser and choke.

34. Practical Adjustment of Class B r.f. Amplifiers—If the station computes power *output* by the "indirect" method (i.e. based on the plate input and the 33 percent plate efficiency assumed by the Federal Communications Commission) the class *B* stage should be adjusted as follows:

1. After proper neutralization (see sections 61–67) apply plate voltage and grid excitation.

2. Gradually tighten the antenna coupling and at the same time increase the grid excitation. (Excessive grid excitation with loose coupling may damage the grid.) Do not exceed the grid current rating for class *C telegraph* services.

3. Continue to increase the coupling (tighten) until the plate *input* is 6.5[7] times the required power *output.* For example, a station licensed for 1000 watts output should now take 6500 watts plate input.

4. Fix the antenna coupling at this point after readjusting the antenna tuning.

5. Reduce the grid excitation until the plate input has come down to 3.0 times the required power *output.*

The stage is now properly adjusted and can follow modulation up to 100 percent. It will undoubtedly be found that the output is somewhat less than the licensed power (in the computed example 800 watts was obtained when the rated power was 1000), but this cannot be avoided with this method of power measurement.

If the power is computed by the "direct" method (i.e. by antenna resistance and antenna current), proceed as follows:

1. After proper neutralization, apply plate voltage and grid excitation.

2. Gradually tighten the antenna coupling and at the same time increase the grid excitation. (Excessive grid excitation with loose coupling may damage the grid.)

3. Continue tightening the coupling until the antenna power is 4.4[8] times the licensed power output. For example, for a licensed power of 1000 watts and antenna resistance 15.1 ohms, the antenna current must reach:

$$\text{Test } I_a = \sqrt{\frac{\text{Test power}}{R_a}} = 4400/15.1 = 17 + \text{amperes.}$$

---

[7] This allows mod. peak to occur about 10 percent below the saturation point.

[8] This allows mod. peaks to occur about 10 percent below saturation.

4. When this point is reached, make final adjustments to the antenna tuning, and fix the coupling at this point.

5. Reduce the grid excitation until the antenna power comes down to the licensed power. The antenna current will now be:

$$I_a = \sqrt{\frac{\text{Licensed power}}{R_a}} = 1000/15.1 = 8.14 \text{ amperes.}$$

The stage is now properly adjusted and is capable of following modulation up to 100 percent.

Caution—During the test output, the stage is operating substantially as class *C* and the antenna tuning may be adjusted for maximum antenna current. With reduced grid excitation, resonance will no longer be indicated by maximum antenna current. Antenna resonance is indicated by *minimum tank* current. Failure to appreciate this fact is responsible for most of the poor performance of class *B* r.f. amplifiers. It is generally advisable to tolerate day-to-day departures from exact resonance (due to changes in weather conditions etc.) rather than to risk disturbing the modulation capability by frequent readjustment.

Alternative Method—Transmitters may be encountered where the design is such that the grid excitation cannot be raised sufficiently high to obtain the test output. In this case, the tank current must be taken as an indicator of the plate efficiency, and the stage adjusted to operate at the required input or output without excessive efficiency. It is not always desirable to adjust for maximum possible efficiency, for the linearity of class *B* and class *C* stages is impaired thereby. Unless computations show a greater value, it is suggested that the plate efficiency at carrier output be limited to 25 percent. This is specially recommended when the power is based on the direct method, so that low efficiency does not involve a sacrifice in carrier power.

It is apparent that the output voltages may be computed by multiplying the reactance of the tank condenser by the observed tank current It. From this voltage, the plate efficiency is determined. For example:

Tank capacity 0.0012 mfd., frequency 1440 KC., plate voltage 4000, find the correct tank current.

The reactance of the tank condenser is first calculated at the working frequency. This is, as for any condenser, equal to $1/2\pi f \cdot c$ ohms, where the capacity is in farads and 2π is as usual 6.28. This for our example makes the tank-condenser reactance:

$$1{,}000{,}000/6.28(1{,}440{,}000)(.0012) = 92 \text{ ohms.}$$

The 1,000,000 above the line comes from the fact that the condenser capacity was stated in microfarads while the equation calls for farads. If, now, the r.f. voltage across the tank were known we should be able to calculate the current through the tank condenser very quickly. This voltage is gotten at as follows:

The efficiency of this type of stage is $0.785(e_{\text{peak}}/E_b)$ where e_{peak} is the maximum voltage during the cycle for full modulation, while E_b is the plate voltage. For reasons already given the efficiency is assumed to be 25 percent. By substituting this in the equation and solving it for e_{peak}, and then converting the peak value to rms, we have:

$$e_{\text{rms}} = 0.225E_b,$$

which is correct only for 25 percent efficiency as assumed. For the present case this gives $0.225(4000) = 900$ volts. The current through the tank-condenser is this voltage divided by the condenser reactance, which is $900/92 = 9.78$ amperes. The antenna coupling is then adjusted until the desired input (or output) is attained with this tank current. After each change it will be necessary to readjust the grid excitation to restore the stated tank current.

(These adjustment methods are conventional rather than ideal.)

35. Means of Improving the Efficiency of Class B r.f. Amplifiers—The low efficiency of class *B* r.f. post-modulated-stage amplifiers (25 to 33 percent) is a constant temptation to adjust for higher output efficiency, but such adjustments ordinarily result in defective linearity, that is in a failure to amplify without distortion of the *envelope* which represents the modulation. A mis-adjusted class *B* stage may either increase or decrease the percentage modulation, depending upon the nature of the misadjustment, but in either case the audio fidelity suffers.

Various means to avoid this situation have been devised and have been put into more or less extensive use. They one and all require added equipment and adjustments, hence each case must be analyzed to discover if such additions are warranted by the power saving, or whether the increased efficiency permits the use of smaller tubes at a considerable saving. Probably the method adding least to the complexities of the transmitter is that of applying carrier-control to the (previous) class *C* modulated stage, by methods explained later in this book. Since the controlled carrier becomes quite small during times when there is small modulation (weak sounds transmitted), it follows that at such times a following class *B* r.f. stage receives little excitation, therefore draws little plate input and in consequence cools down more than if full carrier were used. Since full modulation is (for speech) very infrequent this becomes (for speech) the normal state of the class *B* tube, whereupon it becomes practical to operate it at higher voltage and to secure from it a larger " equivalent " carrier. This is a case where the class *B* stage derives a benefit from a change in a previous stage. The extent of the power increase so made possible depends on the tube-types in the class *B* stage, also the probability of considerable periods of 100 percent modulation. If 100 percent modulation is to be sustained it is clear that the conditions for the class *B* tube are as if no carrier control had been installed—but if 100 percent modulation is infrequent and of brief duration, then increases of 50 or even 100 percent in output are practical, assuming the class *B* tube to have spare filament emission and insulation. The first case is that of the broadcasting station, the second is that of the " speech only " station.

36. The " Expansion " Amplifier in Class B r.f.—Another method of attacking the problem is that of causing some of the d.c. voltages applied to a class *B* tube to wander up and down in accord with the loudness of the sounds being transmitted. There are several possible ways of accomplishing this, some of which have been described in the 1936 and 1937 issues of the magazine " Radio " by J. N. A. Hawkins. In general the thought is that the audio system is tapped and a small portion of its output drawn off, rectified and given sufficient filtering to blur out the actual audio frequencies, but not to remove the syllabic or envelope or loudness variations, the resulting semi-smoothed output then being used to effect control of one or several of the d.c. power supply voltages in accordance with the loudness. The actual control may be accomplished through a saturable reactor in an a.c. circuit of the supply system, or a vacuum-tube used as a varying resistor in a d.c. circuit of the supply system. In any case the principal difficulty is to design such a system as shall be free of instability, yet of prompt action—that is of small time constant, and not very discriminatory as to frequency. Since the device is without intelligence and unable to anticipate future loud sounds it necessarily must maintain the tube-voltages at a level above the need of the moment, the margin allowing time for the device to act when loudness increases.

37. The Doherty Type of High-efficiency Class B r.f. Amplifier—Another attack upon the same problem is that of W. H. Doherty of the Bell System Laboratories. In this case normal modulation with ordinary uncontrolled carrier is used, that is the class *C* modulated stage is not special. It drives a following class *B* r.f. stage so chosen and adjusted that it is approximately fully loaded when only the carrier-stream is being transmitted. Thus it is capable of following modulation down-swings only but cannot follow the positive half-cycles, that is the upward modulations. A second tube is accordingly provided in the class *B* stage, so connected and biased that it draws essentially no power at the carrier-only level and therefore does not deliver any power until the excitation goes above carrier value, that is to say on modulation up-swings or positive half-cycles. The result is that both tubes work at a larger proportion of their rating (when they work) with the increased efficiency common to full-load operation of nearly all electrical and mechanical devices.

This result cannot be attained by mere parallel connection and unequal bias, for such a parallel connection would apply the output of the first (carrier) tube to the plate of the second (peak) tube, thereby preventing the second tube from contributing output *in proportion* to the excitation above carrier level.

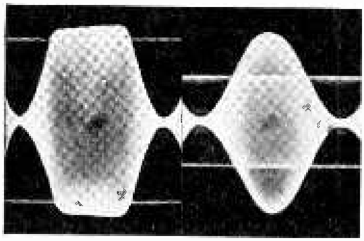
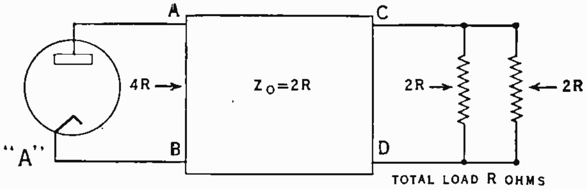


FIG. 144. Cathode-ray oscillograms of the plate potentials of tube no. 2 (left) and tube no. 1 during complete modulation.

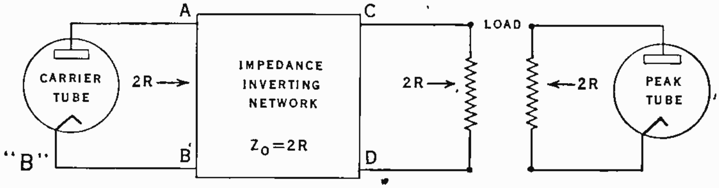
In the circuit developed by Doherty, the output of both tubes is ingeniously combined by using an " impedance inverting " network between the carrier tube and the load. The effect of such a network is to make it possible for both tubes to be connected to the load. When the peak tube begins to supply power, instead of decreasing the output from the carrier tube, it actually increases it. The effect can be understood by referring to figure 145. Imagine the load to be represented by two resistances, each of $2R$ ohms, connected in parallel. At carrier output (or during negative modulation half-cycles) the peak tube is not functioning so the carrier tube is feeding the load resistance through the impedance-inverting network. The load resistance is $2R + 2R$ in parallel or R ohms. At this point it is necessary to consider the action of the impedance-inverting network, because it is connected between the carrier tube and the actual load. The load resistance into which the carrier tube delivers its output is not the resistance R, but is the input terminals of the network. This impedance presented to the tube is expressed as:

$$\text{Load on carrier tube} = \frac{Z_0^2}{\text{Load}},$$

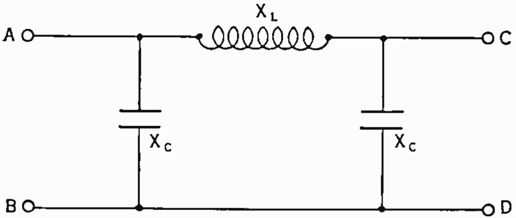
where Z_0 is the "characteristic impedance" of the network, and "Load" is the actual load resistance, in this case, R. The characteristic impedance of the impedance inverting network depends upon the impedances which form it. The simplest form of such a network is a transmission line one-quarter of a wavelength long.



DURING NEGATIVE MODULATION PEAKS, THE CARRIER TUBE FEEDS THE ENTIRE LOAD, A RESISTANCE OF R OHMS. THE LOAD ON THE TUBE IS 4R OHMS, DUE TO THE ACTION OF THE IMPEDANCE CHANGING NETWORK.



AT A POSITIVE MODULATION PEAK EACH TUBE FEEDS HALF THE LOAD. 2R OHMS ON EACH TUBE.



IMPEDANCE CHANGING NETWORK.
THE DESIRED EFFECTS ARE SECURED WHEN: $X_L=2R$. $X_C=2R$. THIS MAKES $Z_0=2R$ ALSO, WHICH IS THE DESIRED CHARACTERISTIC IMPEDANCE.

FIG. 145, A, B, C.

For this network the characteristic impedance is the well known formula:

$$Z_0 = 276 \log 2D/d,$$

where D is the distance between the wires, and d is the diameter of the wires. As it is obviously impractical to use a transmission line inside a transmitter (because of its length), the circuit shown as figure 145*C* is used. In this circuit,

$$Z_0 = X,$$

where X is the reactance of the inductance and either condenser. All three must have the same reactance (equal to $2R$) at the operating frequency to produce the desired effects. In the Doherty circuit, Z_0 is made numerically equal to *TWICE THE EFFECTIVE RESISTANCE OF THE LOAD.* Substituting these values, we find that, under carrier conditions, the load presented to the carrier tube is:

$$\text{Load on carrier tube} = \frac{Z_0^2}{\text{Load}} = \frac{4R^2}{R} = 4R \text{ ohms.}$$

When the excitation increases above the carrier value on a positive modulation half-cycle, the peak tube comes into action. At a 100 percent positive modulation peak, both the carrier tube and the peak tube are operating wide open, nearly saturated, and delivering approximately equal amounts of power. In this case we may assume that the carrier tube is delivering its half of the power into the left-hand resistance $2R$ (on figure 145*B*) and the peak tube is delivering its half of the power into the right-hand resistance $2R$. Such a division is of course purely theoretical as there is actually only one load. It is useful because it shows clearly how the additional power delivered by the peak tube changes the apparent resistance into which the carrier tube is giving its power. When the peak tube was idle, the carrier tube clearly supplied power to both resistances, thus having an actual load of R ohms. Now that the peak tube is delivering half the power, the carrier tube is supplying power to a load of $2R$ ohms. If the impedance inverting network was not used, this increase[9] in the load resistance would cause a reduction in the power supplied by the carrier tube as has been mentioned. Solving to find the load

---

[9] The load resistance at carrier output is R ohms if there is no impedance inverter in the circuit.

presented to the carrier tube with an impedance inverting network in place, we find:

$$\text{Load on carrier tube} = \frac{Z_0^2}{\text{Load}} = \frac{4R^2}{2R} = 2R \text{ ohms.}$$

This is a reduction in load resistance since the load on the carrier tube had been $4R$ at carrier output. This causes an increase in power to twice the carrier. Adding an equal amount of power from the peak tube, we have a peak output of four times the carrier, which is the correct amount for 100 percent positive modulation peaks. Furthermore, with proper adjustments, this power is added gradually with the excitation, thus satisfying the condition for linear amplification.

All impedance-inverting networks have the disadvantage of producing a 90 degree phase shift between the input and output voltage. If the output of the two tubes is to combine properly, it is necessary that an equal or 90 degree phase shift is given to the grid excitation of either tube. This can be accomplished conveniently by using the same sort of network in the grid circuit of the peak tube. As the grid circuit of this tube presents a reactance which varies with the amount of excitation, it is necessary to connect a fixed resistance from grid to cathode to provide a stable termination for the phase-shifting network. If this is not done, the amount of phase shift will vary with the modulation, thus causing erratic operation and serious distortion. Figure 146 shows a block diagram of the essential elements for a Doherty amplifier, and figure 147 is a practical circuit diagram. Note how

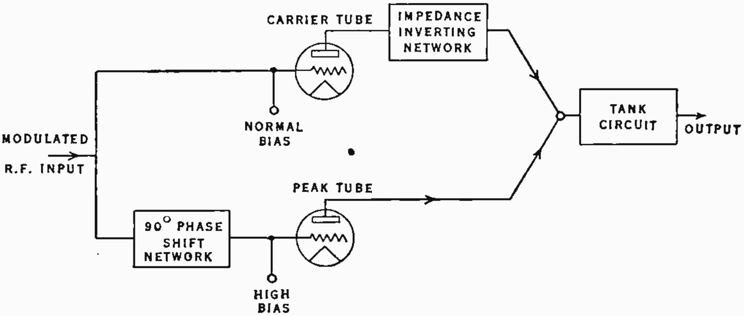


Fig. 146. Essential Elements of Doherty Amplifier.

much more complicated it is than the ordinary class "*B*" r.f. amplifier.

The load resistances required for Doherty amplifiers can be determined by the calculations which were explained under class "*B*" r.f. amplifiers, bearing in mind that two tubes are used, which when both nearly saturated should produce an output of four times the carrier power. The solution may be checked by using the formula,

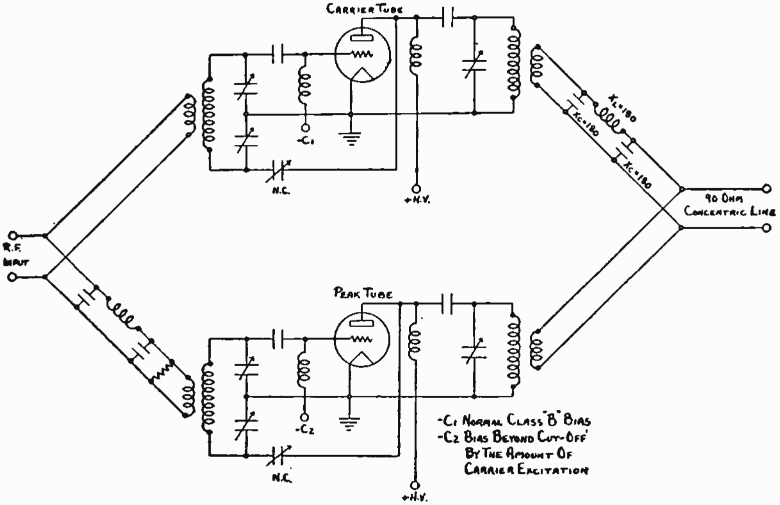


FIG. 147. Doherty Amplifier Circuit.

$$R_L = \frac{0.314 E_p^2}{W} = \frac{0.08 E_p^2}{W_0},$$

where E_p is the d.c. plate voltage and W_0 is the carrier power. This equation gives a rough approximation.

The characteristic impedance of the impedance-inverter will be just twice the value of R_L. The capacities and inductances required are such that their reactances at the carrier frequency is equal numerically to twice R_L.

In the grid circuit where there is no R_L, a fixed resistance must be applied. Its value should be as low as possible without consuming too much r.f. power. When the value has been chosen, twice that figure will be the required reactances for the inductance and capacity in the grid circuit network.

Performance—The Doherty amplifier is not very well suited to high frequency because at those frequencies the capacities required in the inverting circuits become very small. This makes the amplifier easily affected by stray capacities and tube inter-electrode capacities. In addition it becomes increasingly difficult to hold the proper phase relations as the frequency is raised. It is likely that the use of low inter-electrode capacity tubes will permit satisfactory operation at higher frequencies.

At low modulation percentages the peak tube is operating in the region near cut-off where the characteristics of tubes are not very uniform. This introduces distortion. Likewise the high efficiencies which are desired involve operating fairly close to saturation on the carrier tube. This is another source of distortion. A third source is the varying load on the preceding stage. It therefore becomes desirable to reduce the overall distortion. The Western Electric Co. uses feed-back for this purpose. There is no assurance that this can be done satisfactorily in composite transmitters. Doherty amplifiers are now employed in several high-power broadcast stations.

38. Definition of Class C Amplifier—*A class C amplifier is one in which the grid bias is appreciably more than necessary to cut off the plate current to zero when no exciting voltage (a.c. grid input) is present, so that the plate current flows in the tube for appreciably less than one-half of each cycle: in fact flows at all only when excitation is present.* Class *C* operation is confined to radio-frequency stages of transmitters since the high plate-circuit efficiency is attained at the expense of large a.c. grid input and high wave-form distortion. For r.f. work this distortion is harmless as was explained in section 29 of this Chapter. Class *C* stages may be modulated but as amplifiers are suited only to unmodulated current.

The comparatively short pulses of plate current resulting from class *C* operation have two important characteristics:

1. As the pulses become shorter, the efficiency rises.

2. As the pulses of plate current become shorter, the harmonic components in the output current become larger. With suitable tubes, considerable power may be obtained at two, or even three times the excitation frequency by simply tuning the output tank circuit to the desired frequency.

Although class *C* amplifier plate current waves are very complex and contain large harmonic components, the output voltage may be made a nearly pure sine wave by the action of the tank circuit. The explanation is given later under "r.f. output circuits." This is not true if the tank circuit is out of tune, or designed for extreme efficiency. All discussion to follow, however, will assume that a properly adjusted tank circuit is provided as this is usual in commercial equipment. When this is the case, the output voltage is 180° out of phase with the excitation voltage, i.e. the lowest plate voltage occurs when the grid voltage is the most positive, and the highest plate voltage is produced when the grid voltage is the most negative. This relation can be seen clearly on figure 150.

39. Grid Excitation of Class C r.f. Amplifiers—In classes *A* and *B* amplifiers, an essentail feature was that the output voltage varied in direct proportion to the excitation voltage. In class *C* this restriction is removed, and it is necessary to study the effect of increasing the excitation to higher values. Figure 148 shows the performance of the somewhat old-fashioned UV-203-A, operated in class *C*. The power output, peak output voltage, grid current, and plate efficiency are plotted against the excitation voltage. The curves given are for a load resistance of 3100 ohms, plate voltage 1000, and a bias of —75 volts. Up to the point marked "*X*," the output voltage rises almost in exact proportion to the excita-

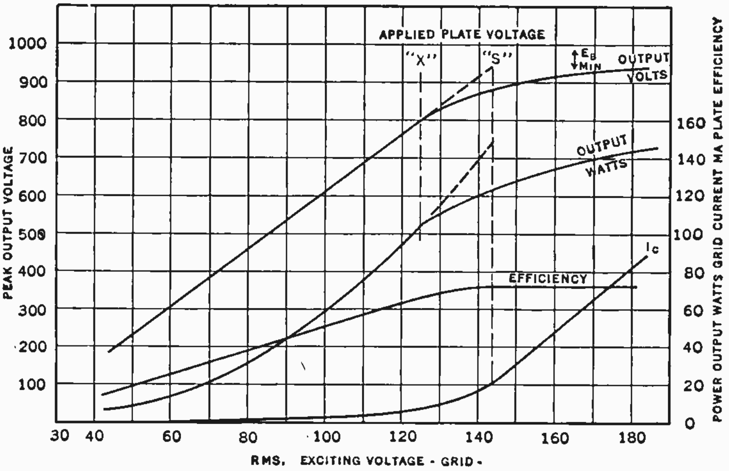


FIG. 148.

tion voltage. (In fact, except that the bias is slightly high, the tube is operating as a class *B* r.f. amplifier up to this point.) This point is where the minimum instantaneous plate voltage (the difference between the plate voltage and the peak output voltage) is about twice as high as the peak positive grid voltage (peak excitation voltage less the bias). At this point the grid current, and consequently the driving power, is fairly low. The plate efficiency is high—66 percent in this case. This is slightly higher than is obtained at full output with class *B* because of the higher bias and consequent shorter plate current pulses. Class *B* employs lower bias to obtain the most linear relation between excitation and output voltage. Beyond the point marked "*X*," the output increases more slowly. This is more evident if the output is plotted against the grid current, as has been done on figure 149. The point marked "*S*" just beyond the "knee" of the curve is termed the "saturation point" because of the fact that the curve resembles a magnetic saturation curve for iron. The point "*S*" is also marked on figure 148, although here the knee is much less pronounced. Note that at point "*S*" the minimum instantaneous plate voltage is just about equal to the positive grid voltage. Here the grid current and driving power are fairly high, although

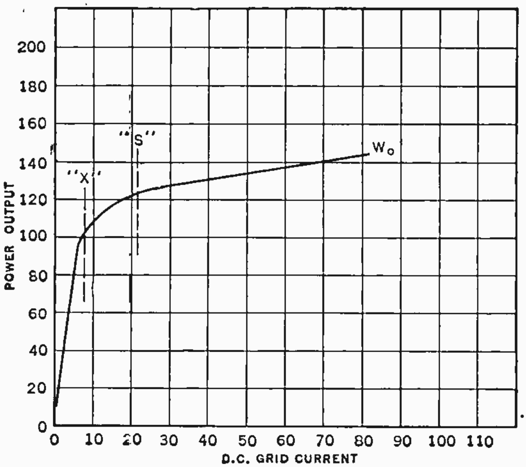


FIG. 149.

not unreasonably so, and the plate efficiency has reached its maximum—72 percent in this case. If the excitation is increased beyond "*S*," the tube is said to be over-saturated. As the peak output voltage approaches the plate voltage as a limit, the grid current and driving power become very high. With the increase of output voltage (however slight) it would normally be expected that the plate efficiency would increase in proportion. That it does not do so is due to the fact that when oversaturated the shape of the plate current wave is greatly disturbed, thus preventing further increase in plate efficiency.

The relation between plate voltage, grid voltage, and plate current flow is shown more clearly on figure 150. Each of the three sections represents a single r.f. cycle of operation. In 1, the grid excitation is too low, the tube is not saturated, and the peak output voltage is considerably lower than the plate voltage. In this condition the plate voltage could be raised or lowered without affecting the output. In 2 the grid excitation is increased just to the saturation point. The peak output voltage is nearly as large as the plate voltage. With this excitation a reduction of plate voltage will immediately reduce the output (by limiting the output voltage). However, the output will not rise if the plate voltage is raised. If a modulated amplifier is operated with this amount of excitation, it will "modulate down." In 3 the excitation is more than enough to produce saturation. The output voltage is practically the same as in 2. Note the unusual shape of the plate current wave. During the portion of the cycle that the positive grid voltage *exceeds* the plate voltage, the plate current *falls* rapidly. This causes a dip in the center of the plate current wave, and reduces the output current. It is this effect that limits the output voltage, since if the plate voltage falls below the grid voltage for too large a portion of the cycle, the output current will not be large enough to maintain the output voltage. (The output voltage and current have a fixed ratio, determined by the load resistance.) This automatically limits the output voltage. In practice, this balance is reached when *THE PEAK OUTPUT VOLTAGE IS NEARLY EQUAL TO THE PLATE VOLTAGE.* This is the basic principle of plate modulation. *IF THE EXCITATION IS SUFFICIENT TO SATURATE AT THE HIGHEST PLATE VOLTAGE REACHED, THE OUTPUT VOLTAGE WILL APPROXIMATELY EQUAL THE PLATE VOLTAGE AT ANY LOWER VALUE.* Thus for 100 percent plate modulation, it is necessary that the excitation be sufficient to saturate the tube at twice the normal plate voltage.

This, of course, makes the tube considerably over-saturated at the normal plate voltage, and requires very high driving power.

40. Class C Grid Bias—The definition does not specify any particular bias, class *C* being defined as operating with *any bias beyond* cut-off. Experience has shown that, for unmodulated amplifiers (such as in telegraph transmitters) bias of about twice cut-off is about right. Higher bias will produce slightly greater efficiency, but the increase is not usually worth the increased driving power (greater excitation voltage is necessary to overcome the higher bias). In plate-modulated stages, it is desirable that the bias be somewhat above cut-off at the highest plate voltage reached. A bias of three times cut-off (1.5 times cut-off for the highest plate voltage) for the normal plate voltage is usually recommended. In neither case is the bias critical, and satisfactory results can be obtained with considerable different values.

In plate modulated class *C* amplifiers, the high grid current and driving power required due to over-saturation at the normal plate voltage can be considerably reduced by providing some resistance (grid leak) in series with the grid bias supply. At carrier plate voltage, a moderate increase in the grid current will add to the bias and thereby reduce the unnecessarily high positive grid swing. As the plate voltage rises during a positive modulation peak, and the over-saturation becomes less, the grid current will fall, reduce the bias, and increase the positive grid swing.

Grid Leak Bias—It is entirely practical to supply the entire bias voltage from such a resistor, termed a "grid leak." Tests have shown that better modulation is secured than with fixed bias. Grid leak bias has the disadvantage of being lost if anything happens to the excitation, as for example, the failure of a tube in a buffer stage. Without bias, many tubes draw dangerously high plate current. For this reason, it is considered good engineering to use a combination of fixed bias and grid leak, the fixed bias being just large enough to hold down the plate current in case of accident to the excitation. With grid leak or combination bias, it is necessary that the bias at carrier plate voltage be greater than that specified, or it may fall too low when the grid current falls during a positive modulation peak. No figures will be given as the bias is not critical. The grid current shown on the meter will not change since each positive modulation peak is immediately followed by a negative peak during which the grid current rises approximately an equal amount. The meter is, of course, too slow to follow these changes.

41. Computations of Class C r.f. Amplifier Performance (including frequency doublers and triplers)—In computations of class *C* r.f. amplifier performance the difficulty arises that the plate-current wave-form is very far from sinusoidal under some conditions. However a practically useful method of calculating performance becomes possible if certain operating points are as-

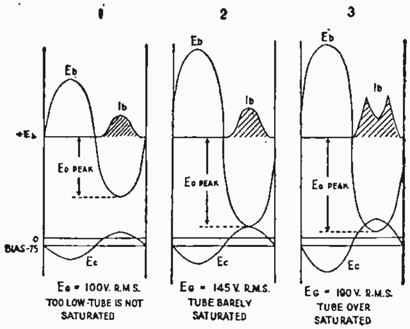


FIG. 150. UV–203A in Class "C." Plate Voltage 1000, Grid Bias —75 V, Load Resistance 3100 Ohms.

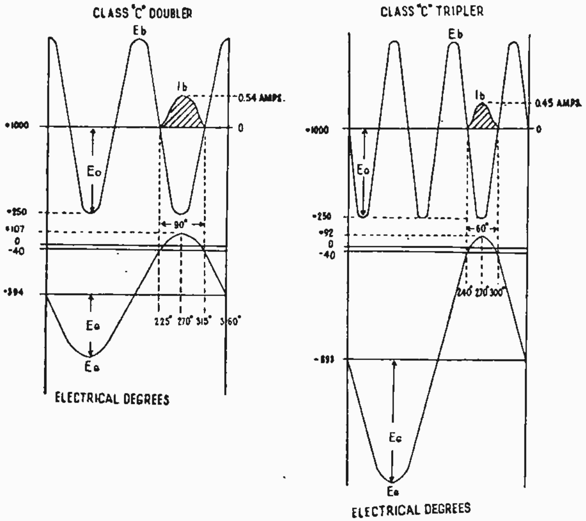


FIG. 151. UV–203A as a Frequency Multiplier.

sumed. Accordingly in the following discussion it is assumed that when working on a single frequency the plate-current wave will flow for somewhat less than 1/2 cycle as in figure 150 (150 electrical degrees), that for a frequency-doubling amplifier it will flow for about 90 electrical degrees as in the left upper diagram, figure 151, and in the case of a frequency tripler it will flow for about 60 electrical degrees as in the right-hand upper curve of figure 151. In each case the assumed current-pulse lasts about 1/2 cycle *at the output frequency.* With these assumptions working constants may be stated as follows: basing on i_b max. which is the "dynamic" peak plate current and can be found either from the curves for the tube, or in some cases from the known d.c. plate current I_b:

For the ordinary class *C* r.f. amplifier at saturation

The average plate current I_b = 0.27 × i_b max.,
The peak output a.c. current = 0.46 × i_b max.,
The peak 2nd harmonic current = 0.255 × i_b max.,
The peak 3rd harmonic current = 0.07 × i_b max.,

Where the bias and drive are chosen to produce maximum second harmonic and the plate circuit is tuned to it:

The average plate current I_b = 0.185 × i_b max.,
The peak output a.c. (2nd harmonic) = 0.271 × i_b max.,

when angle of opening is equal to 90°.

When adjusted for tripling frequency:

The average plate current I_b = 0.112 × i_p max.,
The peak output a.c. current = 0.172 × i_p max.,

when angle of opening is equal to 60°.

The relations between plate voltage, grid voltage, and plate current for frequency multipliers are shown by figure 151. As a general rule, frequency multipliers are not operated at the saturation point as to do so would require unreasonably high driving power. However, if the grid power is available, it is entirely possible to saturate the grid and thereby obtain high output and high plate efficiency.

Plate Dissipation of Class C Modulated Amplifier—An interesting point arises when a class *C* amplifier is plate modulated. Suppose the d.c. plate input is 150 watts, and the r.f. output is 100 watts, leaving 50 watts to be dissipated on the plate. Now under sustained 100 percent modulation, the plate input will be 225 watts—150 watts d.c. from the plate supply, and 75 watts of audio power delivered from the modulator. The output rises in the same proportion, 1.5 times, to 150 watts. This now leaves 225 — 150 or 75 watts to be dissipated at the plate. Although sustained modulation of 100 percent is not often applied, it is a possibility and the transmitter should allow for it. Accordingly, the plate dissipation of a modulated amplifier must be limited to 2/3 of the rated dissipation. Thus in the above example, the tube should have a dissipation rating of *at least 75* watts.

Examples—1. Class *C* telegraph operation.

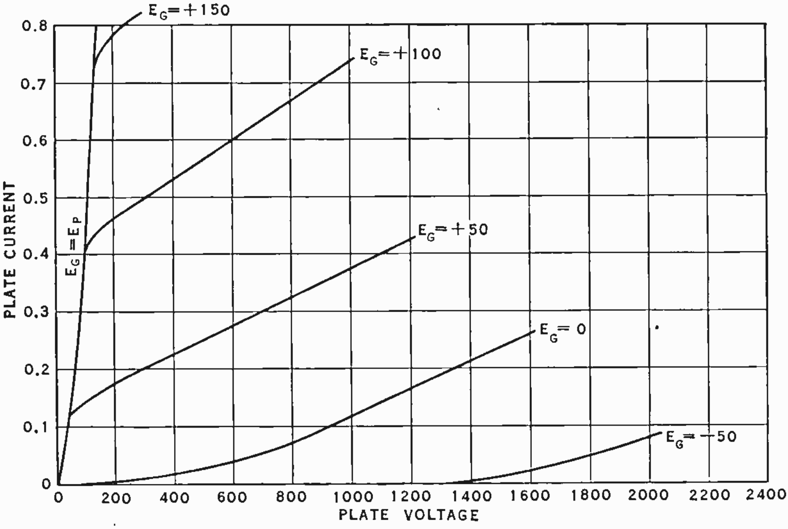


FIG. 152. Characteristic Curves UV-203A.

Given the characteristic curves shown on figure 152, plate voltage 1250, plate current 0.175 amperes, find the power output, load resistance, plate efficiency, grid bias, and excitation voltage for class *C* telegraph operation.

Solution—The peak plate current can be found from the d.c. plate current specified: i_b max. $= I_b/0.27 = 0.175/0.27 = 0.648$ ampere. The constant 0.27 is explained in section 41. This plate current must be attained at the point where the plate voltage and positive grid voltage are equal. From figure 152 it can be seen that the required values are:

$$e_b \text{ min.} = 138 \text{ volts,}$$
$$e_c \text{ max.} = 138 \text{ volts.}$$

The output current is determined from the peak plate current just found, and the factor given in section 41 as 0.46 × 0.648 ampere = 0.298 peak amperes, which is converted to r.m.s. in the usual way: 0.707 × 0.298 = 0.211 amperes.

The output voltage is the difference between the plate voltage and the minimum instantaneous plate voltage, or: 1250 — 138 = 1112 volts peak and this also can be converted to r.m.s., becoming 0.707 × 1112 = 785 volts r.m.s.

The power output can be found conveniently from the peak output voltage and peak output current as in previous examples. $\frac{1}{2}$ peak volts × peak amperes, or $\frac{1}{2}(1112)(0.298) = 166$ output watts. If r.m.s. values are used for the output voltage and output current, the factor $\frac{1}{2}$ is omitted, thus:

$$\text{Power output} = 785 \times 0.211 = 166 \text{ watts.}$$

The plate efficiency is as usual the output power divided by the plate input, or: $165/(1250 \times 0.175) = .758 = 75.8$ percent. (This efficiency is higher than that shown on figure 148 because of the higher plate voltage.)

The plate dissipation is the difference between input and output, or: 218.5 — 166 = 52.5 watts plate loss.

The required loading may be expressed as a resistance, and is determined by dividing the output voltage by the output current:

$$R_L = 1112/0.298 = 3730 \text{ load ohms.}$$

The grid bias for class *C* is not critical, but should be at least twice cut-off; that is, $2(E_b/\mu) = 2 \times 1250/25 = 100$ volts. Slightly higher values may be used with beneficial results. In fact the manufacturer recommends — 125 volts for this plate voltage.

The peak excitation voltage again must exceed the grid bias by the required peak positive grid voltage; that is, it equals 138 + 100 = 238 peak grid a.c. input volts or 0.707 × 238 = 168 r.m.s. grid input volts. Of course, with higher bias more excitation voltage will be needed.

Example 2. Class C Amplifier-Telephone—The tube of figure 152 is to be plate modulated 100 percent. The carrier plate input is 0.100 amperes at 1000 volts. Solve for the bias, excitation voltage, output voltage, approximate plate efficiency, and plate dissipation.

Solution—This problem is solved by determining the conditions for saturation at the highest plate voltage reached, namely 2000 volts. (Twice the unmodulated value.) At this voltage, the plate current will likewise be increased to twice the unmodulated value, or 0.200 amperes, thus the peak value, by the method just used is $.200/.27 = 0.74$ amperes. Note that this peak plate current is more than *seven times* the current shown on the plate ammeter. Inability to produce this high current is sometimes the reason that old tubes may deliver the carrier power but fail to modulate properly.

The peak plate current is as before to be attained with a grid voltage equal to the plate voltage. From the characteristic curves we find the required values; this time:

$$e_b \text{ min.} = 150 \text{ volts} = e_c \text{ max.}$$

The output current again can be found from the peak plate current and the constant 0.46; which gives 0.341 ampere output peak current.

The peak output voltage found as in example 1 is $2000 - 150 = 1850$ peak volts or $0.707 \times 1850 = 1308$ r.m.s. output volts.

The values already found give the power output: as before, P.O. $= \frac{1}{2}$ peak volts $\times$ peak ampere $= \frac{1}{2} \times 1850 \times 0.341 = 315$ watts. *This is the power delivered on a positive modulation peak* (at the instant the plate voltage reaches 2000 volts). *The carrier output* (at 1000 volts plate voltage) *will be one quarter of this amount* or: 78.8 watts.

The plate efficiency may be computed at either carrier output or at a positive modulation peak—the value is the same as far as can be determined by a simple solution. Dividing output by input: efficiency $= 315/(200 \times 0.2) = .788 = 78.8$ percent.

This value is somewhat higher than that given on figure 148 because the loading is lighter (load resistance is higher) and the bias is greater.

The grid bias recommended is twice cut-off at the highest plate voltage, or four times cut-off at the carrier plate voltage:

$$-4E_b/\mu = -4(1000)/25 = -160 \text{ volts bias needed.}$$

Again the excitation voltage must be greater than the bias by the amount of the positive grid voltage required $150 + 160 = 310$ volts peak a.c. grid input or 219 r.m.s. volts grid input.

The load resistance is determined by dividing the output voltage by the output current; $1850/0.341 = 5420$ load ohms.

At carrier output, the plate dissipation is watts in minus watts out or approximately $(1000 \times 0.100) - 78.8 = 21.2$ watts plate loss. Under sustained modulation, this may be increased by 50 per cent, making the highest plate dissipation to be anticipated: 31.8 watts.

Example 3. Frequency Doubler Class C—It is desired to operate a UV–203–A as a frequency doubler at a plate voltage of 1000 and a plate current of 100 Ma. Determine the output, plate efficiency, bias, and excitation voltage.

Solution—As has been stated, frequency doublers are not operated at the saturation point because of the excessive driving power required to do so. Accordingly, we will assume a peak output voltage of only 75 percent of the plate voltage. This will produce a plate efficiency of about 50 percent which is a reasonable value. Thus we assume a peak output of 750 volts. In consequence the minimum plate voltage becomes $E_b - 750 = 1000 - 750 = 250$ volts.

The peak plate current to be attained can be determined by dividing the d.c. plate current by 0.185, that is, $0.100/0.185 = 0.54$ amperes. This current is reached when the plate voltage reaches its 250 volt minimum value. (Found above.) From the characteristic curves shown as figure 152, it is seen that a grid voltage of + 107 volts is necessary. To operate satisfactorily as a doubler, the plate current flow must be restricted to 90 electrical degrees. This means that the grid voltage must pass through cut-off at the angles of 225°, reach a maximum of 115 volts at 270°, and returning pass through cut-off again at 315°. Cut-off is, of course, found by dividing the plate voltage by the amplification constant. Fortunately, the plate voltage is equal to the applied plate voltage at both times whereupon cut-off bias $= E_b/\mu = 1000/25 = -40$. These values can be seen on figure 151 but this is *NOT* the desired value of working bias. The excitation required to produce these conditions is determined from the equation:

$$e_c \text{ peak} = \frac{(e_g \text{ max.}) - (E_c \text{ cut-off})}{1 + \sin 225^\circ} = \frac{107 - (-40)}{1 - 0.707} = 501$$

peak r.f. grid input volts. However the grid is to "go positive" by only 107 volts, hence the required grid bias is $107 - 501 = -394$ volts bias. Note that this bias is nearly *ten times* cut-off. With lower bias the plate efficiency and output would fall rapidly.

The current output is, i_p max. $\times$ 0.271 $=$ 0.54 $\times$ 0.271 $=$ 0.145 peak amperes, hence:

$$\text{The power output is} = \tfrac{1}{2}(0.145)(750) = 54.7 \text{ watts.}$$

The plate efficiency is found by dividing this by the plate input: Efficiency $= 54.7/(1000 \times 0.100) = .547 = 54.7$ percent. This efficiency is typical of frequency doublers *when operated with sufficient bias.* If higher plate current (and higher output) is desired, even higher bias will be required. To keep the bias to a reasonable figure, it is necessary that tubes having a high amplification factor be used, such as the one chosen for this example. Because of the high excitation voltage required, doublers do not as a rule contribute much voltage amplification. A moderate amount of power amplification may be secured, but due to the comparatively low plate efficiency, it is inadvisable to operate the final stage of a transmitter as a doubler.

Example 4. Frequency Tripling Class C Amplifier—A UV-203-A is to be operated as a frequency tripler. The input is to be 0.050 amperes at 1000 volts (experience having indicated that greater input will require excessive bias voltages), with the expectation of realizing an output of about 25 watts.

Solution—As has been mentioned, frequency multipliers are not operated at the saturation point because to do so would require excessive driving power. Arbitrarily limiting the output voltage to 75 percent of the plate voltage, we assume that peak output $= 750$ volts, hence $e_{\text{min.}} = 1000 - 750 = 250$ volts.

The peak plate current can be found by dividing the d.c. plate current by the factor 0.112; that is 0.50 ampere/0.112 $=$ 0.446 peak amperes. As this plate current must be obtained with the minimum instantaneous plate voltage (found above) of 250 volts, by reference to the characteristic curves on figure 152, we find that a peak grid voltage of $+92$ volts must be reached. To show the desired plate efficiency, it is necessary that the plate current flow in a frequency tripler be limited to not over 60 electrical degrees of every grid cycle (180 electrical degrees at the triple frequency of the plate circuit). This means that the grid voltage must pass through cut-off at the electrical angle of 240 degrees, reach a maximum of 92 volts at 270 degrees, and returning pass through cut-off again at 300 degrees. Cut-off is, of course, found by dividing the plate voltage by the voltage amplification factor of the tube as in the doubler example and is again, cut-off $= -40$ volts. These values can be seen on figure 151. The excitation voltage required to produce this condition may be found from the equation:

$$e_c \text{ peak} = \frac{e_g \text{ max.} - E_g \text{ cut-off}}{1 + \sin 240^\circ} = \frac{e_g \text{ max.} - E_c \text{ cut-off}}{1 + \sin 240^\circ}$$

$$= \frac{92 - (-40)}{1 - 0.866} = 985 \text{ volts.}$$

The grid bias is equal to this voltage less the desired positive grid swing of 92 volts or $92 - 985 = -893$ bias volts required. Thus the bias is nearly as great as the plate voltage (negative of course) and the excitation voltage is actually greater than the output voltage. The extremely high bias required indicates that it is impractical to obtain any appreciable amount of power with frequency tripling. The peak output current obtained with this bias is i_p max. $\times\ 0.172 = 0.446 \times 0.172 = .076$ peak output amperes. The output voltage was initially taken as 750. Power output $= \frac{1}{2} \times 750 \times 0.076 = 28.8$ watts.

The plate efficiency may be determined easily as watts out/watts in $= 28.8/1000 \times 0.050 = .576 = 57.6$ percent. This output and efficiency can be obtained only with the very high bias already computed. With less bias, the output power will be greatly reduced even though the plate input may be higher.

42. Practical Adjustment of Class C Amplifiers. 1. *Intermediate Stages*—After neutralization (see sections 61–67 of this Chapter, also sections 13–20 of Chapter 4) apply reduced plate voltage and tune the tank circuit for minimum plate current. After reaching the proper setting, the plate voltage may be raised to the full value. Now check the grid current. If no meter is provided, it is advisable to connect one in the circuit temporarily. Adjust the excitation tap on the preceding amplifier (or oscillator) until the grid current is the amount recommended by the manufacturer for class *C* service.

This procedure is followed through on each intermediate stage, in succession.

2. *Frequency Multipliers*—In adjusting frequency multipliers, it is essential to have sufficient bias voltage and excitation. If grid leak bias is used, both will be obtained more or less automatically if the grid current is kept at the proper point by adjusting the excitation control or tap on the preceding stage. If fixed bias is used, it should be adjusted with the aid of a voltmeter. After obtaining the desired bias, correct excitation can be approximated by adjusting the excitation tap until a small amount

of grid current is indicated. With full bias and full plate voltage (reduced plate voltage if the plate current is dangerously high when off resonance) tune the tank circuit for minimum plate current. As two or more points are sometimes found, it is necessary to identify the proper point by using a wavemeter coupled loosely to the tank coil. When minimum plate current has been located at the proper harmonic, adjust the grid excitation for maximum output. This can be done most easily by noting the deflection on the wavemeter. **Note:** A heterodyne type of frequency meter should not be used for this purpose. The absorption type, consisting of a condenser, coil, and current indicating device should be used.

3. *Final Amplifiers—Telegraph*—After neutralization, apply reduced plate voltage, and with the antenna circuit open, tune the tank circuit for minimum plate current. Shut off the plate voltage, and close the antenna circuit, using loose coupling. Apply reduced plate voltage and tune the antenna circuit for maximum antenna current. When the correct point has been found, gradually tighten the coupling until the plate current taken is the same fraction of the desired plate current as the reduced plate voltage is of the full plate voltage. Now apply full plate voltage and make final adjustment to the coupling until the desired plate current is drawn. After each change to the coupling, it may be necessary to retune the tank circuit slightly for minimum plate current. When finished, note the grid current. Adjust the excitation tap (or other control) until the grid current is the value recommended by the manufacturer. If the excitation had been far off, it may now be necessary to readjust the antenna coupling to hold the desired plate current.

4. *Final Amplifiers—Telephone* (*Plate Modulated*)—After neutralization, apply reduced plate voltage, and with the antenna circuit open, tune the tank circuit for minimum plate current. Disconnect the plate voltage, close the antenna circuit, and adjust for loose coupling. Again apply reduced plate voltage and tune the antenna circuit for maximum antenna current. When obtained, gradually tighten the coupling until the plate current has the same relation to the desired plate current as the reduced plate voltage has to the full plate voltage. (For example, if the plate voltage has been reduced to one-half, adjust the coupling until the plate current is likewise one-half of the desired amount.) After each change in coupling it may be necessary to make a slight readjustment to the tank circuit for minimum plate current. Now apply full plate voltage and note the grid current. (A grid current

meter is essential for proper operation of a class *C* modulated amplifier.) Adjust the excitation control until the grid current is at the point recommended by the manufacturer for class *C* plate modulated service. After obtaining the correct grid current it may be necessary to make a final adjustment to the coupling in order to bring the plate current back to the exact amount desired.

Final adjustment of the grid excitation should be made by an actual modulation test. Insufficient excitation will cause a flattening out on the positive modulation peaks. This may be observed on an oscilloscope, or if apparatus is available, the distortion may be measured at about 90 percent modulation. The excitation should be adjusted until the amount is found which produces the best wave shape (lowest distortion). The grid current should be carefully noted and maintained at the same point thereafter. Quite probably this grid current will be higher than that recommended by the manufacturer as experience often shows a moderate excess of excitation gives better results.

Lacking proper instruments, a crude test of the excitation can be made by noting the class *C* plate current during modulation. Up to 80 or 90 percent modulation, the plate current should be entirely steady. When the modulation exceeds 100 percent, the plate current should *rise*. A *dip* in plate current indicates either insufficient excitation, a defective tube, or low filament voltage. (A slight dip, 5 percent or less, may be experienced if class *B* modulators are used and the modulator load causes a drop in the class *C* plate voltage. A greater drop than 5 percent is poor engineering, and may introduce distortion.) Even then, the class *C* stage plate current should rise as soon as 100 percent modulation is exceeded.) See Chapter 6 on modulation.

43. Oscillators of the Regenerative Type—In section 14 of Chapter 4 it was pointed out that amplifiers of the triode type have a natural tendency to become oscillators through the fact that a portion of the plate-output a.c. tends to return to the grid by way of the plate-grid capacitance inside the tube, thereby driving the grid without any further input from outside sources. This type of oscillation is called regenerative oscillation, but it is quite possible to produce regenerative oscillation without resorting to feedback inside the tube, and various circuits for that purpose have been devised and widely used.

An oscillator almost always acts as a source of r.f. or audio power, and for the sake of efficiency is ordinarily run in class *C*, that is strongly excited, which for an oscillator means with strong feedback. This does not mean that a great deal of power is being turned out for the tube may be a small one operating at a low voltage. Just such small oscillators are in fact used to control most radio transmitters, which consist (section 53, Chapter 4) of a small oscillator followed by a number of radio-frequency amplifier stages, one of which is finally modulated by either key or voice. The purpose of the arrangement is to secure good frequency steadiness or "stability," therefore the small "master" oscillator is well protected from anything which might make it shift its frequency. Numerous methods of doing this have been devised. Some of these methods are to be touched on. There are, however, also recent types of transmitters in which the oscillator is of itself fairly powerful and requires no more than a stage of amplification between itself and the antenna—and there are even portable ultra-short wave transmitters in which the oscillator itself feeds the antenna, naturally at rather low power since ultra-short equipment is mainly used at quite moderate ranges.

A regenerative oscillator operates when the grid exciting (feed-back) voltage is sufficiently large and also of the right phase, that is when the grid a.c. voltage is at all instants approximately opposite that of the plate—though not equal thereto—both being compared to the cathode. Since the two ends of a transformer winding are normally at opposite voltages a fairly obvious method of securing such a relation is to employ a coil, one end of which is connected to the plate, the other to the grid, the coil being tuned with a condenser so that it may be able to determine the oscillation-frequency. The cathode must then be connected to an intermediate point of this tuned system, and suitable condensers (stopping) provided to prevent the d.c. plate and grid voltages from meeting. Two forms of this general idea are in wide use.

44. The Hartley Oscillator—In the Hartley form of the tuned auto-transformer type of regenerative oscillator the cathode-tap is provided by a connection to the coil. In figure 153 is shown the shunt-feed form of this circuit. The gridleak bias shown is a common device of oscillators, to provide a low initial bias so that plate current may flow in order to start the grid excitation—for a class *C* tube cannot draw plate current when not excited unless the bias has been lowered. The a.c. grid and plate voltages are at long waves approximately proportional to the section L_g and L_p respectively, but at short waves the stray capacitances greatly complicate the circuit, adding numerous paths which do not appear in this simple diagram and making it impossible to maintain the desired opposition-phase relation between a.c. grid and a.c. plate voltage except by the use of certain " dodges " such as variable plate and grid condensers which spoil the single-control feature of this circuit. However, this is simply the effect encountered with all oscillators more or less at short waves. The Hartley circuit remains one of the most tractable of oscillators. Incidentally, this circuit is not an inductively-coupled-feedback arrangement in the ordinary sense, the coil may be divided and the two sections shielded from each other without stopping oscillations entirely, as long as the series circuit is not broken—provided the experiment is made at a reasonably long wavelength where the extra capacities and wire-lengths are not objectionable.

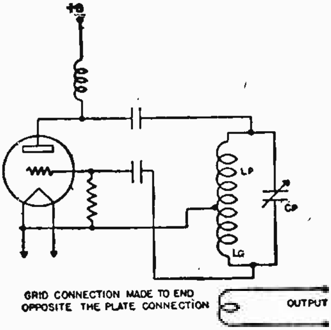


Fig. 153. Hartley Oscillator.

45. The Colpitts Oscillator—In figure 154 is shown the Colpitts version of the same general idea. In this case the cathode tap is taken from the condenser instead of the coil, that is the Colpitts circuit uses two condensers in series across one coil, while the Hartley circuit uses two coils in series across one condenser. Whereas in the Hartley circuit the feedback is controlled by changing the relative inductance of L_p and L_g this is accomplished in the Colpitts circuit by changing the relative capacitance of the two

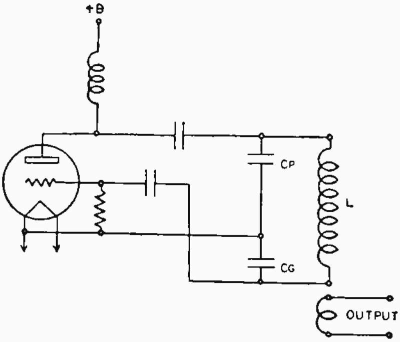


Fig. 154. Colpitts Circuit.

condensers. Thus in one case a tap is moved on a coil, while in the other two condensers are adjusted. In either case a small frequency shift will be encountered in practice and the final step is a small retuning by condenser variation—one only.

Each of these circuits can claim superiorities. From the operator's standpoint the Hartley circuit is less convenient to adjust as to feedback but simpler to tune, though neither side of the condenser is at filament voltage and hence an insulated shaft drive or hand capacitance are met. In commercial practice certain advantages are obtained by use of the Colpitts circuit since plug-in coils or a variable inductance can be used over a wide frequency range with fixed condensers without disturbing the feedback voltage ratio.

46. The Meissner Oscillator—An oscillatory circuit of the regenerative type which is sometimes used unintentionally is that of Meissner, which resembles the Hartley circuit except that the coils L_p and L_g are not tuned but are merely coupled to some external circuit which IS tuned. At times an r.f. amplifier contrives to discover a method of coupling both its grid and its plate circuit to some nearby pipe, wire or bar in such a manner as to produce a Meissner-circuit "parasitic" oscillation of mysterious sort and distressing strength. Because of the shorter wavelengths employed today this circuit is seldom used intentionally, simplicity being a main requirement at shortwaves—and it is to be remembered that the Meissner circuit was devised when 540 meters was a "short wave." The Colpitts oscillator is somewhat less given to parasitic oscillations than the Hartley circuit, but either is subject to the "accidental Meissner" type, and also the type due to an unfortunate choke coil.

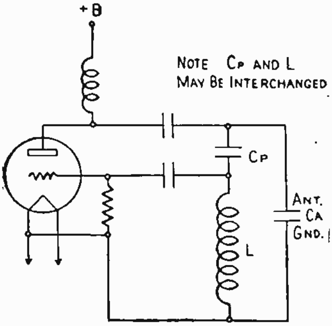


Fig. 155. Ultraudion.

47. The Ultraudion Regenerative Oscillator—The Ultraudion circuit (frequently mis-called "ultra-audion") is historically one of the oldest of all oscillators. Several circuits are known by this name, which is correct as they were described originally under a common name, and all have common features. In figure 155 is shown one form which may be thought of as a cross between the Hartley and Colpitts circuits and may at first appear inoperative.

Another form which is in very extensive use for low-power ultra-short-wave oscillators is obtained by adding a second coil between the upper ends of C_A and C_p in place of the plain wire, removing the plate stopping condenser and choke and feeding the plate supply up through this second coil. This is an exceptionally vigorous oscillator at ultra-short waves. The tuning can then be accomplished at either C_p or at C_A.

48. The Tuned-Plate Tuned-Grid Regenerative Oscillator— We now come to another early and very useful type of oscillator of the regenerative class, due to E. H. Armstrong and known commonly as "tuned-plate-tuned-grid" or "TPTG" from the fact that its two tuned circuits are independent except as coupled through the plate-grid capacity inside the tube. It is somewhat unfortunate that figure 156 shows a shunt-feed form since one of the merits of the circuit is its ability to use series feed without causing the tuning condensers to become "hot" on their rotor sides, at either r.f. or d.c. thus eliminating chokes and their disorders. However the principle merit of this circuit is that the proper feed-back phase is more easily established through the ability to tune the grid and plate independently, thereby providing any desired impedances. The two circuits are NOT working at the same natural frequency; it is necessary that the tuned-plate circuit be inductive in nature, hence non-resonant—but nearly so. If a higher ratio of C/L be used good stability and good efficiency are possible at the same time. If the tuned grid circuit takes the form of a quartz crystal in its holder this circuit is our familiar crystal-controlled "master" oscillator of figure 157, on which many stations, commercial and amateur, are based. No basic change is introduced by substituting a tetrode or pentode as the reduced feedback is more than balanced by the greater sensitivity

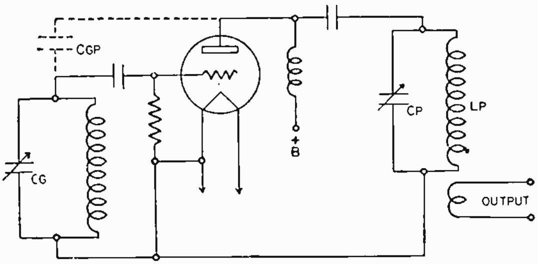


FIG. 156. T.G.T.P. Oscillator.

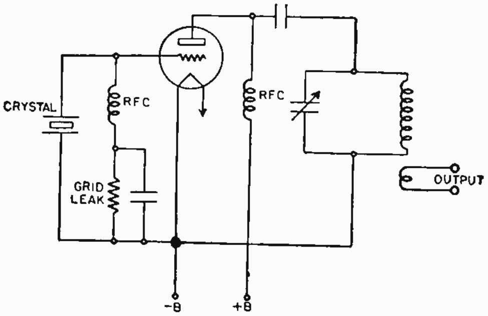


FIG. 157. Triode Crystal Oscillator.

of such tubes. Another interesting variant is the replacement of the tuned grid circuit by a semi-resonant choke coil. This arrangement of a tuned-plate semi-tuned grid offers single-control as its main merit.

49. Electron-Coupled Oscillators—In all the circuits described so far it was necessary to couple the load to the frequency-

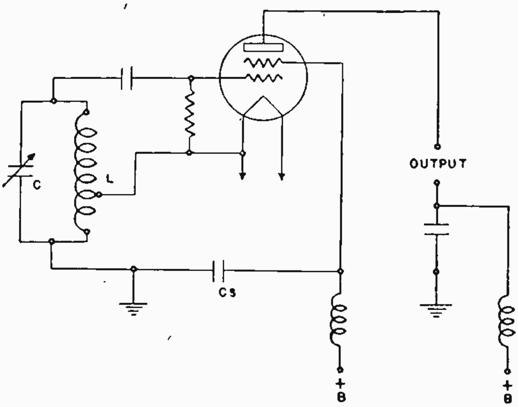


FIG. 158. In the E-C Circuit, the Screen Grid Acts as the Plate in a Hartley Oscillator. It Is Grounded Through By-Pass Condenser Cs, so It also Shields the Plate from the Other Elements.

determining portion of the oscillator. Then any external change, such as a swinging antenna, the modulating or the keying of a subsequent amplifier may cause a frequency waver. Changes in the plate voltage of the following amplifier affect the frequency to an undesirable extent. The Dow "electron coupled" oscillator is comparatively free from such difficulties.

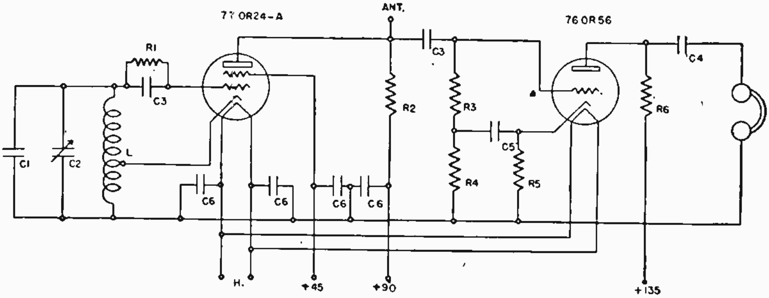


FIG. 159. Electron Coupled Frequency Meter and Detector.

C1. Band Setting Condenser.
C2. Band Spread Condenser.
C3. 250 Mmfds.
C4. 0.1 Mfds.
C5. 0.25 Mfds.
C6. 0.05 Mfds.

R1. 0.1 Meg. 1/2 Watt.
R2. 0.1 Meg. 1 Wattt.
R3. 0.5 Meg. 1/2 Watt.
R4. 0.5 Meg. 1/2 Watt.
R5. 50,000 Ohms. 1 Watt.
R6. 0.1 Meg. 1 Watt.

L. Inductance, Depending Upon Frequency Range Desired.

It is illustrated by figures 158, 159 and 160 and makes use of a four or five element tube. The screen, control grid, and cathode form the three elements of a triode oscillator. The conventional oscillator circuit is modified by grounding the screen (which corresponds to the plate of the oscillator) through a by-pass condenser. This has the effect of shielding the plate of the tube from the inner elements. Thus the plate has no connection with, and is shielded from, the elements which generate the oscillations. The electrons which pass through the screen flow in pulses determined by the oscillations in the inner elements. This pulsating current develops power in the plate circuit load. Thus the only coupling between the oscillator and the load is the electron stream which escapes through the screen, therefore "electron coupling." This coupling is one-way so that plate circuit conditions have little effect upon the frequency. To make full use of this effect, the circuit components must be very carefully shielded and the tube's screening action must be complete. In addition to the frequency stability obtained by the elimination of coupling between oscillator and load, two other valuable advantages exist: (1) By properly proportioning the voltages on the screen (inner plate) and plate, the frequency may be made independent of small changes in the supply voltage. The proportion is maintained by feeding the screen from a voltage divider, thus changing both voltages in

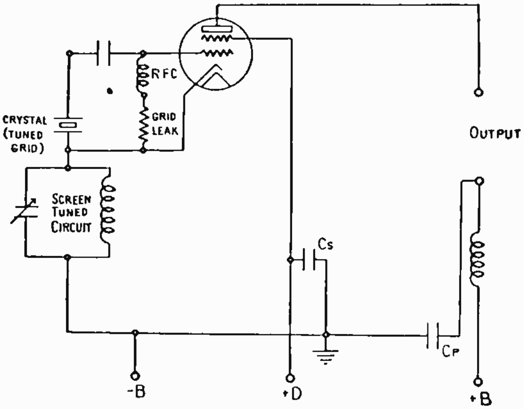


FIG. 160. The "Tri-tet" Circuit, a Form of Crystal-Controlled Dow Oscillator. The cathode tank is tuned to approximately 125 percent crystal frequency, the plate tank to the crystal frequency or a multiple thereof. The same number of tuned circuits is used as for a Pierce oscillator with an amplifier, but a tube is saved. The lower end of the gridleak may be connected to B—instead of the cathode.

proportion if the supply voltage shifts. (2) Substantial output can be obtained at harmonics of the oscillator frequency. The data given below (from QST March 1933) indicates the large amounts of harmonic power that can be obtained:

Type 860 E-C Oscillator. Plate voltage 2,000 volts, screen 800 volts.

Frequency	Power Output	Plate Efficiency
Fundamental	85 watts	42%
Second harmonic	62 watts	31%
Third harmonic	51 watts	25%
Fourth harmonic	32 watts	16%
Fifth harmonic	19 watts	19%

Note that grounding the screen makes the cathode operate above ground potential at radio frequency. With filamentary type tubes, the filament must be connected through r.f. chokes. With certain heater type tubes the chokes are unnecessary, no damage being done by the radio frequency voltage between the heater and the cathode.

The high harmonic output of the *EC* circuit has made it very convenient for use as a heterodyne frequency meter. Figure 159 shows a suitable arrangement for this service. For amateur use, the oscillator usually operates in the 1.75 Mc band. This provides harmonics sufficiently strong to permit measurements up to 28 Mc/s. Only one calibration is necessary, points being transferred from band to band by merely multiplying the frequency by the correct harmonic number. Thus a beat on the setting for 1.765 Mc/s corresponds to 3.530 in the 3.5 band, 7.060 in the 7 Mc band, or 14.120 Mc/s if the frequency being measured in the 14 Mc band. When checking the frequency of a transmitter the beat is heard in the headphones connected to the detector which is shown as a portion of the meter. If the calibration of a receiver is to be checked, or a signal being received is to be measured, the beat is heard in the output of the receiver, and the detector associated with the frequency meter is not used.

Similar devices are supplied to the Field Inspectors of the Federal Communications Commission for frequency measurements on shipboard.

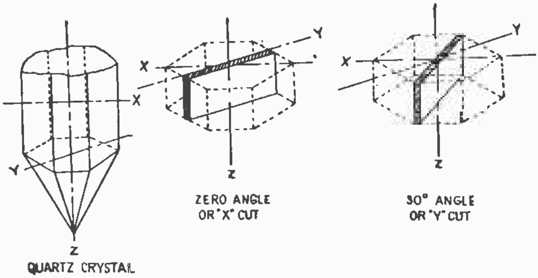
Use of Pentodes in E–C Oscillators—Pentodes can be used as E–C oscillators if two conditions are met. The suppressor must come to a separate pin connection, and not be connected to the cathode inside the tube. Connecting the cathode to the suppressor provides electrostatic coupling between the oscillating circuit, of which the cathode is a part, and the plate. To obtain the full benefits, it is essential that the suppressor be tied to the screen, thereby assisting the shielding action. Further, certain r.f. pentodes have an internal shield. If this shield is connected to the cathode inside the tube, it will provide undesired electrostatic coupling by its capacity to the plate. The type 78 receiving pentode is connected in this way and is therefore unsuitable as an *E–C* oscillator. The type 77 has the internal shield connected to the suppressor and is therefore satisfactory since suppressor, internal shield, and screen can be tied together and grounded to provide an effective shield between the oscillating elements and the plate.

50. Crystal Controlled Oscillators—In a crystal controlled oscillator, the frequency of the oscillations is determined by the piezo-electric effect of a quartz plate, which *in effect* is a tuned circuit of large inductance but very small resistance. The theory of operation of oscillating quartz belongs to the general subject of physics and will not be treated here. Briefly, when a section of quartz crystal (properly cut from the crystal) is subjected to an electrostatic field, a mechanical strain is set up which distorts the shape. The opposite is also true—a mechanical strain in the crystal will produce a voltage difference between the two faces. The mechanical strains only become large enough to produce appreciable voltages when the crystal is vibrating (mechanically) at one of its fundamental frequencies. Every crystal has two fundamental frequencies—one depending upon the thickness, and the other depending upon the surface area. The thickness vibration has the higher frequencies (since crystals are cut so that the thickness is less than either the width or length) and is used exclusively for high frequency oscillations. The surface (or contour) vibration is much lower in frequency and is used only when very low frequencies are desired.

When properly connected in a vacuum tube circuit, as for example in figure 157, the impulse produced by applying the plate voltage is sufficient to start oscillations in the crystal. If the plate tuning and feedback are satisfactory, oscillations will continue at the frequency determined by the crystal. The tuning of the output circuit (of course if the tuning is too far out the oscillations will stop), the voltages on the tube, and the power taken from the tube have only a slight effect on the frequency. When reasonable precautions are taken to keep these factors *and the temperature* constant, the frequency can be made very stable.

51. Crystal Holders—The most familiar mounting for crystals consists simply of a pair of flat electrodes between which the crystal is slipped. The electrodes are in contact with the crystal faces, and a slight pressure (0.1 to 0.5 ounces) is applied to prevent any erratic motion. A newer form of holder is the "air-gap" type. In it a space is left between the crystal and the upper plate. This short air column loads the crystal mechanically and thereby influences, to a small degree, the frequency at which it can oscillate. By varying the air-gap, the frequency can be shifted over a small range. As the air-gap becomes too large, it becomes increasingly difficult to maintain oscillations, and as a consequence, the useful power output from the oscillator is reduced. The manufacturer of such a holder claims that the frequency can be changed over a range of 0.17 percent before the output drops more than 20 percent. This amounts to 6 Kc/s at a frequency of 3500 Kc/s.

52. Temperature Coefficient of Frequency—One of the most important characteristics of crystal oscillators is the frequency change due to the crystal temperature. Crystals may be cut from a parent crystal in several different ways. The principal difference



QUARTZ CRYSTAL

ZERO ANGLE OR "X" CUT

30° ANGLE OR "Y" CUT

FIG. 161. Orientation of X and Y Crystal Cuts.

between crystals cut in these different ways is the temperature coefficient of frequency, that is, how much the frequency changes for every degree change in crystal temperature.

Crystals cut with their major surfaces normal to the "*Y*" axis and parallel to the "*X*" axis and the "*Z*" axis are called "Y-cut"

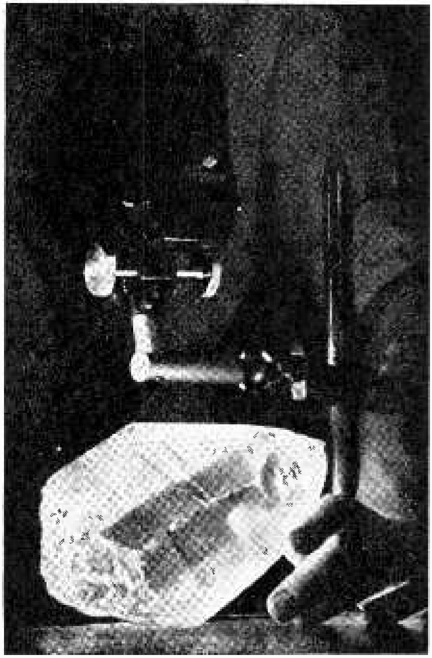


FIG. 161, A. Examining Quartz Crystal Prior to Cutting.

crystals. This and other cuts are shown on figure 161*B*. The temperature coefficient of Y-cut crystals varies from —20 to + 100 parts per million per degree centigrade, however, those most frequently encountered have T.C. of + 70. Notice that the coefficient is usually positive, that is the frequency *increases* as the temperature *rises*.

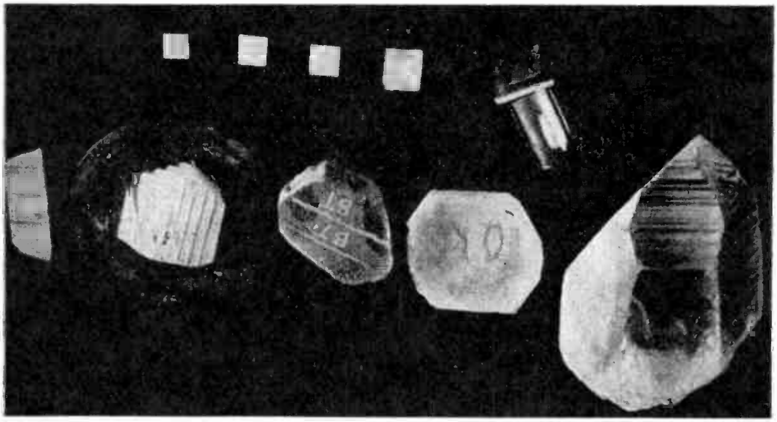


Fig. 161, B. Quartz Crystals in Various Stages of Production.

Apart from the relatively high temperature coefficient of frequency, Y-cut crystals have the reputation of being somewhat

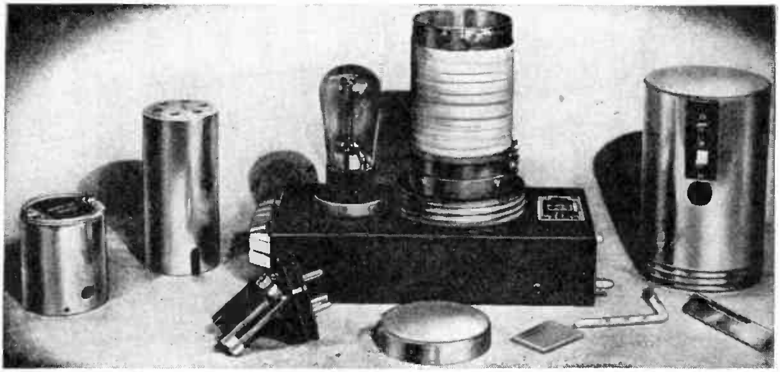


Fig. 161, C. View of the Different Parts of the 702A Oscillator. (Courtesy of Western Electric Co.)

erratic in operation. This is explained to a certain extent by saying that the harmonics of the contour vibration sometimes fall close to the frequency vibration. As the temperature coefficients of the two modes of vibration are different, the effect varies with temperature, introducing a disturbing factor. As the temperature rises, the frequency may shift suddenly at certain points instead of gradually. For these reasons Y-cut crystals are not very popular, and very cheap crystals are frequently of this type.

A somewhat superior crystal is obtained by cutting the plate normal to the *X* axis (electric axis) with major surfaces parallel to the *Y* and *Z* axises. These crystals are referred to as X-cut crystals. The temperature coefficient of frequency of these crystals is about — 22 parts per million (0.0022 percent), per degree centigrade. The coefficient is negative, indicating that the frequency *decreases* as the temperature *rises.*

The fact that the temperature coefficients of *X* and *Y* crystals are opposite suggested that it might be possible to cut a crystal somewhere between them and secure a plate with a zero temperature coefficient, i.e. frequency would not change with temperature. A number of special cuts come very close to this ideal. The AT-cut (made by Bell Telephone Laboratories) and the RCA's V-cut have temperature coefficients of ± 2 parts per million (0.0002 percent) per degree centigrade. Such excellent performance is only possible when the manufacturing processes are held to very close limits, and consequently such crystals are higher in price. Bell Telephone Laboratories, Inc., also manufacture other crystals as follows:

BT-cut	T.C. ± 2
AC-cut	T.C. + 20
BC-cut	T.C. — 20

53. Frequency Changes with Temperature—Although the frequency change per degree is very small, most transmitters are likely to experience such a high range of temperature that the total change is quite considerable. Even transmitters installed in heated buildings may have a temperature range of 50 degrees C. In winter, temporary failure of the heating plant may easily send the temperature down to 0° C. (32° F.). In summer, the warm weather plus the heat dissipated inside the transmitter may raise the crystal as high as 60° C. (140° F.). Transmitters on shipboard, aircraft, or those located in separate unheated houses may have even greater temperature range.

Assuming 60° C. as the expected temperature range, the table below shows the frequency deviation that might result. The third column shows this deviation in percent, and the fourth column shows it in cycles at a frequency of 1500 Kc/s, for comparison.

TABLE 1.—TEMPERATURE CHANGE 60° C.

Crystal Cut	Freq. Coef. Temp. Parts per Million	Deviation in Percent	Cycles at 1500 Kc
Y..........	+70	0.420%	6,300
X..........	−22	0.132%	1,980
AT or V....	± 2	0.012%	180

54. **Constant Temperature Ovens**—The frequency deviations resulting from large changes in temperature exceeds the tolerance allowed by the Federal Communications Commission for many classes of stations. When it does, it is necessary to prevent the temperature change by inclosing the crystal and preferably the tuned plate circuit of the crystal tube as well in a constant-temperature oven. This is simply a well constructed, air-tight box, having heat insulated walls, and containing a thermostat and a small heater. The thermostat is adjusted to open its contacts at a certain temperature. *It is necessary that this temperature be higher than the highest outside temperature expected.* This is due to the fact that the apparatus provided can warm the interior if it gets too cool, but it cannot cool it if it gets too warm. If the temperature inside the box falls below the thermostat setting, the contacts close and current flows into the heater. This warms the box. When the proper temperature is reached, the contacts open and the current is shut off. As the box is above the outside temperature, heat is slowly lost through the walls. When the box has cooled again, the thermostat contacts again close and heat is again applied. Thus the inside temperature undergoes a continuous heating and cooling. The temperature range covered depends upon the sensitivity of the thermostat.

In the recently designed Western Electric 702A Oscillator the low temperature coefficient AT-cut quartz plate is combined with an exceedingly simple temperature control mechanism to provide a stability of generated frequency well within 10 cycles of the nominal value. This oscillator is employed in broadcasting and police radio transmitters operating in the 550 kilocycle to 3000 kilocycle band. Except for the power supply required for the oscillator tube and the oven heater, this oscillator is a self-contained unit, fully automatic in its operation. (See figure 161*C*.)

Its construction is in the form of a chassis, about 4″ × 9″ × 2″, on the top of which are mounted the oven and a Western Electric 247A Vacuum Tube. All other elements of the circuit are contained within the chassis which serves as a shield as well as a mounting frame. Connection to supply voltages, indicating meters, alarm circuit, and the radio-frequency load are all made through spring clip terminals contained in a strip at one end of the chassis.

When an oscillator is inserted into a transmitter, the bottom of the chassis engages two tracks and the terminal strip automatically makes all contacts to a similar strip which is a part of the transmitter. The spring pressure of the contact strip is used to force the oscillator chassis against detents located at the outer end of the tracks, thereby assuring good contact pressure at all times.

The quartz in its mounting, coded as a 7A Quartz Plate, is a plug-in type of unit which is inserted in a socket inside of the oven of the 702A Oscillator. The oven is of the double-wall all-metal type and employs a special bimetallic snap action thermostat to control the temperature which is nominally maintained at about 60° C. On account of its ruggedness and consequent reliability, the snap action type of thermostat is a noteworthy improvement over the mercury-in-glass variety used in the past. It is true that it cannot be made as sensitive as the latter, but the need for sensitivity has been greatly reduced by the introduction of low temperature coefficient quartz plates. Furthermore, the snap action thermostat can control directly the supply of power to the heater, thereby dispensing with the complicated and costly control circuits associated with mercury thermostats.

To enable the user to comply with regulatory requirements, a thermometer is provided to indicate the temperature in the vicinity of the quartz. As a further and more automatic safeguard, an alarm thermostat is provided which, in conjunction with external circuits, will give a positive indication of irregularities of the temperature control system. A pilot lamp on the transmitter panel which remains lighted as long as the temperature control circuits are functioning properly is employed as the indicator.

For broadcast stations, the Commission requires that the crystal temperature be maintained within 0.1° C. for ordinary crystals, or within 1° C. if approved low coefficient crystals are used. Maintaining the temperature within 0.1 degrees requires elaborate arrangements and very sensitive thermostats. Many stations have experienced difficulty in keeping the temperature that close and have changed to low-coefficient crystals. The limit of 1 degree can be held by a comparatively simple and rugged oven. In fact, several ovens are now available which are not much larger than a mounted crystal. They are fitted with plug-in connections, and can be removed and a spare oven (including a crystal) placed in operation in a few seconds. Contacts should be provided to supply power to the heater of the oven not in use so it can be kept at the proper temperature ready for instant use. This is a distinct improvement of the old system of having two crystals (one in use and the other for a spare) in the same oven. It was practically impossible to have both crystals exactly on frequency at the same temperature. As a result, the oven temperature was set for the one in use. The spare crystal would then be off frequency until the oven temperature could be changed. Then too, this did not take care of a failure in the oven heating circuits or thermostat.

For services other than broadcast, the Commission does not specify any temperature limits nor is an oven specifically required. However, compliance with the spirit of the International regulation which requires all stations to maintain frequency as accurately as the state of the art permits might be interpreted to require an oven capable of maintaining the crystal temperature to within 1° C. This is based on the fact that such ovens are reliable, small, and can be obtained on the open market at reasonable prices. On aircraft where weight is an important factor in determining the safety of the plane, and on police cars where the interference problem is not serious because of the limited power, it is impractical to install constant-temperature ovens. In that case, low coefficient crystals are employed to reduce the frequency deviations.

55. **Frequency Drift**—As quartz crystals are not perfectly elastic (no substance is) the rapid vibrations generate a certain amount of heat. This raises the crystal temperature when oscillations begin, causing the familiar drift in frequency during the warm-up period. This cannot be completely eliminated by a constant temperature oven. When not oscillating, the crystal receives all its heat *from* the oven. Its temperature consequently will be equal to the oven temperature. When oscillating, the crystal is delivering heat *to* the oven. Its temperature consequently will be slightly above the oven temperature.

To prevent this frequency drift from being undesirably large, three things may be done:

1. The crystal oscillator may be left running all the time, thus eliminating any warm up period.

2. The crystal oscillator may be operated at very low plate

voltage. This makes the current through the crystal and the heating effect correspondingly low.

3. A low temperature coefficient crystal may be used.

The first suggestion is expensive (from a power bill standpoint) and is often impractical. The second suggestion requires additional intermediate stages thus complicating the transmitter design. The third method is by far the most practical and is recommended.

56. **Crystal Oscillator Circuits and Tubes**—There are three circuit arrangements that are in general use for crystal oscillators. The circuit most often used is shown in figure 157. The circuit is the same for a triode or pentode, the only difference being the additional tube elements which are by-passed and operated at fixed voltages. This circuit is of the tuned-grid, tuned-plate type shown in figure 156. The crystal takes the place of the grid tuned circuit. Feedback is obtained through the internal grid-plate capacity. As the crystal is more efficient than any tuned circuit the feedback capacity required is very small—about 1 mmfd. being usually sufficient.

Radio-frequency pentodes (as distinguished from those intended for audio use) are so well shielded that it is always necessary to add external grid-plate capacity. For this reason, the cheaper audio type tubes are preferred.

The power output that can be obtained from a crystal oscillator is limited by the r.f. current through the crystal. Authorities do not agree very well as to the safe current, but general opinion is that a current of 100 Ma. cannot be exceeded without danger of cracking the crystal. However, this amount of current is sufficient to cause considerable heating, and unless low coefficient crystals are used, the frequency drift will be excessive. It is suggested that ordinary crystals be limited to about 35 Ma. on this account.

When adjusting transmitters, it is suggested that a small 6.3 volt dial lamp be connected in series with the crystal. These burn dimly at a current of 100 Ma., show full brilliancy at 150 Ma., and, it is to be hoped, burn out before the crystal is damaged. At any rate, a bright light indicates the crystal current is too high.

Figure 162 shows a circuit used by the W. E. Co. in their small aircraft transmitters. It is a modification of the "ultra-audion" circuit. The condenser C_1 determines the amount of excitation provided, and the feedback is directly through the crystal. The internal plate-grid capacity is not needed, and the circuit is used with a well shielded r.f. pentode. As the entire output voltage plus the grid excitation voltage appears across the crystal, it is evident that the crystal current may be quite high. In this transmitter the amplifier loads the oscillator heavily, thus *keeping the crystal current down.* For this reason, the circuit cannot be

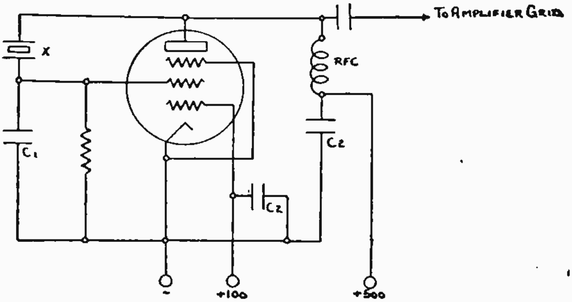


Fig. 162. Special Crystal Oscillator. Not Recommended for General Use. See Text.

C1—Feedback Condenser—Depends upon Frequency—about 0.001 Mfd.
C2—By-Pass Condenser. 0.01 Mfd.

recommended for general use. It is, however, very well suited to aircraft service. Change from day to night frequency (or from the itinerant aircraft frequency to the frequency assigned to the particular airline over which a flight is being made) is effected by simply shifting crystals and tuning the amplifier plate circuit. There are no tuning adjustments necessary in the oscillator circuit. This makes the entire transmitter very simple, compact, and fool proof.

Figure 160 shows an electron-coupled form of the crystal oscillator, which has been placed directly after the Dow circuits of figures 158 and 159 to show their relation. This very useful circuit, due to J. J. Lamb, has been stated to consist of triode oscillator followed by a tetrode amplifier, and thus has been named "Tri-tet," but comparison with figures 158 and 159 will show that the same claim could with equal correctness be made for the original Dow circuits, and that the stress should be laid on the presence of the crystal control. The crystal portion of the circuit is of the usual tuned-plate tuned-grid form. As usual the crystal tunes the grid while the "plate" is the screen just as in the Dow circuits. Incidentally, the Dow circuits (that is the non-crystal circuits) merely happen to be shown with Hartley circuits and will also work quite excellently with the TPTG arrangement, which is to say figure 160 with the crystal replaced by a coil and condenser. Thus the improvement is entirely in the addition of the crystal to a Dow circuit—or perhaps in the addition of electron coupling to a crystal oscillator! None the less it is a useful circuit, though limited to voltages at which a crystal is not endangered while the original Dow circuit of figure 158 is not so limited, hence is being used in tubes of 100 watt size to drive directly the final amplifier of radio transmitters in a service requiring a wide range of frequencies not easily met with crystals. To attain the necessary stability the 100 watt tubes and their associated circuits are enclosed in large constant-temperature ovens. Either figure 158 or 159 is useful in producing harmonics of the oscillator frequency as already noted in section 30. The rather low harmonic level of figure 160 due to the low voltages may be raised by utilizing the facility of phase adjustment peculiar to all Armstrong circuits. By determining the screen tuned-circuit the fundamental or harmonic outputs may be increased. The gap marked "output" is in either the Dow circuit (158) or the Lamb arrangement (160) filled by a tuned-circuit set to the desired frequency, fundamental or harmonic. From what has been said it is clear that while this is not important for harmonic production, a well-shielded tetrode or transmitting pentode is most useful for "straight through" operation on the fundamental, though a pentode with the suppressor separately available may be used also. A suppressor tied to the cathode would be unfortunate.

57. Adjusting the Frequency of Crystal Controlled Oscillators—Operators of composite[10] transmitters sometimes experience difficulty in obtaining the exact desired frequency, and some means of causing a small frequency change is desirable. There are four methods commonly used. *BEFORE MAKING ANY ADJUSTMENT TO THE FREQUENCY, A CHECK SHOULD BE OBTAINED FROM SOME RELIABLE OUTSIDE SOURCE TO MAKE SURE THAT YOUR OWN FREQUENCY MEASURING APPARATUS HAS NOT DRIFTED.*

1. If the thermostat is provided with an adjustment, the temperature of the oven may be shifted slightly. Operators are cautioned that it takes at least three hours, and frequently longer, for the frequency to respond to this adjustment. Unless very carefully done, the tendency is to change the temperature too much and overshoot the mark.

2. A small condenser of perhaps 20 mmfds. maximum capacity

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[10] The question of frequency adjustment of manufactured transmitters should be taken up with the manufacturers.

may be placed across the crystal. Varying this capacity will cause a slight shift in the frequency. This has the advantage that the frequency responds immediately. It has a serious disadvantage in that the frequency can be *lowered* but *not raised.* The condenser must not be too large, or the crystal may loose control.

3. Detuning the crystal plate circuit in the conventional crystal oscillator circuit has a slight effect on the frequency. This is not a good way of shifting frequency because the tank condenser should be set for nearly minimum crystal current consistent with satisfactory output.

4. The use of a crystal with a variable air-gap is recommended as the best way of obtaining the exact desired frequency.

IMPORTANT NOTE: After adjusting the frequency by one of the methods just described, it should remain very close to the exact value without any further adjustment for weeks at a time. If it does not, the frequency control is not satisfactory. It is not good engineering to make an adjustment to the frequency control every day or two. This prevents observation of the true amount of frequency change that might be present. The frequency control is intended to be automatic, and it is not serving its purpose if it requires frequent adjustment.

58. Dynatron Circuit—Examination of the characteristic curves of any tetrode will show that in the region where the screen voltage is about twice as high as the plate voltage (operation is usually confined to the region where the plate voltage is the higher) an increase in plate voltage will cause a reduction of plate current. Such a result would be expected if the internal "plate resistance" was *negative.* If this "negative resistance" is connected in series with a resonant circuit, oscillations will be set up at a frequency determined solely by the circuit. A tube connected in this manner is termed a "dynatron oscillator" and differs from all other types of oscillators in that there is no feed back of energy from the plate circuit to the grid. Although dynatrons are very stable oscillators, the power that can be obtained from present day tubes is very small. For that reason they cannot easily be used to control the frequency of a transmitter. Their

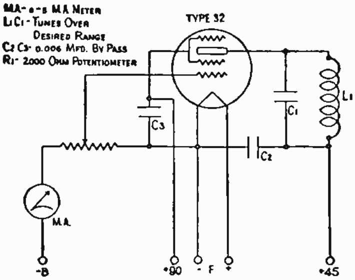

Fig. 163. Dynatron Oscillator for Use as a Frequency Meter.

main use has been as a frequency meter. Even here the dynatron has been to a large degree replaced by the Dow *E–C* oscillator. A typical dynatron frequency meter is shown on Fig. 163. Note the potentiometer grid return, and the cathode current meter. The error introduced by supply voltage changes is reduced by adjusting the potentiometer until the cathode current is at the point it was when the instrument was calibrated.

The dynatron oscillator is rich in harmonics, but not as rich as the *E–C* circuit nor is the power output nearly as great.

59. Non-regenerative Oscillators—In addition to the regenerative oscillators there is another class which may be thought of as depending on the back-and-forth motion of electron clouds at some point inside a tube. Actually these electrons are moving toward a plate and eventually arrive there, but not until they have made several partial returns by pursuing a zig-zag or spiral path. These oscillators have their main usefulness at frequencies so high that there is not time for an electron to go from cathode to plate during 1/2 cycle of the high radio frequency. This, of course, corresponds to wavelength under one meter, the so-called "centimeter waves" therefore the oscillator tube is ordinarily small and the power also small. These are the Magnetron oscillators, the Barkhausen-Kurtz and the Gill-Morell oscillators (see figure 108, Chapter 4). Unfortunately their frequency is determined to an uncomfortable extent by the tube voltages and dimensions and (in the case of the magnetron) by a magnetic field applied to the tube. They are accordingly made to fit a particular job and general statements are hard to make. It is quite possible that this subject deserves more space, yet it is difficult to point to one type that can be thought of as truly commercial, though the idea is many years old. (See also section 31, Chapter 4.)

60. Interstage r.f. Coupling Circuits—In designing interstage coupling circuits, there are three points which must be considered: (1) the desired excitation voltage must be delivered to the grid of the amplifier without overloading the preceding stage; (2) there must be no coupling between the interstage circuit and any other portion of the transmitter; and (3) there must be a path from grid to cathode having low reactance at ultra-high frequencies. The first requirement is obvious but the other two may require a little explanation. If there is any coupling between the interstage circuit and any other portion of the transmitter, r.f. feedback may result which will make the transmitter unstable. This may show as frequency shift, bad note, key clicks, or a tendency to self-oscillation. In phone transmitters, the amount of feedback may change with the modulation so that no ill effects can be detected until modulation is applied. Such difficulties are very troublesome to find and correct and should be avoided, as far as is possible, by the use of suitable circuit arrangements. The third requirement is intended to reduce the tendency toward parasitic oscillations. At ultra-high frequencies, the reactance of even a few inches of wire may be high enough to permit the generation of a parasitic oscillation. When the circuit is so arranged that the grid to cathode impedance is high, parasitic oscillations are almost sure to be produced.

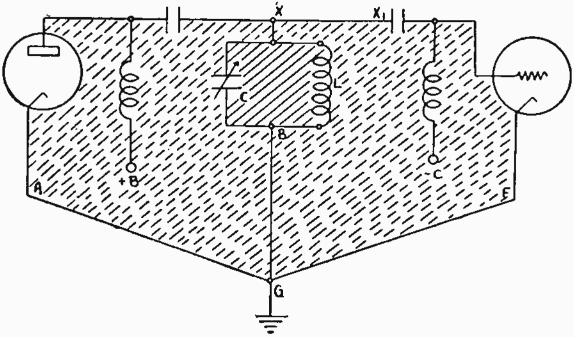

FIG. 164. Simplest Type of Interstage Coupling.

Figure 164 shows the simplest type of direct coupling between the plate of one tube and the grid of the next amplifier. Requirement (1) (listed above) must be satisfied by selecting tube types and operating voltages such that the full output voltage of the driving tube is equal to the desired excitation voltage for the next stage. With the wide variety of tubes now manufactured, this does not present any serious difficulty.

Requirement (2) is more difficult to satisfy. For one thing, points "*A*," "*B*," and "*F*" must be grounded by *separate short leads* to a *single ground point*. The common practice of running grounds to the chassis at the nearest point produces coupling between the ground returns of the several stages, thus introducing regeneration and instability. This is not as serious when the stage is operated as a frequency doubler, but it is always undesirable. The leads *A–G*, *B–G*, and *F–G* should be insulated, and no other connections should be made to these wires. All other ground returns should go to point *G* by means of separate leads. Another requirement of (2) is that the shaded area on figure 164 be kept as small as possible. Any magnetic flux passing through this area will induce a voltage on the grid of the amplifier tube. As such flux is generated by the tank coils and leads of the other stages, and also by the antenna, it forms a type of feedback that cannot be eliminated by neutralization. The area shaded with full lines is especially susceptible because of the voltage step-up action of the tuned circuit.

Feedback from stray magnetic flux can be reduced by employing suitable shielding between the stages. With this particular circuit, a precaution must be observed with respect to passing r.f. conductors through the shield. It is natural to simply pass the lead X–X' through a hole in the shield. The shield then acts as the short-circuited secondary of a one turn transformer. The lead X–X' is the one turn primary. This creates a comparatively heavy r.f. current in the shield around the hole and will introduce losses. The correct construction is to run *both* leads X–X' and G–F through the *same* hole. As the r.f. current in these two wires are equal and opposite, no current should be induced in the shield, thus eliminating the losses. Requirement (3) is satisfied by making the leads X–X', B–G, and F–G as short as possible. (These three leads are the principal reactance between grid and cathode at ultra-high frequencies.)

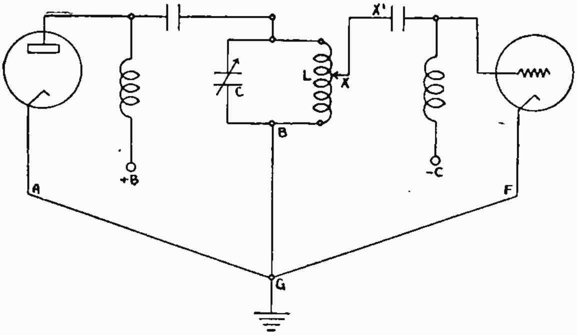

Fig. 165. This Circuit Favors Parasitic Oscillations.

Figure 165 shows a modification of direct coupling that is sometimes resorted to when the output voltage of the driving stage is greater than desired for exciting the next stage. The excitation is varied by simply changing the position of the tap on the coil.

This forms a simple means of satisfying requirement (1). Observing the cautions given for figure 164 will satisfy requirement (2), but it is on (3) that the circuit fails. The path from grid to cathode cannot have the necessary low impedance at high frequencies because a portion of the preceding plate tank coil is in the circuit. The reactance of this coil increases with the frequency, producing a high grid to cathode reactance. This condition is favorable to ultra-high frequency parasitic oscillations and trouble may be expected. For this reason, the circuit should be avoided.

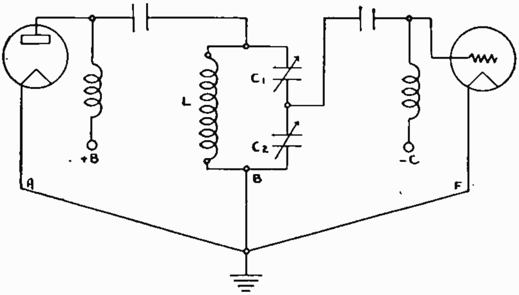

FIG. 166. Excitation May Be Reduced by Dividing the Tank Condenser. C1 and C2 in Series Must Tune L to the Desired Frequency.

Figure 166 answers the objection to figure 165 by tapping in on the tank condenser instead of the tank coil. With short leads this satisfies all the requirements. The precautions with respect to grounding and shielding mentioned under figure 164 must be observed.

Figure 167 is a modification of the circuit shown on figure 165.

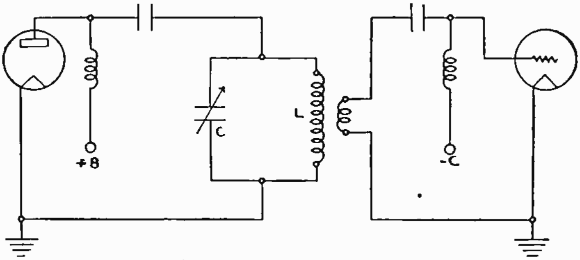

FIG. 167. Although This Circuit Is Superior to Fig. 165, It Does Not Meet Requirement (3).

Although the inductive coupling eliminates the need for careful arrangement of ground leads, it does not answer requirement (3) and for this reason is not recommended.

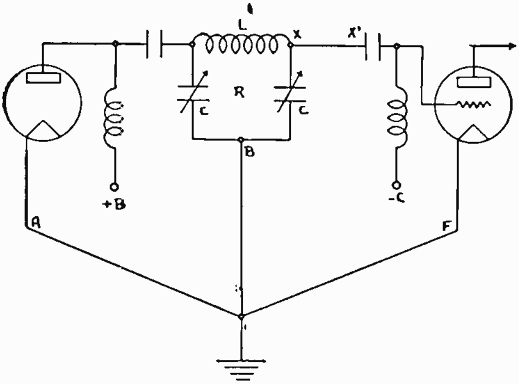

Fig. 168. Capacitive Interstage Coupling.

Figure 168 shows a form of capacitive coupling which satisfies requirement (1) very well. Using two variable condensers, as shown, the excitation voltage can easily be adjusted to the desired point. The area "*R*" must be kept as small as possible, and the grounds must be run separately as shown. Requirement (3) can be met if the parts are located close enough to permit short leads.

In the five circuits just described, the requirements could be met only with all connections as short and direct as possible. This puts the two stages very close together. This is not always possible, nor is it always desirable. Apart from mechanical considerations, the dissipation of heat requires that the tubes be amply separated and well ventilated. It has recently become popular to use short transmission lines between the various stages. This arrangement is shown on figure 169. Twisted pair is most frequently used for the "link" which joins the stages. Such pairs have very considerable losses, at ultra-high frequencies, but these become small for such short lengths. The characteristic impedance ranges from 50 to 200 ohms depending upon the dimensions of the conductors and the character of the insulation. For high power, concentric transmission line is convenient and efficient. For such short distances, a large mis-match of impedance has a negligible effect. Satisfactory results are secured by using a 1 or 2 turn link tightly coupled to the tank inductances. With this "link" coupling, proper excitation voltage can be secured by changing the position or number of turns in either coupling coil. This type of coupling lends itself to shielding very well because the transmission line can be run through a small hole in the shield without any losses. The principal advantage is the fact that it becomes possible to keep all connections extremely short without crowding the stages together. Note that it is not necessary to run separate ground leads to the same ground point. In this circuit the ground wires do not carry r.f. and are put in merely as a safeguard. If one side of the transmission line is grounded, the line acts as an effective electrostatic shield between the stages. This greatly reduces the transfer of energy at frequencies other than the fundamental. This is highly beneficial, because it prevents the transfer of parasitic energy from stage to stage.[11] This improves the stability of the transmitter to such an extent that many amateurs employ this type of coupling between each stage even where the transmission lines are only a few inches long.

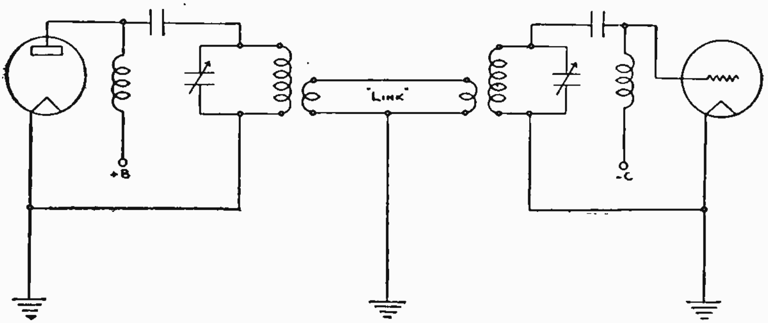

FIG. 169. "Link" Coupling Permits Short Leads Without Crowding the Stages. The Link May Be Any Length. Ordinary Twisted Pair May Be Used for Short Distances with Low Power.

61. Neutralization Circuits for Transmitters—This topic has been covered rather completely in Chapter 4. The causes of regenerative feedback and stability of r.f. amplifiers were given in section 14 and 16 and figure 95—not of this Chapter but of Chapter 4. In section 17 of that Chapter figure 98 shows the Miner reversed-tickler method of stabilization. In sections 19

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[11] Although this reduces the harmonic in the excitation, it does not have any appreciable effect on the harmonics in the final amplifier output. r.f. harmonics which are radiated are generated in the final amplifier and their reduction in previous stages will have no effect.

and 20 of Chapter 4 will be found the fundamental anti-regenerative or neutralization circuits of Rice, Hazeltine and Ballantine, notably in figures 100 and 101.

Allegedly new types of neutralization circuits are published at intervals, but with the exception of the RFL and the Phelps circuits these appear to be minor variants only, and the two circuits just named are not as well suited to transmission, where lies our only present interest in neutralization. As to other common neutralization plans, the so-called "Collins circuit" is simply the Miner circuit with the single difference that the effectiveness of the feedback and probably its stability against frequency-change has been improved by including it in a tuned plate circuit instead of merely placing it in series with the plate. The split-rotor and split-stator condenser systems will be found to differ from the fundamental circuits of figure 100, Chapter 4, only in that they permit the condenser rotor to be "cold," which does reduce some types of instability not controlled by neutralization alone.

One point should be noted—neutralization takes care of feedback through the tube and should not be asked to combat assorted feedbacks external to the tubes. These should be eliminated initially by shielding, filtering and suitable placement of parts. While some neglect can be compensated for by mis-neutralizing the result is ever a stage unstable as soon as the frequency shifts slightly—perhaps even to sidebands.

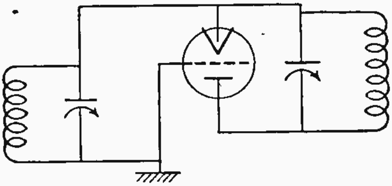


FIG. 170. Grounded Grid Circuit.

62. Grounded Grid Circuit—A circuit arrangement which possesses the unique advantage of not requiring neutralization is that shown on figure 170. Note that the filament power must be supplied through r.f. choke coils.

63. Adjusting Neutralization by Grid Meter Method—When the stage to be neutralized is provided with a grid current milliammeter, it may be used to indicate neutralization as follows:

1. Remove plate voltage from the stage to be neutralized. This must be done on the power supply side of the r.f. chokes and

by-pass condensers as they may affect the neutralizing point. If possible, the best way is to remove the rectifier tubes from their sockets. This can be done, of course, only if the same rectifier does not supply any of the preceding stages.

2. Set the neutralizing condenser at the maximum capacity setting or with inductive feedback systems, put the coils close together.

3. Apply plate voltage to the preceding stages. Grid current should show in the stage being neutralized—probably quite high.

4. Rotate the plate condenser of the stage being neutralized. When resonance is reached, the grid current will dip noticeably.

5. Reduce the neutralizing condenser capacity a little at a time, noticing the grid current dip each time a change is made. As the correct setting is approached, the grid meter dip will become less pronounced. When perfect neutralization is obtained, the grid current meter will not be affected by the setting of the plate condenser. In push-pull stages change both neutralizing condensers at the same time, always keeping their capacity equal. With inductive neutralization, separate the coils a little farther each trial until the location is found where the grid current will not dip.

Note: If grid leak bias is employed, lacking a milliammeter, a high resistance voltmeter may be connected across the grid bias resistor. When the circuit is correctly neutralized, the voltmeter should show little or no change in reading when the plate circuit is tuned through resonance.

64. Adjusting Neutralization by Neon Bulb Method—When the stage to be neutralized has no grid current meter, a small neon bulb may be used to indicate neutralization. This is not as precise a method because (1) the neon bulb requires a certain minimum voltage before it will show any light, and (2) the operator's hand may disturb the conditions so that exact neutralization is lost when his hand is withdrawn. This, of course, cannot be detected and is frequently unsuspected! At any rate, follow steps 1, 2, and 3 under the grid current method (above). Then:

4. Rotate the plate condenser until the neon bulb lights when held close to the tank inductance. If no light is obtained at any setting, touch the glass of the neon bulb to the tank conductor. This makes the bulb somewhat more sensitive but should not be done unless necessary because of the danger of burning the bulb out. When the bulb is lighting brightly, decrease the neutralizing condenser capacity until the bulb becomes very dim. A slight readjustment of the plate condenser will restore a portion of the brilliancy. Continue reducing the neutralizing capacity until the

bulb goes out and cannot be made to light at any setting of the tank condenser. In push-pull amplifiers, figure 101 reduce both neutralizing condensers equal amounts each time, always keeping their capacity equal. With inductive neutralization, separate the coils gradually until the lamp will not glow.

65. **Adjusting the Neutralization by Tank Current Method**—With high power transmitters, the best method of neutralization is the use of a sensitive r.f. ammeter in the tank circuit of the stage being neutralized. The only disadvantage of this method is the danger of burning out an expensive instrument if extreme care is not used.

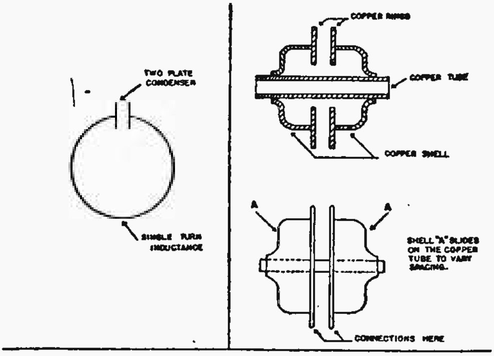
1. Remove the plate voltage from the stage to be neutralized.
2. Replace the normal tank current meter by one having a much lower scale range. Full scale should be about 1/10 of the normal tank current.
3. Set the neutralizing condenser(s) at maximum capacity.
4. Apply power to the preceding stages.
5. Resonate the tank condenser of the stage being neutralized *VERY CAUTIOUSLY.* Observe the tank current meter continuously as this is being done, and stop turning if the r.f. meter shows full scale.
6. When the r.f. meter shows full scale, or the highest reading that can be obtained, reduce the neutralizing condenser (both together in a push-pull amplifier) until the meter just barely deflects.
7. Readjust the tank tuning slightly for maximum tank current shown on the meter. After this point is reached, reduce the neutralizing condenser again until the meter just barely deflects.
8. Repeat step 7 until a point is found where no indication of tank current is shown on the meter.
9. If a precise adjustment is desired, the low reading meter may now be replaced with one even more sensitive, such as an r.f. thermo-galvanometer of 115 Ma. full scale. Repeat steps 7 and 8.

Note: Failure to obtain perfect neutralization may be due to stray coupling between the coils or leads of the driving circuits and the circuit being neutralized. The antenna coupling coil and load should always be connected when neutralizing the final amplifier stage.

66. **Neutralizing with a Flashlight Bulb**—A flashlight bulb is a sensitive and inexpensive r.f. indicator and is frequently employed in neutralization. The bulb is connected in series with a single turn of wire. This turn should have approximately the same diameter as the tank inductance. The bulb socket forms a convenient base upon which the wire loop can stand. This is

placed close to the tank coil and will light when r.f. current flows in the tank. The sensitivity is adjusted by changing the distance between the tank coil and the loop of wire. Neutralization is carried out in the manner described above until the setting is found at which no r.f. current is transferred to the tank.

67. Special Forms of Tank Circuits—At ultra-high frequencies ordinary components such as variable condensers and inductances develop rather serious losses. In amplifier stages, this is not so serious because the power can be made up by simply using larger tubes or higher plate input. In self-controlled oscillators, this involves a serious loss in frequency stability. This type of oscillator is highly important at ultra-high frequencies because in many instances crystal control would require an impractical number of frequency multiplying stages. These intermediate stages, of course, contribute nothing to the output power. In an effort to improve self-controlled oscillator performance, several special types of tank circuits have been evolved. The oldest of these is the use of a quarter-wavelength transmission line of the two wire type. Although such a line can store large amounts of energy with very low losses, difficulty is experienced in making the affair sufficiently rigid mechanically. In addition, the radiation from the 2-wire line is not inconsiderable. Therefore, concentric lines of large diameter have been substituted and are in fairly extensive commercial use, especially at very high frequencies. These are provided with temperature compensation and control fairly powerful oscillators directly. Another form of the low-loss "tank" is



A. Basic Idea. B. High Efficiency Form.

Fig. 171. High Efficiency U.H.F. Tank Circuit.

that developed by Dr. F. Kolster and known by the descriptive title of "hats." Transmitters using both types of devices have shown frequency stability comparable to crystal control. Figure 171 shows the construction of a Kolster "hat." Tuning can be accomplished by sliding the sections together, thus altering the spacing and capacity of the condenser portion.

68. Interstage and Output Coupling Devices for r.f. Amplifiers—In one sense there is no distinction between "interstage" and "output" devices, since both are intended to transfer the r.f. output of a vacuum tube to its load. For the "interstage" device the load consists of the grid of the next tube, the stray losses of the circuit, and in some cases a resistor connected to the interstage coupling device for the deliberate purpose of wasting some r.f. power. For the "output" device the load consists of—almost anything else. From this viewpoint the distinction in names seems rather senseless. However there is a very actual difference from the *user's* standpoint, this difference arising from the very much lesser work and thought which he needs to place on the interstage couplings, neither the design nor the adjustment of which ordinarily cost him much effort or thought. The reason for this is not hard to find. The interstage coupling circuits of a transmitter have a relatively simple task to perform—to drive the next grid hard enough so that a certain plate current shall appear. Adjustment which will produce that plate current is usually satisfactory; the nature of the load is well known, and ample power for feeding it is readily provided. This is the case of the class *C* and class *B* r.f. amplifier. For a receiver the case is less simple, to be sure, but it is not necessary that the reader of this book be capable of designing class *A* r.f. interstage transformers for receivers, since pre-engineered parts are available at moderate costs, and it is quite practical to assemble excellent receivers without any familiarity whatever with the enormous literature surrounding the r.f. and i.f. transformers. In this case the adjustment is nothing but the familiar process of aligning and tuning. For these reasons the following pages consider interstage coupling devices from the transmitting standpoint, and that somewhat briefly. More attention is given to the final-stage output device of the transmitter, which feeds the antenna. This greater attention is justified by the importance of this particular coupling which is called upon to make proper use of the relatively large power consumed by the final-stage tubes, by which is meant a suitable suppression of harmonics without undue damage to modulation, a moderate power loss in the output circuit, and finally a transfer of the major portion of the output to a load which is never exactly predictable—the antenna. These requirements result in a coupling device between the final tubes and the antenna which has larger adjustment range than is necessary in the inter-tube couplings; frequently the adjustments are more numerous as well.

It must not be inferred from the foregoing that all interstage r.f. couplings take the familiar form of a 2-coil transformer with a tunable secondary as is the case in nearly all receiving circuits, which work at very low voltages in class *A* r.f. Such tuned coupling transformers are less practical at higher voltages and powers, because of the difficulties of insulation and the rapid increase in unwanted capacitances as the size of the device grows with increased power. Therefore in the class *C* and *B* stages of the transmitter the couplings normally evade such difficulties by either spacing the interstage transformer primary and secondary apart and providing coupling through an untuned "link" circuit between them (see figure 179) or else by eliminating one winding altogether and providing the necessary separation of d.c. paths through the use of stopping condensers and choke coils, somewhat as described earlier in this chapter, for the choke-coil-coupled audio amplifier (figure 128) but with the difference that the plate coil is condenser-tuned, while the grid resistor is replaced by an r.f. choke coil to prevent introducing high resistance in the path of the grid current necessarily present in class *C* and *B* operation. Occasionally the tuned coil and the choke are interchanged and a great many other minor variations may be encountered, among which the most important is certainly that of so arranging the tuned plate circuit as to eliminate the need of a plate-supply r.f. choke coil. This is the "series plate feed" arrangement of figure 172. Its merit is that choke losses and false loading conditions are avoided; its demerit is that the coil is "hot," as is the tuning condenser in the single-sided stage of sketch 172*A*, so that an insulating drive-coupling is needed for safety in tuning. In the modified circuit *B* and in the push-pull case *C* the stators of the condenser are "hot" but the rotor may be grounded and made safe.

69. The L/C Ratio of the Tuned Plate Circuit or "Tank"—Before going to the (unavoidably) mathematical treatment of the tuned plate circuit in the following pages, it is useful to outline the effect of changing the size of condenser and coil.

It is of course possible to tune to the same frequency with a large coil and small condenser, or a small coil and large condenser. At the same time it seems that there must be a "better" combination. This is true, but the same combination is not best for receiving and for transmitting, since the requirements are different.

In the case of the receiver we are almost always working with very small voltages; even at the last stage of the i.f. system 10 volts of "carrier" is a large signal. Thus the problem is nearly always to get all possible amplification consistent with the limitations of selectivity and noise. Accordingly the interstage transformers are proportioned to secure high voltage-gain. Thus for example in a tunable r.f. stage working (for the moment) at 1000 kc. a voltage-gain of 100 times or more is expected, even though the necessity of tuning over a considerable range compels the use of a variable condenser whose capacity is higher than would be the fixed condenser chosen for a *fixed* 1000 kc. amplifier. Thus the idea here is to use as small a condenser and as large a coil as is reasonably convenient. In the fixed-frequency i.f. amplifier of superheterodynes this idea is carried quite far, with high gains resulting.

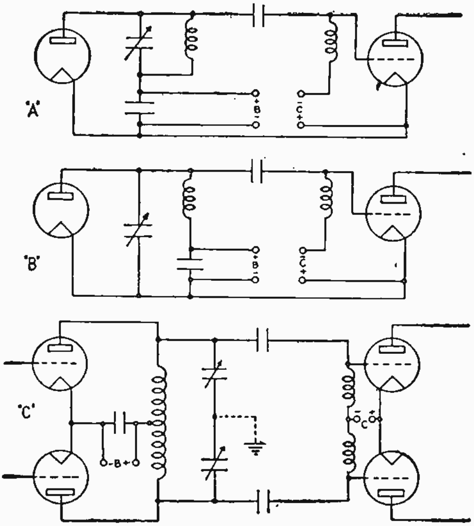


FIG. 172. Interstage Coupling Circuits with Series Plate Feed.

In the case of the transmitter the r.f. stages are working with class *B* and class *C* conditions. In general the voltage gain of class *B* and *C* stages is smaller than for class *A* while the grid-input power and the plate-current distortion are larger. Thus the interstage device has a different task than in class *A*. r.f. An actual *load* is being fed, and there is need of correcting the ***plate current distortion,*** of the driving or previous tube. Consideration of the effects in detail belong later in this Chapter, but for the moment it is helpful to consider qualitatively the consequence of changing *L* and *C* (the coil and the condenser) in such class *C* and class *B* r.f. work. Recalling from earlier paragraphs the intermittent (pulsating) plate current of a single-sided class *B* stage as is frequent in class *B* r.f., and recollecting the deformed current-wave of the class *C* stage (even when push-pull) it is clear that one task of the tuned tank circuit is to convert such deformed current waves into smoother voltage-waves, in particular to reduce their harmonic content. This can best be done by a tank circuit with a rather large *C* and small *L*, the opposite of the receiver requirement. Several explanations can be offered, one of the simplest being that a large *C* and small *L* offer low impedance at non-resonant frequencies and therefore " dump " the harmonics. At resonance the impedance is as high as it would be for a larger coil (within reason) and smaller condenser, hence the frequency to which the circuit is tuned is not damaged materially. This is an inaccurate presentation and to be regarded as merely preliminary to the more exact treatment following.

70. " High Efficiency " Tuned Plate Circuits for Class C Stages—Considerable noise is made from time to time with regard to tank circuits capable of producing very high plate-circuit efficiency. Such tanks use very high inductance and very small tuning capacitance and therefore present to the tube a high-impedance load at both the original (grid input) frequency and the harmonic frequencies. In consequence the amplification at the harmonics is increased and the wave-form highly distorted. The output wattage is reduced, but the input decreases even more, that is the plate efficiency increases. If then the plate voltage, grid bias and a.c. grid input are increased until the plate-heating-loss is once more normal it will be found that the output wattage is materially above normal. The penalties of this type of operation are the exceptional d.c. voltages required, the probable need of an added " driver " stage to supply the high grid input necessary, the high r.f. voltages in the tank circuit, and the inability of such a " high *L* " tank circuits to correct the distortion—in fact this inability is at the bottom of the high efficiency. Thus additional circuits must be provided to suppress harmonics. A high-efficiency stage is ordinarily not suitable for modulation. The very high plate-current peaks are injurious to the filaments of some tube-types. In general efficiencies in the 75–85 percent region should be attempted only after discussion with the tube manufacturer and thorough consideration of all consequences. This type of operation is NOT included in the following paragraphs.

71. Theory of the Tuned Tank Circuit. (Class B and C r.f.)—Harmonics are removed from the output in much the manner that a mechanical flywheel makes the motion of a shaft uniform. During that portion of the cycle that the tube is delivering more power than the load is taking, the spare power is being stored in the tank circuit; during other portions of the cycle the tube is not delivering as much power as the load is taking, hence the tank circuit is giving up its energy. Except for this action of the tank circuit the load (which is the next grid or the antenna, as the case may be) would receive the same proporiton of harmonics which are present in the tube's output. Thus the effect of the tuned tank may be stated in terms of the reduction of harmonics originally present.

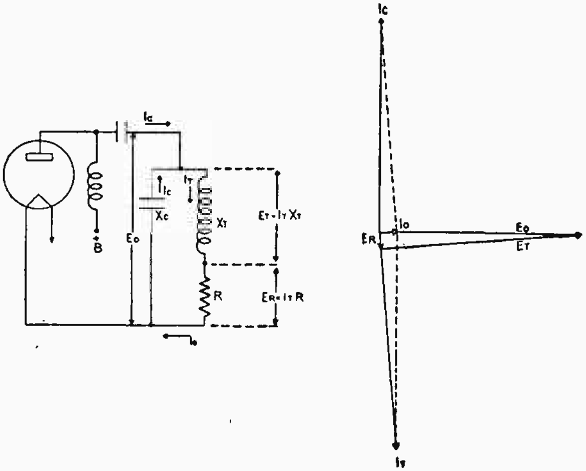


Fig. 173. Simple Tank Circuit. Values Shown Are: Eo. 970 V, Ic. 0.829 A, It. 10.58 A, Ic. 10.55 A, Et. 968 V, Er. 75.1 V, Xc. 92 Ohms, Xt. 91.8 Ohms, R. 7.19 Ohms. 900 Volts volts/inch, 10 Amps. amps./inch.

The proportion of harmonics present in the tube's output current is not definite or predictable. In a single-sided class *B* r.f. amplifier the output consists of plate current pulses having the shape of the positive halves of a sine-wave cycle—during low modulation. For this shape the harmonic components are found easily enough. In class *C* the plate current wave shape is complex and the proportions vary with changes of excitation and loading. It is good engineering to consider the worst condition normally encountered (NOT including the conditions discussed in section 70.) In normal amplifiers the second harmonic (double frequency) current does not exceed 70 percent of the fundamental and the third harmonic (triple frequency) current does not exceed 30 percent. Higher harmonics need not be considered as a rule, because a design which will reduce both the second and third harmonics will reduce the higher ones to a greater degree.

The simplest type of tuned tank-circuit is shown in figure 173. In this circuit the load has been shown as a simple resistance in series with the coil. This is the simplest case. An antenna could have been shown as the load, but this would introduce complications that can be better shown separately. The tuning adjustments have also been omitted for the present, though it is to be understood that the coil or condenser are variable and the circuit has been tuned to resonance with the frequency which is being supplied to the system via the tube's grid. The resonant adjustment is found in the usual way by tuning for the lowest plate current. When this adjustment has been made the following conditions will be found to exist:

1. The a.c. plate current is in phase with the a.c. plate voltage, that is they pass through zero at the same instant.
2. The a.c. current through the tank coil *lags* almost 90 electrical degrees, that is to say it is almost 1/4 cycle *late* as compared to the a.c. plate current, and voltage.
3. The a.c. current through the tank condenser *leads* almost 90 electrical degrees, that is to say it is about 1/4 cycle *ahead* as compared to the a.c. plate current and voltage.
4. From 2 and 3 it follows that the condenser current and the coil current differ by 180 electrical degrees, that is they are 1/2 cycle apart as to time (phase), which is to say that at the instant the current through the coil is maximum downward, it is maximum upward through the condenser—in other words the current circulates *around* this closed tuned circuit, while at the same instant the a.c. plate current itself flows through both coil and condenser in the same (not opposite) direction. Thus the condenser current and coil current are not precisely the same, though nearly so because the circulating current is the larger.
5. There is presented to the tube a load which *for the resonance*

frequency only is a pure resistance which is much higher (in ohms) than the actual load R. The value of the "transformed" resistance depends upon the tank reactances and is *approximately* given by:

$$\text{Load ohms presented to tube} = \frac{X_L^2}{\text{Ohms of actual load}}$$

where the "actual load" is R in the diagram (and is so located), while X_L is the inductive reactance of the tank coil at the working frequency. (It is not felt that the derivation of the equation is of present interest. It is correct where the coil reactance is materially larger than R.)

Thus by choosing a suitable coil the value of R may be "transformed up" in a manner suitable to the tube to be used.

Tank Coil Calculations—What tank constants are necessary to convert an actual 7.19 ohm load into 1170 ohms as seen by the tube?

Putting the known facts into the equation we have:

$$1170 = \frac{X_L^2}{7.19} \quad \text{which is to say,}$$

$$X_L^2 = (1170)(7.19), \quad \text{hence} \quad X_L = 91.8 \text{ ohms.}$$

And since the circuit is resonant $X_c = X_L$.

It then remains to calculate from the working frequency the inductance which has a reactance of 91.8 ohms at that frequency, to provide such an inductance and to place across it a condenser able to tune to resonance. Sometimes it is more practical to calculate the condenser capacity which at the working frequency offers the necessary reactance—same number of ohms as just found for the coil. Then any condenser whose capacity is known may be set at that value and a coil picked by trial to secure resonance at the desired frequency. The coil is then correct, but when connected into a transmitter the tuning condenser will be smaller because it is shunted by other capacitances.

72. Reduction of harmonics by the tank circuit—Assume that the output of the tube contains the largest harmonic distortion considered in section 71, that is to say a 70 percent second harmonic and 30 percent third harmonic. The tube's a.c. output current is as before 0.829 ampere, and the tank condenser reactance is once more assumed to be 92 ohms at the fundamental frequency, the load being 7.19 ohms as before.

Procedure—From the equation of section 71 the tube's load at the fundamental is found to be 1170 ohms. The voltage across this is 1170 ohms × 0.829 ampere = 970 volts.

The tube's load at the second harmonic is much lower than at the fundamental, since resonance is far removed. However, resonance is not so far removed as to disappear altogether, thence instead of assuming that the load at second and third harmonics is 0.5 and 0.33 of the fundamental X_c, it is necessary to assume values near 0.66 and 0.37. Thus at the second harmonic the load may be (0.66) (91.8 ohms) = 61 ohms, and since the second harmonic current is assumed to be 70 percent of the fundamental current, the voltage across the tank is this time:

$$0.7(0.829) \text{ ampere} \times 61 \text{ ohms} = 35.4 \text{ volts.}$$

But—35.4 volts is NOT 70 percent of 970, it is only 2.74 percent. Thus the second harmonic *voltage* has been much reduced as compared to the component of 2nd harmonic current which was present in the original plate current. Moreover this is the voltage across the tank circuit, only a portion of which arrives at the load, the rest being expended upon the inductive reactance of the coil, the final effect being that:

$$\frac{\text{Load current for a harmonic}}{\text{Load current at fundamental}} = \frac{k}{(n^2 - 1)(X_L/R)},$$

where k is 0.7 for the second harmonic, or 0.3 for the third harmonic, n is the number of the harmonic (that is either 2 or 3), X_L is again the reactance of the tank coil at the working frequency and R is once more the actual load ohms connected into the circuit in the manner of figures 173 and 174, while "load current for a harmonic" means the harmonic-frequency current through the actual load R. The values of the harmonic currents found when using the factors 0.7 and 0.3 as suggested are the largest which need be apprehended in normal class C stages. The "high efficiency" condition of section 70 is once more excepted.

73. Significance of the "Tank K" (Circulating VA/Output Watts)—The equations of the last few sections may be re-written in another form on the basis of the circulating tank current. The advantage of this rewriting is that the tank current is easily measured as are the load current and resistance, hence the harmonic reductions are more easily approximated on that basis. Figures 173 and 174 do not apply well here since they show the load resistance directly in the tank circuit so that the load current and circulating current are necessarily the same. However in a case like that of figure 175 it is clearly possible to measure the tank current and the antenna current independently, also to measure the antenna's resistance by the usual means (see Chapter 9). Thereupon the antenna power is clearly $I_a^2R_a$ where I_a and R_a are the antenna's current and resistance (measured at the

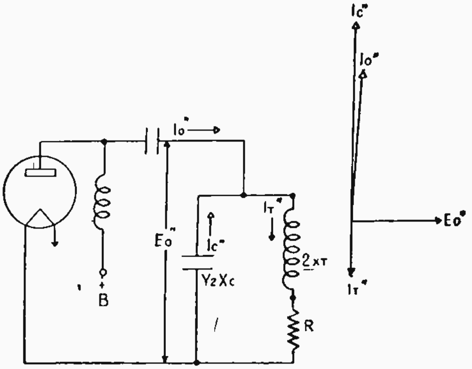


FIG. 174. Simple Tank Circuit at Second Harmonic. Values Shown Are: Eo. 35.5 V, Io. 0.579 A, It. 0.193 A, Ic. 0.772 A, Et. 35.4 V, Er. 1.39 V, 1/2 Xc. 46 Ohms, 2 Xt. 183.6 Ohms, R. 7.19 Ohms. Volts 75 volts/inch, Amps. .75 amps./inch.

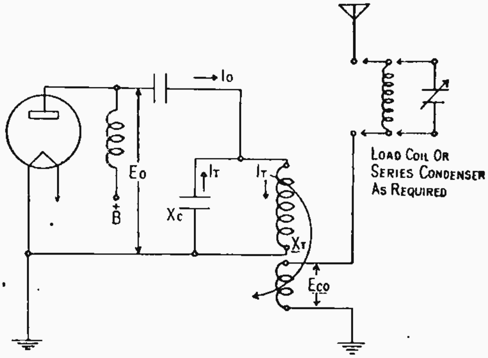


FIG. 175. Inductive Coupling.

same place). This then is the power delivered by the transmitter, which is to say the power taken from the tank circuit. The current circulating in the tank is already measured, and the voltage across it may be found either by measurement (NOT with a peak-reading voltmeter but an r.m.s. device), or it is just as well to calculate that voltage as equal to the tank current times the reactance of the coil (or condenser if unavoidable). Then the circulating " volt amperes " of the tank are the simple product of the tank current and tank volts, and this " circulating volt ampere " product will be found to increase as the condenser is increased and the coil made smaller, resonance being maintained. If all this be stated mathematically we have:

$$VA/W = (E_t I_t)/(I_a^2 R_a),$$

where VA is the volt-ampere product or " circulating voltamperes " of the tank circuit, W is the output watts, and the subscripts t and a indicate tank and antenna respectively, with E, I and R having the usual meanings. The ratio of VA/W is sometimes called the " K " of the tank, though clearly not a property of the tank alone, but of the tank *and* load. Using this " K " the equations already given become:

$$\text{Ohms presented to tube} = (R)(K^2 + 1),$$

where R is the actual load and K is (as just explained) the ratio of the tank's (r.m.s. volts × r.m.s. amperes) to the output watts,[12] and:

$$\frac{\text{current for a harmonic}}{\text{current at the fundamental}} = \frac{k}{K(n^2 - 1)},$$

where k is as before 0.7 for the second harmonic and 0.3 for the third, n is the number of the harmonic (either 2 or 3) and K is the " tank K " as explained in this section. The currents are those through the inductive leg of the tank.

74. Practical Antenna Coupling Circuits—In the simple tank circuits of figures 173 and 174 it was not possible to change the ratio of " resistance transformation " without at the same time changing the ratio of harmonic suppression since the only adjustment (except resonance tuning) was an outright change in the

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[12] If the tank losses can be neglected it is sometimes more convenient to consider the output watts at the tube, the tube's r.m.s. alternating plate current being also easily measured.

condenser-to-coil or *L/C* ratio. A certain degree of independence can be attained by using the tank coil as an auto-transformer, that is by connecting the load across some turns of the coil as in figure 176 rather than in series therewith) but all the advantages of such a circuit, and others as well, are reached by the familiar circuit of figure 175. The circuit of figure 175 permits changes of coupling to be made by mere mechanical movement of the coil at the antenna base, or by removing turns from this coil and restoring the antenna to resonance by adjustment of the loading devices shown at its upper part. In either case there is, of course, a reaction upon the tuned tank circuit, requiring retuning at that point. Figure 176 is equivalent to figure 175 if the coil X_M of figure 176 be thought of as the *mutual* inductance of figure 175. It is convenient to consider the circuit in this way for the sake of comparing its performance with that of the capacitive coupling system shown in figure 177 and formerly in quite extensive commercial use in the simple form here given, though now generally superseded in the same service by systems involving transmission lines.

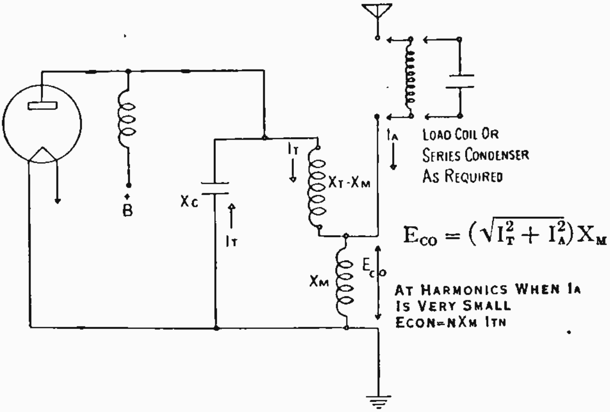

FIG. 176. Direct Antenna Coupling.

In the capacitive coupling system (figure 177) the circuit-element common to the antenna and the tank is the coupling condenser's reactance X_{co} and the coupling can be varied by varying the capacity of this condenser which is always larger than that of the tuning condenser in series with it. At low frequencies and medium frequencies the coupling capacity required is large and mica rather than air condensers are used. Since the voltage which feeds the antenna is developed by the passage of the tank current through the coupling condenser reactance, and since this reactance is smaller for the harmonic (higher) frequencies, it follows that some harmonic reduction is effected by this coupling. On the contrary for the inductive coupling system of figure 175 the antenna-feed voltage is developed across an inductive reactance, and such reactances *rise* with increasing frequency, hence the tendency is to transfer them with an effectiveness increasing with frequency. Therefore the harmonic-reducing effect of the capacitive coupling is n^2 as compared with inductive coupling, where n is the harmonic number, that is 4 times as good for the 2nd harmonic and 9 times as good for the 3rd.

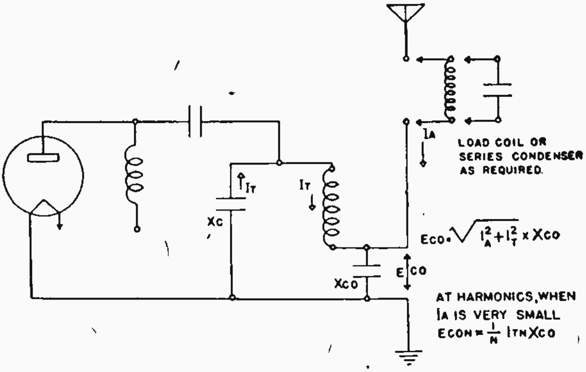

FIG. 177. Capacitive Coupling to Antenna.

75. Effect of the Antenna upon Harmonic Radiation—It is possible for the antenna to effect some harmonic reduction but it is exceedingly unsafe to rely upon this effect to any great extent. Thus a grounded vertical antenna perhaps 1/6 wavelength high, loaded at the base with inductance so that its electrical wavelength becomes 1/4 wavelength in the usual Marconi manner, may be expected to effect reduction of the 2nd harmonic but there will be quite effective radiation of any 3rd harmonic power which reaches the antenna, which after all places the responsibility for harmonic elimination on the circuits between the final tube and the antenna. Whenever the antenna is more than 1/6 wavelength long it is recommended that the harmonic reduction effected in the transmitter be made very large.

76. Push-Pull r.f. Amplifiers—When two or more tubes are properly connected in push-pull, the even harmonics should not appear in the output because they would flow in opposite directions through the two sections of the tank inductance, causing their magnetic fields to oppose. If the load circuit is coupled equally to each half, there will be no even harmonic voltage set up in the load circuit. In this case the harmonic reduction should be based upon the third harmonic. For a given limit of harmonic output, this will require less "*K*" of the tank since the third harmonic is reduced more easily than the second. This reduces the tank currents, permits less expensive parts to be used, and reduces the losses in the tank circuit. A suitable push-pull circuit is shown in figure 178*A*. Note that the tank condenser is divided, the center tap being connected back to the filament circuit. This is necessary to provide a low-impedance return for the harmonic components of the tube's output currents. If such a path is not provided, considerable harmonic voltages can appear between the tank and ground.

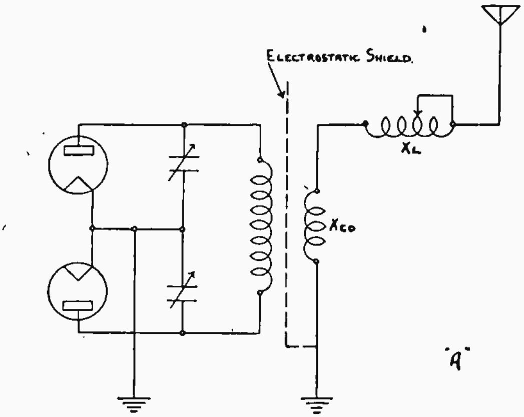

FIG. 178, A. Push-Pull Circuit Inductively Coupled to Antenna with Electrostatic Shield to Suppress Radiation of Harmonics.

Many operators have been surprised to find a strong second harmonic was being radiated from their push-pull amplifier. Although the inductive effects of the two halves of the tank inductance will cancel for even harmonics, the stray capacity between tank and antenna circuit provides an easy path for the harmonic currents to pass into the antenna. As far as this capacity transfer is concerned, the two tubes are in parallel and feed the antenna as shown in figure 178*B*. This is a form of direct

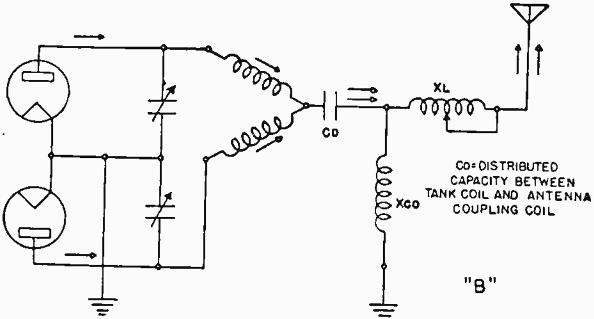

FIG. 178, B. Stray Capacity between Tank and Antenna Circuit Provides Low Impedance Path for Harmonics. See text.

coupling, and unless the reactance X_{co} is very small, the coupling is fairly tight. In fact, at high frequencies it is practically impossible to make X_{co} small because a wire only a few feet long has appreciable reactance. For example, at 7000 kc./s. a thin wire may have as high as 25 ohms reactance per foot.

Push-pull amplifiers should always have an electrostatic shield between the tank coil and the antenna coil. This will entirely prevent the transfer of even harmonics, and the radiation of such harmonics will be solely determined by the accuracy with which the two tubes are balanced (plus, of course, the reducing effect of the tank circuit). *In existing transmitters where it may be difficult to install a shield, improvement can sometimes be effected by using link coupling from the tank to an antenna tuned circuit.* By grounding one side of the link, it can be made to function as a shield itself. The tank and antenna coils should be separated or well shielded, or the isolating effect of the link will be lost.

The circuits of figure 179*A* has been in wide use but is particularly bad from a harmonic standpoint. The two transmission wires act just like a two wire antenna direct coupled to the plates of two tubes in parallel. As there is no voltage difference between the wires (*for even harmonics*) the condensers across the line have no harmonic shunting effect. When modified to the circuit of figure 179*B*, these difficulties vanish and the circuit becomes highly effective. However, it *is in all cases* advisable to make a test of the field strength at the second and third harmonics, and to adjust the antenna coupling device very carefully in order to minimize these harmonics.

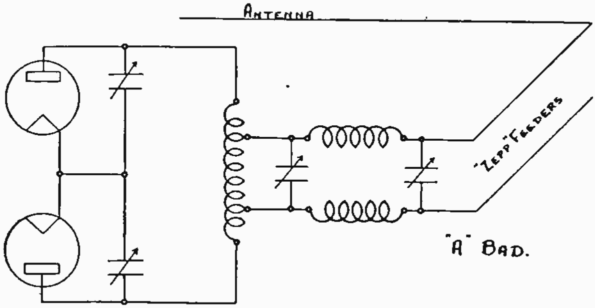

FIG. 179, A. Direct Coupling of Transmission Line Subject to Harmonic Radiation.

Figure 180 is another popular circuit which is bad. Here the electrostatic capacity between the antenna coils and the tank inductance is sufficient to provide excellent coupling for the even harmonics. *Placing the antenna coil over the center of the tank inductance makes no difference because the entire tank inductance is at the same even harmonic voltage.* This circuit can be vastly improved by the addition of a shield, or at least using some

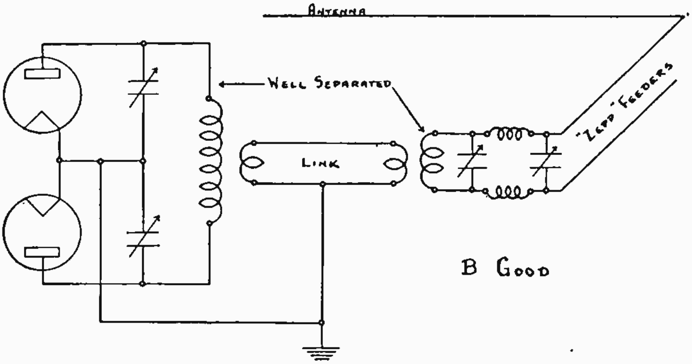

FIG. 179, B. Link Coupling to Transmission Line. Effective in Suppression of Harmonics.

variety of link coupling with one side of the link grounded. While this discussion has been limited to even harmonics, the same effect which passes the even harmonics will prevent the proper reduction of the odd harmonics as well.

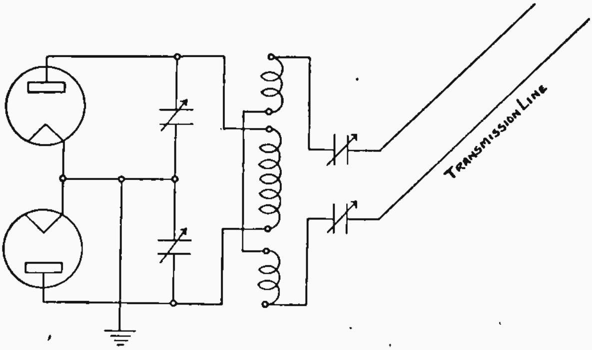

FIG. 180. This Circuit, Which Is Frequently Employed, Will Radiate Strong Harmonics. See text.

77. **Standards of Harmonic Reduction**—Before the equations of previous sections can be applied to the design of output circuits, it is necessary to know how much reduction of harmonics is *necessary*. The general law on this subject is found in the 1932 Madrid Treaty which requires all stations to reduce their harmonics as much as the " state of the art " permits. As the state of the art permits almost any conceivable degree of reduction, strict application of this requirement would be unreasonable. As a practical matter, this is interpreted to require well designed output circuits, in keeping with the power employed and the class of service. The I.R.E. standardization committee suggests that for broadcast stations the harmonic field strength be limited to 0.02 percent of the fundamental field strength. This value is consistent with good engineering practice.

78. **Value of " K " Required to Reduce Harmonics to the Desired Degree**—Although the values of *K* can be easily computed by using the equations developed on the preceding pages, it is more convenient to refer to the curves of figure 181, which have been worked out from these equations. For single-ended amplifiers, the curves marked " Second harmonic " should be used because this will be the strongest. For push-pull amplifiers USING AN EFFECTIVE ELECTROSTATIC SHIELD BE-

TWEEN TANK COIL AND ANTENNA the second harmonic will not be transfered, and the "Third harmonic" curves will be used. Notice particularly that separate curves are shown for inductive coupling and for capacitive coupling. In circuits which use both inductive and capacitive coupling, the capacitive curve is used.

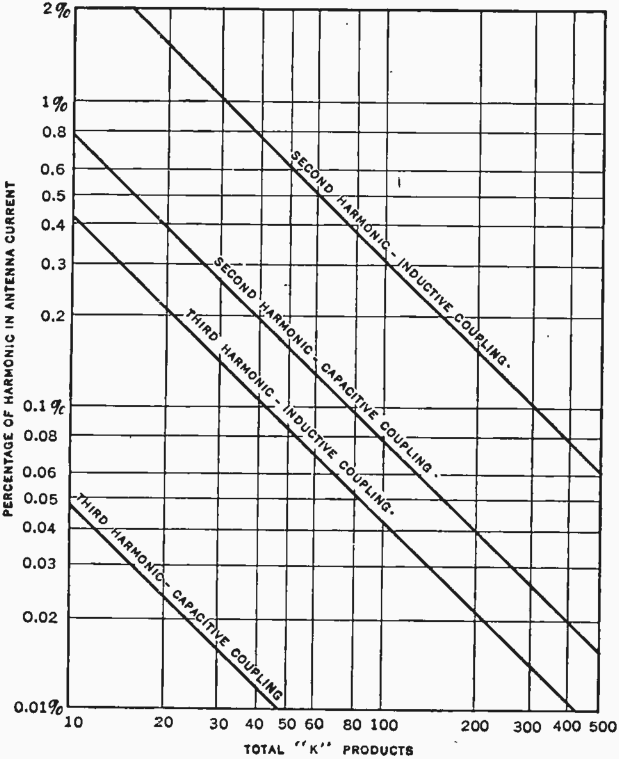

FIG. 181. Relation Between "K" and Harmonic Current in the Antenna.

79. Suitable Circuits for Harmonic Reduction—Although the derivation showed that the *K* of a tank circuit could be made as high as desired by simply increasing the tank capacity, a practical limit is soon reached because of the heavy tank currents that are produced with high *K*. This makes very expensive construction necessary and increases the tank losses. In fact, with *K* values of 200 to 300, the tank losses are so great that very little power is left to deliver to the load. For this reason, *good engineering requires that tank circuits should have a K of not more than 20* (except for oscillators where frequency stability is desired instead of large output). Inspection of the curves on figure 181 show that the recommended harmonic reduction to 0.02 percent of the fundamental requires *K* values far in excess of 20. This necessitates cascaded tank or other tuned circuits. The necessary values are then easily obtained without exceeding 20 in any one circuit because the resulting "*K*" is equal to the product of the individual *K*'s. Thus a *K* product of 120 can be easily obtained by a tank *K* of 20, and an antenna *K* of 6. The *K* products necessary for a harmonic current on not more than 0.02 percent is shown in Table I below. It is evident from Table I that high power transmitters require excessively large values of *K* if a single ended amplifier is used. It is therefore recommended as a design rule that *THE FINAL AMPLIFIER OF ANY HIGH POWER TRANSMITTER SHOULD BE PUSH-PULL.*

An apparent exception to this rule is the Western Electric 5 KW. transmitter which employs a single-ended amplifier. This is explained by the fact that the final stage of this transmitter is operated as a class *B* r.f. amplifier and therefore has lower harmonic components in its plate current wave than were assumed in our analysis. Recent transmitters of this manufacturer use push-pull.

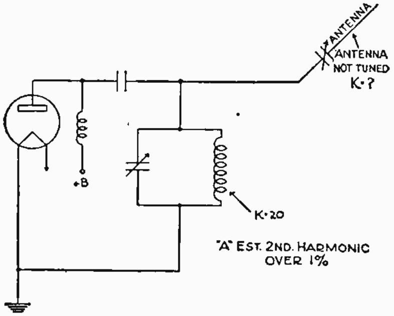

FIG. 182, A. Antenna Circuit Untuned.

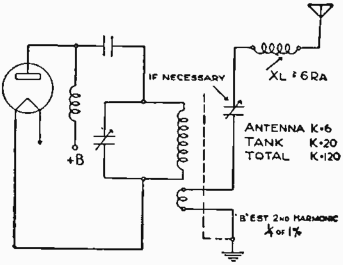

FIG. 182, B. Antenna Circuit Tuned.

Several conventional circuits are shown on figures 182 and 183 to illustrate how various circuit arrangements reduce harmonics. The simplest practical circuit is that of figure 182*A*. Here the antenna is not tuned. The series condenser merely adds reactance to the antenna so that proper loading results when it is connected, as shown, directly to the plate of the tube. With this arrangement the antenna does not contribute anything in the way of harmonic reduction. In fact, with certain lengths of antenna one or more harmonics may be much increased. Neglecting the unpredictable effect of the antenna, the second harmonic current will be above 1 percent of the fundamental even with the highest practical *K* (20) in the tank. This circuit should be used only with extremely low power transmitters (such as 10 watts or less). This circuit is employed in a marine high frequency transmitter rated at 25/50 watts. Here the high harmonic output can be tolerated because it is unlikely that a nearby station will be receiving on a harmonic frequency. With such low power, the harmonics will be weak at any great distance.

Figure 182*B* is a considerable improvement. By tuning the antenna by means of a loading coil an additional *K* of at least 6 can be obtained. *The antenna loading inductance is an essential portion of the circuit* (even if the antenna is large enough to resonate without it) and must be well shielded from the tank circuit. Using a load coil whose reactance is 6 times the antenna resistance and a tank with *K* of 20, the second harmonic should be only 0.26 percent. Unlike figure 182*A*, this will not be much disturbed by an unfavorable antenna length if the shielding is satisfactory. The coupling coil should be placed at the grounded (filament) end of the tank inductance to avoid the necessity of an electrostatic shield between these two coils.

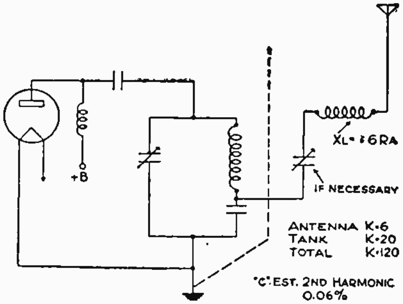

FIG. 182, C. Capacitively Coupled Circuit.

Figure 182*C* is a simple capacitively coupled circuit. This is not suitable for high frequency use because of the difficulty in obtaining a low reactance ground connection. As a consequence, the ground current divides, a large portion going through the set into the power supply wiring and modulators. This r.f. in the wrong place causes all sorts of trouble and generally makes the circuit unmanageable. At low frequencies, the circuit performs very well, and with the constants shown the second harmonic should be reduced to 0.06 percent. This is satisfactory for transmitters of moderate power especially if the final amplifier is operating in class *B* and therefore has only small harmonic components in its plate current wave. However, the advantages of this circuit can not be obtained unless the tuning is carefully done. As this tuning is rather intricate, this circuit can not be recommended for composite transmitters unless the operators are thoroughly familiar with the process.

Figure 182*D* is a simple push-pull circuit. *IT IS ABSOLUTELY ESSENTIAL THAT AN ELECTROSTATIC SHIELD BE PLACED BETWEEN THE TANK COIL AND THE ANTENNA CIRCUIT.* Without such a screen, the second harmonic will be quite strong. With an effective shield the second harmonic will not appear, and the third harmonic should be below 0.035 percent. This is not far in excess of the I.R.E. recommendation. The circuit has the advantage of being fairly easy to tune. The coupling is adjusted by varying the number of turns in the coupling coil. This is necessary because it is usually impractical to vary the separation when the coils are arranged for satisfactory shielding. This is, of course, a mechanical problem and any method of varying the mutual inductance will be satisfactory provided it does not introduce any direct capacity between the two windings.

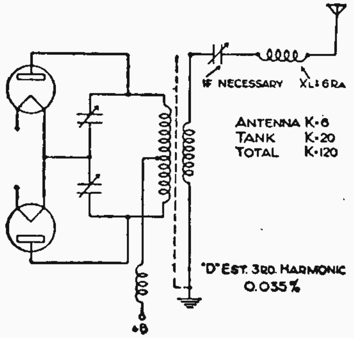

Fig. 182, D. Push-Pull Circuit with Inductive Coupling to Tuned Antenna Circuit and Electrostatic Shield between Coils to Suppress Harmonics.

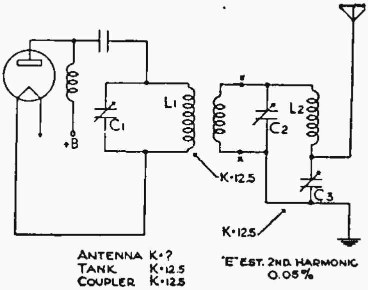

Fig. 182, E. Combined Inductive and Capacitive Coupling to Antenna Circuit.

Figure 182*E* is an adaptation of capacitive coupling especially suitable for high frequency transmitters. In this particular arrangement the antenna is not tuned, the harmonic reduction being effected by two tank circuits in cascade. With the constants shown, the second harmonic should be about 0.05 percent. With a *K* of 20 in each circuit, the second harmonic could be reduced to 0.02 percent but this is usually not necessary at moderate powers. This circuit has two disadvantages (1) the circuits must be very carefully resonated (2) care must be taken to prevent stray capacity between the tank coil and the antenna circuit, and (3) as the antenna is not tuned, it may resonate at some harmonic and increase it. Proper *K* in the second circuit (the coupling circuit) is assured by making *C*–2 four times as large as *C*–1, and having a 2 to 1 ratio between tank turns and coupling coil turns. As *C*–2 is the final resonating adjustment, *L*–2 must be adjusted by trial until resonance and proper loading is obtained with the proper capacity at *C*–2. The procedure is as follows: Disconnect the coupling coil at the points marked *X* on figure 182*E*. Now resonate the first tank condenser, *C*–1, tuning for minimum plate current. After finding the correct point, do not make any further change to *C*–1. Reconnect the coupling coil and set *C*–3 at maximum capacity. Tune *C*–2 for resonance—minimum plate current. If the minimum plate current is too low (loading too light) decrease *C*–3 and resonate with *C*–2. If *C*–2 resonate with too much capacity, increase *L*–2; if *C*–2 resonates with too little capacity decrease *L*–2. Adjust *C*–3 and *L*–2 until proper loading is secured with *C*–2 resonating at approximately the desired capacity. It is not necessary that *C*–2 be exactly four times *C*–1, but it is necessary that it be tuned for exact resonance as indicated by minimum plate current. It is also necessary that adjustments begin with *C*–3 at *maximum*. Proper loading can often be obtained with two values of *C*–3—one very low and the other very high. The high capacity setting is correct, and operating at the low capacity setting will result in strong harmonics.

Figure 183*A* shows a popular circuit for high frequency transmitters. If the transmission line is one-quarter wavelength, or any odd quarter of a wavelength, it will effectively suppress the second harmonic. (The antenna must be voltage fed, i.e. its length must be an even number of quarter wavelengths from the point where the feeders are attached to the ends of the antenna.) To prevent the feeders from radiating, the stray capacity between the tank and the feeder coil is reduced by coupling through a link circuit. A shield could be placed between the tank and the pick-up coil, but the link is more simple and, in this case, quite effective. The link must be placed at the grounded end of the tank inductance. This circuit has the advantage of being rather simple to adjust.

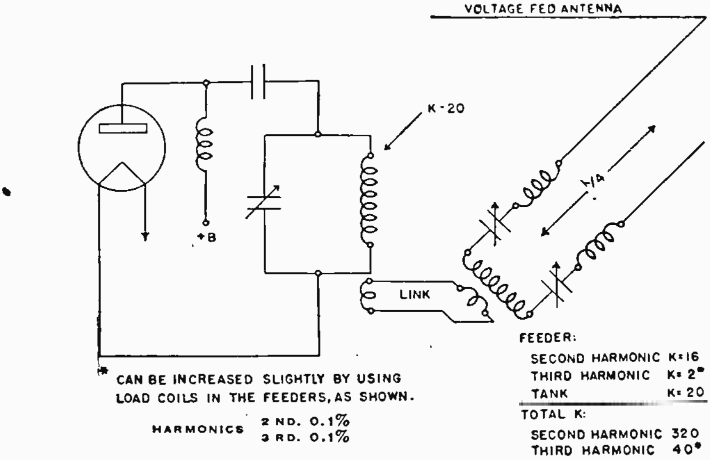

FIG. 183, A. Link Coupling to Zepp Feeders Transmission Line. Voltage or End Fed Antenna.

Assuming 2000 ohms for the antenna resistance and a line of 500 ohms characteristic impedance,[13] the second harmonic reduction should be equivalent to a *K* of 16. This combined with a tank *K* of 20 will reduce the second harmonic to 0.1 percent. At the third harmonic, however, the feeders are not nearly so effective in reducing harmonics, and the effective *K* may be as low as 2. This results in a third harmonic of 0.1 percent (just about as strong as the second). This can be reduced somewhat by inserting properly shielded load coils. These can be tuned by a series condenser at the fundamental, but will assist in keeping the feeder input impedance high at harmonics.

Figure 183*B* shows a circuit which is frequently misused. Depending too much on the push-pull feature, low *K* values in the tank are frequently applied. Unless an effective screen is inserted between the tank and pick-up coil, a strong second harmonic can be transfered. In addition, if the feeders are a quarter wavelength they will have but little effect in reducing the

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[13] Characteristic impedance of a 2 wire line is 276 log D/d, where D is the spacing and d is the diameter of either wire.

third harmonic. To prevent excessive harmonic radiation with this circuit, the tank *K* should be generous—20—and load coils should be placed in the feeder lines. It is, of course, absolutely

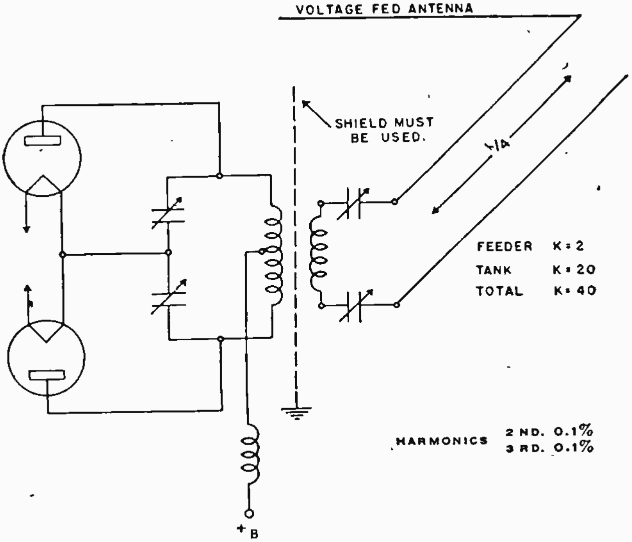


FIG. 183, B. Inductance Coupling with Zepp Feeders. Voltage Fed Antenna Circuit.

essential that a Faraday shield be placed between pick-up coil and tank coil. If link coupling is used, one side of the link should be effectively grounded because the entire tank coil is above ground potential for the second harmonic, that is, there is no grounded section where the link may be applied as is the case with a single-ended amplifier. The center of the tank inductance is at ground potential for the fundamental and odd harmonics but is not at ground potential for the even harmonics. With proper precautions observed, the second harmonic should not be radiated, and the third harmonic should be 0.1 percent or less.

Figure 183*C* is to be recommended over figure 183*B IF IT IS CAREFULLY ADJUSTED.* With a *K* of only 6 in each circuit, the third harmonic should be only 0.013 percent. This excellent reduction can be obtained *only if the shielding between tank coil and feeders is very complete.* Without effective shielding, both second and third harmonics can be very strong. It is difficult for operators to appreciate the great difference between the capabilities of figure 183*B* and this circuit which is so similar. The main advantage is the reduction of 9 times (harmonic number squared) due to the use of capacitive coupling, and the increased *K* obtained by addition of a second tank (the coupling circuit) circuit. Much of this advantage will be lost if the circuits are not properly resonated, or if the shielding is not thorough. This accounts for the difficulty which some experimenters have experienced with it. A re-reading of the instructions for 182*E* will be helpful.

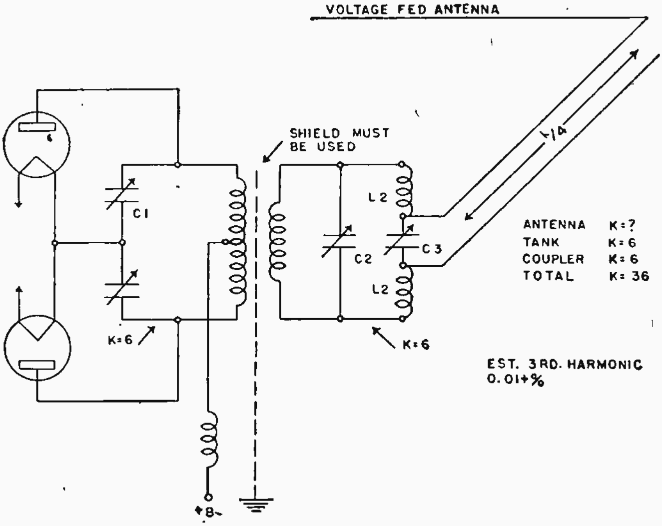


FIG. 183, C. An Excellent Circuit for Suppression of Harmonics.

Figure 183*D* is an example of the excellent results that can be obtained by good design. This circuit is used in transmitters manufactured by the Radio Corporation of America. The antenna circuit is tuned, thereby securing a *K* of about 6 (it varies with each installation, but can usually be made this high). The intermediate circuit, to which the antenna is capacitively coupled, has additional *K*, 6 being the usual amount. The push-pull tank circuit is also proportioned to have a *K* of 6. The overall *K* is $6 \times 6 \times 6$ or 216. Combined with capacitive coupling this provides a third harmonic reduction computed as 0.002 percent. The second harmonic is difficult to estimate as it depends upon the degree of balance between the tubes and the effectiveness of the electrostatic shield. It may be safely assumed that with careful construction and balance, the harmonic radiation will meet the strictest requirements. The remarkable performance shows clearly the importance of proper circuit arrangement and shielding.

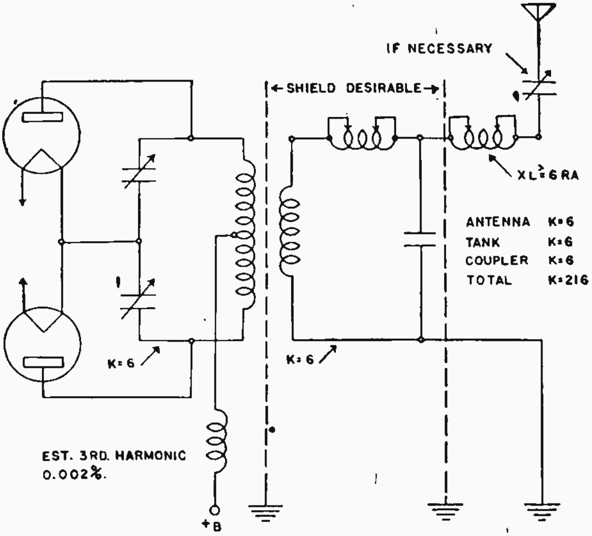


Fig. 183, D. Another Excellent Circuit for Harmonic Suppression and Proper Impedance Matching.

80. Relation between "K" and Tank Capacity—In order to complete the design of output circuits, it is now necessary to determine the tank capacity necessary to produce the desired *K*. This depends upon the frequency, the output voltage and the output current.

The *K* of a tank is found (see section 69 and 73 of this Chapter) by dividing the tank's circulating volt-amperes by the watts to the load:

$$\text{“}K\text{”} = \frac{VA}{W} = \frac{E_tI_t}{E_0I_0} = \frac{E_0I_t}{E_0I_0} = \frac{I_t}{I_0}.$$

I_t is the *circulating* tank current, I_0 is the a.c. current flowing *through* (not circulating in) the tank and also through the power-source, which ordinarily means the plate circuit of a tube. In a well designed tank circuit I_t is larger than I_0. I_0 is in phase with the voltage, but I_t is not—see section 71 of this Chapter. There is but one a.c. voltage involved here since the tank is across the tube and necessarily $E_t = E_0$, *provided the whole tank is actually connected across the tube.* Now the tank current, I_t, depends upon the output voltage and the reactance of the tank condenser X_c; so that we can substitute:

$$K = \frac{E_0}{X_c I_0} \qquad \text{or} \qquad X_c = \frac{E_0}{K I_0}.$$

This equation is useful only if it is possible to measure the a.c. plate voltage and current, not usually a convenient procedure. The numbered paragraphs below give practical rules for avoiding a.c. measurements. If a complete solution has already been made and I_0 and E_0 are known, this equation is a simple means of finding the tank capacity.

Example—The desired operation calls for a peak output voltage 1350, and peak output current 0.592 amperes. Find the tank capacity necessary to give a tank K of 20. The operating frequency is 750 Kc/s. The tube is not neutralized.

Solution—Solving the equation for the tank condenser reactance:

$$X_c = \frac{E_0}{K \times I_0} = \frac{1350}{20(0.592)} = 114 \text{ ohm condenser reactance.}$$

Note that E_0 and I_0 can be either peak or r.m.s. values so long as both are the same. At the operating frequency this reactance requires a capacity of:

$$C = \frac{1{,}000{,}000}{2\pi f X_c} = \frac{1{,}000{,}000}{6.28 \times 750{,}000 \times 114} = 0.00186 \text{ microfarad.}$$

The factor of 1,000,000 is introduced to convert farads into microfarads.

Note—For push-pull amplifiers, use the output current and output voltage *PER TUBE,* and the result will be the capacity of each half of the condenser.

In designing amateur transmitters, or in checking a transmitter already in operation it is desirable to have some rule for deciding tank capacity without the necessity of a complete solution of output voltage, output current, etc. This can be done by using these relations:

1. In class *C* amplifiers the peak output voltage is nearly equal to the plate voltage. Thus for a rough rule we may use:

$$E_0 \text{ peak} = 0.9E_b$$

or

$$E_0 = 0.636E_b \quad \text{(for class } C \text{ amplifiers).}$$

In class *B* amplifiers, the peak output voltage is somewhat less than half the plate voltage. For a rough rule, we may say:

$$E_0 \text{ peak} = 0.4E_b,$$

$$E_0 \text{ rms} = 0.28E_b \quad \text{(for class } B \text{ amplifiers).}$$

2. In both class *C* or class *B* there is a fairly definite relation between the output current and the direct plate current. For a rough rule we may use:

$$I_0 = .9I_b.$$

These rough assumptions may be substituted in the equation for tank condenser reactance, and we have:

$$X_c = E_0/KI_0,$$

$$X_c = \frac{0.57E_b}{KI_b} \quad \text{(for class } C\text{)}$$

or

$$X_c = \frac{0.25E_b}{KI_b} \quad \text{(for class } B\text{).}$$

For rapid calculations, the frequency may be included so that the capacity can be found in one operation. In this form:

$$C = \frac{279{,}000KI_b}{fE_b} \quad \text{(for class } C\text{),}$$

where C is in micromicrofarads ($\mu\mu$fds.),
I_b is in milliamperes,
f is in kilocycles,
E_b is in volts.

These units have been chosen because they are the ones most commonly used.

For class *B*, the constant is simply changed:

$$C = \frac{638{,}000KI_b}{fE_b}.$$

The use of these equations will be illustrated by a typical example:

Example—The tank circuit *C, L,* of figure 183*C* should have a *K* of 6. What capacity per section will be necessary. The frequency is 7020 Kc/s., and the total plate current is 200 Ma. at 1250 volts, in class *C*.

Solution—For the capacity per section it is necessary to use the plate current per tube, or 100 Ma. Substituting:

$$C = \frac{279{,}000 \times K \times I_b}{f \times E_b} = \frac{279{,}000 \times 6 \times 100}{7020 \times 1250}$$
$$= 19 \ \mu\mu\text{fd. per section.}$$

The resultant of the two condenser sections in series is 1/2 of this.

Note that the *K* depends upon the plate current. This explains why reducing the coupling reduces harmonics—actually the *K* is being increased, and the same result could be accomplished by increasing the tank capacity to the proper amount.

Note: Tank circuits of neutralized stages. For a push-pull stage the proper procedure has been indicated. For a grid-neutralized single-sided stage the plate tank is not tapped, hence the procedure given for single stages is correct. For a plate-neutralized stage "*C*" is 1/4 as great if the cathode tap is central as it should be—but keep clearly in mind that this "*C*" is the capacity across the *entire* tank coil, whether a condenser, or two in series.

81. Parasitic Oscillations—When a transmitter acts in an abnormal manner without any apparent cause, the trouble is usually some form of parasitic oscillation. "Parasitics" are defined as the oscillations at some frequency other than the fundamental or a harmonic. Nearly all new transmitters are troubled this way. In manufactured transmitters, the parasitic tendencies of the original design should be remedied before production is begun. The exact duplicates manufactured thereafter should be free from parasitics although this is not always the case. Quite frequently minor changes made to expedite production or to simplify assembly may cause new parasitics which must be corrected when the transmitter is installed.

As each transmitter offers different possibilities for parasitics no textbook can hope to outline the causes and remedies fully. However, the general principles are known, and several of the more common causes are easily remedied. A careful study of these causes will assist the operator in correcting the faults of his particular installation.

1. Parasitic oscillations can be produced if ANY PORTION of the plate circuit is resonant (or nearly so) with ANY PORTION of the grid circuit, thus forming a tuned-plate tuned-grid oscillator circuit. A further condition is that sufficient feedback must be present.

2. Parasitic oscillations can be established if any element of the tube shows a negative resistance (dynatron action) characteristic, and there is a resonant circuit in series with this element.

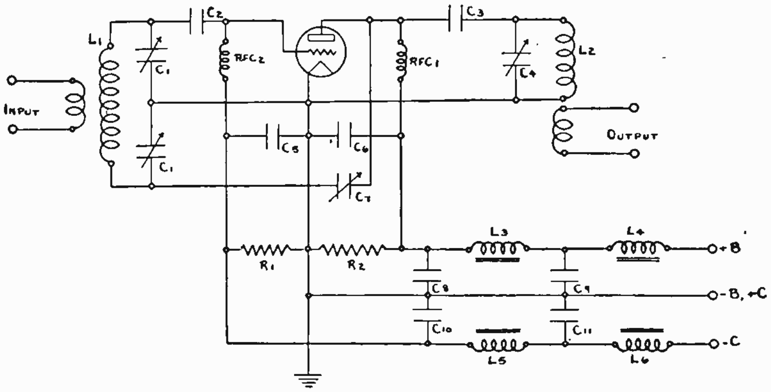


FIG. 184. Conventional Amplifier Circuit of Good Design, to Illustrate Causes of Parasitic Oscillations.

L1—Grid Tank Inductance.
L2—Plate Tank Inductance.
L3—Plate Supply Filter Smoothing Choke.
L4—Plate Supply Filter Swinging Choke.
L5—Grid Bias Filter Smoothing Choke.
L6—Grid Bias Filter Swinging Choke.
RFC1—Plate Supply R.F. Choke.
RFC2—Grid Bias R.F. Choke.
R1—Grid Bias Bleeder Resistor.
R2—Plate Supply Bleeder Resistor.
C1—Grid Tank Condenser.
C2—Grid Blocking Condenser.
C3—Plate Blocking Condenser.
C4—Plate Tank Condenser.
C5—Grid Bias By-Pass Condenser.
C6—Plate Supply By-Pass Condenser.
C7—Neutralizing Condenser.
C8—Plate Supply Filter Final Condenser.
C9—Plate Supply Filter Mid-Section Condenser.
C10—Grid Bias Filter Final Condenser.
C11—Griad Bias Filter Mid-Section Condenser.

82. Analysis of a Typical Circuit for Parasitic Tendencies—Figure 184 shows a conventional amplifier stage of good design including the associated power supply filter circuits. Under the first cause of parasitic oscillations there are several ways in which this amplifier may be affected. In figure 185*A*, the circuit has been redrawn to show that the grid and plate supply filters form tuned circuits which resonate at very low frequencies—perhaps 1 to 25 cycles per second. At such frequencies, the r.f. inductances have no appreciable reactance and are shown simply as conductors. On the other hand, small capacities are practically an open circuit. The remaining circuit elements form a tuned-plate tuned-grid circuit. Fortunately, at these low frequencies the internal plate-grid capacity of the tube is too small to cause any feedback. However, grid and plate supply filters are frequently assembled so close together that considerable magnetic coupling may be present. If this is the case, oscillations at very low frequency (25 cycles or less with usual constants) may result. The remedy for this condition consists of detuning the circuits by using different *CL* products in the grid and plate circuits. Notice that the two condensers are in series as far as this oscillation is concerned. It is more economical to use the higher product in the grid circuit because for the lower voltage and current the parts are less expensive. In addition, the filter chokes of the grid bias and plate supplies should always be separated sufficiently to prevent any magnetic coupling between them.

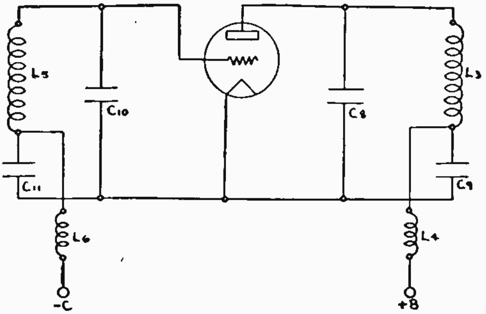


FIG. 185, A. The Grid Bias and Plate Supply Filters Form Low Frequency Tank Circuits. This Portion Is Not Neutralized.

The grid and plate r.f. choke coils often form the inductances of a tuned-plate tuned-grid oscillator, as can be seen by redrawing figure 184 in the manner shown as figure 185*B*. With usual constants; these circuits resonate at a frequency somewhat lower than the normal operating frequency—perhaps 1/4 to 1/10 of normal frequency. In low frequency transmitters, this comes into the audio-frequency region and the internal plate-grid capacity is not large enough to cause feedback. In intermediate or high frequency transmitters, the choke coils and by-pass condensers resonate at a frequency such that the grid-plate capacity may be large enough to produce feedback and oscillations. The remedy for this trouble is to use different inductance values for grid and plate chokes. The plate choke should always have the *higher* inductance.

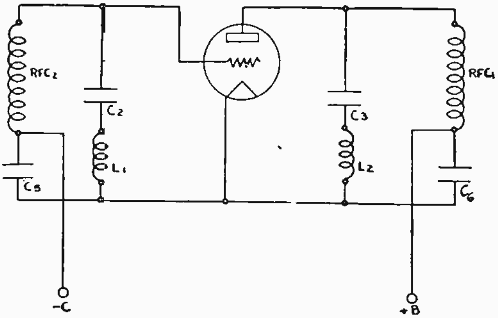


FIG. 185, B. The R.F. Chokes and By-Pass Condensers Form a Set of Tank Circuits. This Portion Is Not Neutralized.

Perhaps the most common parasitic oscillation is that which is due to the length of the plate circuit and grid circuit connecting wires. These connections form single-turn inductances which are tuned by the tube capacities to frequencies in the ultra-high region. At such frequencies the internal plate-grid capacity provides a powerful feedback and oscillations are easily produced. The leads drawn in heavy lines on figure 185*C* form these single-turn inductances. The remedy is to detune the circuits. The prefered method is to insert a small r.f. choke coil at the point marked "*X*." If a suitable inductance value is used, the plate circuit loop will tune to a lower frequency than the grid circuit, thereby preventing oscillations. Although oscillations can be stopped by adding inductance to the grid circuit, it is easier and better to add it to the plate circuit. This is due to the fact that oscillations will persist even when the grid circuit is far off tune on the *low fre-*

quency side of resonance, whereas oscillations will stop immediately when the grid circuit is tuned to the *high frequency* side of resonance. The grid leads should, therefore, be as short and direct as possible, and the plate leads should include added inductance (if necessary) to resonate at a lower frequency.

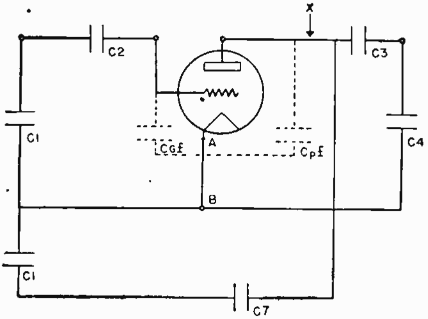


FIG. 185, C. Leads Shown in Heavy Lines Form Single Turn Inductances and Aid in the Generation of Parasitic Oscillations.

When two tubes are operated in parallel, a particularly powerful oscillation can be set up with the tubes acting as an ultra *H–F* push-pull oscillator. The connecting wires between the two plates and the two grids act as inductances tuned by the tube capacities. If the tubes are symmetrically arranged (as they usually are) these connections will naturally be equal in length and therefore resonant to approximately the same frequency. Like the previous type of ultra *H–F* parasitic, this can be prevented by inserting small choke coils in series with each plate lead to tune the plate connection to a lower frequency. This is shown on figure 185*D*.

Small plate chokes inserted to suppress parasitic oscillations are frequently paralleled with a non-inductive resistor of about 100 ohms. The purpose of this resistor is to increase the losses of the circuit at ultra-high frequencies, and thus make oscillation more difficult. Any sign of heating of these resistors is a certain indication of parasitic oscillations since practically all the fundamental current goes through the choke coil which has very low reactance at fundamental frequencies. Parasitic currents are offered a higher impedance by the small choke and tend to go through the resistor.

Notice especially that neutralization does not prevent parasitic oscillations. Proper neutralizing voltages are dependent upon resonance to build up a voltage of opposite phase. This resonance is obtained only at the fundamental frequency. While it is theoretically possible to avoid all of the first type of parasitic oscillations by the use of screen-grid tubes (tetrodes and pentodes), in actual practice the screening action is not perfect, especially for the ultra-high frequencies which are most troublesome. In addition, screen-grid tubes are more inclined to produce second type parasitic oscillations so that all things considered, triodes are more satisfactory for high power applications. In low powered stages (such as buffers and oscillators) the second type of parasitic oscillations is less common and screen-grid tubes are prefered.

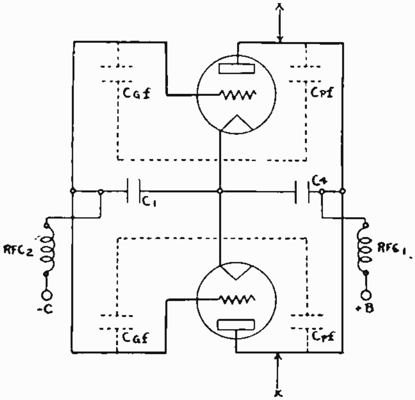


FIG. 185, D. When Two Tubes Are in Parallel, the Wires Between the Sockets Form Tank Inductances. This Portion Is Not Neutralized.

Second Type Parasitic Oscillations—Negative-resistance parasitics appear from a variety of causes, the most usual of which are listed here:

A. The plate may show a negative resistance characteristic when the screen voltage of a tetrode or pentode is higher than the instantaneous plate voltage. This is the usual dynatron action. A similar effect can occur in triodes when the grid voltage is higher than the plate voltage. This condition is obtained during negative modulation peaks on a class *C* plate modulated amplifier. The resulting negative resistance can produce a momentary oscillation in any tuned circuit in series with the plate. This kind of parasitic is hard to locate because it only can exist during negative modulation peaks. As the plate voltage is rather low at that time, the power in the parasitic is limited and little damage will be done. The main effect will be distortion when the necessary high percentage of modulation is reached. The suggested remedy is parasitic chokes in series with the plate. They should be shunted by resistances. This makes the resistance of the circuit greater than the negative resistance generated by the tube, and oscillations cannot be produced.

B. When the grids of a tube are driven far positive, secondary emission may take place from the grids. This reduces the grid current and may proceed to such an extent that an increase in grid voltage produces a reduction in grid current—i.e. a negative resistance. If this happens, any resonant circuit in series with the grids can oscillate. The remedy for this type of oscillations is to load the grid circuit with resistances. In class *B* amplifiers this is ordinarily done to improve the regulation of the driver stage. However, present day tubes are carefully designed to minimize secondary emission so that this type of trouble is not common except where tubes are improperly operated (such as using audio tubes for radio purposes, or using excessive plate voltage).

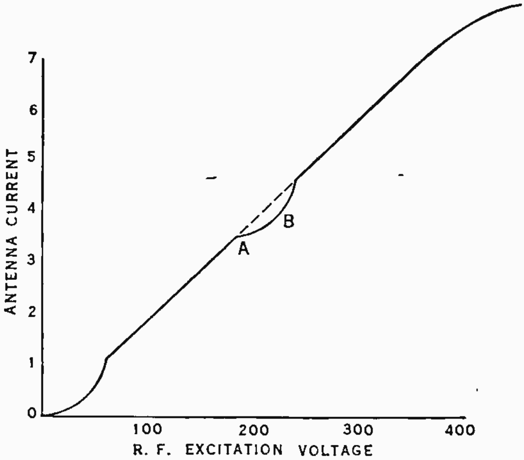


FIG. 186. Typical Saturation Curve.

C. An unexpected source of negative resistance is discovered when a curve is plotted of r.f. output against grid excitation for class *B* r.f. amplifiers. A decided "kink" sometimes appears just in the region where the grid voltage goes positive. This can be seen on figure 186 which shows a typical saturation curve. From point *A* to point *B* the output fails to increase properly with an increase in excitation. Now ordinarily class *B* amplifiers are operated at a constant plate voltage and no curves are ever taken of plate voltage vs. plate current. Mr. A. D. Ring, Ass't Engineer of the F.C.C. found that with the grid excitation at the point of the "kink" in the saturation curve, a negative resistance characteristic is found in the plate current-plate voltage curve. This can cause oscillations in any resonant circuit which is in series with the plate. A frequent case is oscillations at very low frequency in the plate supply filter. Although these oscillations can be prevented by a bleeder resistance across the plate supply, the only satisfactory remedy is to make sure that the unmodulated excitation is *not* at the level of the kink. With this precaution, the negative resistance of the plate circuit will appear only momentarily as the excitation passes through the critical point during modulation.

D. A very troublesome source of negative resistance is the presence of gas in a tube that has been overloaded (gas released from the elements), improperly evacuated, or aged. Although ingenious operators have devised various remedies, the only certain solution is to remove the tube from service and replace it with a good one. In this connection, it is valuable to know that operating the plate circuit slightly off resonance is very beneficial in keeping large tubes free of gas. A suggested amount is to increase the tank capacity beyond resonance until the plate current rises 5 percent.

Length of Cathode Lead—The lead between the cathode inside the tube and the returns from the grid and plate circuits is actually a portion of both circuits. This is seen on figure 185*C* marked *A* to *B*. This lead presents an inductive reactance which varies with the frequency and directly couples the grid and plate circuits. Ordinarily this coupling provides a voltage of improper phase to cause oscillations. At ultra-high frequencies the remaining portions of the circuit will introduce phase shifts which may permit oscillations. The lead should be made as short as possible. A further advantage of shortening this lead is to make the neutralization adjustment less dependent upon frequency. This is a valuable feature when frequencies are changed often.

CHAPTER 6

MODULATION SYSTEMS, ANALYSIS AND APPARATUS

Perhaps the best method of approaching the subject of amplitude modulation in radio telephony is first to review briefly the electrical principles which govern the operation of an ordinary wire telephone.

1. The Simple Wire Telephone—The simplest arrangement of a land telephone consists of a microphone, a telephone receiver and a battery connected in series as show in figure 187. A moving sound wave, composed of alternate regions of air in the state of condensation and rarefaction, impinges upon the diaphragm of the microphone causing the diaphragm to vibrate at the frequency and amplitude of the sound wave. These vibrations are transmitted to a plunger which is rigidly fastened to the diaphragm whose movements cause it to move within the brass cup which contains a small amount of loosely packed carbon granules. The vibrations of the plunger alternately increase and decrease the pressure exerted on the carbon granules and thus vary the resistance of the electrical path between the plunger and the brass cup which forms part of the telephone circuit. As a result, the magnitude of the current flowing in the circuit is varied at a frequency and amplitude in accordance with the impinging sound wave as suggested by

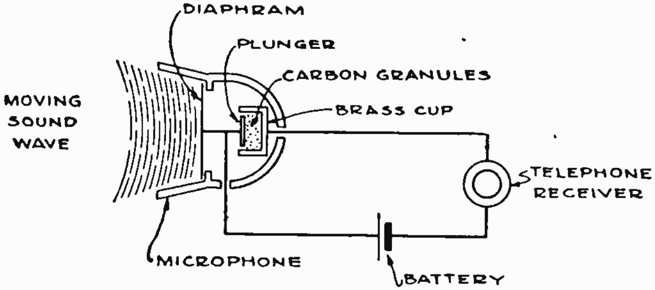


FIG. 187. A Simple Telephone Circuit.

figure 188. This varying current, in passing through the telephone receiver, is converted back into a sound wave similar to that impressed upon the microphone. The sound wave is represented by the variations in the current. The process by which these variations are superimposed upon the normal value of current is called "modulation" and the telephone circuit current is said to be "modulated." The normal value of current which is modulated is called the "carrier current" because it is the agency which makes possible the transmission of the sound wave in the form of current variations. The variations themselves are frequently called the modulation or the modulating current since the modulated carrier can be considered as being composed of two components, the normal or carrier current and the varying or a.c. component produced during the modulation process. Since the amplitude of the "carrier" current is changed during speech this is a case of "amplitude modulation." The magnitude of the

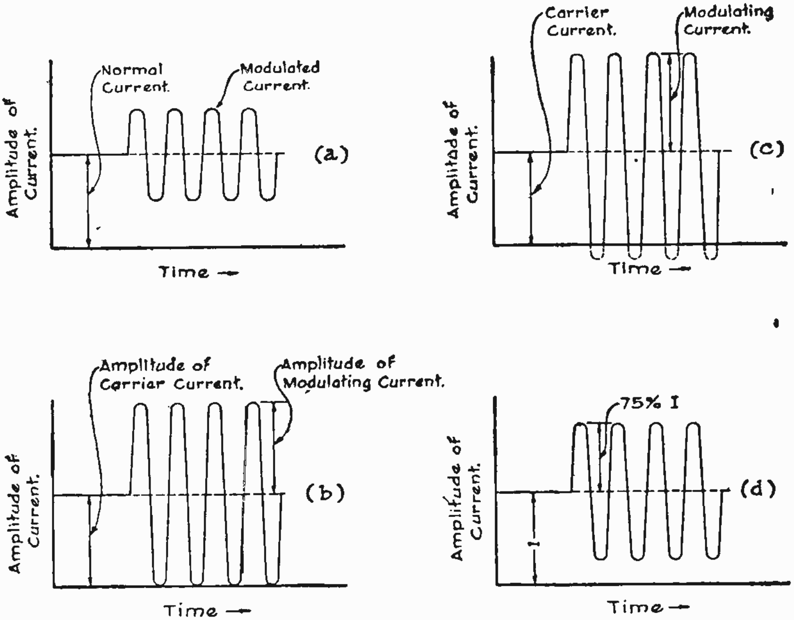


FIG. 188. Graphs Showing the Modulation Process in a Simple Telephone Circuit.

modulating current as compared to carrier current definitely limits the ability of the carrier to properly transmit the superimposed modulation. For example, in figure 188*b* the modulating current is equal in value to the carrier current. Should the modulating current exceed the carrier current, the graphical picture would be as shown in figure 188*c* which indicates that distortion will take place because of the cutting off of the lower peaks of the modulating current wave. The most efficient use of the carrier is accomplished when the modulating current is *just equal* to the carrier current. This mode of operation is called "100 percent modulation." In the case of figure 188*a* where the amplitude of the modulating current is equal to one half of the carrier current the percentage of modulation would be 50 percent. *The percentage of modulation present may be computed by expressing the ratio of the modulating current to the carrier current in percent.* Figure 188*d* illustrates a case of 75 percent modulation. A carrier current having a high percentage of modulation is said to be deeply modulated whereas in the case of a low percentage the modulation is said to be slight. From the standpoint of making efficient use of a given carrier current a high percentage of modulation is desirable, providing it does not exceed 100 percent. When this figure is exceeded, the carrier is said to be "over-modulated" and distortion will be present.

2. The Simple Radio Telephone—In the case of a simple radio telephone transmitter system with the usual amplitude modulation, the battery of the wire telephone is replaced by a high-frequency generator and the telephone receiver by the radio receiving set. The high frequency ("carrier") current supplied by the generator to the antenna is converted into electromagnetic waves, a small portion of which, in passing the receiving antenna are converted back into a high frequency current. This current, though perhaps infinitesimally small in magnitude as compared with the antenna current at the transmitter conforms exactly in frequency and proportional amplitude with the transmitting antenna current. Therefore, any change that we may make in current at the transmitting antenna will be faithfully reproduced on a smaller scale at the receiver. In other words, to all intents and purposes we may consider the antenna current at the transmitter to be a carrier current since any variation in its value will be accompanied by similar variation at the radio receiving set.

The simplest way to vary the antenna current is to insert the microphone directly in the antenna circuit as shown in figure 189. Since the antenna current must necessarily pass through the microphone, its value will be determined to a certain extent by the microphone resistance. A sound wave impinging on the microphone diaphragm changes the microphone resistance and thus

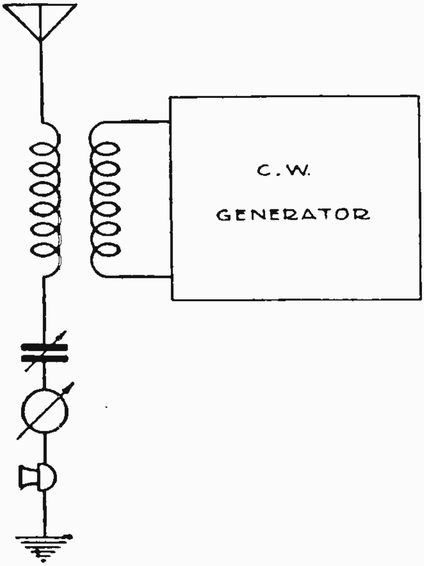


FIG. 189. A Simple Way of Modulating a CW Carrier.

produces modulation of the antenna current as shown in figure 190. It will be noticed that amplitude of the carrier current is symmetrical above and below the zero line; since the positive and negative halves of the r.f. cycle are affected alike by the changes in microphone resistance. Figure 190*a* illustrates the condition of 50 percent modulation while figure 190*b* is that for 100 percent.

The scheme of modulation illustrated in figure 189 is sometimes called the absorption system because the antenna current is modulated by absorbing from it an amount of power which varies with the speech input to the microphone. Two modifications of this scheme, shown in figure 191. The circuit change consists in coupling the microphone to the antenna instead of placing it directly in series with the antenna circuit. In figure 191*a* the coupling is conductive while in figure 191*b* it is inductive. Such an arrangement provides improved operation because matching of the microphone resistance to the antenna resistance is made possible, whereas in the series connection of figure 189 this adjustment is impossible. The proper coupling is ascertained experimentally, by listening to the transmitter with a radio receiver. The scheme shown in figure 191*b* is known as the absorption loop method of modulation. The microphone is placed in series with a few turns of insulated wire which are closely coupled to the antenna inductance. When speaking into the microphone the resistance of the loop circuit is varied and energy is absorbed from the antenna at speech frequency. The percentage of modulation

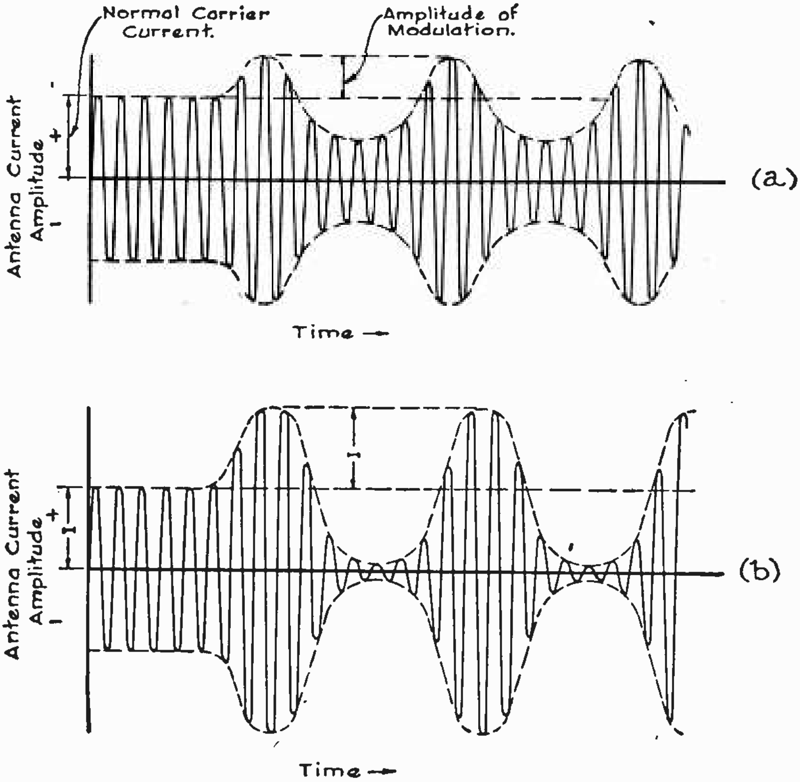


FIG. 190. Graphs Showing Modulation of a CW Carrier Current.

obtainable is of a low order. The scheme is limited to transmitters of small power output because of heating of the microphone due to the absorbed power.

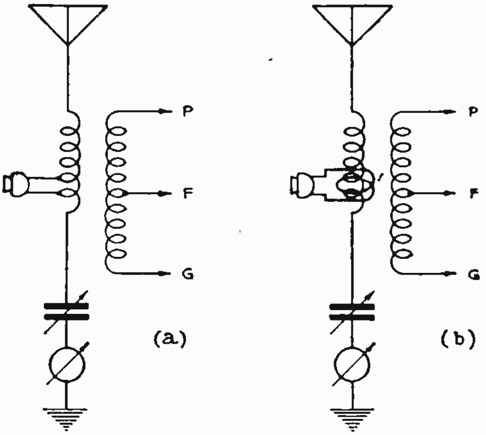


FIG. 191. Connections for Absorption Modulation.

3. **Classification of Modulation Systems**—The absorption scheme of modulation is a poor one when viewed from the electrical efficiency standpoint because it operates on the power output of the CW generator. This mode of operation can be compared to a loaded d.c. generator whose output voltage is varied by changing the value of a resistance in series with the generator armature. A better way to accomplish the same thing would be to operate on one of the factors which governs the magnitude of the generated voltage. In the case of CW generator using an oscillating vacuum tube, it is extremely undesirable to modulate the oscillating tube as its frequency is thereby changed rapidly in the manner sometimes called "wobbulation." Therefore, the oscillator is left *severely alone* and only supplies r.f. power to an r.f. amplifier system. It is to one of the amplifier tubes that the modulation is applied. The output of such an r.f. amplifier can be changed by altering its (1) filament voltage; (2) grid bias voltage; (3) d.c. plate voltage; (4) grid excitation voltage. Of these only the last three are of practical interest. They form the basis of two general systems of amplitude modulation, namely: grid bias modulation, and plate modulation which are used extensively in broadcast

transmitters. Variants of these methods are employed in certain aircraft and amateur transmitters where the modulated amplifier is a tetrode or pentode.

4. Sidebands in Amplitude Modulation—In amplitude modulation, if a single audio frequency modulates the carrier, there results in addition to the carrier frequency, two side frequencies, one of which has a frequency higher than the carrier frequency and another lower than the carrier frequency. In order to distinguish between these two, the first is called the upper side frequency and the second the lower side frequency. If the carrier frequency is 600 kilocycles and the modulating frequency 5000 cycles (that is 5 kilocycles), the upper side frequency would be $600 + 5 = 605$ kilocycles and the lower side frequency $600 - 5 = 595$ kilocycles. It is apparent that the width of the band necessary to transmit a carrier modulated at such a frequency would be 10 kilocycles, the difference between the upper side frequency and the lower side frequency. Ordinarily modulation is not by a single tone but by the many frequencies of speech or music so that we have not a pair of side frequencies, but two " side bands " of frequencies, each as wide as the audio range.

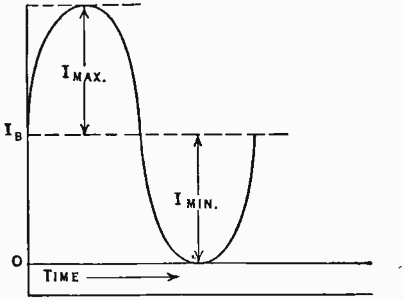


FIG. 192. Diagram Showing Instantaneous Value of Plate Current During Modulation.

When both side bands are transmitted (as usual) the system is referred to as " double side band transmission." It is possible to filter out one side band and thus confine the band width necessary for transmission to that of the highest modulation frequency employed; in the example given 5 kilocycles (1 kilocycle equals 1000 cycles). " Single side band " transmission is used in commercial point to point radiotelephony.

5. Plate Modulation of a Triode Class C r.f. Amplifier—Complete (or 100 percent) plate modulation requires audio power (a.c.) equal to 1/2 the d.c. plate input of the tube being modulated. This can be shown as follows: During modulation the alternating current from the modulators, that is the final tubes of the audio amplifier, is superimposed on the steady direct plate current of the tube being modulated. This may be shown by the diagram of figure 192 where I_b is the steady direct current without modulation and $I_{\text{max.}}$ the maximum variation of plate current during modulation. This is to say $I_{\text{max.}}$ is the peak value of the alternating current, and if we make the usual assumption of sinusoidal wave form, then the effective value of alternating current is $.707 I_{\text{max.}}$. The effective value of steady direct current with the alternating current superimposed is:

$$I_{\text{eff.}} = \sqrt{I_b^2 + (.707 I_{\text{max.}})^2}.$$

Since power varies as the squares of the current the power represented by those two currents may be calculated from the formula:

$P = (I_b^2 + \frac{1}{2} I^2_{\text{max.}}) R_1,$

R_1 = the resistance through which the modulated current flows.

During no modulation the power input to the plate is

$$P = I_b^2 R_1,$$

which may also be stated $P = E_b \times I_b.$

Therefore $E_b \times I_b = I_b^2 \times R_1.$

$$R_1 = \frac{E_b}{I_b}.$$

Since the d.c. portion of the plate input power is constant, the power required to modulate the plate current to $(I_{\text{max.}}/I_b)$ percent is $(I^2_{\text{max.}} R_1/2)$. When the plate current is completely modulated (100 percent) $I_{\text{max.}}$ equals I_b and the a.c. power required is found to be 50 per cent of the d.c. plate input power.

5A. The Modulator's Load—The value R_1 mentioned above has another importance in that it is the load on the a.c. system. Since it is necessary to operate audio amplifiers, including modulators, into a load of the correct value in order to secure from them a sufficient output with low distortion, it is apparent that R_1 must be adjusted to suit the audio amplifier, that is to say modulator. This may be done to some extent by adjusting the d.c. voltages and currents of the class *C* r.f. tube, but is ordinarily accomplished largely by a proper choice of the ratio of primary to secondary turns in the audio output transformer lying between the modulator tubes (as a.c. power supply) and the plate circuit of the r.f. tube (as a load). This transformer is called the modulation transformer, but is a straightforward audio output transformer with the exception that it is sometimes expected to carry the d.c. current of the modulated tube through its secondary winding, in which case it must have a large core with an airgap just as do all iron-core devices carrying both a.c. and d.c.

Antenna Power—When the carrier is unmodulated the power in the antenna is:

$$P_c = I_i^2 R,$$

I_i = unmodulated antenna current,

R = the resistance of the antenna at the point where the current is read,

P_c = Power in unmodulated carrier.

If the carrier is modulated by a sine wave audio frequency the antenna current will increase since additional power is developed by the amplifier tube delivering power to the antenna. The power in the antenna also increases during modulation and can be calculated from the following formula:

$$P_m = I_i^2 R \times \frac{2 + M^2}{2},$$

P_m = Power in modulated carrier,

M = Percent modulation expressed as a fraction. If the carrier is completely modulated M is equal to 1 and the power during modulation is obviously increased 1.5 times and the antenna ammeter (which reads the effective value of the current and not the power) increases its reading to $\sqrt{1.5}$ or 1.226 times the reading during no modulation.

The increased power during modulation appears in the side-band frequencies and it is through the medium of these new frequencies that speech, music, pictures or other forms of intelligence is transmitted and since received signal depends, in general, upon the variation in the amplitude of the carrier wave it is obvious that the most efficient use of the carrier wave is accomplished when it is completely or 100 percent modulated.

Side Band Power—The power in the side bands can be calculated from the formula

$$P_{sb} = \frac{M^2}{2 + M^2},$$

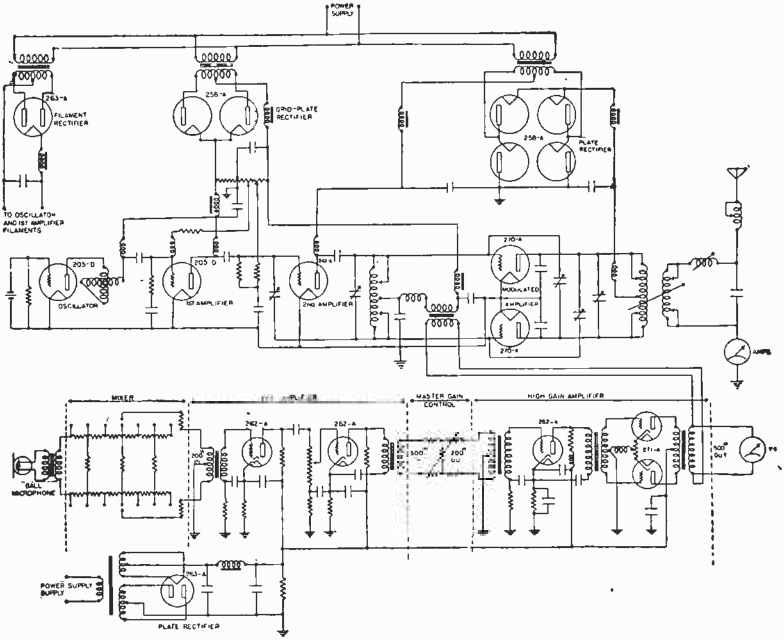


FIG. 192, A. W.E. 100 Watt Broadcast Transmitter and Speech Input Equipment Employing Grid Bias Modulation.

therefore, when the carrier is completely or 100 percent modulated the power in the side bands will be

$$P_{sb} = \frac{1^2}{2 + 1^2} = .333 \times 100 \quad \text{or} \quad 33\tfrac{1}{3} \text{ percent}$$

or only one third of the total power. If the modulation was only 50 percent the power in the side-bands would be

$$P_{sb} = \frac{.5^2}{2 + .5^2} = .111 \times 100$$
$$= 11.1 \text{ percent or only } \tfrac{1}{9} \text{ of the total power.}$$

The power of an a.c. wave varies as the square of the amplitude. Since the amplitude of a modulated carrier is $1 + M$ times the amplitude of the unmodulated carrier, the ratio of the peak power of the modulated carrier to unmodulated carrier can be found by squaring $1 + M$ or as an equation

$$\frac{P_m}{P_c} = (1 + M)^2.$$

In the case of 100 percent modulation M equals 1, so the peak power will be two squared or four times the unmodulated carrier output. Therefore, to ensure complete modulation the stage being modulated must be capable of handling power peaks four times as great as the carrier power.

It is interesting to compute the percentage of modulation obtainable when the audio power available is less than 50 percent of the d.c. plate input of the modulated stage—that is to say less than that required to accomplish 100 percent modulation.

Audio power is proportional to the square of the percentage of modulation (up to 100 percent) or

$$M^2 = K \times P_{\text{audio}}.$$

Put into words this is: "The modulation factor squared is proportional to the modulating power." "K" indicates proportionality, and is a so-called "constant of proportionality." Its value need not be known since it disappears during the calculation as shall be shown. The equation could of course also have been written

$$M = \sqrt{K(P_{\text{audio}})},$$

which in words is: "The modulation factor is proportional to the square root of the audio power."

The use of these equations is to be shown by an example in which the d.c. power input is assumed as 800 watts—which we know can be fully modulated by 400 audio watts. Our problem now is, if we have but 200 audio watts, what is the modulation factor?

For the 400 watt case: $M_1^2 = K(400)$,
For the 200 watt case: $M_2^2 = K(200)$.

Dividing the first equation by the second:

$$M_1^2/M_2^2 = K(400)/K(200).$$

At this point K cancels out and as M_1 is known to be 1 (meaning full modulation) we have:

$$1/M_2{}^2 = 400/200 = 2;$$

inverting

$$M_2{}^2 = 1/2;$$

therefore

$$M_2 = \sqrt{1/2} = 0.707.$$

A modulation factor of 0.707 is also called 70.7 percent modulation.

It is also convenient to make a calculation of the percentage of modulation from the rise in antenna current when the transmitter is modulated by a sustained sinusoidal audio tone. If the unmodulated is denoted by I and the fractional increase during modulation by $_\Delta I$ (delta I) then

$$M = \sqrt{(2{}_\Delta I)(2 + {}_\Delta I)}.$$

For example, suppose the antenna current during no modulation was 4 amperes and during modulation it increased to 4.9 the increase would be 22.5 percent. Substituting

$$M = \sqrt{(2 \times .225)(2 + .225)} = \sqrt{.450 \times 2.225},$$
$$M = 1,$$
$$M\% = 1 \times 100 = 100\%.$$

If the antenna current increased only 10 percent then

$$M = \sqrt{2 \times .1(2 + .1)} = \sqrt{.42},$$
$$M = .65 \text{ or } m\% = 65\%.$$

It is convenient to calculate the percentage of modulation by the use of a current-squared galvanometer coupled to the antenna lead or tank circuit of the modulated stage. The full scale reading of the Weston Model 301 instrument is 115 milliamperes, therefore the current for any deflection is,

$$I = 11.5\sqrt{D}, \quad \text{where} \quad D = \text{the deflection.}$$

If the meter is coupled to the transmitter so that without any modulation a reading of 40 scale divisions is obtained, or from the above equation the current at this deflection will be 72.77 ma. If the transmitter is modulated so that the needle reads 60 scale divisions the current will now be 89.08 ma. The ratio of these two readings is 1.226 which is that required for 100 percent modulation.

The percentage of modulation for current squared values may be calculated from

$$M = \sqrt{2\left(\frac{I_m^2}{I_c^2} - 1\right)}$$

and since the scale divisions are current-squared values,

$$M = \sqrt{2\left(\frac{60}{40} - 1\right)} = \sqrt{2 \times .5} = \sqrt{1},$$

$$M = 1 \quad \text{and} \quad m\% = 100.$$

It will be shown later that the measurement of modulation capability by either of the two methods previously described is of little practical value since the relative values of the positive and negative peaks cannot be determined and there are other sources of inaccuracy. However, it is possible to determine if the transmitter is being modulated " up " or " down " since the average value of modulation can be determined.

Important Warning—In all the discussion of modulating power it has been assumed that the modulating voltage was in the form of pure a.c., therefore the peak value was but 1.4 times the effective value and it was true that overmodulation became possible only when the audio power exceeded 50 percent of the d.c. input. This does not hold true for irregular wave forms such as are common in both speech and music and it must never be assumed that overmodulation cannot occur merely because the audio system is of the correct size or smaller. On the contrary overmodulation is possible even with undersized audio systems (1) because any audio system can be overloaded and (2) because abrupt sounds may have very high peak voltage though representing little average power.

To provide a convenient reference for showing the variation in the various factors previously discussed with the percentage of sinusoidal modulation the following table has been prepared:

Percent Modulation	Percent Increase in Antenna Current	Percent Increase in Current Squared Galvanometer	Relative Audio Power Required	Percent of Power Radiated in Side Bands	Ratio Peak Power to Unmodulated Power
100	22.5	50.0	100.0	33.3	4.0
90	18.5	40.5	81.0	28.8	3.6
80	14.9	32.0	64.0	24.2	3.2
70	11.6	24.5	49.0	19.7	2.9
60	8.6	18.0	36.0	15.3	2.7
50	6.1	12.5	25.0	11.1	2.3
40	3.9	8.0	16.0	7.4	2.0
30	2.2	4.5	9.0	4.3	1.7
20	1.0	2.0	4.0	2.0	1.4
10	.3	.5	1.0	.5	1.2
0	0	0	0	0	1.0

The most striking point of this table is that even for 100 percent modulation the radiated power still consists largely of "carrier" which contains no intelligence-frequencies, and appears to constitute a mere waste of power. In fact the steady carrier component need not, in theory, be radiated as it is possible to accomplish reception provided a correctly adjusted carrier is supplied at the receiver. The strength of the received signal in such a case depends entirely upon the power radiated in the form of side bands. In commercial transoceanic telephony frequently one side band as well as the carrier is restored at the receiver by a radio frequency oscillator. A large power saving at the transmitter results, but unfortunately, the receiver is highly specialized, hence the system is not available for general public use.

The previous calculations of power in a modulated wave assumed a pure tone or sine wave as the source of modulation. The wave form of speech and music is quite complex and engineers do not depend upon the antenna r.f. ammeter increase to calculate the percentage of modulation. In fact meters cannot respond to the rapid changes in antenna current which takes place during a broadcast of speech or music. While a rise in antenna current during modulation indicates upward modulation it gives no assurance that the positive and negative peaks are symmetrical or the amount of harmonic distortion that is present. Special apparatus is required for this purpose and several types of apparatus employed as modulation monitors and distortion analyzers are described in detail later in the chapter.

5B. Plate Modulation of Tetrodes and Pentodes—When a tetrode (or a pentode connected as a tetrode) is to be plate modulated there is a tendency toward distortion at the higher modulation levels. This is largely avoided by supplying the screen current through a series resistor from the *unmodulated* plate-supply, thus introducing a tendency toward self-modulation of the screen, which must not have a large bypass condenser. In the case of a pentode, however, the series screen-resistor must derive its voltage from the *modulated* plate supply for lowest distortion, hence R_1 and the audio power demand must be figured on the basis of the current drawn by both plate and screen, using the full plate-supply voltage as the other factor. Modulation of the screen alone is intermediate between these systems and the suppressor-modulation scheme of section 8 as to both audio-demand and carrier power.

6. Grid-bias Modulation—In this system of amplitude modulation the audio frequency variations are communicated to the grid of an r.f. amplifier stage of the transmitter. Consider the circuit of figure 193. The secondary of an audio frequency transformer is connected directly to the electrical center of a single ended r.f. amplifier whose output is utilized to excite a push-pull amplifier. One terminal of the secondary of the audio frequency

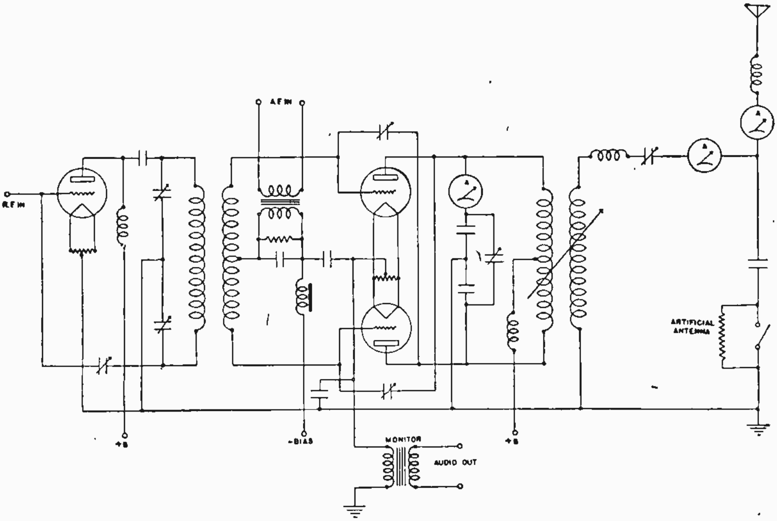


Fig. 193. Grid Bias Modulation. Western Electric Co. 12–A Radio Transmitter.

transformer is returned to the negative bias supply and adequate filtering is provided to prevent radio and audio frequency currents feeding back into the bias supply. The center of the tank inductance is brought to ground through a condenser which is not of sufficient capacity to appreciably by-pass the voice or musical frequencies. This method of grid-bias modulation is employed by the Western Electric Company in several of their transmitters. It will be noted that while the grids are out of phase with respect to the r.f. excitation voltage the audio frequency voltages operate as if the grids were in parallel since the tank inductance offers no reactance to the audio frequencies.

Referring to rule 3.52 of the Federal Communications Commission, it will be noted that the operating power of a broadcasting station is determined by indirect measurement of the plate input power of the last radio stage by multiplying the plate voltage by the total plate current of the last radio stage and by an efficiency factor. Where stations use grid-bias modulation in the last radio stage, the efficiency factor is .25 as compared to .70 for plate modulation. The efficiency is low because when such modulation is employed the r.f. excitation is greatly reduced. The installed tube capacity must be ten times the carrier power. The Western Electric type 12–A transmitter employing grid bias modulation in the final stage uses two 500 watt tubes in push-pull to provide a 100 watt carrier or, 400 watts plate input. Similarly, Federal Communications Commission rates the power of Western Electric 212–E tube as 250 watts when used as plate modulated r.f. amplifier, whereas the same tube when grid-bias modulated is given a rating of only 50 watts.

One advantage of grid-bias modulation lies in the fact that the audio level necessary to accomplish complete modulation is very low thus obviating the necessity of large audio frequency stages and their power supplies. The Western Electric 12–A transmitter (100 watts output, 455 watts input) requires but plus ten decibels (.6 watt audio power) to accomplish 100 per cent modulation.

On the other hand 100 watts of carrier can be produced with plate modulation using a pair of the much smaller "50 watt" Western Electric tubes called 211D, and since the efficiency of plate-modulated tubes is greater (70 percent for 100 watts output), it is found that the d.c. input is about 143 watts. The audio demand is therefore 143/2 = 73 watts which may be supplied by various class B tube combinations whose power-demand varies from about 25 or 30 watts (non modulating) to 150 watts (full modulation). The total power demand is accordingly from 180 to 300 watts at various times. The additional audio stages partly balance off the cost of the larger tubes used in grid-bias modulation.

Referring to figure 194 the direct grid-bias voltage is shown adjusted to approximately one and one-half times cut-off (the value necessary to reduce the plate current to zero). Radio frequency excitation is then applied until the required unmodulated output is obtained. Audio frequency voltages then vary the effective bias so that the peak radio frequency grid voltage is varied between zero-bias and cut-off and a completely modulated radio frequency output is obtained. (The r.f. peak voltage = approximately two-thirds bias, the a.f. peak voltage for full modulation = one-third bias, hence the greatest momentary sum of their two a.c. voltages equals the bias.) In this particular transmitter sufficient radio frequency voltage is applied to the grids to just reach the point where they become positive and grid current flows on the peaks of modulation. 400 watts of peak power is delivered to the antenna when the carrier without modulation is adjusted to 100 watts. The maximum plate efficiency is 50 percent and the unmodulated efficiency one-half of this value or 25 percent, corresponding to the efficiency factor authorized by the Federal Communications Commission for broadcast transmitters employing grid-bias modulation in the stage feeding the antenna. It is

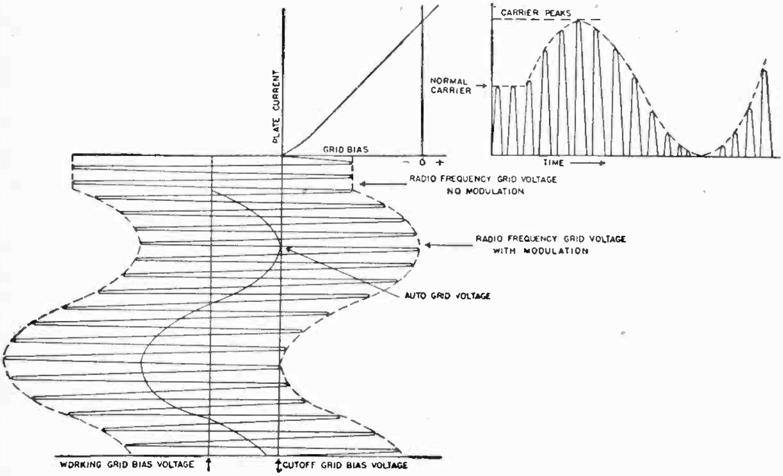


FIG. 194.

apparent that in order to obtain a 100 watt carrier, 300 watts are dissipated by the tube plate when there is no modulation, the input being 400 watts at such times. During modulation the efficiency improves and the plate cools off. Thus it may be said that a grid-bias modulated tube operates with fixed plate input and variable plate efficiency.

7. Grid-bias Modulation at Higher Efficiency—In the scheme of grid modulation described in section 6 very little power is taken from either the audio or r.f. grid-driving sources because the grid is at all times in the negative region. It will be noted that the " carrier " condition compares with ordinary class *A* audio work as to both grid bias and efficiency, while during modulation the system works in the positive grid-region at the efficiencies associated with class *AB* audio work. The logical conclusion is that higher efficiency may be obtained by swinging into the positive grid region providing the consequent distortion can be eliminated as successfully as in the class *B* audio push-pull amplifier. Various experiments along this line may be found described by Frank Jones and J. N. A. Hawkins in the 1934, 1935 and 1936 issues of the amateur radio magazine " Radio." Audio and radio driving systems of suitable regulation are described, and in the Hawkins variation suppression of distortion at high modulation levels is effected by the use of a compound bias, one portion of which is fixed, while the other is derived from a cathode resistor and wanders in the proper manner to effect some correction.

In the case of a grid-modulated pentode the grid-modulation method may be employed in the negative-grid region only if very small output is acceptable. Such tubes are accordingly grid-modulated (usually) with r.f. and audio voltages about twice as great (relative to the bias) as stated in the parenthetical note in section 6.. Under these conditions modulation acceptable for speech transmission can be obtained with a plate-circuit efficiency around 33 percent for the unmodulated carrier, i.e. about 1/2 the carrier provided by the same tube with plate-and-screen modulation. This is about 3 times the carrier obtainable with negative-grid operation. While the input grid does in this case demand some power from both the r.f. and audio sources, the demand is moderate because of the ease with which a pentode is driven for *moderate* positive grid excursions.

8. Suppressor Grid Modulation—The circuit arrangement shown in figure 195 is used to modulate pentode r.f. stages by varying the voltage of the 3rd or suppressor grid. This method of modulation falls into the same class as the " higher efficiency " grid-bias modulation just discussed. Approximately the same degree of efficiency is obtained and the tube operates with variable efficiency. The adjustment is somewhat easier than in the grid-bias case, and the distortion on positive modulation peaks tends to be somewhat higher. This form of modulation is encountered principally in amateur transmitters intended primarily for telegraphy, but given the simplest possible auxiliary modulation equipment.

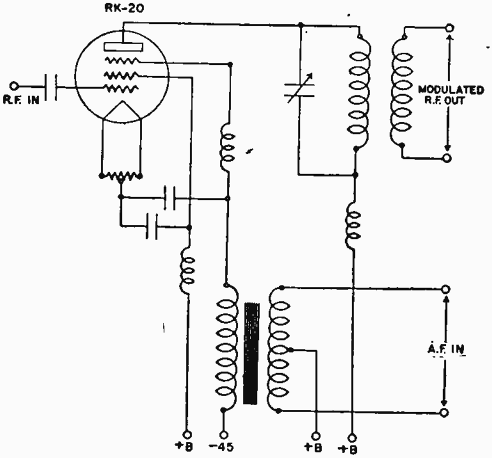


FIG. 195. Suppressor Grid Modulation of Pentode.

IT MUST BE UNDERSTOOD THAT FOR EITHER SUPPRESSOR MODULATION OR INPUT GRID MODULATION IT IS NECESSARY TO EMPLOY DIFFERENT D.C. AND A.C. VOLTAGES THAN ARE USED WHEN THE SAME PENTODE IS USED FOR PLATE-SCREEN MODULATION OR AS A TELEGRAPH AMPLIFIER. The correct values are given in tube maker's data.

9. The Constant-current (Heising) Method of Amplitude Plate Modulation—It has already been stated that input-grid and suppressor-grid modulation operate by varying the conversion-efficiency of a tube with constant input. This is not true for plate modulation (including plate-and-screen modulation of pentodes, of course), in which the plate-circuit efficiency remains nearly constant and modulation of the output is accomplished by varying the input. That is to say during modulation the normal (d.c.) input of the tube is increased by the superimposition of an additional (a.c.) audio input. The d.c. input becomes converted into the carrier power, the a.c. input becomes converted into the sideband power. If modulation is effected by a single-tone a.c., that is to say a smooth sinusoidal wave, and the modulation amounts to just 100 percent then the a.c. input power is 1/2 the d.c. input power and thus the side-band power is half the carrier power as was already shown in the tabulation of section 5.

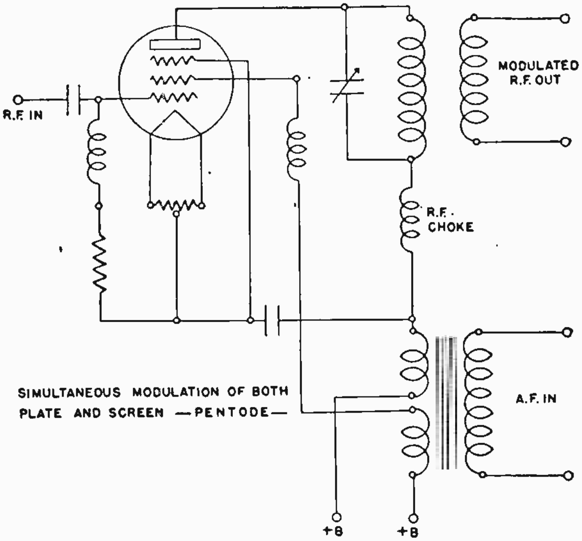


FIG. 195, A.

The original circuit arrangement used to impose the additional (audio a.c.) input upon the tube is that shown in figure 196. It is neither capable of 100 percent modulation *nor intended to provide it,* for the tube which was modulated in the days of this circuit was the oscillator for which 100 percent modulation is impractical. However the circuit serves to explain the basis of later variations. The plate supply *B* furnishes current to both the oscillator and the modulator tubes through the iron-core choke whose purpose is to keep the supply current constant. When no modulation takes place that portion of the current flowing to the audio tube is merely wasted in plate-heating. When audio a.c. is applied to the grid of the audio tube its plate resistance wavers up and down in accordance with speech, and in consequence its plate-current varies. However the large choke coil (30 to 200 henries) prevents the supply current from following these changes,

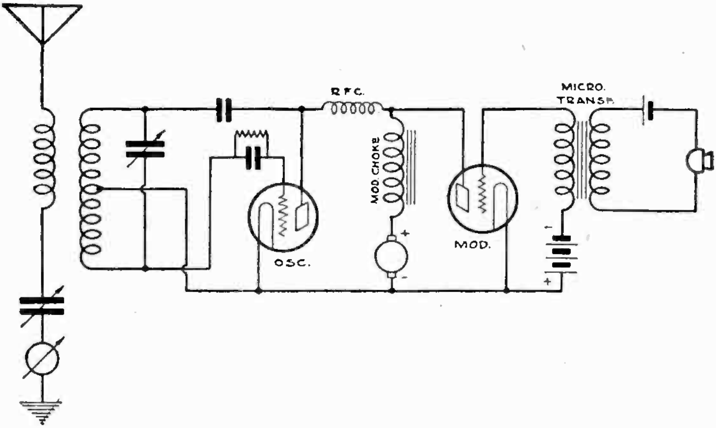


FIG. 196. Schematic Circuit Diagram Showing the Heising System of Plate Modulation.

hence any current "refused" by the audio tube is compelled to enter the r.f. tube, whose input thus rises. When the audio tube is on the opposite half of the cycle its current demand rises, and the input to the r.f. tube falls. Thus the r.f. tube's input is varied in accordance with the speech. The variations of input result in similar variations of antenna current and modulation has been accomplished. The energy transfer may be understood more easily by reference to figure 197.

With the appearance of more numerous stations and more selective receivers it became essential to abandon modulation of the oscillator because of the rapid frequency-waver consequent upon the modulation. This "dynamic instability" has the practical effect of making the signal tune very broadly and hence produce inordinate interference. To avoid this the modern radiophone transmiter (except in low-power portable device or in emergency) does not modulate the oscillator, *nor even a tube adjacent to the oscillator.* Thus the simplest r.f. system capable of proper modulation by present standards consists of a well stabilized small oscillator (frequently under crystal or tuned-line control and further stabilized by temperature control and separate power supply), which feeds a "buffer" amplifier, after which comes the r.f. amplifier stage to be modulated. More intermediate stages are common in transmitters of considerable power, either to raise the power level, or to provide additional oscillator protection—or in some cases to double or otherwise raise the frequency before

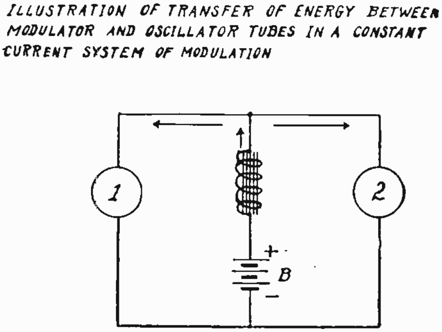


FIG. 197. Illustration of Transfer of Energy between Modulator and Oscillator Tubes in a Constant Current System of Modulation.

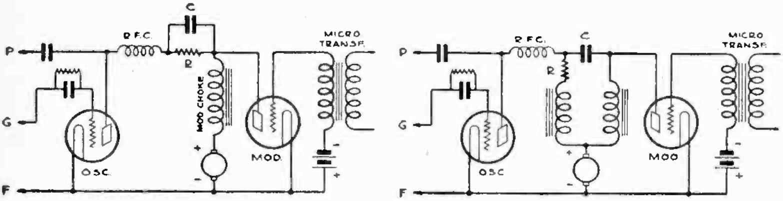
the modulated tube is reached. The general form of the system is then that of figure 122, Chapter 4.

The apparently onerous complication of the r.f. system by these additions is justified by the lesser interference created, and also by a *great increase in effectiveness.* The reason for this is that when modulating the oscillator no modulation above 50 percent (an optimistic estimate) was possible with acceptable fidelity. From the table of section 5 it is seen that this meant that about 11 percent of the power radiated was in the form of sidebands—the useful part of radiation. To accomplish even this required 4 tubes, one working as oscillator, and 3 of the same sort working in parallel at the same voltage as class *A* audio amplifiers (modulator), and consuming (together) a plate current about equal to that of the oscillator. Thus when not modulating the efficiency of the oscillator is the usual 66 percent but the 4 tubes considered together show an efficiency (plate supply to antenna) of only 42 percent at 50 percent modulation, and of this 42 percent only a trifle over 1/10 is in the form of sideband power representing sound at the distant receiver. It is evident that the general low efficiency is due to two discrete causes:

a. The low modulation percentage unavoidable with modulation of an oscillator.
b. The low efficiency of the class *A* audio (modulator) amplifier.

Of these two causes the first, *A,* is of immediate concern here.

It can be shown that a class *C* tube with *fixed* r.f. grid excitation is capable, when properly loaded, of accepting 100 percent modulation (nearly) without serious distortion. This is possible because it is *NOT* self excited—i.e. because it is not dependent on its own plate for grid excitation. The importance of this possibility can be seen by referring again to the table of section 5 from which it is seen that for 100 percent modulation it is possible to apply 4 times as much audio power to the tube, which is to say the sideband power is multiplied by 4 *WITHOUT NEED OF MORE OR LARGER R.F. TUBES.* If it is desired to retain class *A* operation of the audio (modulator) tubes this larger audio power may be attained by using but two audio tubes (instead of 3) and operating them at a voltage equal to 120–150 percent of that applied to the r.f. tube (depending on the tubes used), with due regard for limitations of rating. This higher voltage is then blocked off from the r.f. tube by methods similar to those used in ordinary class *A* audio work to transfer the plate-output to a following grid—except that here the power is sent to the r.f. plate. Possibly the simplest circuit is that shown in figure 198*a,* in which the dropping resistor must be chosen for the particular combination of r.f. and audio tubes employed, the drop being a simple d.c. drop. To prevent an a.c. drop in the resistor there is provided the by-pass condenser whose reactance must be low as compared to the resistance of the r.f. plate circuit, the latter being figured from the plate current and voltage. At least 4 microfarads are usually indicated. The arrangement of



(a) (b)

FIG. 198. Schematic Circuit Diagram Showing Two Means of Obtaining 100% Modulation.

figure 198*b* is simply a "double choke coil coupling." It has the advantage that neither choke is required to carry the entire supply current, and the cost of (good) chokes goes down faster than their current-carrying capacity for the same inductance and distributed capacitance. It is possible to wind both coils on the same core and to choose the direction of winding to balance out magnetic saturation due to the direct current. Still another variation is to replace the choke coil in the d.c. supply lead of the r.f. tube by a transformer, the secondary lying in this lead while the primary is fed by an audio amplifier which may of course then operate in class *A*, *AB* or *B* depending on the requirements as to fidelity and power. In any one of these arrangements the Heising principle is still plainly apparent. Several aspects of the recent forms are now to be discussed.

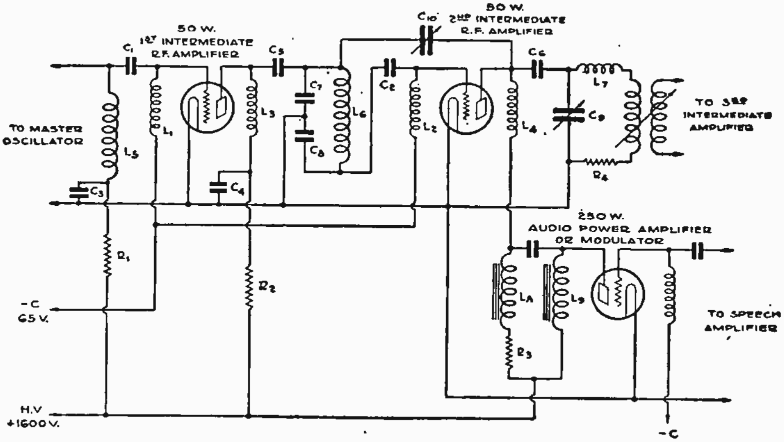


FIG. 199. Schematic Diagram Showing 100 Percent Modulation System Used in a Western Electric Transmitter.

The diagram of figure 199 illustrates a portion of the schematic diagram of a Western Electric Company's 5 kw. telephone Type 105–C and is introduced at this point for the purpose of showing a commercial application of the arrangement for obtaining percentage of modulation approaching 100 percent. The circuit falls under the low power modulation classification because the modulator tube works into the plate circuit of the second intermediate amplifier. The modulated r.f. current is amplified by the third intermediate amplifier. The second intermediate amplifier is plate modulated by the audio power amplifier or modulator. Deep modulation, approaching 100 percent, is obtained in this stage by using the double choke arrangement of figure 198*b*. A single 250-watt tube is used as the modulator to modulate the 50-watt second intermediate r.f. amplifier tube instead of using two or three tubes of the 50-watt size. This design provides a wide margin of safety in regards to heat dissipation in the modulator and permits operation of the second intermediate amplifier at its full power output and plate voltage rating. If 50-watt tubes were used in the modulator, it would be necessary to operate the intermediate amplifier at a plate voltage below normal and would thus limit the power output to a value lower than the rating. The purpose of the other circuit components is as follows: The r.f. grid chokes L_1 and L_2 serve to keep r.f. currents from backing down into bias supply. The r.f. plate chokes L_3 and L_4 serve a similar duty for the plate supply. Condensers C_1 and C_2 are grid isolating condensers and are used for the purpose of keeping the bias voltage from being applied to the tank circuit inductances L_5 and L_6. Condensers C_3 and C_4 are by-pass condensers. Condensers C_5 and C_5 are plate blocking condensers. The condensers C_5 and C_8 serve as the tank tuning condensers for the tank circuit of the first intermediate r.f. amplifier. C_9 serves a similar duty for the tank circuit of the second intermediate r.f. amplifier, the tank inductance being L_7. C_{10} is the neutralizing condenser for the second r.f. amplifier. The resistance R_1, R_2, R_3 are used for the purpose of reducing the plate supply voltage of 1600 volts to 1000 volts, the rated value for the 50 watt tubes. The iron core chokes L_8 and L_9, together with the condenser C and resistor R_3 form the circuit modification for obtaining deep modulation. In this and many other large radiophone equipment, the modulated tube does not feed the antenna, but is followed by a class B r.f. stage. The resistance R_4 serves as a loading resistance for the tank circuit of the second (modulated class C) r.f. amplifier. Its function is to provide a high constant load so that the variable load imposed by the third (class B) r.f. amplifier, due to increase in the grid current of the latter during modulation, will not cause distortion. This loading of the modulated tube is essential because distortionless plate modulation can only be obtained under constant load conditions. By making the variable load (produced by variation in grid current during modulation) small in comparison to fixed resistance load satisfactory operation is obtained.

10. Class B and A audio Amplifiers as Modulators—The theory and operation of triodes operating as class B audio amplifiers has been treated in detail in Chapter 5 so the treatment at this point will be limited to their use as modulators. Figure 200 shows the circuit arrangement for plate modulation of a class *C* amplifier.

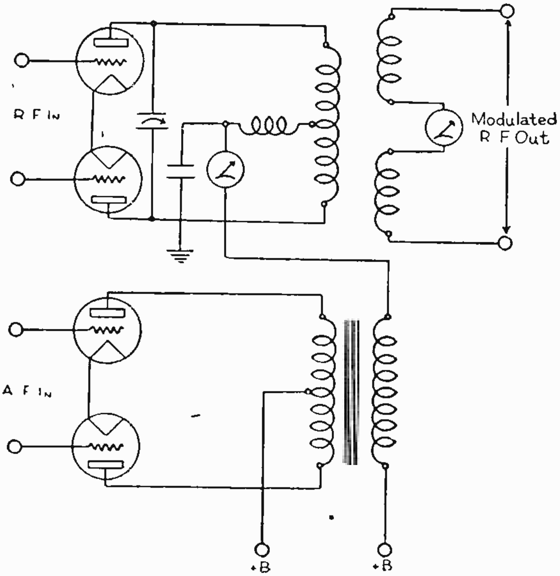


FIG. 200. Class "B" Amplifier as Modulator.

The secondary of the class *B* audio transformer is connected to the center tap of the plate tank and in this manner the audio frequency power is superimposed upon the radio frequency power developed in the class *C* amplifier. Not all class *B* output transformers are designed to permit the class *C* current to flow through the secondary windings. The class *C* plate supply current may instead be fed through an audio frequency choke coil and a large capacity blocking condenser connected between transformer secondary and choke. Frequently the secondary is wound in two sections and permits either series or parallel connections, the choice depending upon the types of tubes used in the class *C* amplifier.

It has been previously stated that when an audio power amplifier is employed as a modulator the load resistance is an important consideration. Consider the case of class *A* or constant current modulation in which 100 percent modulation is accomplished by providing a dropping resistance in series with the r.f. amplifier plate.

The load or impedance into which the modulator works is determined by dividing the d.c. plate voltage by the plate current and it should approximate the modulator's rated load impedance. A close agreement is not essential for low impedance class *A* audio tubes. Assume the modulator is operating with 1000 volts at 60 milliamperes plate current and that the rated power output as a class *A* amplifier is 35 watts for a load resistance of 3500 ohms. The plate voltage and plate current of the modulated stage can be determined by the application of Ohm's law as follows:

$$E_b = \frac{P_{in}}{I_b} \quad \text{and} \quad I_b = \sqrt{\frac{P}{R_L}},$$

where E_b = d.c. voltage on r.f. amplifier,
I_b = d.c. current in amperes to r.f. amplifier,
P = product of E_b and I_b and twice modulator output power in watts,
R_L = load resistance for modulator in ohms.

Solving for I_b by substituting the known values

$$I_b = \sqrt{\frac{2(35)}{3500}} = .140 \text{ amp.} = 140 \text{ ma.}$$

and
$$E_b = \frac{2(35)}{.140} = 500 \text{ volts.}$$

The voltage drop between the modulator and r.f. amplifier is calculated by subtracting the applied voltage on the former from that required on the r.f. amplifier or 1000 — 500 = 500 volts. The total d.c. current of the r.f. amplifier will flow through the resistor so its value is also calculated from Ohm's law.

$$R = \frac{500}{.140} = 3571 \text{ ohms}$$ (3500 ohms resistor will be satisfactory). The heat dissipation is I^2R or 70 watts. A 200-watt resistor will provide a margin of safety.

It has been stated previously that the resistance which the class *C* stage presents to the secondary of the modulation transformer is found by dividing the class C plate voltage by its plate current. Class B output transformers have a specified load resistance and the turns ratio of the transformer is so proportioned that when this resistance is connected as the load to the secondary the modulators are operating into their optimum load for maximum undistorted power output. In addition, the power required to modulate the class C amplifier 100 percent, as previously stated, is 50 percent of the d.c. power input; i.e., the product of the plate voltage and current as read from the meters.

The impedance of the modulated tube is also calculated from

$$R_p = \frac{E_b}{I_b}.$$

If the value of R_p is higher than that required to match the secondary of the class B modulation transformer the power output will be reduced as well as the harmonic distortion. If R_p is low the power output will be increased and the harmonic distortion increased. The extent to which the power is increased or decreased is dependent upon the degree of mismatch.

In broadcast transmitters where the class C stage feeding the antenna is modulated the operator is confronted with problem of making correct adjustments for authorized power output and at the same time presenting the proper load to the secondary of the class B modulation transformer. The problem is sometimes difficult when a station is authorized a day power in excess of that authorized for night particularly if the modulated amplifier is not operating as a true class C amplifier.

11. **Series Modulation**—The principles of series modulation have been known for years, however, its use has been confined generally to European stations. Tests have proved that satisfactory frequency response is obtainable at both high and low power. The British Marconi Company has, since 1933, employed series modulation in a transmitter having an output of 30 kw. which in turn operated into a 300 kw. class B linear amplifier and with this linear amplifier operating at 30 percent efficiency, it was found possible to modulate up to 90 percent with a distortion factor of less than 4 percent. Since the use of a modulation choke or transformer is not required the modulation circuit is capable of uniform frequency response over a wide band of frequencies and the Marconi Company had no difficulty in securing a frequency characteristic level within 0.5 db from 50 to 10,000

cycles.[1] This feature will undoubtedly encourage the use of series modulation in television transmitters as they are required to transmit a very wide band of frequencies with a minimum of frequency discrimination.

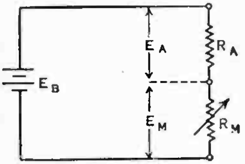


FIG. 201.

The equivalent theoretical circuit of a series modulation system is shown in figure 201 and an elementary circuit showing the tube arrangement in figure 202. It will be noted that the filament circuit of the class *C* r.f. stage is above ground potential. If desired the modulator can be placed above ground potential and the filament of the radio frequency amplifier grounded; however, the former permits a more convenient arrangement of grid bias. The capacity of the r.f. by-pass condenser *C* must be very small, otherwise high modulation frequencies will be shunted to ground.

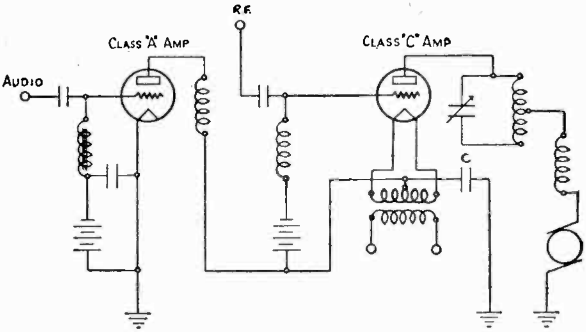


FIG. 202.

Referring to figure 201 the plate supply E_b has connected in series with it, two resistances, R_A corresponding to the class *C* r.f. amplifier of figure 202 and R_M variable in value and corresponding to the class *A* modulator. If it is assumed that R_A and R_M are equal the plate supply voltage E_b will divide equally across them ($E_A = E_M$). Now if R_M is varied in value from zero to infinity, the voltage across the fixed resistance R_A (modulated amplifier) will vary from its normal value (unmodulated

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[1] The Marconi Review, March–April, 1933—Series Modulation, W. T. Ritchman.

carrier) to twice that value and to zero therefore accomplishing complete modulation of the r.f. amplifier.

In practice it is not possible to employ tubes having the ideal ohmic resistance required to reduce the modulator resistance to zero, or with a symmetrical grid swing to make its resistance infinite. However by judicious choice of modulator tube and by correct adjustment of modulator grid bias such that with no modulation the voltage across the modulator is higher than that of the class *C* amplifier, it is possible to obtain a peak voltage on the latter of twice the carrier value and also reduce it close to zero thereby accomplishing a very high percentage of modulation and since in a practical circuit, inductance at audio frequencies is absent and the only loss through capacity to ground is by the by-pass condenser and filament transformer, which by proper design is made small, frequency discrimination is practically eliminated.[2]

The relatively high plate supply voltage required for series modulation is a less serious difficulty since generators have largely been replaced by rectifier-filter systems, but the series arrangement of tubes, and the high voltage itself, continue to make the system comparatively costly and somewhat more dangerous to equipment and personnel.

11A. High Level and Low Level Modulation—A "high level" modulation system is one in which the last tube of the transmitter is modulated, that is the tube feeding the antenna is a class *C* modulated stage. In "low level" modulation the modulation is accomplished at some earlier stage of the r.f. amplifier system, hence the final stage (or two stages) operate as class *B* r.f. amplifiers of the modulated carrier. In high-power radiophone transmitters the second (low level) system is the cheaper, especially when the class *B* r.f. amplifiers are operated in one of the recent improved-efficiency circuits (see section 35, Chapter 5).

12. Frequency Modulation—All the discussion of this Chapter has been concerned with amplitude modulation, that is modulation by variation of the amplitude of the radio frequency carrier. It is also possible to secure transmission by frequency modulation, that is by wavering the frequency of the carrier at a rate in accordance with the pitch of the modulation tones. Such systems have been the subject of occasional theoretical investigation as well as practical experiment.

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[2] A detailed report of experiments with Series Modulation can be found in Proc. I. R. E., May 1935—Series Modulation—Chas. A. Culver.

In figure 203 is shown a simple method of securing frequency modulation of an oscillator. Here the audio signal to be transmitted is sent through an amplifier to a loudspeaker whose moving element is mechanically connected to one part of the tuning condenser of an oscillator. As the loudspeaker vibrates the condenser element, and varies the capacity, it follows that the oscillator frequency also varies in accord with the sound vibrations. Similarly in figure 204 the electrode-spacing of the crystal-holder is varied in an audio manner producing frequency modulation.

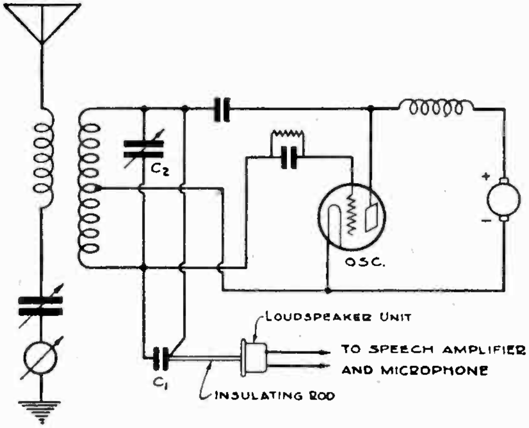

FIG. 203.

Reception of frequency modulated signals compared to the reception of amplitude modulated signals differs chiefly in regards to the detection of the signal itself. The ordinary vacuum tube detector is a voltage operated device, and demodulation of an amplitude modulated carrier is only made possible because the carrier voltage varies. The voltage of a frequency modulated carrier is constant in value and since the vacuum tube detector is a voltage device demodulation is not possible unless some arrangement is made for converting the frequency fluctuations into voltage variations. A sharply tuned resonant circuit is capable of performing this function, the efficiency of conversion being dependent upon the sharpness of tuning. It would seem that any ordinary receiver would therefore be suitable for receiving frequency modulated signals since a tuned circuit is usually associated with the detector tube. Such is the case provided the circuit tunes sharply as in a regenerative receiver adjusted close to the point of oscillation or a receiver employing a number of radio frequency amplifying stages preceding the detector tube. In adjusting a receiver for the reception of frequency modulated signals it is essential to tune a trifle off resonance from the normal carrier frequency otherwise the efficiency of conversion from frequency modulation to amplitude modulation is poor. This is better understood when it is considered that the conversion efficiency is dependent upon the variations in the frequency of the modulated wave.

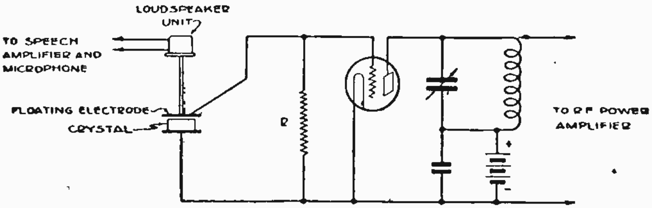

FIG. 204. Schematic Diagram of Arrangement for Producing Frequency Modulation of a Crystal Oscillator.

An analysis of a frequency modulated wave shows that it contains the same side bands that are present in an amplitude modulated wave and in addition higher order of side bands that differ from the carrier frequency by integral multiples of the modulation frequency. In amplitude modulation the sideband amplitudes are proportional to the sound amplitudes while in frequency modulation the sideband amplitude depends on both the amplitude and the frequency of the sounds.

In the system of frequency modulation due to Major E. H. Armstrong there appear certain additional features which in part account for the demonstrated ability of the system to reduce interference from static and other electrical disturbances. Modulation is not accomplished by varying the oscillator frequency, but by employing the modulator currents to create phase-shifts proportional to the amplitude of the modulating current and inversely proportional to the sound frequency. The resultant output is put through a large frequency multiplication by cascaded amplifier stages with the final result of (if the expression be permitted) converting the phase shifts into frequency modulations. An exceedingly wide frequency band is intentionally used so that by comparison the noise-perception-band of the ear becomes small.

The conversion of frequency-change into voltage-change (mentioned in the previous paragraph) is accomplished by an improved push-pull form of the "off tune" detector principle suggested in the same paragraph. To protect these detectors against ordinary voltage-response they are preceded by a "limiter" amplifier stage whose response to voltage is set at about the normal signal level, thus limiting to this level even those noises which fall inside the perception band. The subject is not one to be discussed in a paragraph and the reader is referred to the original published description by Major Armstrong in the Proceedings of the Institute of Radio Engineers, May 1936, or the less theoretical description edited by him and appearing in "Radio" for January 1936, p. 62.

13. Uncertainty of Measuring Modulation by Antenna Current Increase—(*Note*—The rest of this Chapter is again concerned with *amplitude* modulation.) When an r.f. carrier is modulated, the r.m.s. output is increased. As the amount of increase depends upon the percentage of modulation (see table in section 5) it is theoretically possible to measure the modulation percentage by noting the rise in antenna current. Experience has shown that this is too inaccurate to be of any practical value. There are two reasons why this is so.

In measuring modulation, we are concerned with *peak* values (instead of average or r.m.s. values) because it is the peaks which may overload the transmitter and cause distortion. *If the modulation is a single pure tone,* there is a fixed relation between the peak value and the r.m.s. value. For such modulation the antenna current should increase 22 1/2 percent when the peaks of modulation are 100 percent. Unfortunately, the modulation is *not* a single pure tone (except when the transmitter is being tested with an audio signal generator) but is very complex. *For complex waves such as occur in speech and music there is no fixed relation between the r.m.s. value and the peaks.* This makes it utterly impossible to determine the value of the peaks by reading the antenna ammeter which is affected by the r.m.s. value. The increase in antenna current during modulation is a measure of modulation only to this extent—no increase indicates a low percentage of modulation; a slight increase of perhaps 5 to 10 percent indicates fairly high modulation; and an increase of more than 15 percent is almost certain to mean overmodulation. These are general statements and are by no means a measurement.

The second reason why the antenna current is an unreliable indicator of modulation is the fact that it is difficult to determine how much of the antenna current change is properly caused by the modulation. Unless the transmitter has absolutely no distortion, the positive and negative modulation peaks will not be equal.[3] If the positive peaks are greater than the negative peaks, there will be a greater tendency for an antenna current increase and the change will be greater than would be computed for the degree of modulation present. On the other hand, if the negative peaks are the greater, the antenna current will have less tendency to rise and the change will not be as large as would be expected. In fact, in extreme cases the antenna current will not rise, or may even dip during modulation. Although such an extreme only occurs when the distortion is quite noticeable, even an unnoticeably small amount of distortion can produce a large change in the computed modulation. Thus the increase in antenna current cannot be used as a measure of modulation even under test conditions (pure tone modulation).

14. "Carrier Shift" (Asymmetrical Modulation)—A class *C* amplifier tube to be plate-modulated should behave in one regard like a pure resistance, that is the plate current should vary in direct proportion to the plate voltage. This condition can be approximated (assuming there is no un-neutralized feedback) by the application of proper load and bias, and especially by the use

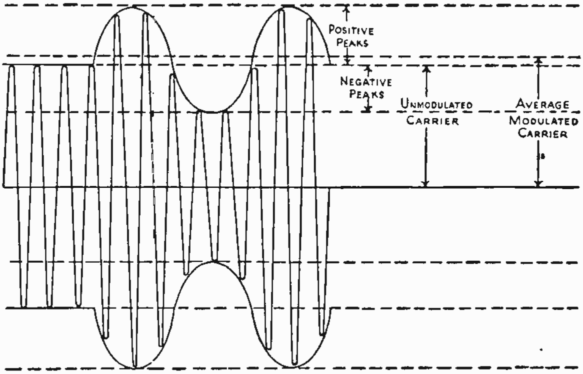

FIG. 205. Showing Positive Carrier Shift.

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[3] If the positive and negative peaks *are* equal, it does not prove that there is no distortion, since it is possible that both peaks are distorted equally.

of adequate r.f. grid input (excitation). The ratio of plate voltage to r.f. output current then remains essentially constant during voltage-variations (modulation) and there is little distortion during modulation. Failure to attain this condition will result in unequal amplitudes of the positive and negative modulation peaks, and this effect may be regarded as constituting a *shift in carrier amplitude.* Referring to figure 205 the positive peaks of modulation are greater in amplitude than the negative peaks and consequently the carrier *power* has shifted upward. The expression, "carrier shift" should *not* be interpreted to mean that the *frequency* of the carrier has changed during modulation. Such a frequency shift is termed dynamic instability of the carrier and has been discussed previously. Carrier shift upward occurs if the time average of the positive half cycles exceeds that of the negative half cycles, and downward, or negative shift, if the negative half cycles exceed the positive half cycles. The half wave linear diode rectifier shown in figure 206 is the simplest device which permits monitoring a transmitter for evidence of overmodulation or carrier shift. In operation the inductance L is coupled to the stage of the transmitter it is desired to monitor and the coupling adjusted so that sufficient radio frequency voltage is picked up to provide at least a half scale deflection on the low reading milliammeter (0–1 milliamperes) M. The filtering circuit consisting of the r.f. choke and two condensers C_1 and C_2 permit the rectified carrier to pass through the resistance R and milliammeter M. The resistance R improves the linearity of the rectifier. If the transmitter is free from carrier shift the needle of the milliammeter will remain stationary during modulation. An upward movement of the needle is indicative of positive or upward carrier shift and a downward deflection, negative or downward carrier shift.

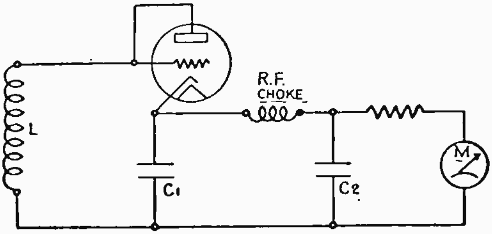


FIG. 206.

A d.c. milliammeter in the plate circuit of a plate modulated transmitter while not as sensitive or accurate as the linear rectifier, will also show an excessive movement either upward or downward if a transmitter is overmodulated, therefore, resulting in carrier shift. However, a downward movement of the needle might in some instances be attributed to the poor regulation of the power supply.

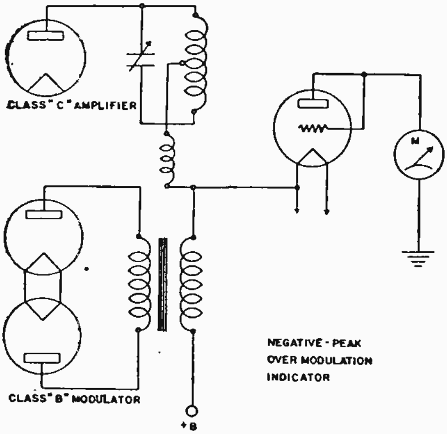


FIG. 207.

15. Negative-Peak Overmodulation Indicator—The vacuum tube rectifier as connected in figure 207 operates as an indicator of negative peak overmodulation. When overmodulation occurs the negative peaks are flattened out or cut-off resulting in a discontinuity of the carrier. When this occurs the plate voltage on the modulated tube reverses and the filament of the rectifier, while normally positive with respect to ground, becomes negative and rectified current passes through the meter *M*.

16. Electron Tube Peak Voltmeter—The electron tube peak voltmeter has for many years been used to measure the percentage of modulation of radiotelephone transmitters. The diagram in figure 208 shows the electrical connections for a peak vacuum tube voltmeter and the operation is as follows:

The potentiometer R_1 is set at zero (movable arm set at negative connection to R_1) and sufficient negative bias is applied to the grid of the tube by adjustment of potentiometer R_2 until the plate current is just at zero. Sufficient unmodulated carrier current is obtained from the transmitter by adjustment of coupling and variations in condenser C until the milliammeter reads a convenient deflection, at least half scale. The potentiometer R_1 is then adjusted until the milliammeter deflection is just at zero. The voltmeter reading E is then equal to the peak radio frequency voltage of the carrier and is proportional to the carrier current $I_{\text{car.}}$.

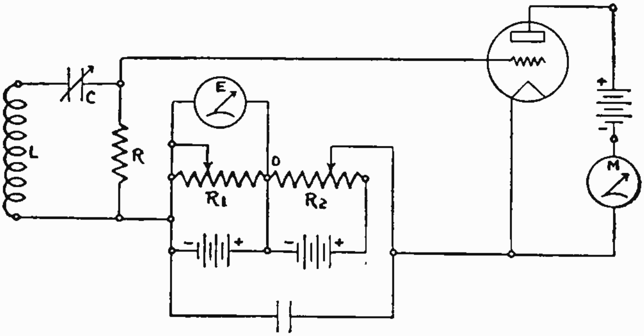


FIG. 208. Peak or Slide-Back Type Vacuum Tube Voltmeter.

The coupling is left undisturbed and sustained sinusodial modulation is applied and R_1 is then further adjusted until the plate milliammeter again just reads zero. The voltage E as read from the voltmeter is the peak value of the modulated radio frequency voltage and is proportional to $I_{\text{mod.}}$. The percentage of modulation is then calculated by substituting the voltage readings in the formula as they are proportional to the current values:

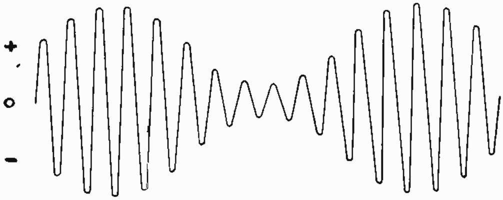
$$M\% = \frac{I_{\text{mod.}} - I_{\text{car.}}}{I_{\text{car.}}} \times 100,$$

$I_{\text{mod.}}$ = peak value of modulated carrier current,

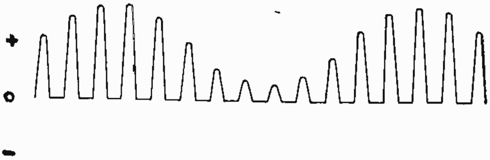
$I_{\text{car.}}$ = peak value of unmodulated carrier current.

This device permits of a determination of the percentage of modulation but does not give any indication of the symmetry of the positive and negative peaks.

17. Modulation Measurement by the Component Method—A simple means of measuring modulation is to separate the d.c. and the a.c. components of the modulated wave after it has been rectified and filtered. The d.c. is proportional to the carrier, and the a.c. is proportional to the modulation. By comparing the two values, the percentage of modulation can be found. This is shown by figure 209. *A* shows the modulated r.f. wave. After rectification it becomes a pulsating d.c. The pulsations have both radio and audio components. The r.f. components can be filtered out, and we then have the pulsating d.c. shown as *C*. The a.c. and d.c. components of this pulsating d.c. can be separated by the arrangement of figure 210. The d.c. will pass through branch 1, but not through branch 2. The a.c. component can flow through the blocking condenser into branch 2, but is kept out of branch 1 by the audio choke coil *L*–2.



"A" MODULATED R.F. WAVE



"B" MODULATED R.F. WAVE AFTER RECTIFICATION

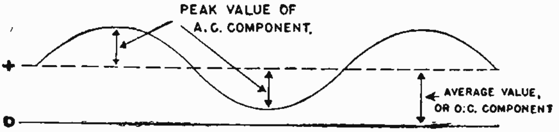


FIG. 209. Modulated R.F. Wave After Rectification and R.F. Filtering Becomes Pulsating D.C.

The d.c. component, which corresponds to the carrier, can be read very conveniently by a high resistance d.c. voltmeter. With conventional tubes (small receiving triodes with grid and plate connected are quite satisfactory) it is suggested that the r.f. pickup be adjusted to produce about 50 to 100 volts of rectified carrier. The meter should have an internal resistance of about 100,000 ohms. (This corresponds to a 0–100 volt meter with a

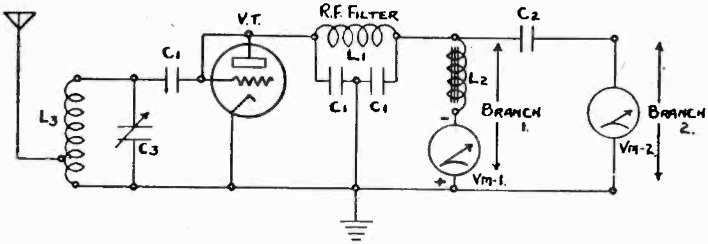


FIG. 210. Modulation Meter Using the Component Method.

Vm–1. D.C. Voltmeter 0–100 Volts. Sensitivity 1000 Ohms-Volts.
Vm–2. A.C. Voltmeter (Rectifier Type) 0–50 Volts. Sensitivity 1000 Ohms-Volts.
C–1. 0.001 Mfds. C–2. 0.25 Mfd. C–3. 0.0005 Mfd. Variable (Smaller for H.F.).
L–1. 30 Mh. L–2. 300 H. At 1. Ma. L–3. Inductance to Tune Desired Range with C3.
V.t. Any Receiving Type Triode. Grid Must Be Connected to the Plate as Shown.

Instructions: Tune C3. to Resonance as Indicated by Maximum Deflection of Vm–1. Then Adjust the Length and Position of the Antenna Until Vm–1. Reads 70.7 Volts. Vm–2. Will Now Read Full Scale (50 Volts) at 100 Percent Modulation. Multiply Vm–2. Volts by 2 to Obtain the Percentage of Modulation. See Text for Probability of Error.

resistance of 1000 ohm resistance.) It should be mentioned that mercury vapor rectifier tubes are not suited to this circuit as the constant internal drop interferes with the measurements.

The a.c. component can be measured in any one of a number of different ways. The simplest is by means of a high resistance a.f. voltmeter. The instrument must be accurate over the entire audio range, and should have a sensitivity of 1000 ohms per volt. While simple, this method is open to the serious objection that meters of the ordinary type measure the r.m.s. value, and not the peak value. Accordingly, the readings will be useful only when the modulation is a single pure tone. In addition, the reading is an average of positive and negative modulation and there is no means of measuring them separately.

18. Modulation Measurement by the Double Rectifier Method—The simplest arrangement capable of measuring peak modulation is illustrated on figure 211. The rectified and filtered modulated wave appears as a pulsating d.c. across terminals *A* and *B*. Terminal *A* is negative and terminal *B* is positive with the rectifier connections as shown. In this pulsating d.c., the average value represents the carrier, the highest voltages reached are caused by the positive modulation peaks, and the lowest voltages result from the negative modulation peaks. In series with this rectified modulated wave (or pulsating d.c. as it now is) is a variable d.c. voltage, supplied from battery *B* and adjustable by means of potentiometer *P*. The switch *S* in series with the potentiometer is merely to keep the potentiometer from discharging the battery when the device is not in use. It has no function in making measurements. The battery polarity is opposite to that of the pulsating d.c. (the rectified modulated wave). The sum of these two voltages is connected to a reversing switch (points *A* and *C* on the figure).

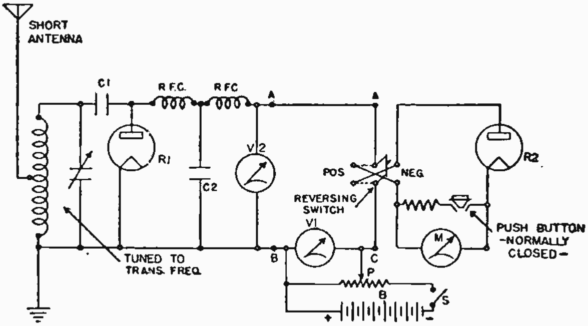


FIG. 211. Modulation Meter.

R–1, 2. Rectifier Tubes (Such as 646–37, with Grid and Plate Tied Together).
B. 100–200 Volt Battery.
M. 0–200 Microamperes.
V–1. 0–200 Volts, 1000 Ohms per Volt.
V–2. 0–100 Volts, 1000 Ohms per Volt.
P. 10.000 Ohm Potentiometer.
R.F.C. 60 Mh. Chokes.
C–1, 2. 0.002 Mfds.

When the reversing switch is in the position shown by the dotted lines, current can flow through the meter *M* only when point *C* is positive with respect to the point *A*. The rectifier *R*–2 prevents any current flow in the opposite direction. This will occur if the pulsating d.c. (the rectified modulated wave) becomes greater than the battery voltage at any portion of its cycle. By carefully adjusting the potentiometer until current just begins to flow through meter *M*, and reading voltmeter *V*–1, we can determine the highest value attained by the rectified modulated wave. This corresponds to the positive modulation peak.

If the reversing switch is thrown to the opposite position, the meter *M* will register only when point *C* is negative with respect to point *A*. The polarity of the rectified modulated wave is such as to oppose this condition. The least opposition is given at the moment of a negative modulation peak. The voltage at this instant can be measured by carefully adjusting the potentiometer to the point where current just begins to flow through the meter *M*, and then reading the voltmeter *V*–1.

The carrier voltage may be read by an ordinary high-resistance d.c. voltmeter connected across the terminals *A–B*. It is important that this meter be connected in the circuit when the measurements are made as removing it will allow an increase in the rectified carrier voltage. (The voltmeter *V*–1 cannot be used for both readings as it is necessary that both are connected at the same time.) If the carrier voltage is Vc, the positive modulation peak voltage Vp, and the negative peak voltage Vn, the percentages of modulation are expressed as:

$$\begin{aligned}\text{Positive modulation }\% &= 100(Vp - Vc)/Vc,\\ \text{Negative modulation }\% &= 100(Vc - Vn)/Vc,\\ \text{Percentage modulation}^{4} &= 100(Vp - Vn)/2Vc.\end{aligned}$$

This type of modulation meter is subject to an inherent error. All positive measurements are slightly lower than the true value, and all negative measurements are slightly higher than the true value. This occurs because the equation assumes that the voltages (instantaneous rectified carrier voltage and potentiometer voltage) are equal. Actually one of them must be slightly greater in order to produce a detectable current through the meter *M*. The error depends upon the sensitivity of this meter, and the amount of rectified carrier voltage. To assure an accuracy of 2 percent the meter should have a full scale sensitivity of 200 microamperes (0.2 Ma.) and the rectified carrier be at least 50 volts. Somewhat higher voltage is desirable provided the amount of power taken from the transmitter is not excessive. *CAUTION: THE MICROAMMETER SHOULD BE PROVIDED WITH A HEAVY SHUNT.*[5] *AFTER AN APPROXIMATE SET-*

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[4] The percentage modulation is defined by the F. C. C. as the average of the positive and negative modulation percentages.

[5] A suitable shunt is one which would make the full scale reading about 5 Ma.

TING HAS BEEN FOUND, THE SHUNT CAN BE REMOVED BY A PUSH-BUTTON TYPE SWITCH AND A PRECISE ADJUSTMENT FOUND. UNLESS THIS PRECAUTION IS TAKEN, IT IS QUITE PROBABLE THAT THE METER WILL BE BURNED OUT BEFORE THE FIRST READING IS TAKEN.

Although modulation meters of this type are very satisfactory for testing transmitters, they do not give a continuous indication of the modulation and are, therefore, not well suited for monitoring. For example, if the potentiometer is set at a voltage corresponding to 75 percent modulation, the meter will "kick" each time the modulation exceeds this figure. This should occur only during the loudest passages of music. The remainder of the time the instrument will give no indication as to the percentage of modulation unless readjusted continuously.

19. Direct Reading Double Rectifier Modulation Measurement—For monitoring it is highly desirable that the modulation meter shall indicate the percentage of modulation directly on a meter. The double rectifier type of modulation meter can be made to do this by the addition of a condenser, a resistance, and a more sensitive microammeter. Figure 212 shows the cir-

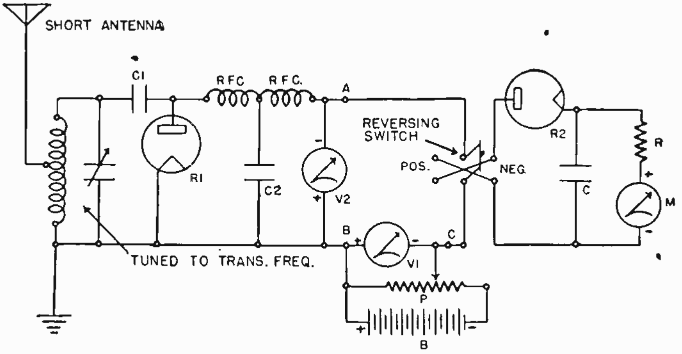


FIG. 212. Direct-Reading Modulation Meter.

Adjust Antenna Pickup Until V–2 Reads 50 V.
Adjust "P" Until V–1 Reads 50 V.
Then "M" Will Read Full Scale for 100 Percent Modulation.
C = 0.25 Mfds.
R = 1,000,000 Ohms.
M = 0–50 Microamperes.
Other Values Same as Fig. 103.

cuit arrangement. The potentiometer is fixed at a voltage just equal to the rectified carrier voltage. The voltage across the terminals *A–C* is alternating, the positive half cycles representing the positive modulation peaks, and the negative half cycles representing the negative peaks. The rectifier tube uses either series (depending upon the position of the reversing switch) of half cycles to charge the condenser *C*. This is the equivalent of a condenser-input filter. It is characteristic of such a filter that the d.c. voltage is nearly equal to the peak value of the impressed a.c. In this case the peak value of the impressed a.c. corresponds to the peak modulation. The resulting d.c. voltage is measured by means of the sensitive meter in series with the resistance *R*. The condenser *C* can charge up quite rapidly—the only resistance to charging being the internal resistance of the two rectifier tubes and a portion of the potentiometer, in all probably not more than 5000 ohms. On the other hand, the condenser can discharge only through the resistance *R*. With a capacity of 0.25 mfds. and a resistance of 1,000,000 ohms, it will take roughly 1/4 second for the condenser to discharge. Before this much time can elapse, successive modulation peaks will have renewed the charge, so that the condenser voltage will always stay close to the peak value of the rectified voltage. This action is shown in the upper part of figure 212*A*.

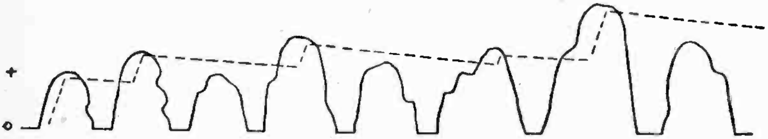


Fig. 212, A.

– – – – – – – Condenser Voltage.
———————— Second Rectifier Output.

With the Circuit of Figure 104, the Condenser Charges Rapidly but Discharges Slowly, Thereby Producing a Steady Voltage Nearly Equal to the Highest Instantaneous Peaks.

The first peak charges the condenser almost to its peak value. The condenser is still fairly well charged when the second peak comes. This raises the condenser voltage almost to the peak value. The third peak is lower but does not affect the condenser because the condenser voltage has not fallen to that point. As this process goes on, it will be observed that the condenser voltage reflects the peaks very well. Also note that its variation is very small so that a meter would show a fairly steady reading, rising rapidly when a new peak is reached, and then falling back slowly. This is ideal for modulation monitoring.

With the suggested resistance value of 1,000,000 ohms, and a carrier pick-up of 50 volts, the microammeter should read full scale (50 microamperes) for 100 percent modulation. The rectified carrier voltage is read across *A–B* in the usual way with a sensitive d.c. voltmeter. (Suggest 1000 ohms per volt.)

20. Commercial Monitoring Devices and Requirements—Commercial monitoring devices, of which some have been approved by the Federal Communications Commission for use at broadcasting stations, are in general based on the same principles as the simple devices so far described. However they have been refined to permit more rapid and convenient operation, also to make possible some additional measurements. Since such devices change from time to time the operation should in each case be based on a close reading of the manufacturer's instructions for the device. To attempt to carry the practices of one device over to one of a different make may result in serious errors. *Commercial monitoring devices for broadcast stations are described in the last part of this Chapter.*

Rule 33.8. (*a*) A licensee of a broadcast station will not be authorized to operate a transmitter unless it is capable of delivering satisfactorily the authorized power with a modulation of at least 85 percent. When the transmitter is operated with 85 percent modulation, not over 10 percent combined audio frequency harmonics shall be generated by the transmitter.

(*b*) All broadcast stations shall, on and after November 1, 1936, have in operation a modulation monitor approved by the Commission.

(*c*) The operating percentage of modulation of all stations shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice and in no case less than 85 percent on peaks of frequent recurrence during any selection which normally is transmitted at the highest level of the program under consideration.

(*d*) The Commission will, from time to time, publish the specifications, requirements for approval, and a list of approved modulation monitors.

The specifications that the modulation meter shall meet before it will be approved by the Commission are as follows:

1. A d.c. meter for setting the average rectified carrier at a specific value and to indicate changes in carrier intensity during modulation.

2. A peak indicating light or similar device that can be set at any predetermined value from 50 to 120 percent modulation to indicate on positive peaks, and/or from 50 to 100 percent negative modulation.

3. A semi-peak indicator with a meter having the characteristics given below shall be used with a circuit such that peaks of modulation

of duration between 40 and 90 milliseconds are indicated to 90 percent of full value and the discharge rate adjusted so that the pointer returns from full reading to 10 percent of zero within 500 to 800 milliseconds. A switch shall be provided so that this meter will read either positive or negative modulation and, if desired, in the center position it may read both in a full-wave circuit.

The characteristics of the indicating meter are as follows:

Speed—The time for one complete oscillation of the pointer shall be 290 to 350 milliseconds. The damping factor shall be between 16 and 200. The useful scale length shall be at least 2.3 inches. The meter shall be calibrated for modulation from 0 to 110 percent and in decibels below 100 percent with 100 percent being 0 db. The accuracy of the reading on percentage of modulation shall be ± 2 percent for 100 percent modulation, and ± 4 percent of full scale reading at any other percentage of modulation.

4. The frequency characteristics curve shall not depart from a straight line more than ± ½ db from 30 to 10,000 cycles. The amplitude distortion or generation of audio harmonics shall be kept to a minimum.

5. The modulation meter shall be equipped with appropriate terminals so that an external peak counter can be readily connected.

6. Modulation will be tested at 115 volts ± 5 per cent and 60 cycles, and the above accuracies shall be applicable under these conditions.

7. All specifications not already covered above, and the general design, construction, and operation of these units must be in accordance with good engineering practice.

21. Cathode Ray Oscilloscope Modulation Measurements—The cathode ray oscilloscope is especially valuable because the modulation can be seen continuously on the screen. It is not very satisfactory as a *measuring* device because the pattern is quite small, even with the comparatively large tubes. It is likely that an accuracy of 10 percent is about the best that can be obtained with a 5″ tube; with smaller tubes it is even less. The oscilloscope should be considered as a supplement to the more accurate modulation monitors, the cathode ray tube on the other hand affords advantages in trouble shooting and for the making of photographic records.

Cathode ray tubes can be utilized in several ways, differing in the source of the sweep voltage. These ways will be discussed separately in order to show their advantages and disadvantages.

A. Modulated r.f. on Vertical Plates, and 60 Cycle a.c. on the Horizontal Plates

The use of commercial 60 cycle a.c. to supply the sweep voltage has the one advantage of simplicity as it requires no additional apparatus. It has several serious disadvantages. For one thing, unless the modulation frequency *happens* to be 60 cycles or an exact multiple of 60 cycles, the whole pattern will appear to be in rapid motion. This is true of all music where the frequencies of properly tuned instruments bear a definite relation to 256 cycles. This lacks 16 cycles of being an exact multiple, thus producing rapid motion. For another thing, the 60 cycle sweep goes back and forth across the screen 120 times per second. Vision persists for about 1/15 of a second, so that at least 8 separate traces can be "seen" at once. Unless the screen is very "fast" it too will retain the image for a fraction of a second, increasing still more the number of images that will be seen at the same time. The result is a jumble of images, constantly changing, that is difficult to watch and practically impossible to measure.

A third objection (which holds for all cases where the modulated radio-frequency voltage is applied directly to either set of plates) is that the beam covers an *area* on the screen. This is shown on figure 216. This involves two faults—the negative peaks are covered over by the positive peaks that may occur on the following traces; and the whole figure is not very well focused. The lack of focus is due to the heavy beam current that is necessary to produce a brilliant image over the large area. When the figure is only a *line* the beam current is much more concentrated and gives a much brighter image even with lower beam current. At the lower current the focusing action is much more perfect. This defect is characteristic of all tubes on the market at present and no doubt will be eliminated by future improvements.

The only really definite measurement that can be made on the negative peaks is the point where bright flashes appear along the center line. They indicate 100 percent negative peaks. At such instants the r.f. is momentarily cut-off and the pattern becomes a line. The line is much more brilliant than when the beam was spread over an area, thus making the flashes stand out very definitely.

B. Modulated r.f. on Vertical Plates, and Sweep from a "Saw-tooth Wave" Generator on Horizontal Plates

Replacing the 60 cycle sweep voltage by a "saw-tooth wave" is a decided improvement. During single-frequency modulation the sweep frequency can be adjusted to equal the modulation frequency or an exact integral fraction thereof. This makes the pattern stationary, and to a certain extent the succeeding traces coincide. During music-transmission the sweep frequency is adjusted to 256 cycles or an integral fraction thereof. Instead of a jumble of moving figures we can thus usually obtain a single pattern. The pattern changes with the inflections of the voice or music, but this is much less violent than the rapid motion resulting from improper sweep frequency. The sweep frequency may be synchronized by hand, or the sweep oscillator may be controlled by the modulation so as to secure precise synchronism automatically. In this latter scheme, the sweep frequency is adjusted roughly by hand and fed a small modulation-frequency voltage through the proper terminal of the oscilloscope. When an exact ratio is approached, the oscillator will pull into step.

For measuring the percentage of modulation, a low sweep frequency is desirable—perhaps 32 cycles. For examining the wave-shape of the modulation, a higher frequency may be desirable. In either case the precise adjustment can be maintained automatically.

C. Modulated r.f. on the Vertical Plates and a Portion of the Modulating Voltage on the Horizontal Plates

If a portion of the modulating voltage is used for the sweep, the resulting figure is very simple—a trapezoid. The figure is stationary, but the shape changes with the percentage of modula-

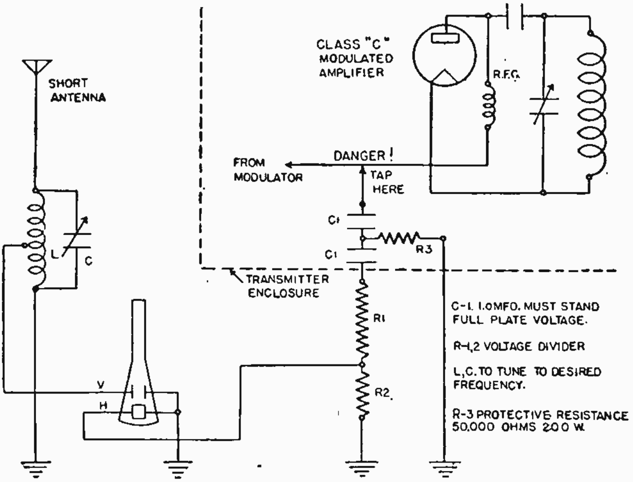


FIG. 213. Circuit for Obtaining Trapezoid Pattern—*Warning: Dangerous!*

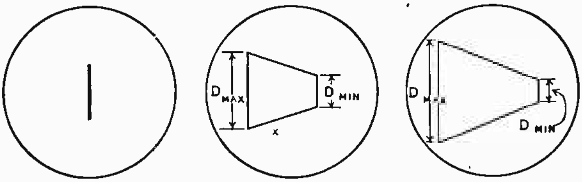
C-1. 1.0 MFD. MUST STAND FULL PLATE VOLTAGE.

R-1,2 VOLTAGE DIVIDER

L, C. TO TUNE TO DESIRED FREQUENCY.

R-3 PROTECTIVE RESISTANCE 50,000 OHMS 200 W.

tion. Figure 213 shows how the oscilloscope is connected, and figure 214 shows the figure for several different percentages of modulation. This pattern is very easy to photograph or to measure. In addition to showing the percentage of modulation, this pattern is valuable because it shows overloading and overmodulation very clearly. In figure 215*A* overloading is clearly indicated as the r.f. fails to increase with the modulation. The dotted lines show how the figure would appear if the overloading was corrected. This does not show the cause of the overloading, but the effect of remedies can be quickly and definitely checked. Figure 215*B* shows overmodulation. The modulating voltage is greater than is necessary to produce complete cut-off of the carrier on



0% 50% 80%

FIG. 214. Trapezoid Patterns for Different Modulation Percentages. R.F. on Vertical Deflection Plates, Modulating Voltage on Horizontal Deflection Plates.

$$M = 100 \times \frac{(D_{max} - D_{min})}{(D_{max} + D_{min})}$$

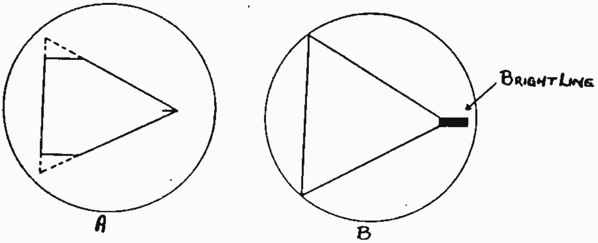


FIG. 215.

Overloading R.F. Failing to Increase Properly on Positive Peaks. This Pattern Indicates Distortion When Modulation Exceeds 60 Percent. See Text for Causes and Remedies.

Over 100%.

Over Modulation on Negative Peaks Shows as a Bright Line at the Apex of the Triangle. (R.F. on Vertical Deflection Plates, and Modulating Voltage on Horizontal Deflection Plates.)

negative peaks. This shows up as a bright line extending from the right-hand apex of the triangle.

In applying this method, two cautions are necessary. First, since certain types of overloading and distortion can be plainly seen, operators sometimes assume that a perfect triangle pattern is a guarantee of no distortion. This is not true as distortion in any of the preceding audio stages will not show up. The second caution is with respect to the high voltages involved. A failure of any one of several parts would result in placing the entire modulator plate voltage on the oscilloscope. It is, therefore, recommended that the case of the oscilloscope be grounded very carefully and all wiring should be protected against contact by insulation capable of withstanding at least *twice* the modulator plate voltage. This *twice* is not a safety factor because during modulation the voltage at the modulator plate approaches twice the d.c. value on modulation peaks.

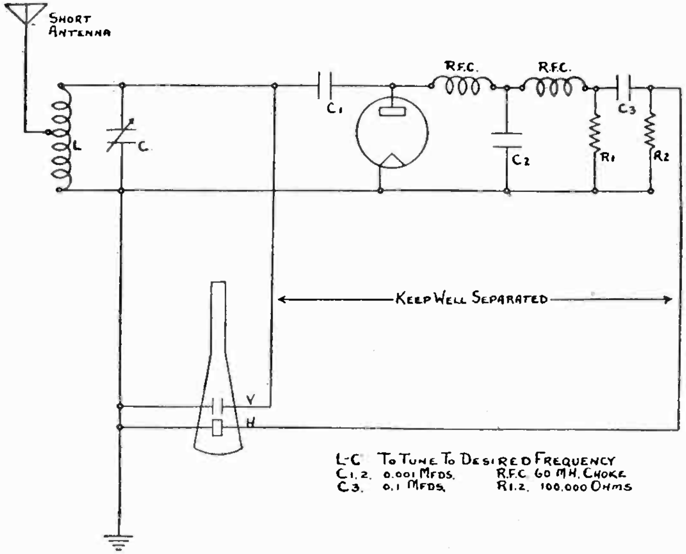


FIG. 216.

A safer arrangement is shown by the diagram, figure 216. The carrier is picked up by the short antenna and is rectified to provide its own sweep voltage.

With the trapezoid figure, modulation is computed by measuring the height of the pattern on both sides. Denoting the greater height as $D_{\text{max.}}$ and the least height as $D_{\text{min.}}$, the modulation percentage is:

$$\text{Percentage modulation} = 100 \left(\frac{D_{\text{max.}} - D_{\text{min.}}}{D_{\text{max.}} + D_{\text{min.}}} \right).$$

Due to the small size of the figure (it is limited by the area of the screen) the dimensions cannot be measured accurately. As a consequence the measurements cannot be depended upon to closer than about 10 percent.

The cathode ray patterns shown in figure 217 to figure 229 inclusive are shown by courtesy of John F. Rider as published in his book, The Cathode-Ray Tube at Work. They were obtained by equipping a transmitter with many controls so as to permit correct as well as incorrect adjustments and a variable percentage of modulation. The patterns shown are typical of the conditions stated and tests conducted on other transmitters under similar conditions will result in patterns similar to these herein, but not necessarily identical. Mr. Rider states that it has been his experience that the closest resemblance is obtained when the trapezoidal pattern is employed rather than the modulated wave envelope pattern.

The transmitter used for the tests employed a class *B* modulator system and the effect of the departure from the correct impedance load upon the modulator is shown in a number of illustrations.

In all the tests the modulating frequency was 400 cycles and the input was of sine waveform. Where an audio waveform is shown, the vertical plates are connected to the source of the audio modulation voltage and the oscillograph is adjusted for regular waveform observation as described previously in this Chapter. Whenever trapezoidal patterns are shown and no statement is made to the contrary, the audio voltage for the horizontal displacement is secured from the modulator stage output circuit.

The patterns shown in figure 217 were obtained when correct 100 percent modulation was being accomplished. Diagram 217*C* is the same as 217*B* except for a 45 degree phase shift. Sometimes such pattern can be rotated by means of a condenser across the audio source to produce the more convenient 217*B* form, which permits modulation linearity to be judged by the straightness of the triangle's sides. This is difficult for the 217*C* form. Directly below, as figure 218*A* and *B* are shown patterns for the same conditions with the single exception that the r.f. grid input

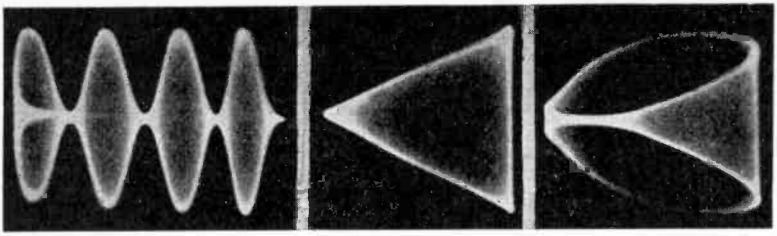


Fig. 217, A, B, C.

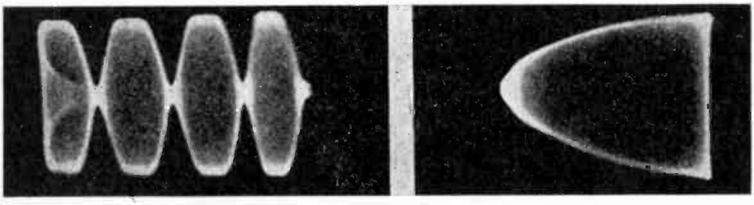


Fig. 218, A, B.

Fig. 219, A, B, C.

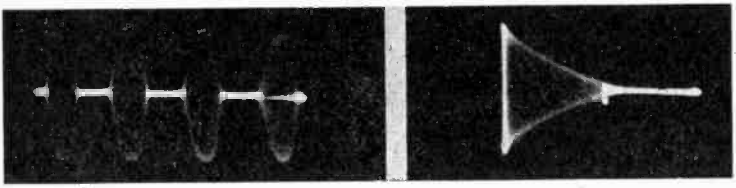


Fig. 220, A, B.

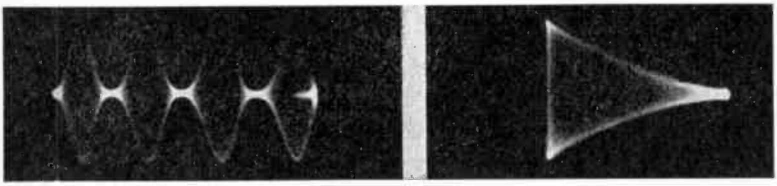


Fig. 221, A, B.

to the modulated stage has been lowered until the carrier is insufficient to "fill the modulation peaks." This is an extreme case as is shown by the early failure of the triangular pattern to follow the direction in which the sides first start outward. Other incorrect conditions shown by the various oscillograms are as follows:

Figure 219, inadequate r.f. input as in figure 218 plus overmodulation, which is usually characterized by the bright white lines appearing at the negative peaks of this figure. The pattern shown as 219*C* differs from 219*B* in the same manner as explained for figure 217.

Figure 220 shows the effect of insufficient excitation and excessive bias.

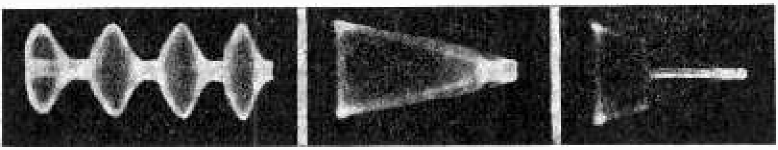


FIG. 222.

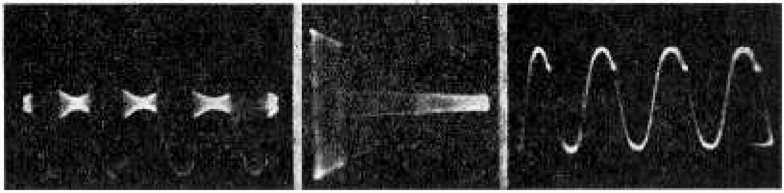


FIG. 223.

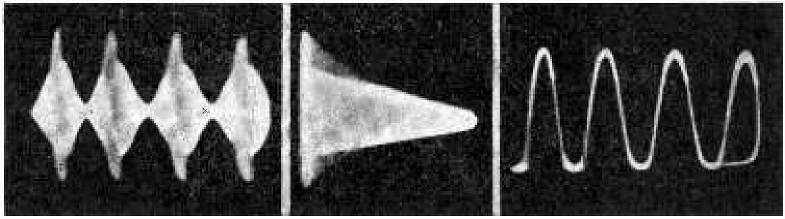


FIG. 224.

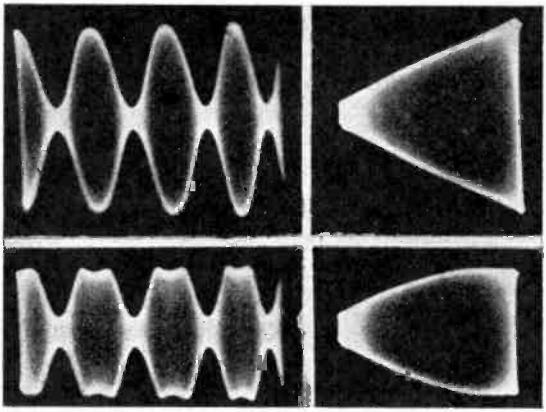


FIG. 225.

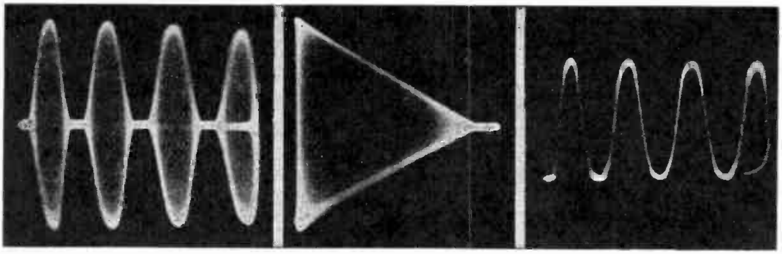


FIG. 226.

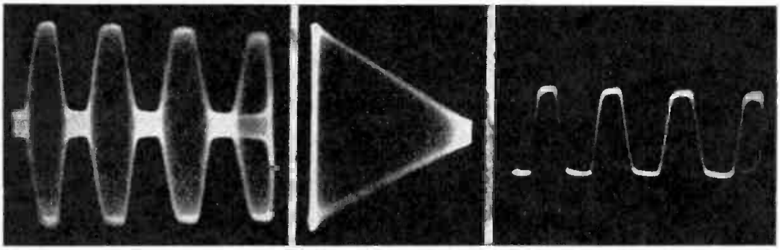


FIG. 227.

Figure 221 shows approximately correct r.f. input but non-linear operation of the stage, probably occasioned by incorrect bias.

Figure 222 shows the very severe sort of distortion occasioned by imperfect neutralization, which causes abrupt changes in output to take place during the cycle of modulation voltage. This is bad but intelligible.

Figure 223 shows a more extreme case of the same thing, with intelligibility severely injured.

In figure 224 the regeneration is still greater, oscillation is taking place during a considerable part of the modulation cycle and the effect on speech is easily understood to be ruinous.

Figure 225 shows the importance of proper tuning of the tank of the modulated tube. The upper two diagrams are for correct tuning and are seen to be of the same grade as figures 217*A* and 217*B*, though for a slightly lower percentage of modulation. By merely mistuning the tank it was found possible to obtain the severe distortion of the lower diagrams of the same figure.

Figures 226 and 227 show the effect of incorrect loading of the class *B* modulator stage. In each case the left and central figure have the same significance as before while the right-hand one shows the audio wave form as measured across the audio transformer secondary. Figure 226 was obtained with a 6000 ohm load on the audio system—too high, while figure 227 was obtained with a 2000 ohm load—too low.

Figure 228 shows two other sorts of audio difficulty. In the left-hand column the modulation is reasonably linear but severely distorted audio is being used (see lower left pattern which is the audio wave), and in consequence the triangle and the upper diagram also show bright and dark portions. In the right hand column of the same figure a further difficulty exists in that the audio power was insufficient. The trapezoidal figure showed that complete modulation had not been effected though the full available audio power was in use, and overload-distortion of the audio wave form is very evident from all 3 diagrams in this column.

Figure 229 is merely illustrative of the large number of unexpected patterns which may be encountered during tests. The hourglass figure is due to 60 cycle hum in the presence of 1000 cycle modulation, while the complex figure is due to an accidental leakage from audio-frequency wires left connected to nearby terminals. The latter illustrates the important point that the cathode ray tube is an essentially no-current voltmeter and may be disturbed by stray field which would be short-circuited and

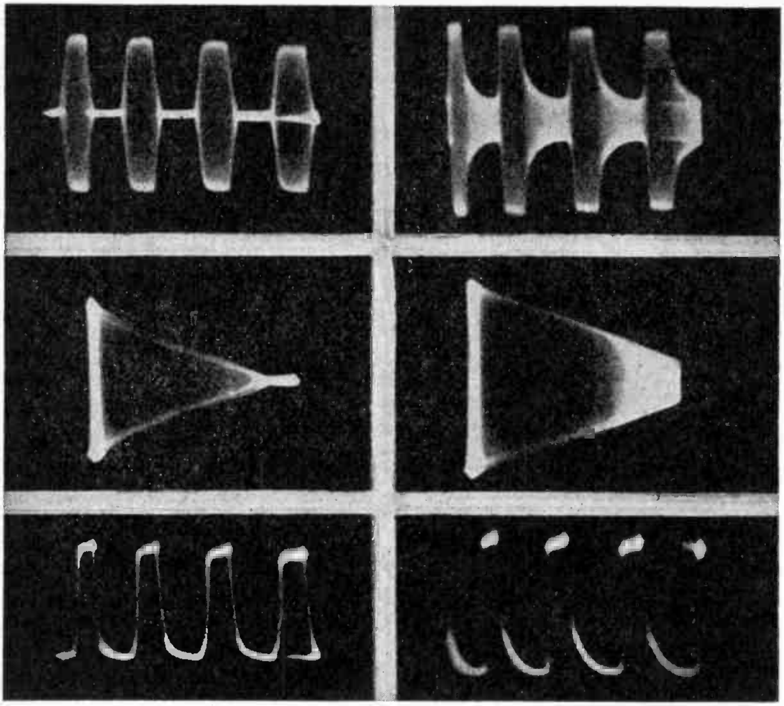


FIG. 228.

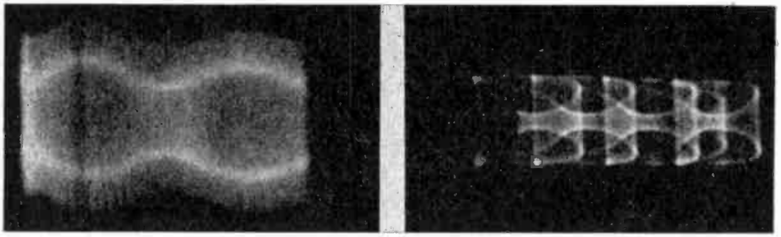


FIG. 229.

eliminated from consideration by the grosser machinery of ordinary meters.

Grid Bias Modulation Patterns—The patterns shown in figure 230 are shown by courtesy of Radio and were published in that magazine for October, 1935, accompanying an article by Frank C. Jones entitled, Oscilloscope Studies of Plate and Grid Modulation.

The trapezoidal figures show undesirable modulation characteristics more clearly than the modulated wave patterns. Commenting on the patterns Mr. Jones states, " inability to modulate 100 percent linearly, is readily shown when grid current flows. To obtain a good figure, it is necessary to have a heavy antenna load, zero grid current and steady plate current, otherwise grid modulated phone patterns usually look like the figure noted as typical heavy grid modulated phone. The grid current in the latter case ran up to a few milliamperes and the plate current at about 300 ma. Linear modulation was not obtained with more than 275 ma. Reducing the grid r.f. excitation, rather than changing antenna load, is the proper way to vary the current. Too low a value of *C* in the final tank circuit will also cause non-linearity, and values as high (or higher) than values needed for plate modulation, are necessary."

22. Class B r.f. Amplifiers—The class *B* linear amplifier as used after a modulated stage requires critical adjustments of loading, bias and excitation. The necessity of having good regulation of the r.f. driver has been stressed in the previous chapter. If the linear amplifier is operated with bias beyond cut-off it is possible to have complete modulation of the positive peaks even though the class *C* amplifier stage is modulated only 60 to 70 percent. This was intentionally done in several early broadcast transmitters for the purpose of " picking up modulation." When done accidentally after a fully modulated class *C* stage it produces over-modulated output.

A positive carrier shift in a linear amplifier usually indicates excessive negative bias or too low an output impedance, or both. A negative shift is indicative of too low a bias, excessive r.f. excitation or load impedance too high, or the combination of all three.

23. Adjacent-Channel Interference—It is desired to review here some of the conditions which if existent usually result in causing interference to other stations.

1. Overmodulation—Whenever a transmitter is modulated in excess of 100 percent (or the modulation capability exceeded

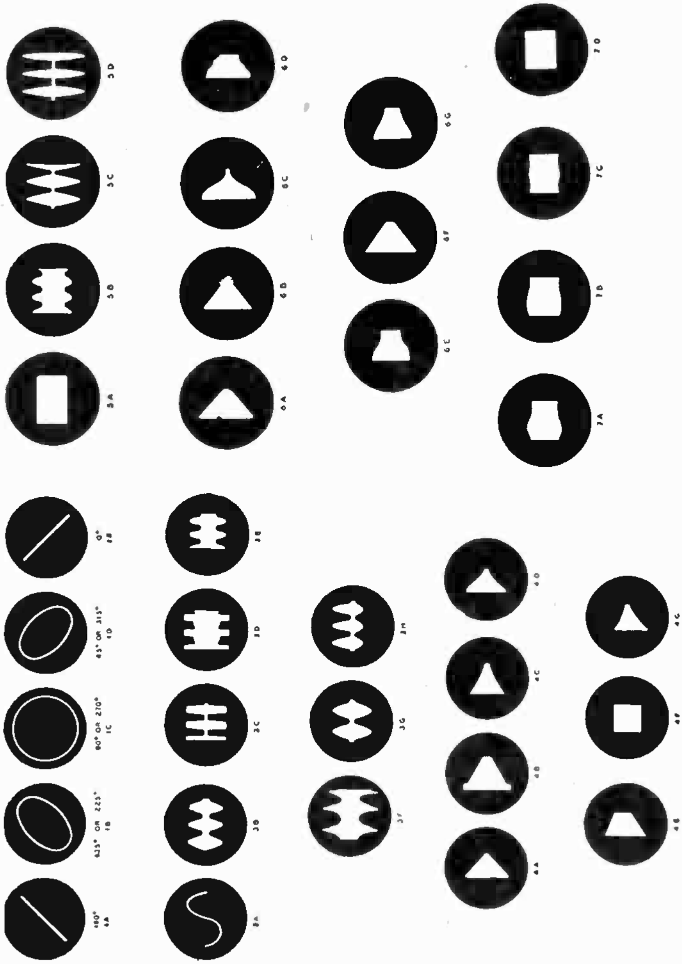

5D
5C
5B
5A
6D
6C
6B
6A
6G
6F
6E
7D
7C
7B
7A
0° 1E
45° OR 315° 1D
90° OR 270° 1C
135° OR 225° 1B
180° 1A
2E
2D
2C
2B
2A
3H
3G
3F
4D
4C
4B
4A
4G
4F
4E

FIG. 230.

before reaching 100 percent) interference beyond the normal band width required for transmission results. "Modulation capability" is the limit of symmetrical modulation.

2. *Parasitic Frequencies*—Certain types of high voltage tubes utilize the effects of secondary grid emission to aid excitation during the positive swing. This results in a form of regeneration and at times may result in the generation of self-oscillations having a frequency determined by the grid circuit. Other causes may likewise produce parasitic frequencies. See section 81 of Chapter 5.

3. *Improper Neutralization*—Failure to neutralize the class *B* or *C* amplifier properly will frequently cause generation of spurious sidebands during peaks of modulation.

4. *Phase Modulation*—There are several conditions which may cause phase modulation, such as poor regulation of the driving stage, the presence of a regenerative or degenerative voltage in the grid circuit (picked up from the tank or antenna circuit) or failure to tune the tank circuit to exact resonance.

5. *Frequency Modulation*—Frequency modulation is also a frequent cause of excessive band width of an amplitude modulated transmitter. It may be caused by the crystal oscillator being amplitude modulated by reaction from the modulated amplifier. This condition if present, can be identified by failure to secure a steady zero beat during modulation when the carrier is tuned in on a receiver and heterodyned by a stable oscillator.

24. Miscellaneous Modulation Difficulties. Defective Tubes—When distorted modulation cannot be remedied by adjustments of excitation, loading and bias, it is well to look for a defective tube particularly in the modulator, modulator driver or the tube being modulated.

If the modulation monitor shows excessive negative peaks and carrier shift downward with normal r.f. excitation there is evidence of lack of filament emission of the tube being modulated. Before subjecting the tube to an emission test or substituting another tube the filament voltage should be checked *at the socket* terminals.

If the carrier shift is downward and the modulation peaks equal, the power supply should be checked for regulation. Usually this condition is observed when the class *B* modulator and modulated amplifier have a common power supply.

Class *B* modulators are very likely to produce distortion due to the necessity of a close balance between the two tubes. Since it is rare for both tubes to develop trouble at the same time, tube trouble can usually be noticed by an unequal swing on the two plate current meters. (This is impossible if only one meter, reading the total current, is provided.) Unequal swings may be due to other causes. For this reason, the two tubes should be switched in the sockets. If the low swing changes to the other meter when the tubes are shifted, the trouble is most likely a defective tube. The tube showing the lower plate current swing should be replaced. If practical, it is better to replace both tubes with a pair which have been specially selected for a good balance. If the same meter continues to show a low swing when the tubes are interchanged, the trouble is not with the class *B* tubes but is in the modulated amplifier (the r.f. portion of the transmitter). (This assumes that the driver and all the preceding audio amplifier stages are operating properly—that is, why it is recommended that the checking begin in the speech amplifiers.) Likewise, if the class *B* plate current swings are equal for both tubes it is probable that the distortion is in the r.f. end.

A frequent cause of distortion that is difficult to isolate is a weak plate supply rectifier tube. This shows up at once when the plate voltages or plate currents are checked. The remedy is obviously to replace the rectifier tube. This trouble usually develops rather slowly and can be avoided if all tubes are tested at reasonable intervals.

If one of the class *A* stages is in trouble, the most likely cause is a defective tube. This can be conveniently tested by substituting a new tube. If the trouble persists, it is necessary to check the operating voltages. Apart from defective connections, resistances often change in value, or go open. Likewise, by-pass condensers puncture and short-circuit plate or grid bias voltage. Do not neglect to measure the filament voltage as improper voltage (too high as well as too low) may cause low filament emission and thus introduce distortion. Occasionally some fault will short-circuit a portion of a de-coupling circuit. This will not change the voltages on the tube and is therefore often difficult to locate. Such trouble can be cleared only by carefully checking each circuit item.

If class *B* modulators are used, it must be noted that the stage immediately preceding the modulator (the "driver" stage) may show a slight increase in plate current in normal operation. In this case trouble in this stage will be indicated by an abnormal action of the plate current—either by dipping instead of increasing, or by an irregular shift, easily distinguished from the small upward pulses that follow heavy modulation when operating normally. A large upward shift indicates trouble in the class *B* stage rather than trouble in the driver.

Most radiotelephone transmitters have several stages of audio amplification, as well as the modulators, included in them. As no jacks are provided (the level is much too high to permit it) the performance of each stage cannot be checked by a listening test. As a general rule, all stages preceding the modulator are operated in class *A*. Fortunately, class *A* amplifiers indicate distortion by a change in their plate current. Accordingly, a plate current reading should be taken of each speech amplifier stage in order, starting at the input. The proper order is necessary because the distortion introduced by the defective stage passes an unsymmetrical signal to the next stage and may cause a varying plate current in that stage even though it is working properly.

RCA MODULATION MONITOR

TYPE 66-A

25. Operation—Briefly the operation of the type 66-A monitor may be described as follows: A small radio frequency voltage is obtained from the tank circuit of the final amplifier by means of a small pick-up coil which is in turn connected to the r.f. input terminal of the monitor. A part of this r.f. voltage—controlled by a series rheostat in the input circuit—is fed to a diode rectifier consisting of an RCA-1-V Radiotron. Filtering removes the r.f. component in the output of this rectifier, allowing a pulsating direct current to remain. A meter reads the average value of

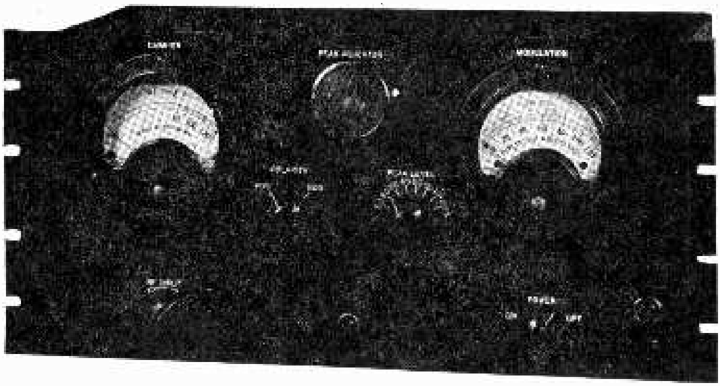


FIG. 231. 66A Modulation Monitor.

this current, which is, of course, proportional to the average value of the transmitter carrier. By means of the input r.f. control this meter is set to read 100 for normal or unmodulated carrier. Then, if unsymmetrical modulation occurs the meter will read, directly in percentage, the resulting change in average carrier value. And —if the input coupling is fixed—will also serve as a check on carrier changes due to other causes.

Peak-Flash Indicator and Relay Circuit—The audio component of the voltage across the load resistance of the first diode (above) is used to drive the peak-flasher and modulation metering circuits. The flasher circuit consists of an RCA–76 as a triode detector driving an RCA–885 grid-controlled gas triode. The latter is normally biased beyond cut-off by an amount determined by the setting of the peak-level selector. When the audio voltage exceeds the value determined by this setting, the tube passes current and operates the neon lamp and relay in its plate circuit. In addition to the flasher indications on peaks provided by the neon lamp, the high-speed relay included in Type 66–A—which is capable of breaking 6 amperes at 110 volts a.c.—may be utilized to operate an auxiliary indicating light, alarm or peak counter. (This describes the operation of the peak indicator required in paragraph 2 of F. C. C. specifications.)

Percent Modulation Indicator Circuit—The modulation metering circuit—which is entirely separate from the flasher circuit—is essentially a two-tube v.t. voltmeter. In this circuit the audio voltage across the load resistor of the diode rectifier (above) is rectified by an RCA–76 operating as a diode detector, and used to charge a condenser. This condenser has only a very high resistance load, so that it discharges at a relatively slow rate. The voltage across it controls the grid of a second RCA–76 connected as a triode. The plate current of the latter is, of course, proportional to the degree of modulation, and the microammeter in the anode return is, therefore, marked to read directly in percent. The plate supply of this modulation metering circuit is so designed that the meter reading is independent of supply voltage over a considerable range. (Paragraph 3 of F. C. C. specifications as to a positive and negative modulation indicator.)

Time Characteristics of Modulation Meter—Since the meter needle is required to closely follow the peaks of modulation, a high-speed action is necessary. However, this high-speed action by itself would result in such violent fluctuations of the pointer that accurate reading would be very difficult and constant monitoring extremely tiring. The slow discharge circuit mentioned above overcomes this. It allows the pointer to rise very rapidly on peaks, but markedly retards the falling off from these peaks. Thus between peaks a "floating" reading is obtained which greatly facilitates monitoring and, in addition, further increases the rapidity of response to peaks since the upward travel required of the pointer is ordinarily much less. The time characteristics thus obtained are most convenient—and comply with the F. C. C. requirements in every respect.

Response Characteristics of Modulation Meter—The Type 66–A Monitor because of very careful design and construction, meet in every respect the stringest requirements set up by the F. C. C. as to response, accuracy and stability. This means: (*a*) that the frequency characteristics do not depart from a straight line by more than ± 5 db from 30 to 10,000 cycles, (*b*) that the accuracy of the percentage modulation indications is within ± 2 percent at 100 percent modulation, and within ± 4 percent of full scale reading at any other percentage of modulation, and, (*c*) that the percentage modulation indications are unaffected by ± 5 percent changes in supply voltage.

Provisions for Transmitter Response Measurements—The new Modulation Monitors provide a convenient means of determining the transmitter amplitude characteristic. The modulation meter is calibrated in decibels below 100 percent modulation as well as in percent modulation. However, since the percentage scale is substantially linear, the db scale is necessarily too cramped below —15 db to be useful in amplitude measurements. To extend the range for lower amplitudes of modulation a shunt resistor is provided which, when connected, permits the r.f. input to be increased approximately 10 db, thereby increasing the reading on the modulation meter by the same amount. This extends the useful range approximately 10 db.

26. Detailed Explanation of Operation—The following is a more detailed explanation of the operation of the monitor. Referring to figure 232 the r.f. signal to be monitored is impressed across the input binding posts, controlled by the "r.f. Input" control, and rectified by the first diode (RCA 1–V). The r.f. component is then filtered out of the signal by $C1$, $L2$, $C2$, allowing a pulsating direct current to flow in the first diode load resistor, $R2$, $R3$. The "Carrier" meter, $M1$, reads the average value of this direct component of the voltage across this load resistor excites two indicating devices—one a meter, $M2$, calibrated directly in modulation percentage and decibels, the other, a flasher

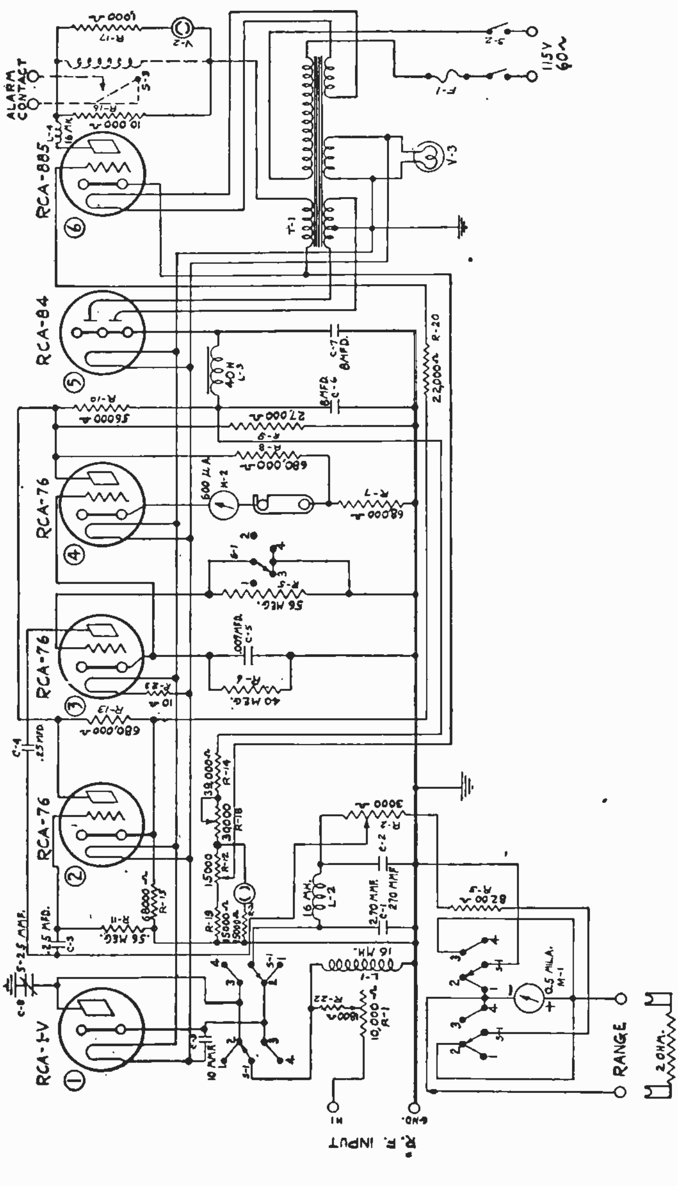


FIG. 232. Schematic Diagram 66A and 66B Modulation Monitor.

and alarm circuit for providing a warning when a certain degree of modulation is exceeded.

The modulation meter is driven in the following manner: The previously referred to audio component is rectified by the second diode detector (RCA–76) and charges a condenser, *C*5. Since this condenser has only a 50 megohm load, *R*6, across it, appreciable time is required for it to be discharged. The voltage across this condenser is impressed across the grid circuit of a voltmeter tube (RCA–76) which has the modulation meter, *M*2, in its cathode circuit. The only unusual feature of this voltmeter tube circuit is its indifference to plate voltage changes. The resistance-condenser combination referred to above gives the modulation meter the characteristic of rapid increases and slow decreases in readings. This feature serves two important functions. It makes for better readability of the meter, since the needle does not fluctuate as violently as if it were allowed to try to follow the audio voltage, and it allows the meter to read peaks of shorter duration then it otherwise would be capable of indicating.

The flasher (a neon lamp, *V*2) and relay, *S*3, are driven in the following manner:

The same audio component referred to above is impressed across the grid circuit of a triode detector (RCA–76). The output of this detector exists across the cathode resistor, *R*15, and is impressed across the grid circuit of the relay tube, RCA–885. The bias on the relay tube is controllable from the front panel, and this control is calibrated from 50 to 120, representing percent modulation. The relay tube is normally biased to cut-off, and when the audio voltage exceeds a value determined by the " Peak Level " control the tube passes current and operates the relay and neon signal lamp which are connected in its plate circuit. The contacts of the relay are connected to binding posts so that the relay may be used to key a counter or an auxiliary alarm system such as a buzzer, bell, or additional lamp.

Two binding posts are provided for shunting the " Carrier " meter with a resistor which will be furnished with the monitor. The function of this resistor is to change the calibration of the modulation meter by 10 decibels. With this shunt, the zero level becomes — 10 db, — 20 db becomes — 30 db, etc. The purpose of this added range is to facilitate using the instrument for taking amplitude characteristics of the transmitter. Appreciably more r.f. power is required by the monitor when this shunt is employed, and it will usually be necessary to increase the coupling to the transmitter.

Two binding posts are provided for the insertion of one or more additional modulation meters when desired. These two posts are shorted by a link when not in use. A switch is provided for selecting the polarity of the audio peak being monitored. This is effective on both the meter and flasher circuits.

27. **Installation**—The monitors are designed for a standard 19 inch relay rack mounting. The dust cover is slotted so that permanent connections can be made to the binding posts in the rear without interfering with its removal.

A 110–120 volt 50–60 cycle power supply at 40 watts is required at the power receptacle.

The r.f. input binding posts should be connected to a small pick-up coil which is coupled to the tank circuit of the final amplifier.

The "Meter" binding posts are for the connection of an additional "Modulation" meter external to the instrument, whenever desired. When no additional meter is used, these binding posts should be shorted by the link provided.

The "Range" binding posts are normally open, but are shunted by a resistor provided for that purpose when it is desired to check very low percentages of modulation, such as for amplitude characteristics.

The 66A includes a high speed relay which is connected in the plate circuit of the relay tube (RCA–885). The purpose of this relay is to provide a pair of heavy contacts which are keyed by over-modulation. The contacts of the relay used are rated at 6 amperes, 115 volts a.c., and are intended to be used for keying a counter or alarm circuit. In the case of the 66B monitor, no relay being included in the equipment, the voltage across a resistor in the plate circuit of the relay tube is available at two binding posts in the rear. If the counter or alarm to be used requires 110 volts a.c. at not more than 50 milliamperes it can be operated by this voltage. If it requires different operating voltages or more power, a relay (which may be the type included in the 66A) must be used.

In the type 66A instrument, the "Alarm Contact" binding posts are connected to the relay contacts. In the type 66B instrument, the "Alarm Contact" binding posts are connected across a resistor as stated above.

28. **Adjustments**—After the instrument is installed, the following initial adjustments should be made. The zero-setting of the meters should be checked. They should be set to zero with the power switch "on," but with no r.f. signal. With the trans-

mitter operating at normal power, adjust the coupling coil so that the "Carrier" meter reads somewhere around full scale (130) with the "r.f. Input" control at maximum. Of course, in making this adjustment usual safety precautions in regard to high voltage should be taken. Observe reading of "Polarity" switch, then reverse this switch and note whether "Carrier" meter reads the same. If not, adjust the compensating trimmer, *C*8, to compensate for assymmetry of the r.f. voltage so that with the same r.f. input the meter reads the same when the switch is thrown from one position to another. This does not affect the calibration of the "Modulation" meter of "Peak Indicator."

If for any reason the adjustment of the audio calibration control potentiometer *R*2 has been altered from its original setting, it may be re-adjusted as follows:

With the Transmitter and Modulation Monitor in operating condition, set the polarity switch to "Negative" position. Feed sufficient signal into the transmitter (constant-frequency modulation) to cause over 100 percent modulation. Adjust the "r.f. Input" control until the carrier meter reads 100. Adjust *R*2 until the modulation meter reads 100 percent. This condition is dependent upon the transmitter being in proper operation and properly neutralized so that the negative peaks on over-modulation reach 100 percent.

When the flasher circuit is properly adjusted, the neon lamp will just begin to flash when the percentage modulation indicated by the flasher adjustment control corresponds to the percentage modulation indicated by the modulation meter. If the RCA–885 Relay Control tube has been changed, or the adjustment of *R*–18 disturbed, re-adjustment should be made as follows:

With sufficient carrier and modulation to give a reading of 100 percent on the "Modulation" meter, turn the flasher control knob until the neon lamp just flashes and note position of the pointer. Reduce the "Modulation" meter reading to 50 percent (this may be done by either reducing the r.f. input or reducing the percentage modulation). Again rotate the flasher control knob until the neon lamp just flashes, and measure the distance between the positions at 100 percent and 50 percent. This distance should be the same as 100 to 50 on the pointer scale. If not, it is necessary to change the setting of calibration control *R*18 until this condition results. When this condition has been satisfied, it is only necessary to loosen the nut of the flasher control mounting and rotate the potentiometer itself until the neon lamp just breaks down with the pointer of the flasher control on 50, and with the

"Modulation" meter still reading 50 percent. Correspondingly, with the "Modulation" meter reading 100 percent the neon lamp should now just break down with the pointer on 100.

	Heater	Plate to Ground
(1) RCA 1-V RF Rectifier	6.3 ac	
(2) RCA-76 Flasher Amplifier	6.3 ac	115 Volts
(3) RCA-76 Audio Rectifier	6.3 ac	
(4) RCA-76 Voltmeter Amplifier	6.3 ac	115 Volts
(5) RCA-84 Rectifier	6.3 ac	
(6) RCA-885 Relay Control	2.5 ac	

Total d.c. from reactor to ground 350 volts. Voltage to other tube elements than given above is r.f.

29. Operation—To operate the instrument, supply it with 110–120 volt, 60-cycle power at the plug marked "115-V," and with a portion of the signal to be monitored at the "r.f. Input" binding posts. The smaller of these two posts is connected directly to the chassis. Only about .25 watts of r.f. power are required by the indicator on normal range. By means of the "r.f. Input" control adjust the input so that the "Carrier" meter reads 100. The "Modulation" meter now reads the percentage modulation directly, and of such polarity as is shown on the "Peak Level" switch. If the modulation percentage exceeds the setting of the "Peak Control," the neon tube will light and the "Alarm Contact" binding posts will be shorted by the relay. The unit is designed for either rack or cabinet type mounting, a dust cover replacing the cabinet for rack mounting.

30. Applications—Aside from general monitoring, which is the primary function of these instruments, amplitude and frequency characteristics of the transmitter may be taken if a suitable audio voltage source is available. The procedure for taking a frequency characteristic is described in this chapter. An overall amplitude characteristic may be taken by using the "Modulation" meter as an output meter and impressing measured audio voltage on the input of the speech amplifier. In order to facilitate the reading of smaller levels than would otherwise be possible, a resistor is provided for shunting the "Carrier" meter. When this resistor is connected across the "Range" binding posts, and the r.f. input is increased to give a reading of "100" on the "Carrier" meter, the decibel scale on the "Modulation" meter is changed by the specified amount (approximately 10 db). In other words, under the latter conditions, an observed reading of —15 db on the meter would indicate that the level was approximately —25 db.

GENERAL RADIO—CLASS 730–A

TRANSMISSION MONITORING ASSEMBLY

31. **Purpose and Use**—The Class 730–A Transmission Monitoring Assembly is intended for use in radio broadcasting stations as a means of measuring and continuously monitoring the quality of the transmission. Besides permitting measurements of har-

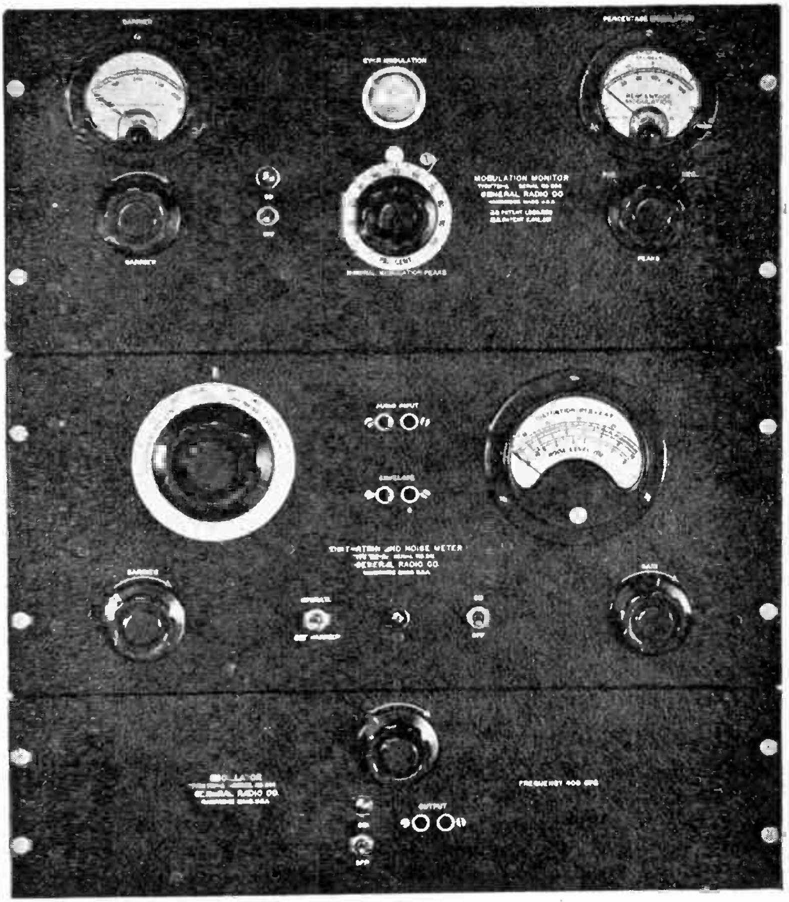


FIG. 233. 730–A Transmission Monitoring Assembly.

monic distortion, noise level, and percentage modulation on either positive or negative peaks, a flashing lamp is provided for indicating modulating peaks in excess of any predetermined value.

It is possible, therefore, first to measure the over-all performance of the transmitter, locating and correcting sources of distortion and second, to monitor the transmission continually thereafter with a visual indicator of deviations from normal performance.

The assembly consists of three instruments:

Type 731–A Modulation Monitor.
Type 732–A Distortion and Noise Meter.
Type 733–A Oscillator.

TYPE 731–A MODULATION MONITOR

32. Description—The Type 731–A Modulation Monitor performs two functions: It gives a continuous indication of percentage modulation on either positive or negative peaks and an indication of over-modulation peaks in excess of any predetermined modulation level.

Percentage modulation is indicated on a high-speed meter whose scale is calibrated from 0 to 110 percent. An additional decibel scale is provided to facilitate adjusting the transmitter input. Positive or negative peaks, as desired, are selected by means of a switch. The over-all accuracy of measurement at 400 cycles is within 2 percent at modulation percentages of 0 percent and 100 percent. The possible error rises to a maximum of 4 percent at 50 percent modulation.

The frequency response is linear within less than 0.5 db between 40 cycles and 15,000 cycles.

The over-modulation indicator is a lamp which flashes whenever the percentage modulation exceeds the value at which the *NOMINAL MODULATION PEAKS* dial is set.

The decibel scale on the percentage modulation indicator can be used for measurements of the over-all frequency characteristic of the transmitter if a beat-frequency oscillator is available.

33. Principle of Operation—The operation of the Type 731–A *Modulation Monitor* is shown by figure 234.

A modulated radio-frequency voltage is applied to the input terminals. This is applied to a diode rectifier and the level is adjusted to a specified value by means of the condenser-type voltage divider and a d.c. meter in series with the diode. The positive half of the modulated radio-frequency wave is demodulated by the diode and passed through a filter which removes the radio-frequency components.

The filter output voltage consists of an a.c. component (corresponding to the varying envelope of the original modulated signal) superposed on a d.c. component produced by rectification of the carrier. The ratio of amplitudes of the a.c. and d.c. components is identical with the ratio of the amplitudes of the a.c. component of the envelope and average carrier in the original signal.

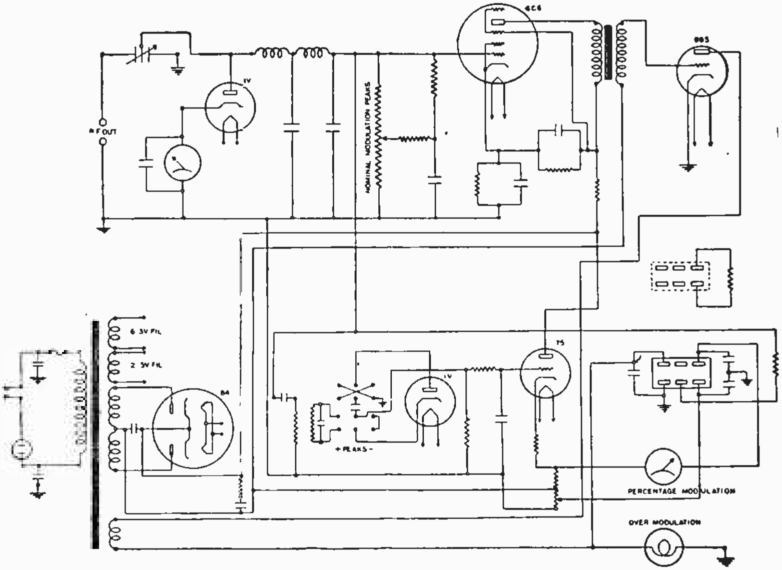


FIG. 234. Type 731A Modulation Monitor.

The d.c. component, E_0, is used to supply a negative grid bias for the amplifier tube, 6C6. The a.c. component is applied directly to the amplifier grid. The grid bias is variable between zero and the full value of E_0 and is controlled by the *NOMINAL MODULATION PEAKS* dial, given fractions of E_0 corresponding to the same values of fractional modulation, that is, half scale corresponds to 50 percent modulation.

Whenever the peak value of the a.c. component exceeds the grid bias, the grid becomes positive, and plate current flows, tripping the Type–885 gas-filled triode and flashing the over-modulation lamp.

The percentage modulation indicator is fed from the output of the radio-frequency filter. The a.c. voltage is rectified by means of a diode and its amplitude indicated by a vacuum-tube voltmeter device. A phase reversing switch for selecting either positive or negative audio frequency peaks is provided.

Operation—Turn on power switch. With the power on and no carrier applied, the carrier meter should read zero. The mechanical adjustment should be used, if necessary.

With power on and no carrier applied the percentage modulation meter should read zero. The mechanical adjustment on the meter may be used to bring it to zero. This check can be made with the carrier input to the instrument, if the carrier is unmodulated. If this is done be sure the modulation due to noise is not sufficient to deflect the meter. *CAUTION:* On some of the instruments a variable resistor has been included for factory adjustments. This must not be disturbed. It is not for zero adjustment.

With no modulation on the transmitter, adjust *CARRIER* control and/or the coupling to the transmitter until *CARRIER* meter reads 100. This standardizes all direct-reading scales. When modulation is applied the carrier shift may be read directly in percent on the *CARRIER* meter.

If the transmitter is now modulated, the *PERCENTAGE MODULATION* meter will read the instantaneous percentage modulation, and readings for either positive or negative peaks can be obtained by means of the PEAKS switch.

The *NOMINAL MODULATION PEAKS DIAL* can be set at the maximum value of percentage modulation at which it is desired to operate, and the *OVER MODULATION* lamp will flash whenever this percentage is exceeded. The lamp operates on negative peaks.

In case an external *PERCENTAGE MODULATION* meter is used, this should be set to zero along with the meter on the panel.

General Radio Distortion and Noise Meter Type 732-A

34. Distortion Measurements in the Broadcasting Station— Excessive audio-frequency distortion is annoying to the radio listener, and the difference between good-quality and poor-quality stations is easily distinguishable in modern receivers. Tests have indicated that a 10 percent total distortion is about the maximum which can be tolerated if the signal is to sound reasonably pleasant to the listener. Fortunately, it is not difficult to keep distortion well below this level in transmitting and receiving equipment.

In order to insure acceptable quality of transmission, The Federal Communications Commission has required that no broadcast transmitter shall have more than 10 percent combined audio-harmonic distortion when operating at a level of 85 percent modulation. This has been covered in a paragraph of the F. C. C. rules governing operation of broadcast stations.

Note: Total harmonic distortion may be measured in terms of the r.m.s. of the total harmonic content or in terms of the arithmetic sum.

Example of the difference may be cited. Assume the value of the second, third and fourth harmonics are 3 percent, 5 percent and 2 percent respectively, the arithmetic sum would be 10 percent. The r.m.s. value would be found by taking the square root of the sum of the squares or

$$\text{Total rms harmonic value} = \sqrt{3^2 + 5^2 + 2^2} = \sqrt{38} = 6.2\%.$$

During recent years, transmitter manufacturers have placed a good deal of emphasis on freedom from distortion and, as a result, transmitters are now available with distortion levels as low as 3 percent. Complete performance characteristics of all transmitters intended for general sale are submitted to the Commission as proof that the requirements are being met.

Holding distortion at a low figure has consequently become a problem of maintenance rather than of transmitter design. In the carefully balanced electrical circuits that make up the modern transmitter, changes in the operating biases and the characteristics of vacuum tubes, as well as the slow aging of other circuit elements, may result in excessive distortion. Proper care and maintenance are necessary to obtain best performance. Periodic tests are the obvious safeguard against excessive distortion and, when made as part of a definite maintenance routine, they add very little to the duties of the operating staff. Simple test methods and direct-reading instruments have reduced the testing time to a few seconds.

35. **Test Method**—A transmitter which distorts at one audio frequency will usually do so at all frequencies, although the magnitude of harmonic components will vary with frequency in accordance with the overall characteristics of the transmitter. A single-frequency test in the middle of the audio range, therefore, is generally accepted as an indicator of transmitter distortion. A standard test frequency of 400 cycles has been arbitrarily selected because it is commonly used in transmitter and receiver testing. Measurements made at this frequency are proof acceptable to the

F. C. C. that the transmitter is operating properly as long as the combined audio frequency distortion is less than 10 percent at 85 percent modulation.

The method of test is to apply a pure sine wave at the input of the preamplifier or speech amplifier and to measure the total harmonic distortion placed on this sine wave by the complete transmitting system up to the antenna.

Routine—In many broadcasting stations where the Type 732–A Distortion and Noise Meter is already installed, it is customary to make a routine distortion measurement at the beginning of the day's operation and at the end, and to record these readings in the station log along with the other details of the daily operations.

36. Noise Measurement—Another feature of the meter which is very useful in broadcast-station maintenance is the fact that it permits the measurement of the residual noise and hum level of the system. This measurement is made by comparing the residual noise in the transmitter to a reference tone level. For example, after the distortion measurement has been made with a modulation percentage of, say, 85 percent the test tone is turned off, and the noise meter is switched by the single control dial to another position where the meter will register the residual noise in terms of decibels below the test-tone level. In this way excessive hum or a noisy transmitter tube can be discovered immediately.

Sources of noise, whether in lines or amplifiers, can be located quickly by patching out the various amplifiers and equipment in the system until the noise disappears. The fact that the noise level is measured in decibels is most useful in evaluating the amount of noise introduced by any element in the system. This method of test is very quick and serves in emergencies to isolate any noise promptly so that it can be cleared with a minimum of interruption to the program.

No standard of background noise level has been established as yet, but in good transmitters the noise level is sometimes kept as low as 60 decibels below 85 percent modulation. It is not difficult to keep the noise level at least 40 decibels below the distortion test-signal level, a figure which is good enough for most practical purposes.[7]

37. Distortion in the Audio System—In addition to its use

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[7] The carrier-noise measurement will usually be made only once, with reference to the highest modulation level of which the transmitter is capable. To find the noise level with respect to 100 percent modulation, the sum of the meter reading and the scale reading should be reduced by the decibel reading of the Type 731–A Modulation Monitor.

in measuring the over-all quality of the transmitter, the Type 732–A Distortion and Noise Meter has an equally important application in measurements on the audio-frequency system alone. Two audio-frequency input circuits are provided for this purpose. One of these circuits has an input impedance of 500 ohms balanced to ground, and the other an impedance of 50,000 ohms unbalanced. Both circuits are available by means of jacks in the front panel. To make distortion measurements at the 500-ohm impedance, it is necessary to have a signal with a level of about plus 1 decibel, or about 2 volts as a reference level. The exact adjustment of this input voltage level is provided for by the panel meter. Approximately 20 volts are required across a 50,000-ohm circuit. The 500-ohm input circuit is carefully balanced to ground so that the measurement can be made on balanced as well as unbalanced circuits without disturbing the circuit under measurement.

Residual noise measurements in audio-frequency circuits can also be made by the same means.

38. General Radio Type–732–A Distortion and Noise Meter—The distortion and noise meter is designed for measurements of total harmonic distortion (with 400-cycle modulation) and of the noise level present in the output of the broadcast transmitter. Means are also provided for making distortion and noise measurements on the audio-frequency system alone, and, if a wave analyzer is available, for analyzing the components of distortion at any audio frequency.

Both percent distortion and noise level are read on a large meter and a multiplier dial. A calibrating point is provided on the dial and the calibration adjustment is easily and simply made, making use of the modulation from the transmitter.

To permit corresponding measurements in audio-frequency circuits simple means are provided for removing the radio-frequency rectifier and connecting the equipment directly to the audio system. The same principles apply.

39. Principle of Operation—Figure 235 is a schematic diagram of the distortion and noise meter. The input circuit is similar to that of the Type 731–A Modulation Monitor and consists of a condenser-type potentiometer, a diode rectifier and a radio-frequency filter. A meter for reading carrier amplitude can be switched in series with the diode. This same meter is used as the indicator in the vacuum-tube voltmeter.

The 400-cycle-modulated carrier is demodulated by the diode. The output passes through the radio-frequency filter which removes the radio-frequency components.

For measurements of harmonic distortion, the output of this filter is passed through a 400-cycle high-pass filter, removing the 400-cycle fundamental of the audio frequency but leaving all its harmonics. The amplitude of the harmonic voltage is then indicated by the attenuator and the output meter. The attenuator dial

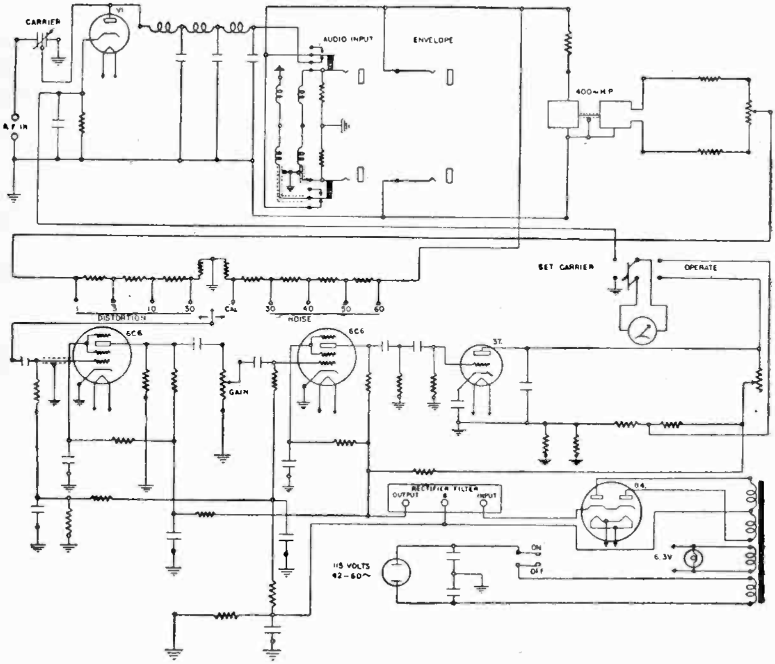

FIG. 235. Type 730-A Distortion and Noise Meter.

is provided with a calibrating position which is used to standardize the meter scale in terms of the original 400-cycle amplitude, before making the measurement. This setting is made by adjusting the amplifier gain for a full-scale deflection on the meter, when a known fraction of the envelope amplitude is applied to the amplifier.

For noise and hum measurements the output of the radio-frequency filter is applied directly to an attenuator. The calibration adjustment is made with the transmitter modulated at the level with which it is desired to compare noise. With the modulating voltage removed from the transmitter, the noise level in decibels below the modulated signal level is indicated on the meter.

TYPE 733-A OSCILLATOR

40. Description—This oscillator is a source of audio-frequency voltage of good waveform at a frequency of 400 cycles per second. It is intended for use in modulating the radio transmitter when measurements are to be made with the Type 732-A Distortion and Noise Meter.

A complete circuit diagram is shown in figure 236. The oscillator is of the Hartley type. A filter is used in the output to eliminate harmonic voltages. Output terminals for load impedance of 50, 500, and 5000 ohms are provided.

The output is available at jacks on the panel and at binding posts at rear.

A potentiometer is provided for controlling the output.

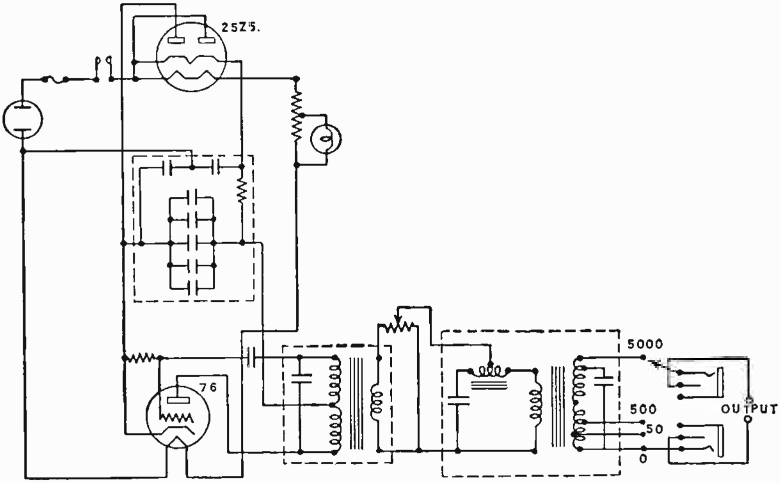

FIG. 236. Schematic Wiring Diagram of Type 733-A Oscillator.

INSTALL VACUUM TUBES: All tubes are supplied with the instruments.

MOUNTING: Install the panels in a 19-inch relay rack in the order from top to bottom of oscillator, modulation monitor, and noise meter.

CAUTION: It is important that no appreciable a.c. hum from the assembly be picked up by the speech input equipment. This can be determined by listening to the output of the speech amplifier with phones and turning on and off the a.c. supply to the transmission monitoring assembly. If the difference in level is large, the location of the assembly, or its orientation with respect to the speech input equipment, should be changed.

CAUTION: Dummy connector must be inserted at rear of Type 731–A Modulation Monitor.

POWER SUPPLY—Connect panels to 113-volt, 60-cycle line by means of cord-and-plug combination supplied. If any difficulty with a.c. hum is encountered, reverse the line plug.

GROUND—Be sure to ground the low side of the carrier input circuits of both the Type 731 and Type 732 Units.

PICKUP—There are several possible methods of coupling the assembly to the transmitter and the choice must be determined largely by local conditions. Following is a list of possible methods:

(1) Coupling to antenna through a small condenser.
(2) Use of a small receiving antenna.
(3) Coupling to antenna or tank inductance by means of a small 3-inch coil. About 1.5 watts total power will be required.

The pickup circuits for both the modulation monitor and the distortion and noise meter can be connected in parallel, if desired, with a single coupling circuit to the transmitter.

The pickup to the Type 731–A Modulation Monitor should be so arranged that when the instrument is turned on, the carrier meter can be set at 100 by the carrier control. Some tolerance should be possible on both sides so that corrections may be made for changes in the transmitter output.

The pickup of the Type 732–A Distortion and Noise Meter should be so arranged that when the Instrument is turned on and the meter thrown to *SET CARRIER* the meter can be adjusted to at least half scale. (By this is meant half scale, mechanically, which comes at about 7 on the 10 scale.) This adjustment is not critical. The *CARRIER* knob should be set so that the meter reads between 7 and 10 on the 10 scale. No further adjustment of this control is necessary during tests, unless the transmitter power or the coupling to it is shifted.

In some few cases where the same antenna is used for more than one transmitter, some filtering will be necessary to choose the signal to be monitored.

In case two transmitters are used in the same building (as, for example, a short wave transmitter in addition to the ordinary broadcast transmitter), some obvious precautions may be necessary to separate them in monitoring. Turning them on and off independently during installation will settle any question of this sort. When using an antenna for pickup, some difficulty may be experienced, particularly when the short-wave antenna direction is changed.

41. **Initial Adjustment of Distortion and Noise Meter**—Turn on the power switch and allow the tubes to warm up for few minutes. With the radio-frequency terminals disconnected and no carrier input, throw the transfer switch to SET CARRIER and adjust the meter to zero by means of the knob on the case. Next, throw the switch to OPERATE and again set the meter to zero, using this time the adjustment at the rear of the instrument. Make this adjustment with the dial set at CAL and the GAIN control at zero. When this adjustment has been made, the needle will remain at zero for either position of the switch.

42. **Standard Signal**—The Type 733–A Oscillator is used to supply a standard 400-cycle signal of good waveform for distortion measurements. The oscillator output, which is available at panel jacks and binding posts at the rear, should be connected to the speech input equipment as desired, usually in one of the mixer positions.

If it is desired to attenuate the output of the oscillator to very low levels a *T*- or *H*-pad may be inserted between the output terminals and the voice circuit. If an *H* section of high attenuation is used, it is desirable to use a balanced and center grounded section to avoid undirectional 60-cycle strays.

Operation—When first installing the equipment the meter should be set to zero as outlined in paragraph 41. Furthermore, the carrier amplitude should be adjusted as noted under paragraph 40. After these preliminary adjustments have been made the operating procedure should be as follows:

Turn on power switch and allow tubes to heat for two or three minutes. Throw switch to *OPERATE*. With the *GAIN* control set at zero, set the meter to zero by the knob on the meter. (This should not usually be necessary more frequently than once every hour or so.) If the knob on the meter scale does not have sufficient range, adjust the control on the terminal strip at the rear of the instrument. Set dial on Cal. Modulate transmitter at desired level with the Type 733–A Oscillator; the level may be read on the modulation meter.

Adjust *GAIN* for full scale on meter. Harmonic distortion in percent can then be read directly on the meter in terms of the full scale value indicated by the dial position.

Noise level measurements are made by removing the modulation from the transmitter and turning the dial to the noise level scale. For this measurement, dial reading and meter reading are *added*. The noise level is expressed in decibels below the modulation level at which the calibration adjustment is made.

For measuring the distortion of an audio frequency amplifier a filtered 400-cycle signal should be applied to the amplifier by the Type 733-A Oscillator and the output level properly adjusted. The output should be connected to the audio-frequency input jacks, thereby automatically disconnecting the radio frequency.

The impedance of the Type 732-A Distortion and Noise Meter at the Audio Input jacks is 500 ohms and is balanced to ground, as shown in figure 235. *The Type 732-A should not be used as a bridging device but as a dummy load.* This is important because an amplifier which operates satisfactorily into a load of 500 ohms may not work properly into a load of 250 ohms, the resultant impedance if bridged across the normal 500-ohm load.

The Type 732-A may be used as an unbalanced device (i.e. having one side grounded) of approximately 50,000 ohms impedance by using the envelope jacks for input and putting a wooden dummy plug in the left.[8]

In measuring audio-frequency distortion and noise the same procedure is used as at radio frequencies.

For telephone line noise terminate the line at the *AUDIO INPUT* jacks and apply a tone at the sending end for reference. Remove tone and read directly residual noise in db below tone level. Noise as low as 65 db down from a 6-milliwatt reference can be accurately measured.

Fluctuations in a.c. power line supply will cause slight fluctuations of the indicating meters. This is normal and is not an indication of trouble.

When measuring audio-frequency noise or distortion do not use a tone reference level in excess of + 20 decibels.

43. Type 733-A Oscillator—To operate the Type 733-A Oscillator it is only necessary to throw the power switch to the ON position.

The output of the oscillator should be plugged, as desired, into the speech input portion of the transmitter. The maximum level from the Type 733-A Oscillator is about 7.5 db above a 6-milliwatt reference, and an output control is provided. The output

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[8] In instruments with vertical jacks the upper should be used.

can therefore be applied to the speech amplifier at the point where lines from the studios normally terminate. The output transformer has a tapped secondary and the output impedance is selected by connecting the lead from the output jack to the terminal engraved with the desired impedance.

SUGGESTIONS FOR USE

44. **Performance Test**—In making complete measurements on a transmitter, the recommended procedure is to measure, first, modulation; second, distortion; and finally noise. In order to get a complete picture of transmitter performance, it is desirable to measure distortion at a number of modulation levels, including values below and above the normal operating levels, and to plot peaks. After readjustments have been made on the transmitter, new data can be referred to the plot for evidence of improvement. It is possible to make a complete run of this sort, through the range of audio-frequency input which the transmitter will handle, in less than 10 minutes.

Routine Checks—After the transmitter has been adjusted for the best operating conditions, it is necessary only to check the operation periodically to be sure that no changes have occurred. These checks, however, should be made as frequently as possible.

The procedure in making such measurements is outlined below:

A. Modulation.

1. Set carrier to 100.
2. Set to *NEGATIVE PEAKS.*
3. Adjust tone from modulation oscillator to give desired modulation percentage.
4. Turn switch and read positive peak.

B. Distortion (a check of distortion at any one level can be made in considerably less than one minute).

1. Set carrier.[9]
2. Throw switch to *OPERATE.*
3. Adjust tone from modulating oscillator to give desired modulation percentage.
4. Set dial to CAL position.
5. Set gain to full scale.
6. Select distortion scale.
7. Read meter.

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[9] It is necessary to set the carrier amplitude only when the equipment is first installed. This adjustment is not critical and after it is once made, it need not be touched thereafter unless the *coupling system or transmitter* power is changed. See Paragraph 40.

C. Noise.

1. Adjust tone from modulating oscillator to give highest modulation level of which the transmitter is capable.
2. Set dial to CAL position.
3. Adjust GAIN for full scale.
4. Turn off modulating tone.
5. Select noise scale.
6. Read meter plus scale.

45. **Fidelity Measurements**—If a beat-frequency oscillator (such as General Radio Types 513–B, 613–B, or 713–A) is available, the over-all frequency characteristic of the transmitter can be taken on the Type 731–A Modulation Monitor. Modulate the transmitter at the desired level by means of the beat-frequency oscillator, holding the input level at a constant value with a volume indicator. The variation of transmitter output level with frequency is then read directly from the decibel scale on the percentage modulation meter. The measurement is accurate within 0.5 db over the range from 40 to 15,000 cycles.

46. **Analysis of Distortion**—Two terminals engraved ENVELOPE are provided on the panel of the Type 732–A Distortion and Noise Meter. The audio-frequency voltage corresponding to the carrier envelope is available at these terminals. A Type 636–A Wave Analyzer can be connected to these terminals for making an analysis of the distortion components or harmonic content, and for measuring distortion at any modulating frequency giving audible harmonic components in the range from 50 to 16,000 cycles.

47. **External Indicators**—Terminals 11 and 12 are provided on the 6-point plug-connector at the rear of the Type 731–A Modulation Monitor for connecting an additional flashing lamp. If it is desired to use an auxiliary meter, this should replace the 500-ohm dummy resistor connected between terminals 7 and 8 inside of the plug. Terminal 7 is positive, 8 negative. This meter should be set to zero mechanically in the same manner as the meter on the panel.

Recording—An audio-frequency voltage proportional to percentage modulation is also available at the 6-point connector at the rear of the modulation monitor, which can be used to operate a continuous recorder, if desired. This voltage is obtained at terminals 10 and 12.

SERVICING

Tubes—The calibration of the instruments is independent of the tubes used, with one slight exception. The Type 37 Tube used on a voltmeter in the Type 732–A Distortion and Noise Meter to some extent affects the meter scale. It will be found necessary to discard about one tube in ten for failure of the 10 scale to agree with the 30 scale, etc.

The 885 gas-filled triode is of much shorter life than high vacuum tubes and it will be found necessary to replace it occasionally.

Fuses—Fuses are required in all of the instruments. These are Bussman Manufacturing Company Type TAG, one ampere.

Auxiliary Plug—Should the Type 731–A Modulation Monitor cease to operate, make sure that the auxiliary plug is firmly in place. This plug contains a 500-ohm resistor which is in series with the meter. This is provided so that it may be replaced by a series meter for remote observation of the percentage modulation.

Flashing Lamp—Should the lamp in the Type 731–A Modulation Monitor cease to operate, the lamp itself may be burned out. An ohmeter measurement between terminals 11 and 12 of the plug receptacle will show open circuit when the instrument is turned off.

Switch Contacts—If trouble occurs due to poor switch contacts, clean the contacts with crocus cloth and wipe with carbon tetrachloride, then apply a thin film of high quality vaseline.

RCA Type 68–A Beat Frequency Oscillator and Type 69–A Noise and Distortion Meter

Each unit is completely a.c. operated and contains its own integral power supply. All meters and dials indicate directly in percentages, decibels or cycles, depending on their functions and no additional calculations are required. Either unit may be obtained for either rack or table mounting and the standard dull black finish is used. Both units are equipped with input and output jacks which are mounted on the front panels and which take the regular double-plug patch cords. Standard, inexpensive tubes are used throughout.

48. Type 68–A Beat Frequency Oscillator—This unit fulfills the requirements for a compact, a.c. operated, variable frequency oscillator which has negligible hum and distortion voltages present in the output signal.

The instrument is of the beat frequency type wherein the output of two r.f. oscillators operating at nearly the same frequency are combined in a detector system to produce the audio frequency. Push-pull detectors and amplifiers are used to reduce distortion to a minimum. The frequency scale of the instrument is approximately logarithmic and can be supplied with a true logarithmic

FIG. 237. Type 68-A Beat Frequency Oscillator.

scale at a slight additional cost. A magic eye is used as a frequency indicator so that the frequency may be accurately adjusted to sub-harmonics of the power supply frequency and to harmonics up to at least the fifth. A meter is supplied in the instrument by means of which the amplifier and detector tubes may be tested for plate current balance to obtain minimum distortion. In addition to output terminals, jacks are provided for convenient connections to amplifiers being tested. A volume control is provided for adjusting the output level.

SPECIFICATIONS

Frequency Range:	20 cycles to 17,000 cycles. The instrument may be operated down to 5 cycles per second with good wave form.
Output Power:	Maximum 120 mw.
Output Impedances:	5000, 500 and 250 ohms.
Frequency Characteristic:	5000 ohm tap ± 0.5 db. 500 ohm tap ± 1 db. 250 ohm tap ± 1 db.
Distortion:	Total arithmetic sum below 100 cycles, 0.3%. above 100 cycles, 0.2%.
Hum (zero level output):	-60 db.
Power Supply:	110–120 v. 25–60 cycles, 70 watts.
Weight:	Cabinet model—55 pounds. Rack model—50 pounds.
Tube Complement:	6—RCA 6-C-5-G 1—RCA-874. 3—RCA 6-J-7 1—RCA-5-Z-4. 1—RCA 45 1—RCA-6-E-5.
Size:	Rack model: 8¾″ high, 19″ wide, 10″ deep. Cabinet model: 9″ high, 19¼″ wide, 12″ deep.

49. Type 69–A Noise and Distortion Meter[10]—This instrument is a compact, a.c. operated device which will measure directly the r.m.s. percentage distortion present in the output of an amplifier or transmitter for any audio frequency signal between 50 and 7000 cycles. It also measures hum and noise levels down to a — 88 db level. It operates on the principle of balancing (180 degrees out of phase) a pure wave form against the distorted wave form and so cancelling the fundamental frequency component. The r.m.s. value of the remaining wave form is then measured and the percent distortion thereby indicated. Controls are provided for adjusting the phases and amplitudes so that complete cancellation is obtained.

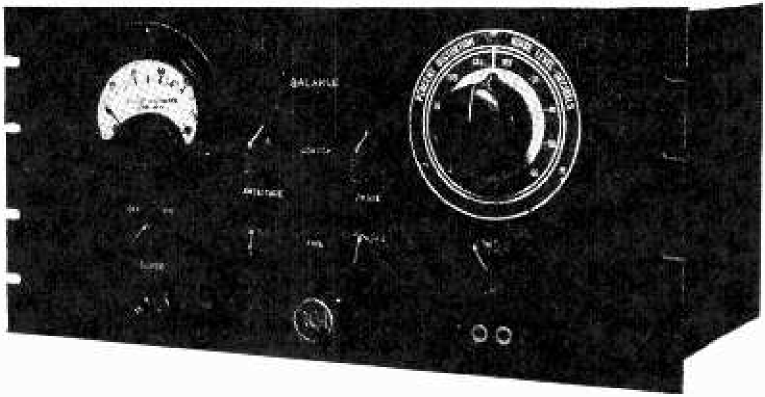

FIG. 237, A. 69A Distortion Meter.

The amplifier voltmeter used in the instrument has a flat frequency response from 30 to 22,000 cycles thus providing for accurate distortion measurements which will include the third harmonic for a 7000 cycle fundamental. The same amplifier voltmeter is used in conjunction with an attenuator which has a range of 60 db for hum measurements.

A linear r.f. rectifier is provided within the instrument and is used for the measurement of the overall distortion of transmitters or signal generators. For r.f. measurements, the input terminates directly at the diode rectifier and may be fed by a twisted pair line

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[10] For distortion measurements a pure sine-wave source of audio frequency is required. The Type 68–A Beat Frequency Oscillator has been specially designed and is recommended for use with this meter.

from a coupling coil located near the output tank inductance of the transmitter.

All measurements are indicated directly on the meter dial in percentage or db depending on the type of measurement being taken.

SPECIFICATIONS

Frequency Range for Distortion Measurements:	50 to 7,000 cycles.
Distortion Measurement Range:	Full Scale, 1% to 100%. Minimum reading, .3 of 1%.
Hum Measurement Range:	Any hum level down to − 88 db below a 12.5 mw. level on a 500 ohm line. Also, any hum level above − 88 db below 100% modulation.
Input Level:	
20,000 ohm input:	− 18 db to + 10 db, audio frequency.
250,000 ohm input:	½ volt to 100 volts, audio frequency.
For Distortion Measurements:	10 to 100 volts, R.F.
For Hum Measurements:	½ to 100 volts, R.F.
Audio Input Impedance:	20,000 ohms bridging input balanced to ground. 250,000 ohms unbalanced to ground.
Tube Complement:	1—RCA-1-V 1—RCA-6-N-5. 3—RCA-6-C-5 1—RCA-5-Z-4.
Power Input:	50 watts, 110 volts, 60 cycles.

CHAPTER 7

STUDIO AND CONTROL ROOM APPARATUS AND OPERATING TECHNIQUE

1. **Zero Level**—In this Chapter, as well as others, reference has been made to "zero level." Zero level expresses the magnitude of the output or signalling power at any point in a communication system either in some absolute unit or with reference to an arbitrary base value. In general, 6 milliwatts is used as the reference or zero level, however, the RCA Manufacturing Company, Inc., expresses the gain or loss of their devices with respect to the level of 12.5 milliwatts.

2. **The Decibel**—There are in use two units to express the logarithmic ratios of powers, voltages or currents in communication or transmission system; namely, the napierian unit called the neper and a decimal unit called the bel. It is more convenient to use decimal multiples or submultiples of either of these units such as a decineper and decibel. In audio and radio communication systems the latter is generally used and abbreviated as db.

The number of decibels corresponding to the ratio between two amounts of power P_1 and P_2 is determined by:

$$\text{db} = 10 \log_{10} \frac{P_1}{P} \cdot$$

When two voltages or two currents operate in the same or equal impedances the number of decibels are found as follows:

$$\text{db} = 20 \log_{10} \frac{E_1}{E_2} \quad \text{or}$$

$$\text{db} = 20 \log_{10} \frac{I_1}{I_2} \cdot$$

It has been determined that a change of the power level of a sound by 1 db is approximately the smallest the ear can detect. It is interesting to note that if the power output of an audio amplifier is doubled a gain of only 3 db will result and only a perceptible change in the intensity of the output will be noted.

The decibel table on pages 410–411 is shown by courtesy of The Commercial Radio Equipment Company of Kansas City, Mo., and appeared in their house organ, The Radio Engineer. An explanation of the use of the table by Mr. Everett L. Dillard, editor of The Radio Engineer follows:

3. **Decibel Facts at a Glance**—This chart has been prepared as a quick and ready reference for the transmission engineer in computing power levels using the two more common zero db power reference levels, namely, 6, and 12.5 milli-watts. Such information could have been supplied in graph form, but graphs, while telling a more continuous story, are generally complex to read and require much more time to use than the simple tabulated results as given on the opposite page. In the form as printed all the information necessary is instantly available in the most commonly used power levels from minus 60 dbs to almost plus 80 dbs.

The chart lists both r.m.s. and peak voltages existing across the line as well as the r.m.s. current flowing in the line for 600, 500, 200, 74, 50 and 37 ohm lines.

(*a*) Since the 600, 500 and 200 ohm transmission lines are used for both high and low power transmission of both r.f. and a.f. power, complete data have been tabulated over the total power range covered by the table for these line impedances. The 50 ohm line is almost solely confined to audio work and the maximum power level in such a line hardly ever exceeds 6 watts. For the 50 ohm line the data is tabulated from minus 60 dbs to plus 30 dbs, that range over which the 50 ohm line is most generally used. The 74 and 37 ohm transmission lines have their only application in the transmission of r.f. power from transmitter to antenna. These values are mostly used in that they represent the normal effective resistance at the current loop of a half-wave Hertz and a quarter wave Marconi respectively. With their use impedance matching networks may be eliminated and the transmission line connected directly to the antenna at the current loop without serious mismatch or power loss. Radio frequency transmission lines having surge impedance values of less than 200 ohms are generally of the concentric tube type.

(*b*) Knowing the power level using one zero level reference power a conversion to the other level can be made instantly. Since the 6 milliwatt level is the more commonly used in audio work, the 12.5 milliwatt level has been compared to integral db values of the 6 milliwatt reference level. If a standard db meter based on a 6 milliwatt zero level reads plus 2 dbs, then on a basis of the 12.5 milliwatt reference level the correct db rating is minus 1.19 dbs. They both represent the same amount of power in the line, namely 9.5009 milliwatts.

(*c*) Reference to the chart will show that for a given power level rating in dbs based on a 6 milliwatt zero level the proper db rating using the 12.5 milliwatt zero level is always 3.19 db below that of the reading of a meter calibrated on the 6 milliwatt zero reference power level. Using a meter on this basis a reading of 7 dbs indicates that on the 12.5 milliwatt basis the converted rating is 3.81 db, if the meter reads plus 5 dbs then the corrected 12.5 milliwatt reference level reading is 1.81 db, etc. The previous explanation has been based on power levels only. Suppose that the power level is known either in watts or in either of the zero db reference levels given. Then it is a simple problem to determine the voltage and current existing in the line.

(*d*) Reference to the chart will show that data has been prepared for those power levels, for a given surge impedance, for which purposes the lines are most generally used.

(*e*) Suppose a standard db volume indicator calibrated for use on a 500 ohm line is available with a calibration, say, on the 6 milliwatt reference level. If the meter reads a level of plus 2 db when used on a 500 ohm line, then, reference to the table shows that, at this power level there exists across the 500 ohm line an r.m.s. voltage of 2.18 volts. The second column under the 500 ohm section shows that this represents a peak voltage of 3.08 volts and the third column of the section indicates that there is flowing in the line an r.m.s. current of 4.36 milliamperes.

5. Carbon Microphones—The action of the single button carbon microphone can be explained by referring to figure 238. The front and rear electrodes, the granular carbon and mica washer which is associated with the front electrode are all mounted in a cup, the mica washer being clamped in position and fastened rigidly to the front electrode leaving this electrode free to vibrate. The rear electrode is fastened rigidly to the bridge. The granular carbon is placed between the front and rear electrode so as to be in contact with both. The carbon chamber is never completely filled. The diaphragm is fastened directly to the stud of the front electrode, and is held in position by two damping springs. These springs are also to prevent the diaphragm from vibrating at its natural period, instead of at the periodicity of the sound-waves striking it.

DECIBEL TABLE

Prepared by the Staff of The Commercial Radio Equipment Company, Kansas City, Missouri

Power in Watts	Db if Zero Db. =.006 Watts	Db if Zero Db. =.0125 Watts	600 Ohms			500 Ohms			200 Ohms		
			Rms. Voltage	Peak Voltage	Current in Milli-Amperes	Rms. Voltage	Peak Voltage	Current in Milli-Amperes	Rms. Voltage	Peak Voltage	Current in Milli-Amperes
6×10^{-9}	−60	−63.19	.0019	.0027	.0032	.0017	.0024	.00346	.0011	.0016	.0055
6×10^{-8}	−50	−53.19	.006	.0085	.0102	.0055	.0078	.0109	.0034	.0038	.0173
6×10^{-7}	−40	−43.19	.019	.027	.032	.0173	.0243	.0346	.0109	.016	.055
6×10^{-6}	−30	−33.19	.06	.085	.102	.0548	.0777	.1095	.0346	.038	.173
6×10^{-5}	−20	−23.19	.19	.27	.316	.1732	.232	.346	.1095	.16	.546
6×10^{-4}	−10	−13.19	.6	.85	1.02	.5478	.777	1.095	.346	.38	1.73
.000755	− 9	−12.19	.673	.953	1.13	.614	.869	1.23	.386	.546	1.94
.000951	− 8	−11.19	.755	1.07	1.26	.689	.976	1.38	.433	.613	2.18
.001197	− 7	−10.19	.848	1.20	1.42	.774	1.094	1.55	.487	.682	2.44
.001507	− 6	− 9.19	.952	1.35	1.58	.868	1.228	1.74	.546	.773	2.75
.001897	− 5	− 8.19	1.07	1.56	1.79	.974	1.378	1.95	.613	.866	3.08
.002388	− 4	− 7.19	1.19	1.68	2.03	1.09	1.541	2.19	.687	.973	3.46
.003007	− 3	− 6.19	1.35	1.91	2.24	1.23	1.74	2.45	.775	1.1	3.87
.003786	− 2	− 5.19	1.51	2.14	2.52	1.38	1.95	2.75	.870	1.23	4.34
.004766	− 1	− 4.19	1.69	2.39	2.83	1.54	2.18	3.09	.971	1.37	4.88
.006000	0	− 3.19	1.89	2.68	3.17	1.73	2.45	3.46	1.095	1.54	5.46
.007553	+ 1	− 2.19	2.13	3.01	3.56	1.94	2.74	3.89	1.22	1.73	6.14
.009509	2	− 1.19	2.39	3.38	3.99	2.18	3.08	4.36	1.37	1.94	6.89
.01197	3	− .19	2.72	3.85	4.47	2.48	3.51	4.89	1.56	2.22	7.72
.01250	3.19	0	2.74	3.88	4.57	2.50	3.54	5.00	1.57	2.23	7.9
.01507	4	+ .81	3.02	4.27	5.03	2.75	3.89	5.49	1.73	2.45	8.66
.01897	5	1.81	3.38	4.78	5.74	3.08	4.36	6.16	1.94	2.74	9.74
.0239	6	2.81	3.79	5.36	6.33	3.46	4.89	6.91	2.18	3.08	10.9
.0301	7	3.81	4.26	6.03	7.11	3.89	5.51	7.76	2.45	3.47	12.3
.0379	8	4.81	4.76	6.74	7.96	4.35	6.15	8.70	2.74	3.88	13.7
.0477	9	5.81	5.35	7.57	8.94	4.88	6.92	9.76	3.08	4.36	15.7
.06	10	6.81	6.00	8.49	10.20	5.47	7.74	10.95	3.45	4.88	18.31
.6	20	16.81	19	26.9	31.7	17.32	24.5	34.64	10.9	15.4	54.8
6.0	30	26.81	60	85	104	54.77	77.5	109.5	34.5	48.8	173
25	36.19	33	122.2	171	204.3	111.8	158	223.9	70.3	99.5	353
50	39.21	36.02	173.5	245	288	158.2	224	316.1	99.5	140.5	500
75	40.10	36.9	212	300	354	193.5	273.5	387.5	121.9	172	613
100	42.22	39.03	244	346	410	222.6	316	447	140.5	199	708
150	43.98	40.79	300	425	502	274	388	548	172.5	244	865
200	45.23	42.04	346	489	578	316	415	631	199	282	999
250	46.2	43.01	388	549	646	354	502	707	223	316	1,120
500	49.21	46.02	548	776	915	500	707	1,000	315	446	1,580
1,000	52.22	49.03	775	1,097	1,295	707	1,000	1,141	446	631	2,240
2,500	56.2	53.01	1,222	1,710	2,043	1,118	1,580	2,239	703	995	3,530
5,000	59.21	56.02	1,735	2,450	2,880	1,582	2,240	3,161	995	1,409	5,000
10,000	62.22	59.03	2,440	3,460	4,100	2,226	3,160	4,470	1,405	1,990	7,080
25,000	66.2	63.01	3,880	5,490	6,460	3,540	5,020	7,070	2,230	3,160	11,200
50,000	69.21	66.02	5,480	7,760	9,150	5,000	7,070	10,000	3,150	4,460	15,800
100,000	72.22	69.03	7,750	10,970	12,950	7,070	10,000	14,140	4.460	6,310	22,400
500,000	79.21	76.01	17,350	24,500	28,800	15,820	22,400	31,610	9,950	14,090	50,000

The broadcasting industry has adopted a new standard reference level, the definition of which reads: Zero or reference volume level shall be defined by specifying (a) the characteristics and method of use of the volume instrument and (b) a steady state reference of one milliwatt. The impedance of the circuit across which the instrument is calibrated shall be 600 ohms. The readings of the new instrument are in terms of "VU," numerically equal to the number of db above the reference volume level.

DECIBEL TABLE—*Continued*

Prepared by the Staff of The Commercial Radio Equipment Company, Kansas City, Missouri

74 Ohms			50 Ohms			37 Ohms			Db if Zero db =.0125 Watts	Db if Zero db =.006 Watts	Power in Watts
Rms. Voltage	Peak Voltage	Current in Milli-Amperes	Rms. Voltage	Peak Voltage	Current in Milli-Amperes	Rms. Voltage	Peak Voltage	Current in Milli-Amperes			
This impedance used only in radio frequency transmission lines and seldom with powers less than 25 watts			.00055	.00077	.01095	This impedance used only in radio frequency transmission lines and seldom with powers less than 25 watts			−63.19	−60	6×10^{-9}
			.00173	.0024	.0346				−53.19	−50	6×10^{-8}
			.0055	.0077	.1095				−43.19	−40	6×10^{-7}
			.0173	.0244	.346				−33.19	−30	6×10^{-6}
			.0548	.077	1.095				−23.19	−20	6×10^{-5}
			.173	.244	3.46				−13.19	−10	6×10^{-4}
			.194	.274	3.89				−12.19	−9	.000755
			.218	.308	4.36				−11.19	−8	.000951
			.244	.346	4.87				−10.19	−7	.001197
			.275	.389	5.46				−9.19	−6	.001507
			.308	.436	6.14				−8.19	−5	.001897
			.344	4.78	6.79				−7.19	−4	.002388
			.389	.55	7.84				−6.19	−3	.003007
			.436	.616	8.7				−5.19	−2	.003786
			.487	.689	9.75				−4.19	−1	.004766
			.546	.773	10.95				−3.19	0	.006000
			.614	.869	12.3				−2.19	+1	.007553
			.679	.96	13.8				−1.19	2	.009509
			.784	1.11	15.4				−.19	3	.01197
			.792	1.12	15.84				0	3.19	.01250
			.87	1.23	17.3				+.81	4	.01507
			.975	1.38	19.4				1.81	5	.01897
			1.095	1.55	21.8				2.81	6	.0239
			1.23	1.74	24.4				3.81	7	.0301
			1.38	1.95	27.5				4.81	8	.0379
			1.54	2.18	31				5.81	9	.0477
			1.73	2.44	34.5				6.81	10	.06
			5.48	7.75	109.5				16.81	20	.6
			17.3	24.4	345				26.81	30	6.0
42.3	59.8	582	This line impedance seldom used where power levels exceed 6 watts, and then mainly for audio applications			30.4	43	822	33.	36.19	25
60.8	86	821				43	60.8	1,162	36.02	39.21	50
74.5	105.2	1,008				52.7	74.5	1,425	36.9	40.10	75
86	121.6	1,161				60.8	86	1,643	39.03	42.22	100
105	148.5	1.450				74.5	105.4	2,015	40.79	43.98	150
121.5	172	1,644				86	121.5	2,325	42.04	45.23	200
136	192	1,840				96.3	136	2,600	43.01	46.2	250
173	244	2,590				136	192.3	3,679	46.02	49.21	500
272	388	3,675				192.3	272	5,220	49.03	52.22	1,000
423	598	5,820				304	430	8,220	53.01	56.2	2,500
608	860	8,210				430	608	11,620	56.02	59.21	5,000
860	1,216	11,610				608	860	16,430	59.03	62.22	10,000
1,360	1,920	18,400				963	1,360	26,000	63.01	66.2	25,000
1,730	2,440	25,900				1,360	1,923	36,790	66.02	69.21	50,000
2,720	3,880	36,750				1,923	2,720	52,200	69.03	72.22	100,000
6,080	8,600	82,100				4,300	6,080	116,200	76.01	79.21	500,000

6. Operation of Microphone—The operation of the microphone is as follows: Normally the current flows from battery to the front electrode through the granular carbon to the rear electrode, and back to the other side of the battery. This circuit has a certain resistance. When the microphone is spoken into or sound waves otherwise created, the diaphragm will vibrate, the pressure on the carbon granules will change and the resistance of the microphone will vary thereby causing a variable current to flow in the local transmitter circuit.

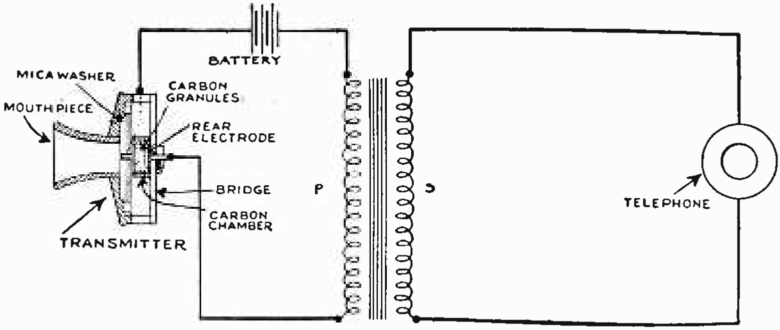


Fig. 238. Details of Single Button Microphone Circuit.

7. Double Button Microphone—The carbon type microphone employed in radio broadcasting differs somewhat in construction from that described, but the principle of operation is the same. In ordinary conversation it is only necessary for the telephone microphone to convert from sound vibrations into electrical impulses with frequencies ranging from 200 to 2000 cycles per second, whereas the studio microphone must convert all the voice and musical frequencies ranging from 30 to 10,000 cycles per second. A microphone used for such purpose is generally of the double button type, the diaphragm of which is of duraluminum .002 inch thick and is so stretched and damped that its frequency response is flat up to about 1000 cycles, beyond which it has a rising frequency characteristic up to 6000 cycles, after which its response drops off rapidly.

On each side of the diaphragm is a gold-plated area against which the carbon rests. The carbon is held in place by means of a felt or paper ring separated .003 of an inch from the diaphragm and as the smallest carbon granules are about .005 of an inch in diameter they stay in place. As the sound waves strike the diaphragm they compress the carbon in one button and loosen it in the other, thereby changing its resistance. By the arrangement of the push-pull action, distortion is minimized and the output increased. The microphone circuit is shown in figure 239. The current through each button is regulated by the potentiometer in shunt to the 12-volt battery. It is essential that the resistance of each button is balanced, otherwise the output will be distorted. Packing is a condition caused by excess mechanical pressure between points of contact or by adherence between points of contact resulting from excess voltages. It is evidenced by decreased resistance and sensitivity of the microphone and it is then necessary to remove the old carbon and repack with new. A form of packing may also be caused by excessively loud musical passages.

FIG. 238 (*a*). A Pack Transmitter W3XGO Showing Announcer Stewart Kennard Reporting the Races for WFBR Using a Double Button Carbon Microphone.

This type of microphone because of its poor frequency response and hiss produced by the carbon itself when the current is flowing through it, is rarely used for studio pick-up but has some advantages for use in remote pick-up such as that associated with relay broadcasting of sport events and public address systems. The output of this microphone is about —30 to —45 db.

8. Condenser Type of Microphone—The condenser type of microphone makes use of the principle of a variable capacity actuated by sound waves. It consists of two plates having an air dielectric. One plate of the condenser is usually a steel plug while the other plate, which is the diaphragm, is made of duraluminum of approximately .0018 inch thick. The diaphragm is stretched nearly to its elastic limit in order to make its resonant frequency above audibility. The plug and diaphragm are separated about .0015 inch.

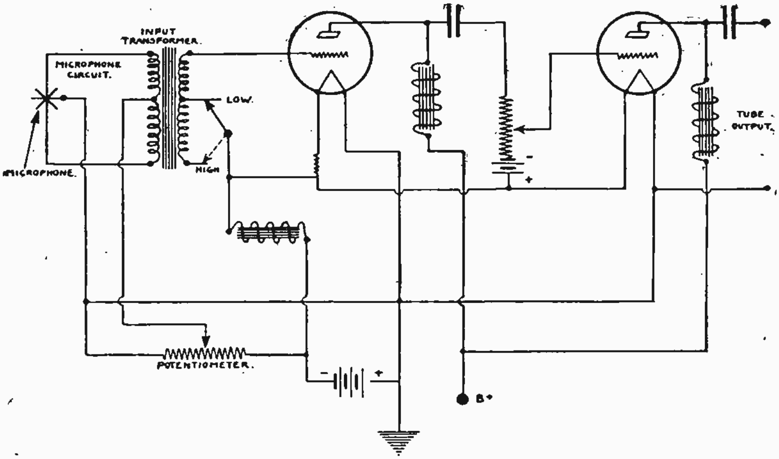


FIG. 239. Schematic Double Button Microphone and Speech Amplifier Circuit.

Usually a charge of approximately 200 volts is maintained on the condenser by means of a battery. When the sound waves strike the diaphragm and cause it to vibrate the electrical capacity of the condenser is varied which in turn changes the voltage applied to the grid of the amplifying tube.

9. Description of Western Electric Condenser Microphone (No. 394-W Transmitter)—The transmitter consists essentially of a very thin duraluminum diaphragm tightly stretched in front of a perfectly flat plate and spaced from it only .001 inch. The outside air is excluded from the space between the diaphragm and the plate and effects from variations in atmospheric pressure are taken care of by a compensating diaphragm at the rear of the plate. One side of the compensating diaphragm is in contact with the outside air while the other side through holes in the plate is in contact with the space between the plate and diaphragm. The latter will compensate for a variation in pressure of approximately 3 inches of mercury either side of normal pressure at sea level.

The frequency response of the condenser-type of microphone is somewhat more uniform than that of the double button carbon type, however, tests have shown that the frequency response is subject to variations with changes in temperature, an increase in temperature accentuating the response in the region of 5000 to 6000 cycles and conversely a drop in temperature decreases the response in this frequency region and at higher frequencies.

The condenser microphone is not as sensitive as that of the double button carbon type, its output level being approximately — 60 db. Figure 240 shows the circuit arrangement. This microphone is of the high impedance type and generally a preamplifier or head amplifier is built in the case housing the unit and the output reduced to low impedance and fed to a studio amplifier.

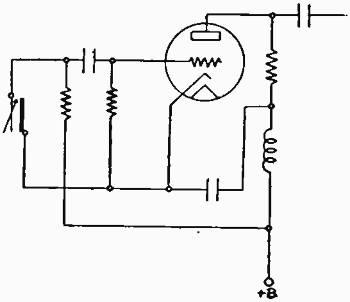


Fig. 240. Condenser Microphone Circuit.

10. Voltage-Generating Microphones (moving coil, moving iron, ribbon and crystal). The microphones mentioned so far have merely varied a resistance in a direct-current circuit, or varied a capacitance into which was permitted to flow the current from an external source of voltage. There is another family of microphones which generate their own voltages, neither needing nor using any external source, but resembling various sorts of alternators (a.c. generators). Of these the " dynamic " or moving-coil type is a miniature of the " dynamic " loudspeaker; the voice waves pushing the diaphragm in and out cause the coil at its center to move in the field of a strong magnet, thereby inducing in the coil a weak a.c. voltage corresponding in frequency and amplitude to the motion of the diaphragm—and therefore also having the form of the original sound waves. Therefore, the " dynamic " microphone is an a.c. generator, whereas the " dynamic " speaker is an a.c. motor.

Similarly a " magnetic " loudspeaker (also a motor) may be caused to act as a microphone since in this case the voice-operated diaphragm moves the iron armature, varies the reluctance of the magnetic circuit, in turn thereby varies the magnetic flux through the (stationary) coil, and induces a.c. in that coil.

In the "ribbon" or "velocity" microphone the moving member is not a coil but only a short length of thin dural ribbon hung in a strong magnetic field and driven back and forth by voice-waves without intervention of a diaphragm, but with generation just as in the moving coil type. This type of generator can also be reversed and used as a rather feeble loudspeaker, that is as a motor.

In the crystal microphone the conversion of voice power into a.c. depends upon a combination of thin slices of crystal, usually of Rochelle salt, to which electrodes are applied. This also can be used as either motor or generator, and is commonly so used. Indeed the crystal control of oscillators (by quartz slabs) depends upon the ability of a crystal slab to receive electric power from the oscillator at certain times (motor) and to return it to the oscillator at other times (generator).

Commercial examples of these various types are now to be discussed.

11. **Pressure Doubling**—The carbon, condenser and moving coil type microphones are designed to have a uniform voltage output over a wide band of frequencies as a result of uniform acoustical pressure on the diaphragm, however, it has been found that the conditions under which the microphone is used alter the response. The response at low frequencies (wavelengths large compared with the size of the microphone) is somewhat uniform, however, at the higher frequencies, above 1000 cycles, the response is accentuated due to what is termed pressure doubling. This occurs when the wavelength of the sound waves becomes comparable to the size of the microphone. In general a sound field is disturbed by the presence of the microphone, and as a result the pressure at the face of the microphone will not be the same as it was before the microphone was placed in the position for pick-up. The effect is one of diffraction and reflection considering the microphone as an obstruction in the sound field. It is limited to the frequencies above 1000 cycles and is a function of the size and shape of the microphone and the direction from which the sound waves approach the microphone.

12. **Directivity Effect**—The variation in frequency response with variations in the angle of sound incidence is called the directivity effect. When a microphone is employed to pick-up a large orchestra or chorus the major portion of the sound waves do not

impinge directly on the diaphragm of the microphone but reach it after one or more reflections from the walls and other objects in the room. If the response in these various directions differs the output will not be representative of the sound at the point of pick-up and directional distortion results.

13. **Cavity Resonance**—When the diaphragm is recessed or a concavity exists at the face of the microphone, the pressure on the diaphragm may be increased at certain frequencies since in effect an acoustical resonator is formed. Obviously distortion results since the higher frequencies will be accentuated.

14. **Diaphragm Resonance**—Carbon and condenser type microphones are subject to another form of distortion due to diaphragm resonance. As the term implies, the diaphragm resonates within the working range of the microphone and as a result the frequencies in the resonance range are greatly accentuated. Manufacturers attempt to eliminate this effect by making the resonance period of the diaphragm beyond audibility. Engineers can compensate for the distortion by equalization, that is, by providing filters to reduce the amplification in the resonance region.

15. **Western Electric Type 630–A Moving-Coil Microphone**—The Western Electric Type 630–A is representative of the latest development of the moving coil type of microphone. The chief disadvantages of the earlier types operating on the principle of a moving coil or conductor in a magnetic field were of nonuniformity of frequency response and directivity.

The 630–A microphone, a development of the Bell Telephone Laboratories, the research laboratories of the American Telephone and Telegraph Company and the Western Electric Company, is reported as having a high grade pick-up independent of the angle of sound incidence, throughout the range of from 40 to more than 10,000 cycles. At 10,000 cycles the maximum difference in response for any two directions is only about 5 db. This microphone is designed to be mounted so that the diaphragm is horizontal, and thus its response is uniform for all horizontal angles. A slight residual directional effect exists only in the vertical plane.

FIG. 241.

Western Electric 630–A Moving Coil Type Non-directional Microphone. (Courtesy of Western Electric Co.)

The 630–A microphone in appearance, as well as size, is comparable to a billiard ball, and is dubbed the "8 ball mike" by radio engineers and operators.

A spherical microphone mounted with its diaphragm horizontal would have a tendency to accentuate the response of high frequencies coming down directly toward the diaphragm. On the other hand the response to high frequencies arriving at the diaphragm from angles very much below the horizontal would be down. The effects have been almost completely avoided in the 630–A microphone, and an essentially uniform response obtained from sound coming from all directions by mounting an acoustic screen in front of the diaphragm. The screen is designed to produce a loss in sound passing through it, and to reflect back to the diaphragm sound coming from behind the microphone. Compensation is thereby accomplished for unequal diffractive effects and makes the instrument non-directional in its response characteristics.

The general construction is shown in figure 242. As previously mentioned, in many of the earlier types of microphones the cavity in front of the diaphragm introduced an undesirable resonance. In the 630–A microphone this resonance condition is controlled by the design of a protective grid, which is that part of the outer shell directly in front of the diaphragm. Instead of being the source of undesirable distortion, the grid and cavity have become a valuable aid in improving the response of the instrument at very high frequencies. This grid also incorporates a screen to

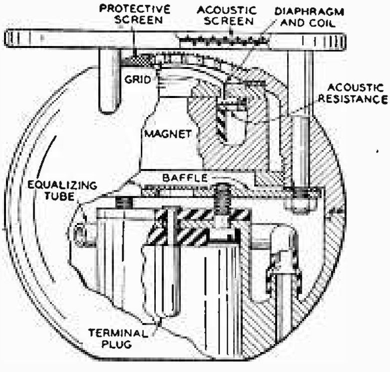


FIG. 242. Simplified Cross-sectional View of W. E. 630–A Non-directional Microphone.

prevent dust and magnetic particles from collecting on the diaphragm. The diaphragm is light in weight and of very low stiffness.

As reported by the supplier, the Western Electric Company, the size and shape of the housing was selected with particular reference to the requirements that had to be met. The size is such that the housing fits closely over the diaphragm and thus produces little more diffractive effects than would the diaphragm itself, and the spherical form allows the maximum amount of air space behind the diaphragm, which is essential to minimize the impedance to vibration. To prevent resonance within the case, an acoustic-resistance baffle is provided to divide the space into two parts. A tube, with its outlet at the back of the housing, serves the double purpose of equalizing the inside and atmospheric pressures, and of increasing the response of the instrument at low frequencies.

The acoustic screen that compensates for the directional effects is mounted over the grid in front of the diaphragm, and is thus an additional protection for the diaphragm. This places it in a vulnerable position, however, but it is designed to withstand considerable shock and the acoustic screen itself is a separate unit and easily replaceable. The terminals of the microphone are provided in the form of a plug recessed in the housing behind the microphone unit. This arrangement provides protection for the terminals and serves to conceal the connecting jack.

16. **The Velocity (Ribbon) Microphone**—The velocity microphone is quite different in principle and construction compared to the other types of microphones previously described. Instead of a diaphragm, the velocity microphone contains a thin duraluminum ribbon suspended between the poles of a fixed magnet with its length perpendicular to, and its width in the plane of the magnetic lines of force.

The vibrations of the ribbon due to an impressed sound wave induces an e.m.f. in the ribbon circuit consisting of the ribbon and primary of a transformer corresponding to the undulations of the sound wave.

The e.m.f. induced in the ribbon is given by the formula:

$$E = B\ I\ X,$$

where $B =$ the flux density,
$I =$ the length of the ribbon,
$X =$ the velocity of the ribbon.

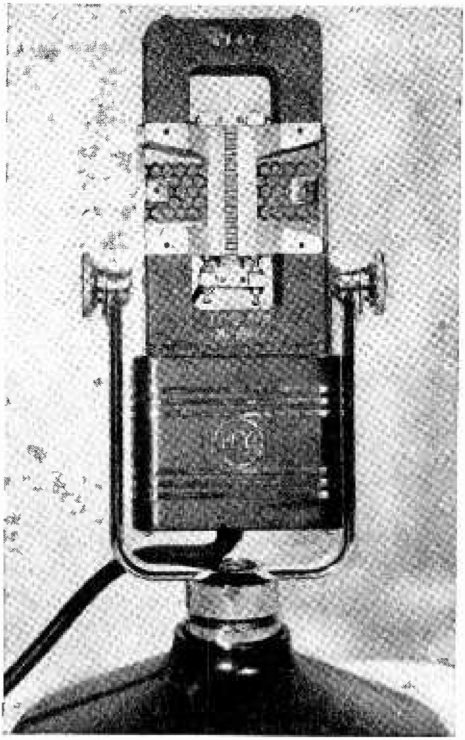


FIG. 243. RCA 44-B Velocity Microphone with Cover and Wind Shield Removed.

17. RCA Velocity Microphone Type 44-B—The velocity microphone shown in figure 244 consists of a microphone unit mounted on a swivel at the top of a program stand. The swivel mount permits the "aiming" of the transmitter in any desired direction. The transmitter is enclosed within a perforated metal casing which serves to protect it from mechanical injury and adverse wind effects.

The line coupling transformer is contained in a metal case as a part of the microphone unit.

With an input sound pressure of 10 dynes per square centimeter perpendicular to the plane of the ribbon, the ribbon microphone unit will deliver 800 microvolts across a 250-ohm load, which is equivalent to an output level of —67 db as compared with zero level of 12.5 milliwatts, or —64 db as compared with a zero level of 6 milliwatts.

On an open circuit basis of measurement, i.e., with an input of 1 dyne per square centimeter (1 bar) perpendicular to the ribbon, the output of the microphone across an open circuit is the equivalent of —81 db with reference to a zero level of 12.5 milliwatts.

18. Frequency Response—The operating range of the microphone extends from 30 cycles to 15,000 cycles.

When a velocity microphone is placed close to a source of sound the low frequency response is accentuated. In view of this fact, provision is made in the Type 44–B microphone to enable the user to alter its frequency response in such a manner as to suit best the particular purpose desired: viz., the pick-up of voice (i.e. within 2 feet of the microphone), or the pick-up of music (which takes place at greater distances from the microphone). Emphasis is here placed on the fact that this feature of the Type 44–B microphone is not provided with the intention that such alterations in frequency response be made at will, i.e., between selections on a broadcast program; but is furnished for the sole purpose of supplying a microphone with the best possible characteristics for vocal pick-up or for musical pick-up. It is recommended that the frequency response be adapted to either of these types of pick-up and the use of the microphone be restricted to that type of pick-up only.

FIG. 244. RCA 44–B Microphone Mounted on Program Type Stand.

19. Altering Frequency Response—To alter the frequency response proceed as follows:

A small circular hole will be found in the cover plate of the transformer casing. Though this hole will be visible the letter "*V*" (voice) or the letter "*M*" (music), depending on whether the microphone is at the time adapted for vocal pick-up or for musical pick-up.

Vocal pick-up requires the use of a jumper (upon which appears the letter "*V*"), which is to be placed across the two terminals marked "*M*" (music), located on the terminal block within the transformer housing. Access to this terminal block is obtained by removing the cover plate of the transformer housing.

When the jumper "*V*" is used, it connects a reactor in parallel with a part of the transformer winding (when the 250-ohm output connections are used), or with all the transformer winding (when the 50-ohm output connections are used).

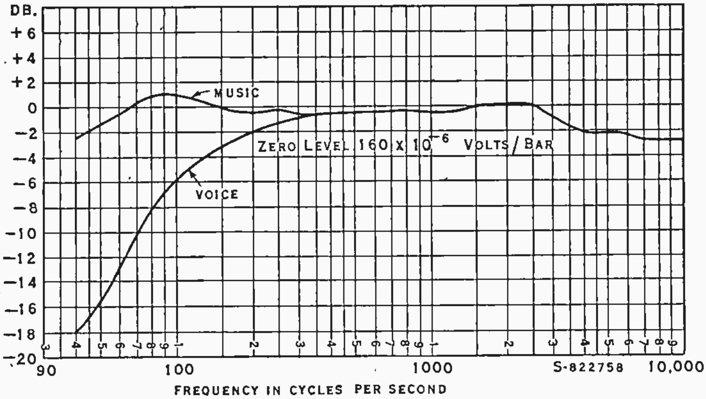


FIG. 245. Frequency Response of Type 44-B Microphone.

A response curve taken with and without the "*V*" jumper is shown in figure 245. As will be observed from examination of this curve, there is a sharp decline at the low frequency end of the curve when the "*V*" jumper is used. It is to be noted that this curve was taken in a plane wave field, and that the curve is flat when the speaker is located at a distance of 1 foot from the microphone.

20. Directional Properties—One of the most important characteristics of the velocity microphone is its directional property. Since the ribbon is suspended in free space, sound waves approaching the microphone from a direction in the same plane as the ribbon have no effect upon it. Sound waves from either direction along an axis perpendicular to the plane of the ribbon have the maximum effect. For equal distances from the transmitter, the relative response to sound originating at various angles to the axis perpendicular to the ribbon is shown in figure 246.

It is at once apparent that this characteristic is of considerable value in the solution of some of the difficulties usually encountered in reverberant locations by the reduction of the effect of undesired sound reflections, and in the increased possibilities of obtaining better balance, clarity, naturalness and selectivity in sound pick-up. Extraneous direct or reflected sounds approaching the microphone from side directions will have little effect, and therefore background noises and reflected sounds in the broadcast are considerably reduced, which increases, by comparison, the quality of the direct sounds reproduced. The degree of sound-proofing necessary for sound originating within the "dead zone" is, of course, dependent upon the reflecting surfaces present which may return the undesired sound to the microphone from such directions that response may be obtained.

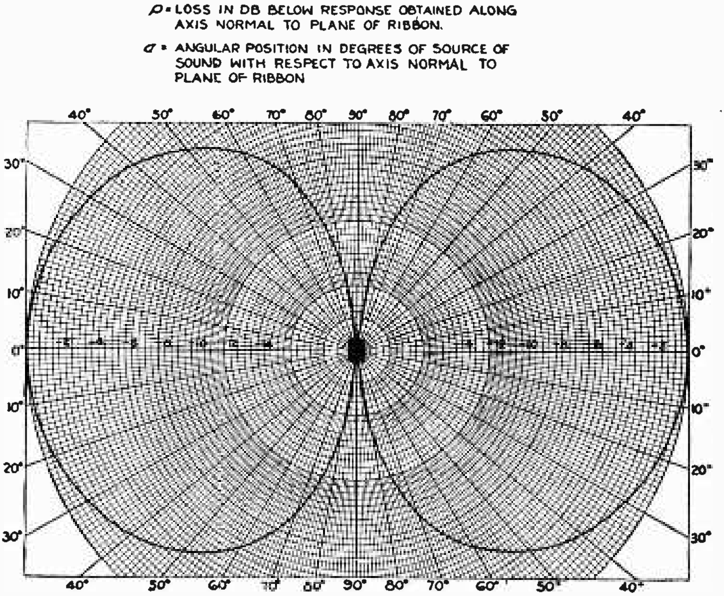


FIG. 246. Directional Characteristics of Velocity Microphone.

For the same allowable reverberation pick-up the operating range of the velocity microphone is approximately 1.7 times greater than a non-directional microphone having the same sensitivity.

When used for public address and sound reinforcement purposes the directional characteristic is of considerable value in reducing feed-back effects between the microphone and loudspeaker.

Sound concentrators and baffles used with condenser microphones are unnecessary with and inapplicable to the velocity microphone because of the fundamental difference in the principle of its operation. The transmitter must be used in free space where the flow of air particles is unimpeded. However, "pick-up" from the rear direction of the microphone may be eliminated by placing a baffle or shield of heavy sound absorbing material, such as heavy felt, at a distance of not less than three feet from the transmitter and so confine the "pick-up" to the area in front of the microphone.

21. Technique of Velocity Microphone Placement—The proper placement of the microphone is essential in order to realize fully its inherent advantages. For this reason, the following instructions should be carefully studied, and close attention be given to the results of any special placement with a view towards future improvement of the technique. These instructions can of course only serve as a guide, and a study should be made to determine the best microphone placement for each condition.

(*a*) *General*—The source of sound, speaker, announcer or musical instrument, should not be placed closer to the microphone than 2 feet and a distance of 3 to 4 feet is to be preferred. At shorter distances there is a tendency toward accentuation of low frequencies, which may result in making voices sound "boomy." In this respect, the use of the velocity microphone differs greatly from that of the condenser microphone with which the speaker or soloist has usually worked at a distance of 4 to 6 inches.

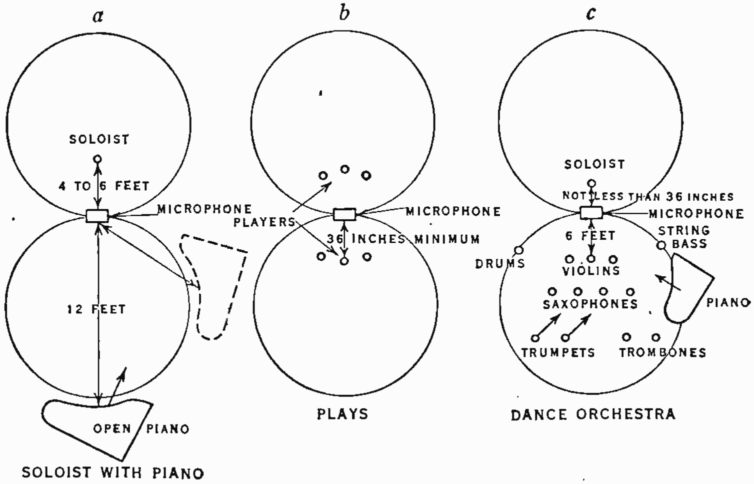
The placement of a speaker or musical instrument off from the center line of the microphone will in no way affect the quality of pick-up, but will merely attenuate the direct sound pick-up, thereby raising the ratio of reverberation to direct pick-up.

The microphone is bi-directional. Speakers, instruments, or players may be placed on either or both sides of the microphone with equal effect. The diagrams (figures 247*a, b, c*) will serve as examples of the advantages which arise from the bi-directional characteristic.

For the most satisfactory results, the microphone should not be placed closer than 3 feet to any solid reflecting surface. This statement is, of course, general, and specific conditions may require otherwise, such as in footlight mounting.

The diagrams referred to in the subsequent paragraphs and the discussion concerning them can only serve to indicate some of the possible placements under particular conditions. The final decision as to what constitutes the proper placement must rest with someone who is competent to judge the quality of the results as reproduced by the monitor speaker.

(*b*) *Soloist with Piano*—Interesting effects may be obtained by changing the angle of the microphone with respect to the piano, thus changing the ratio of reverberation to direct pick-up. The distance between the soloist and microphone should be determined by the strength of his (or her) voice, and the piano should be placed accordingly. The general arrangement is shown in figure 247*a*. Under no conditions should the soloist be less than 2 feet from the microphone.



SOLOIST WITH PIANO

PLAYS

DANCE ORCHESTRA

FIG. 247. *a*, *b* and *c*, Various Microphone Arrangements.

(*c*) *Plays*—The bi-directional characteristic of the microphone may be used to its fullest advantage in broadcasting by grouping the players about the microphone at such positions that their voice levels match to form the desired composite. See figure 247*b*. With such an arrangement, considerable if not all of the moving and dodging back and forth of the characters seeking positions advantageous to the presentation may be avoided.

When the microphone is used by a speaker located at a table or desk, the microphone should be so placed that it picks up direct sound from the speaker rather than reflected sound from the surface of the table, desk or manuscript.

(*d*) *Dance Orchestra*—The diagram (figure 247*c*) is self-explanatory, the only precaution necessary being to keep the soloist at least 2 feet, and preferably 3 feet, from the microphone.

Due to the fact that artists and announcers cannot work close to the microphone, some difficulty may be experienced in obtaining the proper balance between the artist or announcer and the orchestra. This difficulty can be overcome quite satisfactorily by using two microphones, one to pick up the orchestra and the other to pick up the artist or announcer. The artist's microphone should be located so that its "dead zone" is toward the orchestra. By properly setting the mixing controls, the level of the orchestra can be controlled so that a satisfactory background accompaniment of music is obtained.

In locating the microphone with respect to an orchestra, care should be taken to avoid reflected pick-up from hard surfaced floors. Such reflections can be avoided by the use of carpets or similar material on the floor.

(*e*) *Public Address*—For public address use the microphone can usually be placed near the speaker (within 3 or 4 feet). It is important to see that the direction of minimum pick-up is toward the loudspeaker system to prevent acoustic feed-back. If the speaker must have latitude of movement on the stage, it may be necessary to have a microphone installed at each side to obtain satisfactory pick-up.

(*f*) *Sound Reenforcing*—Microphones used for this purpose must generally be concealed and may be placed and successfully operated in the wings, footlights, flies, etc., of the stage. When the microphone is placed in a footlight trough, heavy sound absorbing felt should be placed behind the microphone to prevent undesirable reflection effects. Such a system usually requires a number of microphones and the detailed location of these microphones is largely determined by the exact use of the microphone, constructional details of the stage and other conditions so numerous as to preclude any definite statement of rules or methods of application. The plane of zero sound may be utilized to great advantage in eliminating undesirable resonance, reflection and diffraction effects usually encountered when a microphone is located in a cavity. This fact accounts for the highly successful application of this microphone to footlight trough mounting.

22. RCA Uni-Directional Velocity Microphone Type 77-A—The unit is designed to pick up sound arriving from one direction—or, more accurately, from one side—while almost completely rejecting sound from the other side, it is admirably adapted to studio pick-up, public address and sound reenforcement applications.

Instead of a diaphragm (in the commonly accepted meaning of the word), the uni-directional microphone contains a thin metallic ribbon suspended between the poles of a permanent magnet with its length perpendicular to, and its width in the plane of, the magnetic lines of force. The ribbon is rigidly clamped at the center, as well as at the top and the bottom. The lower half is open front and back and operated as a regular velocity microphone. In order to make the upper half of the ribbon operate as a pressure microphone, it is, of course, necessary that the rear of this section of the ribbon be enclosed. At the same time it is not possible just to block this section off, as such a contrivance would result in a response increasing with the frequency. Rather, it is necessary to present an acoustic impedance to the back part of the ribbon. An infinitely long tube would be the ideal impedance; but this, of course, is impossible. Instead, an ingenious labyrinth, which gives practically the same effect, is used. While this labyrinth has a finite length, the desired damping of reflection

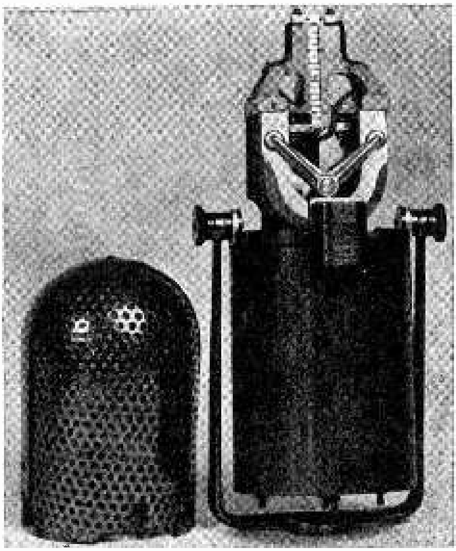


FIG. 248. RCA 77-A Uni-directional Microphone with Cover Removed.

is obtained by filling it very loosely with sound-absorbing material. The labyrinth consists of a series of circular sections, the interior of each section having a spiral partition, an opening at the beginning or the end of which communicates with the beginning or the end, respectively, of the section of the labyrinth that immediately precedes or immediately follows it. The sections occupying the upper part of the labyrinth are so designed as to provide a cavity to accommodate the line coupling transformer, which thus forms a part of the microphone unit. The result is that the upper half of the ribbon becomes an efficient pressure-operated microphone.

The vibration of each part of the ribbon is in exact accordance with the sound vibrations and, occurring as it does within the magnetic field, sets up corresponding alternating electric potentials across the primary of its associated transformer. Since the two microphones (i.e., the velocity-operated section and the pressure-operated section of the Type 77–A microphone) are a part of the same ribbon, the voltages developed in the two sections are, of course, in series, and the output level is obtained from the ends of the ribbon in essentially the same manner as in the case of the velocity microphone.

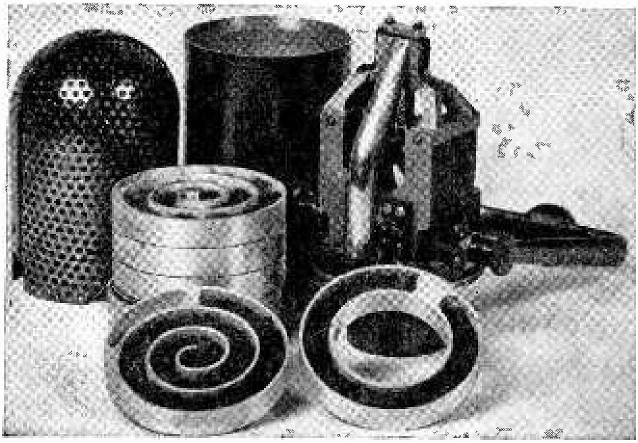


FIG. 249. Disassembled View of the Type 77–A Microphone.

The uni-directional microphone shown consists of a microphone unit mounted in a horizontal swivel on the top of a program stand. "Aiming" is accomplished partially by means of this swivel and partially by rotating the vertical column of the program stand. The transmitter is enclosed within a circular, perforated metal casing, so designed as to conform to the circular construction of the labyrinth, which occupies the lower part of the unit.

The Type 77–A microphone unit is supported in a mounting yoke (containing the aforementioned horizontal swivel), which permits it to be tilted as desired. This mounting yoke is supplied with a threaded stand flange to fit a standard Type AZ–4090 program type microphone stand. A suspension mounting (Type UP–4212–A) is supplied to permit the suspension of the unit overhead when desired.

The microphone program stand (Type AZ–4090) is of the adjustable single vertical column type with a three-point base. The height of the transmitter may be adjusted to maximum and minimum heights of 84 inches and 59 inches respectively.

With an input sound pressure of 10 dynes per square centimeter perpendicular to the plane of the ribbon, the Type 77–A unidirectional microphone will deliver 317 microvolts across a 250-ohm load, which is equivalent to an output level of —75 db as compared with a zero level of 12.5 milliwatts, or —72 db as compared with a zero level at 6 milliwatts.

On an open circuit basis of measurement, i.e. with an input of 1 dyne per square centimeter (1 bar) perpendicular to the ribbon, the output of the microphone on open circuit is the equivalent of —89 db with reference to a zero level of 12.5 milliwatts.

23. Frequency Response—The operating range of the microphone extends from 60 cycles to 10,000 cycles. When the microphone is located less than 2 feet from the source of sound the low frequency response is increased somewhat, and when operated at a greater distance (up to 4 feet) the low frequency response is slightly attenuated. Beyond the 4-foot operating distance the response characteristic is unchanged by changes in the operating distance. The frequency response is essentially unchanged by the direction of the incident sound over an angle of 150 degrees at the front of the microphone.

24. Uni-directional Property—One of the most important characteristics of the Type 77–A microphone is its uni-directional property. On the front, or operating side, of the microphone the response is very uniform, while at the rear of the microphone sounds are attenuated an average of 20 db, thus giving a 10-to-1 ratio of desired to undesired pick-up. Sound waves originating in front and along an axis perpendicular to the plane of the ribbon will naturally have the maximum effect.

The outstanding advantage of the Type 77-A microphone is derived from the fact that the unit combines the action of a velocity-operated and a pressure-operated microphone and results from the manner in which the velocity-operated and the pressure-operated parts of the ribbon add together.

Without going into mathematical expressions for these voltages, it is possible to obtain a picture of the action from a consideration of the three patterns shown in figure 250. In this illustration (*a*) is the directional pattern of a velocity microphone (*b*) is the directional pattern of a pressure microphone. While these figures are the theoretical or idealized patterns, they correspond, for ribbon microphones, quite closely to actual measured characteristics.

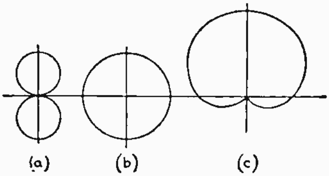


FIG. 250. Development of Directional Pattern of 77-A Microphone.

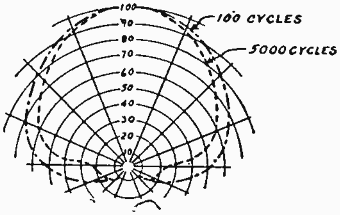


FIG. 251. Cardioid Pattern of 77-A Microphone.

When these patterns are added, the forward lobe of the figure-8 pattern adds to the circular pattern, while the rear lobe, which is 180 degrees out of phase, opposes. The result is the same as that obtained when the signals of a vertical antenna and a loop antenna are added; viz., a cardioid of revolution, as shown at (*c*). In practice, the actual measured response of the Type 77-A uni-directional microphone, as shown in figure 251, approaches this cardioid very closely. For all frequencies up to 6000 cycles the cancellation is very good. At higher frequencies a small "tail" occurs because of the slight phase displacement that begins to become noticeable in this range.

It is at once apparent that the uni-directional characteristic is of considerable value in the solution of some of the difficulties encountered in reverberant locations by the reduction of the effect of undesired sound reflections, and the increased possibilities of obtaining better balance, clarity, naturalness and selectivity in sound pick-up. Extraneous direct or reflected sounds approaching the microphone from side directions and from the rear will have little or no effect and therefore background noises and reflected sounds in the broadcast are considerably reduced, which increases, by comparison, the quality of direct sounds reproduced. The amount of sound-proofing necessary for sound originating within the "dead zone" can be greatly reduced—and, in many cases, "dead end" construction can be entirely eliminated.

For the same allowable reverberation pick-up the operating range of the uni-directional microphone is approximately 1.73 times greater than a non-directional microphone having the same sensitivity.

When used for public address and sound reenforcement purposes the directional characteristic is of considerable value in reducing feed-back effects between the microphone and the loudspeaker.

Sound concentrators and baffles used with non-directional microphones are unnecessary with and inapplicable to the uni-directional microphone because of the fundamental difference in the principle of its operation. The transmitter must be used in free space where the flow of air particles is unimpeded. "Pick-up" from the rear of the microphone is eliminated by the design and construction of the unit.

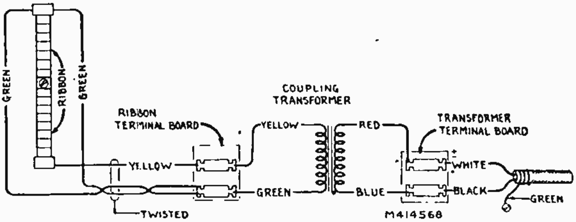


FIG. 252. Schematic Wiring Diagram of 77-A Microphone.

25. **Microphone Assembly**—The Type 77-A uni-directional microphone is shipped with the stand flange attached by means of three screws to the microphone mounting yoke. The suspension fitting is shipped in an envelope in the box with the microphone unit.

(*a*) *Stand Mounting*—If it is desired to mount the microphone unit on a program stand, it is necessary merely to screw the microphone (using the stand flange) securely to the stand column.

(*b*) *Suspension Mounting*—If it is desired to suspend the microphone overhead, the stand flange must be removed from the microphone mounting yoke and replaced with the suspension fitting, which contains the eyelets for cord attachment. The fitting must be attached securely to the yoke by means of the three screws formerly used for mounting the stand flange.

Note—When the microphone is suspended see that its weight is carried on the suspension fitting, with no strain on the cable.

(*c*) *Cable Connections*—The microphone is shipped with the microphone cable already connected at the microphone terminal board. This terminal board is rendered accessible for inspection or service by taking out the three screws located about the microphone screen mounting flange and removing the screen.

26. Technique of Uni-directional Microphone Placement—The proper placement of the microphone is essential in order to realize fully its inherent advantages. For this reason, the following instructions should be carefully studied, and close attention should be given to the results of any special placement, with a view toward future improvement of technique. These instructions can, of course, serve only as a guide, and a study should be made to determine the best microphone placement for each condition.

(*a*) *General*—The Type 77–A uni-directional microphone has a pick-up angle of approximately 150 degrees. The source of sound, speaker, announcer, actor or musical instrument, should not be placed closer to the microphone than 2 feet, and a distance of from 3 to 4 feet is to be preferred. At shorter distances there is a tendency toward accentuation of low frequencies, which may result in making voices sound "boomy." In this respect the use of the uni-directional microphone differs greatly from that of the condenser microphone, with which the soloist usually works at a distance of from 4 to 6 inches. As a point of useful information, it may be mentioned here that the uni-directional microphone may be used as a close-talking microphone by talking in the plane of the ribbon. In this position, only the pressure-operated part of the ribbon is used.

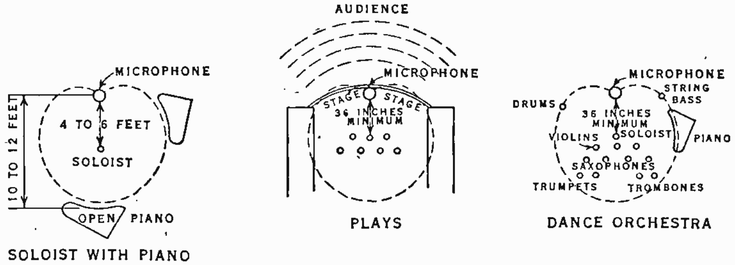
The placement of a speaker or musical instrument off from the center line of the microphone will in no way affect the quality of pick-up, but will merely attenuate the direct sound pick-up, thereby raising the ratio of reverberation to direct pick-up.

The microphone is uni-directional. Speakers, instruments or players may be placed on the operating side of the microphone only. The diagrams will serve as examples which arise from the uni-directional characteristic.

For most satisfactory results, the microphone should not be placed closer than 3 feet to any solid reflecting surface. This statement is, of course, general, and specific conditions may require otherwise.

The diagrams referred to in the subsequent paragraphs and the discussion concerning them can only serve to indicate some of the possible placements under particular conditions. The final decision as to what constitutes the proper placement must rest with someone who is competent to judge the quality of the results as reproduced by the monitor speaker.

(*b*) *Soloist with Piano*—Interesting effects may be obtained by changing the angle of the microphone with respect to the piano, thus changing the ratio of reverberation to direct pick-up. The distance between the soloist and the microphone should be determined by the strength of his (or her) voice, and the piano should be placed accordingly. The general arrangement is shown in figure 253. Under no condition should the soloist be less than 2 feet from the microphone.



SOLOIST WITH PIANO PLAYS DANCE ORCHESTRA

FIG. 253. Various Microphone Arrangements.

(*c*) *Stage Plays*—In the case of stage plays and those pick-ups of the type that occur in the case of auditorium-type studios, where a sizable audience is present—and in remote pick-ups at theatres, night clubs and the like, where audience noise presents a serious problem, the use of the uni-directional microphone possesses a distinct advantage. By placing the microphone with its dead-side toward the audience and close to the footlights, or in an equivalent position, the 20 db discrimination will provide the desired attenuation of audience noise, while the broad pick-up angle—useful through nearly 150 degrees—will afford pick-up of the whole stage, or that part of the studio where the artists are located.

(*d*) *Dance Orchestra*—The set-up for dance orchestra is similar to that just outlined for stage plays, the dead-side of the uni-directional microphone being toward the dance floor. The diagram (figure 253) is self-explanatory, the only precaution necessary being to keep the soloist at least 2 feet, and preferably 3 feet, from the microphone.

In locating the microphone with respect to an orchestra, care should be taken to avoid reflected pick-up from hard surfaced floors. Such reflections can be avoided by the use of carpets or similar material on the floor.

(*e*) *Large Orchestra*—An arrangement for a large symphony orchestra is shown in figure 254. It is to be noted that the wide angle of coverage (150 degrees) of the uni-directional microphone will permit a satisfactory pick-up in many cases, such as that shown, with but one microphone. It must be borne in mind, however, that the physical proportions and acoustic properties of the studio have a direct bearing on the arrangement of the orchestra and the placement of the microphone. Where space considerations do not govern, changes from the arrangement shown should not

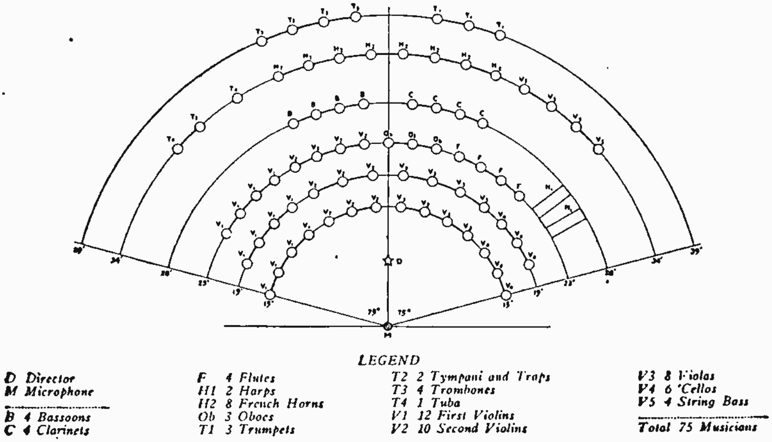


FIG. 254. Microphone and Orchestra Arrangement for Symphony Orchestra.

necessarily be very extensive in order to give excellent results under the usual acoustic conditions.

(*f*) *Public Address*—For public address use the microphone can usually be placed near the loudspeakers (within 3 or 4 feet). It is important to see that the dead-side of the microphone is toward the loudspeaker system—more specifically, the microphone should not be placed in front or directly behind the loudspeakers—to prevent acoustic feed-back. If the speaker must have latitude of movement on the stage, it may be necessary to have a microphone installed at each side to obtain satisfactory pick-up.

(*g*) *Sound Reenforcing*—Microphones used for this purpose must generally be concealed and may be successfully operated in the wings, flies, etc., or at the front of the stage, where some simple method may be devised for their concealment. Such a system usually requires the use of a number of microphones and their detailed location is largely determined by their exact use, the constructional details of the stage and other conditions so numerous as to preclude any definite statement of rules or methods of application. The uni-directional feature of the microphones may be utilized to great advantage in eliminating undesirable noise emanating from the audience area. It is also to be noted that, because of the wide pick-up angle of the uni-directional microphone, fewer units of this type than of any other will be required for proper coverage.

27. The Inductor Type Microphone—The inductor type of microphone was developed by RCA Victor Company particularly to meet the requirements of outside pick-ups. The conductor in which the voltage is generated is coupled rigidly to an aluminum diaphragm. The diaphragm is slightly concave for the purpose of increasing its rigidity and the supporting edges are corrugated in order to secure the proper value of compliance. The magnetic field is supplied by a fixed horseshoe magnet. The electrical resistance of the moving conductor is approximately .07 ohm and a transformer mounted between the open portion of the magnet permits matching the moving conductor to a 250 or 25 ohm line.

The mass of the moving system and the compliance edge of the diaphragm are so chosen that the resonant frequency is about 400 cycles. This results in a system sufficiently stiff to be relatively unaffected by shock. The useful range of the inductor microphone is purposely limited at 60 cycles. Below this frequency pressure equalization exists between the front and back of the diaphragm. This feature assists in the reduction and elimination of noise due to wind and permits the microphone to be used out-of-doors under adverse conditions.

The directional properties are practically spherical for frequencies below 1000 cycles with some variation at frequencies above this value.

The output level of this microphone is about —70 db.

28. The Velotron Microphone—The Velotron, developed by the Bruno Laboratories, is a velocity microphone employing a static field. instead of the heretofore usual magnetic field. It displays all the directional characteristics of the magnetic velocity microphone. The back or grounded plate consists of a totally insulated perforated plate, the insulation forming predetermined hills and dales. Across this are loosely laid a number of ribbons of thin duraluminum. During operation, a polarizing voltage is applied between the back plate and the ribbon through a high value of resistance. The ribbons being free to move change their position in accordance with the velocity of the incoming sound wave. This causes corresponding changes in capacity between ribbon and plate and, due to the charging current through the series resistance, a voltage appears across it which is an exact translation of the original sound wave.

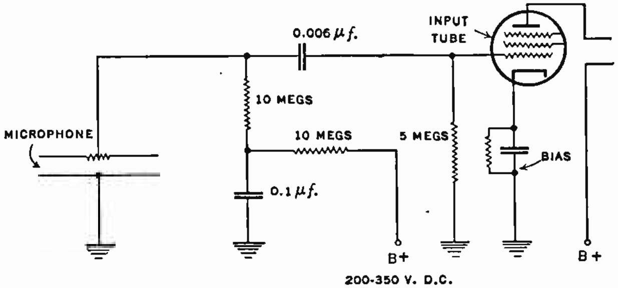


FIG. 255. Input Connections of the Static Velocity Microphone. The polarizing voltage may be obtained from any point in the power supply.

The frequency response of the microphone may be controlled by variation in polarizing voltages used. Voltages on the order of 50 to 100 give a flat response. Increasing these voltages from 100 to about 200 restricts the low frequency response, the increased static pull changing the position of the ribbon in its relation to the back plate.

29. Crystal (Piezo-Electric) Microphone—Figure 256 shows a cross-sectional view of a Brush sound cell as employed in a piezo-electric microphone developed by The Brush Development Company. The sound cell consists of a rectangular frame, usually of bakelite, in each side of which is supported a thin Rochelle salt crystal bimorph element. (See section 10 for a brief explanation of the principle.)

A bimorph element is the name used to identify a combination of two plates of Rochelle salt crystal cemented together in a suitable manner that when a voltage is applied to electrodes attached to the plates, one plate will tend to expand and the other to contract, resulting in a bending of the whole unit, in a manner similar to a bimetallic thermostat. Conversely, when the unit is mechanically deformed as it would be by the pressure of sound waves, a voltage is generated which is proportional to the pressure.

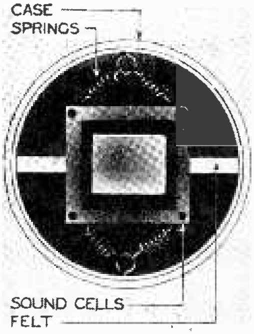


FIG. 256. Internal Construction of Type BR25 Sound Cell Microphone.

FIG. 257. Type BR43 Sound Cell Microphone (Brush).

In the Brush sound cell the crystals are supported by the frame at two points, and a clearance is provided between the frame and the crystal sealed by a flexible, air-tight annulus, thereby leaving the crystal free to be distorted by the variations of pressure of the sound waves. Silver leads are brought out from the crystals at the point of support and are usually connected in parallel or series parallel. The cell is impregnated to render it air-tight and moisture proof. The result is a small, flat, hollow air-tight box the two major sides of which generate voltage in proportion to the pressure. It is important to remember that the voltage generated by one side is in phase with that of the other when acted upon by sound waves and out of phase when caused by mechanical shock or vibration. The Brush broadcast type of spherical microphones have an output level of —60 to —67 db.

30. **Microphone Output Levels**—The table on page 439 showing the output level of various microphones is taken from the Kenyon Amateur Transmitter Manual and published by courtesy of the Kenyon Transformer Co., Inc. The levels as given in the text are figures supplied by the manufacturers of the devices. The RCA microphones are rated on the basis of zero level at 12.5 milliwatts; the others on zero level at 6 milliwatts. See section 3 (*b*) and (*c*) of this Chapter for conversion from one level to the other.

31. **Volume Indicator**—The volume indicator is employed as a part of the control apparatus of all broadcasting equipment to indicate the volume level of the program at the output of the speech amplifying apparatus which feeds the line or modulator tubes. Indication is given by a sensitive galvanometer in the plate circuit of a vacuum tube. The grid of the tube is energized by the output of the speech amplifier. A potentiometer is employed to permit adjustment of the negative grid bias. A level measuring key for the large steps and a level measuring switch for small steps connected in the grid circuit are calibrated directly in decibels from zero level of volume. By adjustment of these keys the volume level at the input can be determined as indicated by a certain deflection of the galvanometer in the plate circuit of the tube. If the volume level is too high as indicated by the db reading the correct adjustment can be made at the speech amplifier until the level is at the value desired.

It is the duty of the control operator, by watching the volume indicator meter, to adapt the fixed volume range of the transmitter to the frequently greater volume range of the program. He accomplishes this by the master gain control of the line amplifier and in some instances it is necessary to compress the natural

Data on Various Microphones

Manufacturer	Model	Type	Level in db
Amperite Corp.	RE-1	Velocity-Ribbon	– 90 db
Amperite Corp.	RAE	Velocity-Ribbon	– 90 db
Amperite Corp.	RB	Velocity-Ribbon	– 65 db
Amperite Corp.	RS	Velocity-Ribbon	– 68 db
Astatic	K-2	Crystal	– 64 db
Astatic	218	Crystal	– 56 db
Astatic	D104	Crystal	– 60 db
Bruno	RA-2	Velocity-Ribbon	– 90 db
Bruno	RA-3	Velocity-Ribbon	– 78 db
Bruno	RV-3	Velocity-Ribbon	– 70 db
Bruno	Vel	Static Velocity	– 53 db
Brush Development	G-2S2P	Crystal	– 70 db
Brush Development	G-4S6P	Crystal	– 60 db
Brush Development	G-1	Crystal	– 90 db
Brush Development	G-20	Crystal	– 80 db
R. C. A.	44A	Velocity-Ribbon	– 78 db
R. C. A.	4010	Velocity-Ribbon	– 65 db
R. C. A.	50A	Inductor	– 67 db
Shure Bro.	3B	Double button	– 45 db
Shure Bro.	22B	Double button	– 45 db
Shure Bro.	70S	Crystal	– 56 db
Shure Bro.	701	Crystal	– 55 db
Thomaston Labs.	MC30	Dynamic	– 86 db
Universal	A	Single-button	– 40 db
Universal	X	Single-button	– 45 db
Universal	BB	Double-button	– 45 db
Universal	LL	Double-button	– 50 db
Universal	CB	Double-button	– 45 db
Universal	RL	Velocity-Ribbon	– 63 db
Western Electric	337	Single-button	– 15 db
Western Electric	395	Single-button	– 8 db
Western Electric	615A	Single-button	– 15 db
Western Electric	600A	Double-button	– 45 db

volume in variation of speech and music, which may be as high as 60 db, into a range of about 40 db so as to avoid overmodulation on one hand and to prevent the program level going below the noise level on the other.

When the program reaches the level on high passages where overmodulation would occur the control operator compresses the range by inserting loss and removing it during the passages when the level would be comparable to the noise level inherent in the equipment.

The meters associated with volume indicators have in the past been of either the slow movement type which indicate the average level of the peaks of the program or of the high speed type which respond rapidly and indicate approximately 90 percent of the peaks of the program material. Both possess disadvantages since it is difficult to maintain a high level of modulation without avoiding overmodulation on peaks and consequently distortion.

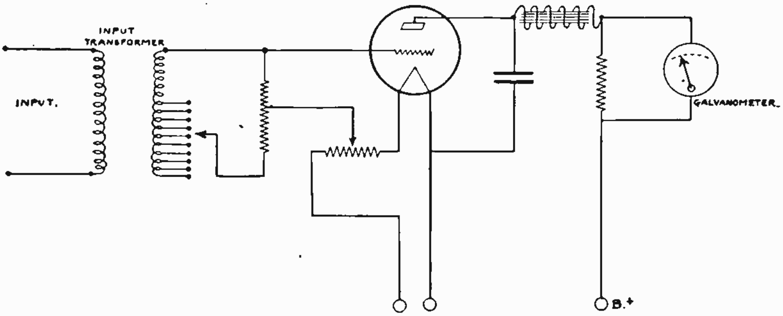


FIG. 258. Schematic of Volume Indicator.

Realizing the shortcomings of the older types of volume indicators broadcast engineers are now rapidly replacing these units with the new type of power level indicators. A recent contribution to the art in the line of power level indicators is that distributed by General Radio Company known as the type 686–A Power-Level Indicator and by courtesy of that company a brief description of the operation and electrical characteristics of this unit follows:

32. General Radio Type 686–A Power-level Indicator—The sluggishness of old-style indicators and the rapid needle movement of high-speed meters are avoided through the use of an electrical storage indicating circuit similar to those in broadcast modulation monitors. The circuit is that of a vacuum-tube voltmeter with a linear preamplifier so that no distortion is introduced into the channel, and, because of the high input impedance, a negligible amount of power is absorbed.

Designed to meet a set of rigid specifications for electrical performance, it registers faithfully and follows accurately the rapid fluctuations of speech and music. Particular attention has been given to mechanical features such as ease of reading and accessibility of component parts.

The indicating meter is of the highest speed which is commercially available. It will reach full deflection in about 0.15 second, which is about the shortest pulse occurring in most speech and music circuits. By the use of suitable damping, the meter is momentarily stopped at its maximum swing, and an electrical storage circuit allows it to return slowly toward zero. In this way the meter registers each peak accurately, while its slow return action makes it possible to observe the peak amplitude and at the same time eliminates the fatiguing erratic motion of the ordinary high-speed meter.

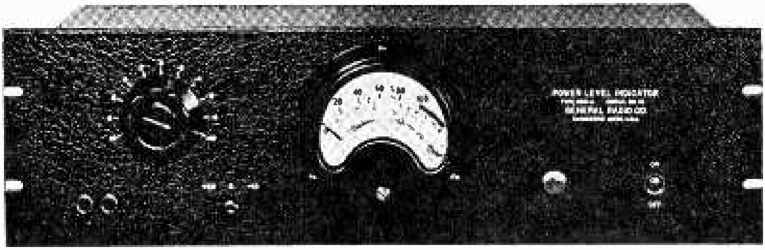


FIG. 259. General Radio Type 689A Power Level Indicator.

Psychologically, the slow return gives the impression that the indicating needle is following the speech amplitude as it sounds to the ear. The "floating" reading makes monitoring relatively a simple matter.

The meter itself is large and has a total swing of 3 1/4 inches. The needle is lance-shaped, and only enough of it is exposed to make continuous reading simple and not tiring. The scale of the meter is printed on a yellow background and simple bold figures are used. The main scale reads in percent utilization of channel and an auxiliary scale is calibrated in decibels.

The operating range is very wide. The zero level on the meter which is about three-quarters of the way up-scale, corresponds at greatest sensitivity to an operating circuit level as low as — 20 decibels. A level of — 40 decibels represents a deflection of about 1/4 inch and is easily readable. The maximum level is + 33 decibels. The operating level of the instrument is adjustable by means of a 10-step switch in 2-decibel steps and a multiplier.

Other features include a doubly-shielded, high-impedance input transformer, easily accessible vacuum tubes and terminals, and a.c. operation. Since the instrument is frequently used near high-gain audio amplifiers, no coils are used which can induce power-line hum into them. All filtering and voltage reduction in the power circuits are accomplished by condensers and non-inductive resistors.

SPECIFICATIONS

Scale: The scale is illuminated for use in dark monitoring booths. It has two sets of figures, the principal one reading from 0 to 100 in black figures. With the peak operating point set at 100, indicating 100 percent modulation of the speech channel, the other black figures give percentage utilization of the channel. An auxiliary scale printed in red is provided showing the power level in decibels. The scale above the black 100 mark is red to warn against over-modulation. The background is yellow, and the meter needle is lance-shaped to provide ease of reading.

Meter—A large high-speed Weston Model 643 Meter is used. Provision is made for using an external meter, if desired. An electrical delay circuit retards the return swing of the pointer, giving the impression that the pointer "floats" on the peaks.

Power Level Range—Zero decibels on the meter scale (100 on black scale) will represent from — 20 to + 30 decibels, depending on attenuator setting. Total over-all calibrated range — 40 to + 33 decibels. All ratings are for a zero level of 6 milliwatts in a 500-ohm line.

Internal Input Impedance—The input impedance is resistive and greater than 15,000 ohms. There is an insertion loss of less than 0.15 decibel. The input presents a resistive load to the line, and therefore introduces no distortion. The input transformer is balanced to ground and doubly shielded.

Frequency Characteristic—The frequency response is flat within one decibel from 60 to 10,000 cycles; within two decibels from 40 to 12,000 cycles.

Vacuum Tubes—Five all-metal tubes are used, easily accessible from back of panel: 3 Type 6F5, 1 Type 6H6, 1 Type 25Z6.

Design Features—No power transformers or filter choke coils are used. Therefore, the instrument cannot induce 60-cycle hum into surrounding high-gain amplifiers by inductive pick-up. All tubes are easily accessible from back of relay rack. The input may be connected to a terminal board in rear or to normal-through standard double patch-cord jacks at front of panel.

Calibration—The instrument is pre-calibrated at the factory, and any change from tube replacements can be easily corrected.

Power Supply—115 volts alternating current, 50 to 60 cycles.

33. **Pre-Amplifiers**—The high quality microphones described in the preceding paragraphs are characterized by extremely low

output. Consequently, amplifiers, having a total gain of some 100 db must be placed between the microphones and the transmitter. Usually a pre-amplifier is placed between each microphone and the mixing system. This amplifier must be carefully designed, because any noise originating in it will be tremendously amplified by the following amplifier stages. The extent of this amplification is indicated by the fact that in the output of such a system the noise due to thermal agitation in the microphone leads and shot effect in the first amplifier tubes is easily distinguished. From this it is obvious that ordinary amplifier noises, such as microphones and hum background, must be practically non-existent in an amplifier intended for this use. In the design of the amplifier about to be described these stringent requirements have been given full consideration. Special provisions to insure low noise-level have been made at a number of points as, for instance, in the extremely heavy shielding of the input transformer, in the use of tubes having the new type quiet heater and a separate a.c. filament transformer thereby eliminating the necessity of bringing 115 volts a.c. close to the low-level audio circuits thus reducing the possibility of a.c. pick-up.

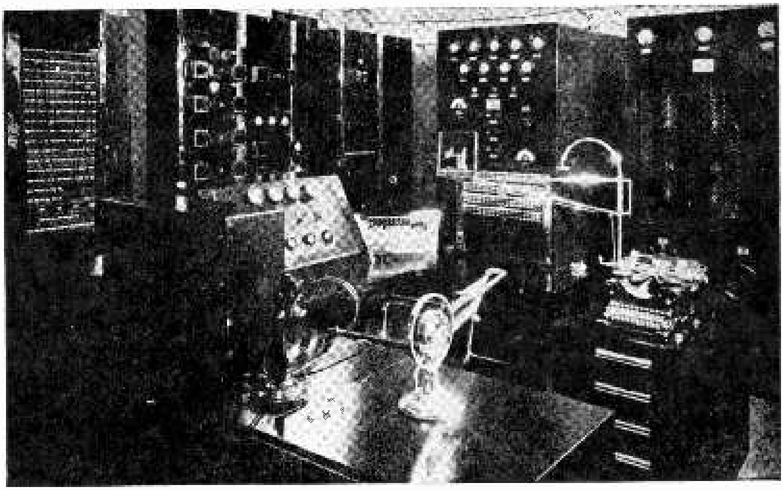


FIG. 260. Control Operator's Desk and Emergency Transmitter (WCAU).

RCA Microphone Pre-amplifier Type 41–B

34. Introduction—The Type 41–B microphone pre-amplifier is a two-stage amplifier utilizing two RCA–77 Radiotrons operating as triodes. The tubes are resistance-capacity coupled with transformer coupled input and output circuits. This amplifier is designed to operate at low levels and to feed into a studio voltage amplifier, thus taking the place of the usual microphone amplifier. It is designed especially for use with the velocity microphone, Type 44–A operating from a 250-ohm microphone circuit and into a load of either 250 ohms or 500 ohms. A total gain of 42 db may be obtained in the amplifier.

The entire unit is mounted on a panel which is slotted to provide for mounting on standard speech input equipment racks. The tubes are mounted horizontally and readily accessible for inspection or replacement.

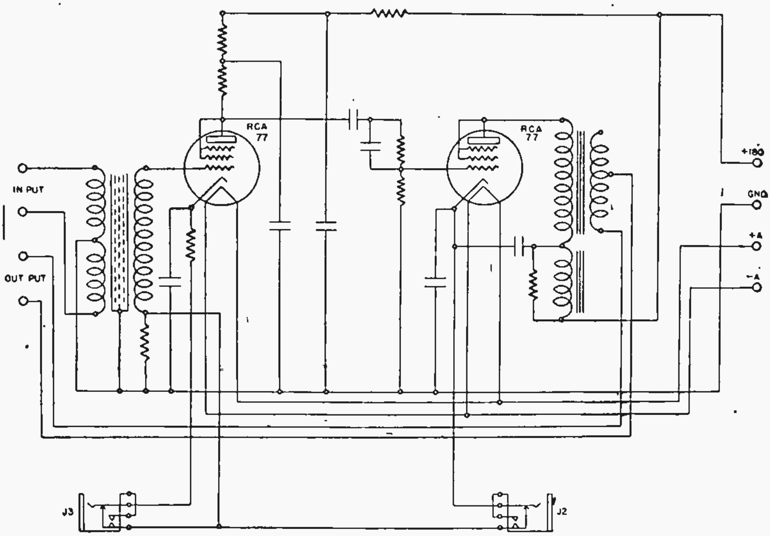


FIG. 261. RCA Diagram of RCA Type 41–B Microphone Pre-Amplifier.

Equipment—The following equipment is supplied by the manufacturer: 1 Type 41–B amplifier as herein described. 1 Type RT–255 filament lighting transformer (at customer's option).

The following are required for the proper operation of the amplifier unit:

2 RCA–77 Radiotrons. (It is to be noted that Radiotrons RCA–1603 are interchangeable with and preferable to the Radiotrons RCA–77 when used in the Type 41–B Microphone Pre-Amplifier also in the Type 40–C General Purpose Amplifier.) The Radiotrons RCA–1603 have the same electrical and physical characteristics as the Radiotrons RCA–77 except that their microphonic action is less and the signal-to-hiss ratio is better.

1 plate supply voltage source, 180 volts d.c.

1 filament supply voltage source, 5.8 to 7.5 volts at the amplifier terminals.

1 a.c. power supply source, 105–125 volts, 25–60 cycles. Necessary only if Type RT–255 filament lighting transformer is to be used.

Specifications

Input impedance—To operate from a circuit of	250 ohms
Output impedance—To operate into a circuit of	250 or 500 ohms
Gain	42 db
Plate voltage	180 v. d.c.
Plate current drain	4.4 ma.
Filament voltage (across amplifier terminals)	6.3 v. d.c. or a.c.
Filament current drain	0.6 amp. (0.55 to 0.71 amp.)
Bias supply	None required, self-biased
Tubes used	2 Radiotrons RCA-77
Unit dimensions	19 inches wide $5\frac{1}{4}$ inches high $7\frac{3}{4}$ inches deep

The input transformer is designed to operate from an impedance of 250 ohms, and, the 500-ohm output transformer is tapped to provide for connection into a load of either 250 or 500 ohms. The amplifiers are wired for the 250-ohm output connection when shipped.

Jacks are provided for plugging in meters to measure tube plate currents. The jacks are of the type used with a standard tip-and-sleeve type of plug (radio phone plug).

Feed-back problems (cross-talk, howling, etc.) have been minimized by suitable filters in the plate circuits to provide stability when operating from a plate supply in common with other amplifiers. The input transformer is mounted in an individual metal container and the output transformer and plate isolating reactor are mounted in another metal container to prevent external interference and undesired pick-up.

35. **Installation**—In selecting the location for the Type 41–B pre-amplifier, careful consideration should be given to microphonics

as well as inductive coupling from stray fields. Special precautions have been taken in the design of the amplifier to guard against the possible pick-up by the input transformer of stray a.c. fields, but, considering the low audio level at which this amplifier is required to operate, it is not desirable to mount it adjacent to a circuit carrying a.c. power voltage or adjacent to a filament or plate power rectifier. The tube socket mounting board is shock-mounted, but the pre-amplifier should be located where the mechanical vibration is not liable to be excessive. (Amplifiers which seem to be excessively microphonic should be carefully inspected to see that the tube socket mounting board is flexibly mounted, and various tubes should be tried in the amplifier in order that those selected for this use will have the lowest microphonic content.)

Caution—In handling the amplifier it should never be set on its back side when the cover has been removed, as the resistors may become seriously damaged. When the amplifier is to be inspected, it should be laid upon its side or upon the front panel, care being taken not to scratch the panel.

The amplifier should be mounted on the rack and secured in place by two screws on each side of the panel. With all power turned " off " connect the input and output leads to the terminal strip at the right of the panel when viewed from the rear, and connect the external ground, filament, and plate supplies to the terminal strip at the left of the unit when viewed from the rear.

If a.c. filament operation from the Type RT–255 filament lighting transformer is to be used, the transformer should be mounted at least three feet from the Type 41–B pre-amplifier in order to avoid any inductive coupling to the input circuit or to the low level microphone circuit. If trouble from excessive hum is encountered, the filament transformer should be oriented so that the minimum disturbance is obtained.

(*a*) *Operation*—Insert the Radiotrons RCA–77 in their sockets and attach the clip leads to the contacts at the tops of the tubes.

The wiring to the " 180 " and " GND " terminals (plate supply) may be a No. 19 A. W. G., rubber-covered, shielded, twisted pair insulated for 200 volts. In wiring to the " A " and " — A " terminals (filaments supply), No. 14 A. W. G., rubber-covered, shielded leads, insulated for 200 volts, may be used. When the filament supply is obtained from an a.c. source a shielded twisted pair should be used.

(*b*) *Wiring for a.c. Filament Operation*—If a.c. filament operation from the Type RT–255 filament lighting transformer is to be used, proceed as follows:

Connect the "GND" terminal of the amplifier to a suitable ground and to the arm of the hum adjusting potentiometer incorporated with the Type RT–255 transformer assembly. (The "GND" terminal must not be connected to either "A" or "—A" terminals.) The terminals numbered "1" and "2" on the Type RT–255 transformer should be connected to the 105–125-volt, 25–60 cycle, a.c. line. The transformer terminals numbered "3" and "5" are to be connected to the "A" and "—A" terminals of the Type 41–B amplifier.

(*c*) *Wiring for d.c. Filament Operation*—If d.c. filament operation is to be used, proceed as follows: Connect the amplifier "GND" terminal to the station ground and to either the "A" or "—A" terminal, but this connection must agree with the ground connection made in the power supply system.

It is recommended that the positive plate lead and one side of the d.c. filament supply be run through power control switches and individual fuses, as such switches and fuses are not provided in this amplifier.

(*d*) *Audio Wiring*—The input and output leads should be connected to the amplifier as indicated, and in no case should they be run adjacent to or in the conduit with any power supply circuits. The leads need not be larger than No. 19 A. W. G. and should be a shielded, twisted pair insulated for 200 volts. The Type 41–B amplifier is normally connected for a 250-ohm circuit, but a 500-ohm output connection may be provided by moving the lead from terminal "4" on the output transformer, T–2, to terminal "5" on this transformer.

Be careful to see that the clip leads to the Radiotron caps are separated from each other as far as possible in order to avoid undesirable feed-back effects.

(*e*) *Current Measurements*—The plate current of the first stage should be approximately 0.82 milliampere and that of the second stage should be approximately 3.62 milliamperes. If the plate current readings obtained vary greatly from these values, new tubes should be tried in the circuits. The plate currents may be measured by means of the Type 15–B meter panel or similar unit providing the meter-to-plug connections are properly made.

(*f*) *Phasing*—When more than one microphone is used in a single pick-up, it is possible that the output of the various microphone circuits may not be in phase when fed into a common circuit. The microphone circuits include the microphones themselves, microphone pre-amplifiers, microphone attenuators (mixers) and the necessary connecting lines. The output of the microphone attenuators (mixers) when fed into the overall attenuator (mixer) must be in phase, or varying degrees of distortion will result, depending upon the relative placement of the microphones. If two microphones are placed close together, the result will be practically zero output if their circuits are out of phase at the overall mixer.

For this reason each unit of all RCA Victor speech input equipment is carefully wired in accordance with a definite wiring color scheme in order that they will always be in phase when the inter-unit connections have been made according to a uniform plan; i.e., where the " ± " connection of one microphone is connected to a certain input terminal of its pre-amplifier, then the " ± " connection of *all* microphones must be connected to a corresponding terminal of their respective pre-amplifiers, and so on through the system up to the overall mixing control.

In set-ups in which velocity microphones are used, it is possible to phase them by tuning those out of phase through 180 degrees. This is not possible with any pressure operated microphone.

It is particularly important that the phasing problem be borne in mind when inspecting, testing, repairing or replacing any unit or component thereof, and care be taken to see that the internal connections of the various units are made strictly in accordance with their wiring diagrams.

(*g*) *Operation*—With the amplifier properly connected and the current readings correct, the amplifier is ready for operation.

Observe the plate current of the second stage, while a signal is being fed into the amplifier. If the plate current changes with the application of signal voltage it is an indication that this stage is being overloaded and that, therefore, steps should be taken to reduce the input signal voltage. In this case, the microphone may be moved farther from the source of sound, or, if possible, the volume of sound emanating from the source should be reduced, or, if a mixer is used ahead of the pre-amplifier, its control may be adjusted so as to reduce the input voltage to the pre-amplifier.

(*h*) *Maintenance*—With a stable source of plate and filament voltages, this amplifier will give satisfactory service over a long period of time. If the amplifier becomes unstable or noisy, Radiotrons should be checked and replaced by removing the access door which is held in place in the front panel by two thumb screws. The tube socket, and Radiotron cap contacts should be cleaned with carbon tetrachloride or crocus cloth at least once every three months to insure noiseless operation.

Location of Troubles

(*a*) *Filaments Do Not Light*—If both tubes fail to light it may generally be supposed that the filament supply circuit is open or defective. Check the setting of all filament power supply switches and the condition of all fuses in this circuit.

If one tube should fail to light while the other does, the tube which fails to light is probably burned out, its socket contacts are not properly made, or there is a defect in the wiring to its socket.

(*b*) *No Plate Current in Either Stage*—If no plate current reading can be obtained in either stage, check the setting of all plate power supply switches and the condition of all fuses in this circuit. Also, measure the plate supply voltage at the amplifier terminal board to see that power is available and that its polarity is correct. This test should be made between the "GND" and "180" terminals in every case. If the foregoing steps do not disclose the defect, the amplifier wiring should be carefully checked.

(*c*) *No Plate Current in One Stage*—If a plate current reading can be obtained in one stage but not in the other, place a new tube in the non-operating stage. If this procedure does not remedy the trouble, check the amplifier wiring and test for open bias resistors, open plate resistors, open output transformer primary, or open plate filter ractor.

(*d*) *Excessive Plate Current*—Excessive plate current readings may be due to defective tubes, defective by-pass capacitors C–1, C–3, C–4, C–7, C–5, defective coupling capacitor C–2, defective or short-circuited plate loading resistors R–2, R–4, and R–5, or failure to properly attach the grid caps on the Radiotrons.

(*e*) *No Signal at Output Terminals*—If the trouble is not disclosed as a result of the above tests, use a pair of head phones, connected through two 0.5 mfd. capacitors to a pair of test leads, to determine in what part of the circuit the signal is lost. These phones may be connected across the following points in the order given and signals should be heard: Input terminals; primary of the input transformer T–1, terminals "1" and "4"; secondary of the input transformer T–1, terminals "5" and "6"; grid cap on first tube and ground; grid cap on second tube and ground; primary of the output transformer, T–2, terminals "1" and "2"; secondary of output transformer, T–2, terminals "3" and "4" (or "3" and "5" if 500-ohm output connection is used); and, finally, the output terminals of the amplifier, a capacitor charging click may be expected when testing from the Radiotron grid caps to ground.

By following the above routine test it should be possible to localize the trouble. It is well to note that trouble arising from the fixed parts of the circuit, except transformers, is usually accompanied by changes in plate current, bias voltage, or both.

In testing for signals across the input terminals, input transformer, and grid of the first tube to ground, some other source of signal should be used in place of the microphone, such as the output of a phonograph, in order that the signal may be heard in an ordinary pair of headphones.

(*f*) *Noisy Operation*—Special care should be taken first to ascertain that the noise is not originating in the line or input circuit, or in the power supply equipment. Leakage or dirty cells in the plate battery or defects in the charging equipment may cause noisy operation. Loose switch or fuse contacts in both plate and filament circuits may likewise result in noisy operation.

Atmospheric conditions may cause a deposit to form on the contacts of the tubes and tube sockets which may ultimately result in noise in the amplifier output.

(*g*) *Improper Audio Frequency Response*—If capacitor C–6 is short-circuited the high frequency response will be reduced. If resistor R–6 is open the low frequency response will be greatly reduced. If resistor R–8 is open, the low frequency response at 30 cycles will be slightly increased. If the reactor between terminals 6 and 7 in T–2 is open there will be a decrease in gain and the low frequency response will be decreased.

36. Mixer Circuits—A mixer circuit is an arrangement of volume controls which permits combining into a common output circuit the output of microphones, phonograph pick-ups, photoelectric cells and other sources of program.

Since the various devices have widely different impedance characteristics it is necessary to provide an impedance matching network so that each program source and the load, as represented by an amplifier, will see its image impedance when looking into the terminals of the mixer to which it is connected, otherwise the frequency characteristics of the device will be disturbed and distortion of program will result. The mixer network which permits of this accomplishment is a group of resistors connected in a series and series-parallel arrangement and of such values that each circuit is properly terminated in its own impedance.

Such a group of resistors is also commonly called a pad, or attenuating network, since at the same time that it accomplishes a match in impedance for the circuits, it also produces a reduction or attenuation of the program. The resistance constants of the pad depend upon the required loss and the input and output impedance for which the pad is designed.

FIG. 262. Western Electric 267A Control Unit (Mixer).

A mixer circuit is also used to "fade down or up" a musical transmission so as to permit announcements, advertising talks, or noise effects to be superimposed upon the program or theme music. The variable resistor by which this is accomplished is commonly called the "fader."

There are three basic types of mixers, the L-type, T-type and H-type and from the latter the Ladder-type has been developed and represents the latest type of mixing control, used in broadcasting and recording practice. The choice of a mixer circuit is dependent upon the number of program channels in use and the impedance requirements of the system. Mixers employed with circuits balanced to ground must be of the constant-impedance type, thereby permitting of adjustments of one or more circuits independent of each other without disturbing the impedance characteristics of the associated circuits. Good engineering practice demands a separate input fader channel for each microphone, phonograph pick-up or other source of program, thereby making it unnecessary to patch circuits, while a program is in progress.

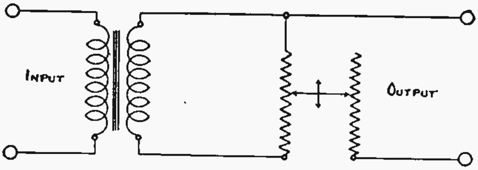


FIG. 263. L Type Fader.

L-type Fader—The circuit arrangement of figure 263 is that of the L-type fader. This type of fader is used where the requirements for constant-impedance are not so rigid as, for instance, where one side of the line is unbalanced to ground with respect to the other.

T-type Fader—The circuit arrangement of figure 264 is that of a T-type fader and represents a considerable improvement over the L-type with respect to constant-impedance requirements and frequency characteristics. In this type of fader the series resistance is all in one side of the line and thus causes an unbalanced condition. Where a balanced line is not an essentiality the T-type fader can be used.

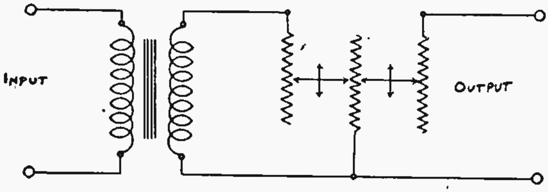


FIG. 264. T Type Fader.

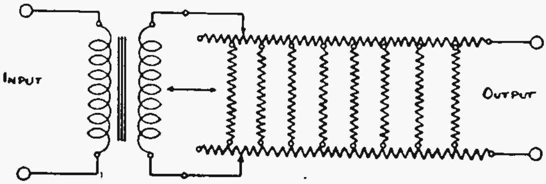
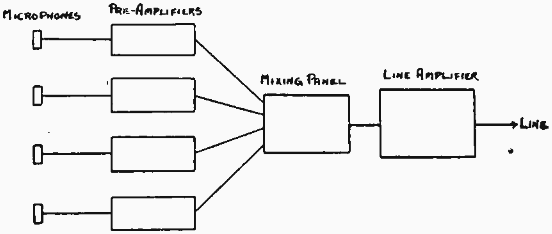


FIG. 265. "Ladder" Type Control.

The Ladder-type of Fader—The Ladder-type fader, a development from the balanced T- or H-type, as shown in figure 265 has the series resistances divided into two equal parts in order that a balanced line may be obtained. The Ladder-type of control provides the following advantages over the L- and T-type fader since both the input and output impedances remain constant over the entire range of attenuation between 0 and 45 decibels, permits gradual increase in attenuation to infinity beyond the 45 decibel point, thereby providing a means of fading out the program gradually and noiselessly and has good frequency characteristics.

37. **High-level and Low-level Mixing**—The arrangements shown in figure 266 illustrate the difference between "high level" and "low level" mixing. Low-level mixing is confined to low impedance microphones as of the ribbon and dynamic type having



High Level Mixing System

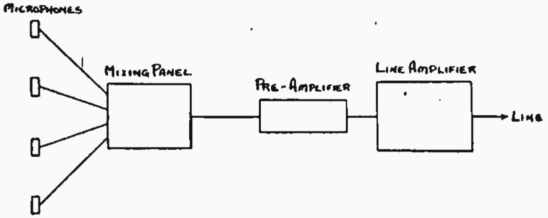


Fig. 266. High- and Low-level Mixing.

an output of — 75 to — 85 db. However, when the same microphones are connected to pre-amplifiers the mixing is accomplished subsequent to the amplification and at a level of approximately — 30 db and is referred to as high-level mixing. High-level mixing is preferred because of the higher ratio of signal to noise. Experience indicates that, even when all extraneous noise pick-up can be eliminated, the background noise due to thermal agitation in the microphone leads and shot effect in the first amplifier tube will be roughly 10 db higher in a low-level mixing system than in a corresponding high-level mixing system.

38. Master Control—A master control, although not absolutely required, provides definite advantages and convenience where the monitor operator is required to operate more than two channels and where considerable ranges of gain must be covered. The master control is interposed between the channel mixer and the amplifier and is of the T- or Ladder-type.

39. Isolation and Impedance Matching Transformers—In a series-type mixer of more than two channels, some channels must be above ground potential. Usually this is of no consequence if the equipment connected to these channels is not grounded and the leads are reasonably short. However, if noise pick-up or cross-talk is encountered, it may be remedied by using a 1 to 1 ratio transformer having an electrostatic shield between the windings and a center on each winding for balancing to ground if desired. Such transformers also permit coupling circuits at ground potential to circuits above ground potential. Impedance matching transformers are employed for the purpose their name implies as for example, matching a 500 ohm line to the input of a 200 ohm fader.

40. Multi-channel Mixers—Multi-channel mixers generally are of the series or series-parallel type. In the former the output impedance is equal to the sum of the channel impedances and in the series-parallel arrangement the output impedance is equal to the input-impedance of each channel provided the number of fader-positions per group connected in one manner equals the number of groups connected in the other manner.

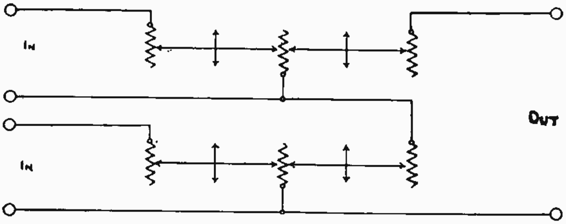


Fig. 267. Two Channel Series Fader.

The circuit arrangement of a 2-channel series mixer is shown in figure 267 and that of a 4-channel series mixer in figure 268 and four-channel series parallel in figure 269.

41. Impedance Matching Network Data—The following impedance matching attenuation network chart is published by permission of Broadcast News and accompanied an article by Mr. J. B. Epperson in the September, 1935 issue of that periodical.

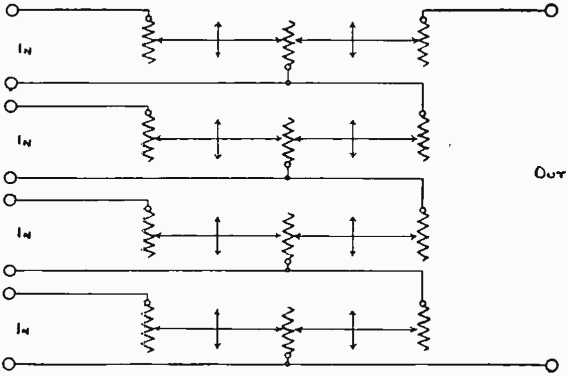


FIG. 268. Four Channel Series Fader.

With reference to the pad resistance constants Mr. Epperson furnishes the following information:

The values of *R*1, *R*2, and *R*3 are sufficiently accurate for practical networks to work between given impedance and loss values. The values given apply to the " H " pad, it being necessary to double *R*1 and *R*3 where a " T " pad is to be used. The minimum insertion loss is given for each impedance combination, and represents the minimum loss for which that particular pad may be designed. The first column which lists resistance values for pads to work between two 500 ohm impedances may also be used for determining resistance values for pads to work between any two equal impedances. For two equal impedances other than 500 ohms, it is only necessary to find from the table the 500 ohm values for the desired loss, and multiply these values by the factor Z/500. For instance, a 50–50 ohm pad having a loss of 20 db is desired. From the table it is found that for a loss of 20 db, the 500 ohm values are: *R*1, *R*3 equals 204.5 ohms, and *R*2 equals 101 ohms. Multiplying these values by Z/500 (50–500 in this case) or .1, we find *R*1, *R*3 equal 20.4 ohms and *R*2 equals 10.1 ohms, the values for the 50–50 ohm 20 db pad.

The 500–500, 500–200, 500–50, and 200–50 ohm values for *R*1, *R*2, and *R*3 can be read directly from the table. A 500–50 ohm pad may be inverted and used for a 50–500 ohm pad etc., so that the values given may be used for impedance expansion as well as reduction. In practice, the resistor values employed are not critical so that values within 5 percent of the computed table values will be satisfactory.

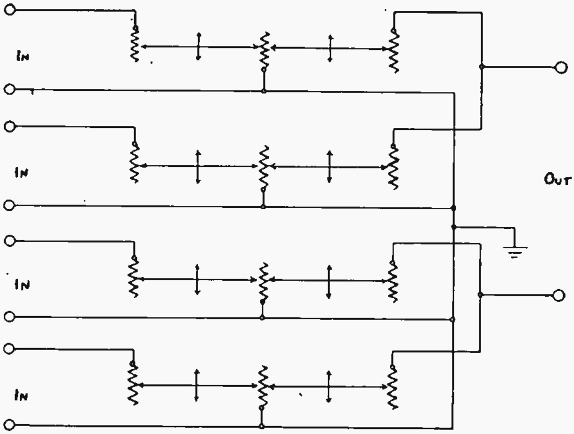


Fig. 269. Four Channel Series-Parallel Fader.

42. Microphone Phasing—When more than one microphone is used in a single pick-up, it is possible that the output of the various microphone circuits may not be in phase when fed into a common circuit. The microphone circuits include the microphones themselves, microphone pre-amplifiers, microphone attenuators (mixers) and the necessary connecting lines. The output of the microphone attenuators (mixers) when fed into the overall attenuator (mixer) must be in phase, or varying degrees of distortion will result, depending on the relative placement of the microphones. If two microphones are placed close together, the result will be practically zero output if their circuits are out of phase at the overall mixer.

To check the phasing of two or more microphones connected in a single pick-up, place the units close together, two at a time, with the attenuators (mixers) turned to the off position. Turn on the attenuator of one microphone to some arbitrary position where the output will be distinctly audible or register definitely on the volume indicator meter, if such a device is used. Talk into the

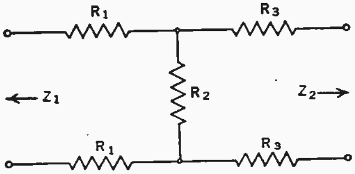
IMPEDANCE MATCHING ATTENUATION NETWORK DATA

(Resistance values in ohms)

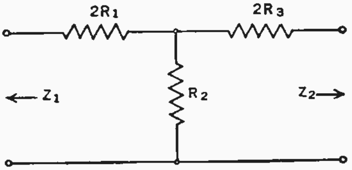
Loss in db	500–500		500–200			500–50			200–50		
	R1. R3	R2	R1	R2	R3	R1	R2	R3	R1	R2	R3
1	14.3	4333	—	—	—	—	—	—	—	—	—
2	30	2150	—	—	—	—	—	—	—	—	—
3	40	1430	—	—	—	—	—	—	—	—	—
4	55	1050	—	—	—	—	—	—	—	—	—
5	72.5	820	—	—	—	—	—	—	—	—	—
6	82.5	670	—	—	—	—	—	—	—	—	—
7	100	525	—	—	—	—	—	—	—	—	—
8	107	476	Min. Loss 8.9 db			—	—	—	—	—	—
9	119.5	406	194.2	256.7	.63	—	—	—	—	—	—
10	129	352	193.7	222.6	10.7	—	—	—	Min. Loss 11.4 db		
15	174	184	207.8	116.3	48.2	Min. Loss 15.8 db			88	36.8	8.2
20	204.5	101	223	64	70	239	31.9	9.5	91.9	20.2	15.4
25	223	56	233.3	35.4	82.7	242.1	17.7	16.2	94.8	11.2	19.5
30	234.1	31.6	240	20	90	245	10	20	96.8	6.4	21.8
35	241	17.7	244.3	11.2	94.3	247.2	5.6	22.2	98.2	3.6	23.2
40	245	10	246.8	6.3	96.8	248.4	3.16	23.4	99	2	24
45	247	5.6	248.2	3.5	98.2	249.1	1.78	24.1	99.5	1.12	24.5
50	248.5	3.1	249	2	99	249.5	1	24.5	99.7	.64	24.7
55	249.2	1.7	249.4	1.18	99.4	249.7	.58	24.7	99.7	.37	24.7
60	249.5	1	249.4	.65	99.4	249.7	.32	24.7	99.8	.20	24.8
65	249.8	.56	249.6	.39	99.6	249.8	.19	24.8	99.8	.12	24.8
70	249.8	.31	249.8	.20	99.8	249.9	.10	24.9	99.9	.06	25
75	249.9	.17	249.9	.12	99.9	249.9	.06	24.9	100	.04	25
80	249.9	.10	249.9	.06	99.9	249.9	.03	24.9	100	.02	25

Z1/Z2 or Z2/Z1	Min. Loss db
1	0
1.5	5.73
2	7.67
2.5	8.94
3	9.96
4	11.42
5	12.50
6	13.46
8	14.79
10	15.80
12	16.65
16	17.98
20	18.96
25	19.94
100	26.00

"A"



"B"



microphone and note the output volume. Now, without disturbing the setting of the attenuator of the microphone just used, turn on the attenuator of the second microphone to the same setting. Talk into the two microphones and note the result. If there is an increase in volume, the microphones are in phase. If there is a decrease in volume, remove the screen of one microphone and reverse the connections at the microphone cable terminal board. If more than two microphones are employed, using one microphone as a reference, check the other units against it, one at a time, in the manner outlined above. If any are found to be out of phase, reverse the cable connections, at the microphone cable terminal board, of the lesser number of microphones necessary to bring all the units into phase.

In set-ups in which velocity microphones are used, it is possible to phase them by turning those out of phase through 180 degrees. This is not possible with any pressure operated microphone.

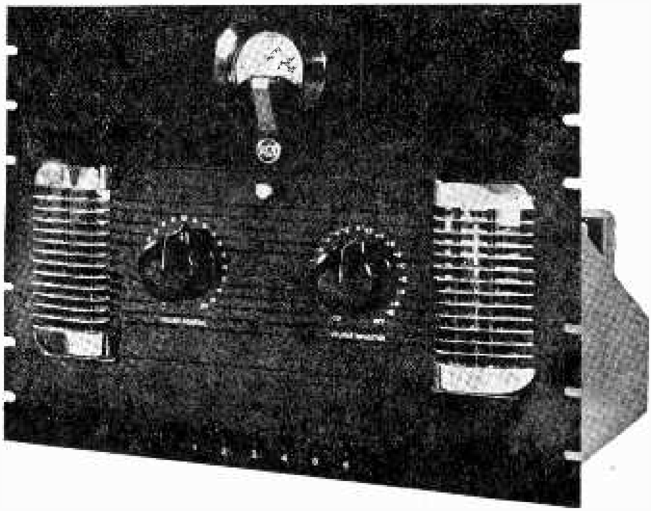


FIG. 270. Front View of Type 40-D General Purpose Amplifier.

It is particularly important that the phasing problem be borne in mind when inspecting, testing, repairing or replacing any unit or component thereof, and care be taken to see that the internal connections of the various units are made strictly in accordance with their wiring diagrams.

RCA—GENERAL PURPOSE AMPLIFIER TYPE 40–C

43. **Introduction**—The Type 40–C general purpose amplifier is a completely a.c. operated amplifier having linear characteristics designed to amplify the outputs of microphones or microphone pre-amplifiers, having a suitable output impedance, to a level suitable to apply to broadcast telephone lines or radio transmitter inputs. It may also be used as a line terminating amplifier where the incoming signal is not lower than — 50 db. The amplifier comprises three stages of amplification utilizing resistance-capacitance coupling between the first two stages, resistance-capacitance-transformer coupling into the push-pull output stage, and transformer coupled input and output circuits. Provision is made to supply plate power to one, two or three Type 41–B microphone pre-amplifiers.

The electrical connections are shown in figure 271.

EQUIPMENT

The equipment furnished by the manufacturer is:

1. General purpose amplifier, Type 40–C.
2. Isolation transformer, Type RT–262 (for 50/60 cycle power lines) or Type RT–263 (for 25/40 cycle power lines).[1]

The following are required for the proper operation of the amplifier unit:

1. Radiotrons as follows:
   - 2 RCA–1603
   - 2 RCA–89
   - 1 RCA–25Z5
2. Power supply 105–125 volts, 25–60 cycles.

SPECIFICATIONS

Input impedance	To operate from a circuit of either 250 or 500 ohms
Output impedance	To operate into a circuit of 500 ohms
Maximum gain	68 db
Volume control range	38 db in 2 db steps
Maximum undistorted output	500 mw. (16 db)
Frequency characteristics	Flat 1 db from 30 to 12,000 cycles
Tubes used	See EQUIPMENT
Power consumption	75 watts (approximately)
Unit dimensions	19 inches wide, 14 inches high, 9 inches deep (approximately)

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[1] The Type RT–262 isolation transformer is regularly furnished with the general purpose amplifier Type 40–C (MI–4292–C). When it is required, the Type RT–263 isolation transformer must be specially ordered from the manufacturer.

The input transformer is designed to operate from an impedance of 500 ohms with taps to provide for operation from a 250-ohm circuit. The input transformer primary and secondary are mid-tapped.

Across the secondary of the input transformer is connected a volume control potentiometer which provides a gain reduction of 38 db in steps of 2 db each. The volume control is applied to the grid of a Radiotron RCA–1603 (pentode), connected to operate as a triode. This tube is resistance-capacitance coupled to another of the same type also connected to operate as a triode. The RCA–1603 of the second stage is resistance-capacitance coupled to an interstage push-pull transformer which drives a pair of Radiotrons RCA–89 (pentodes) in a push-pull circuit. These tubes are connected to operate as triodes. A push-pull output transformer with a tapped secondary is used to couple the amplifier to the output circuits and a volume indicator is connected across the output terminals. The transformer is designed to feed a 500-ohm line, but taps are provided so that connections may be made for feeding a 250-ohm line.

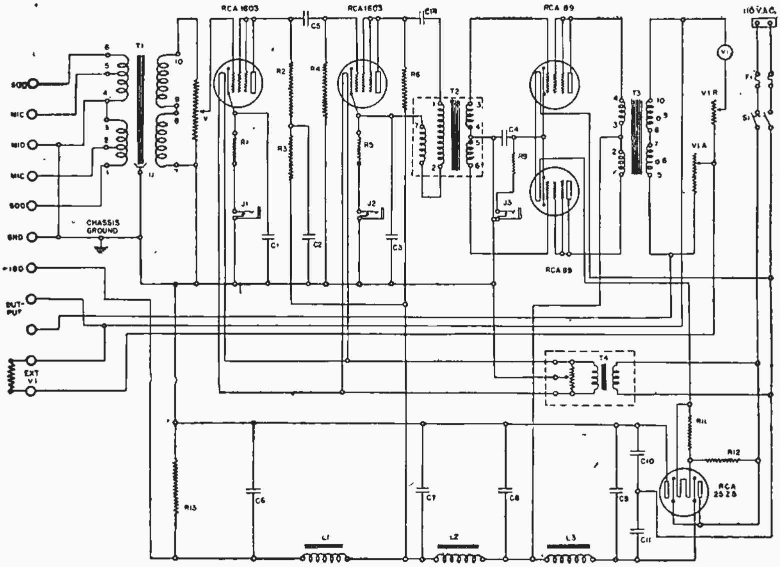

FIG. 271. Diagram of RCA 40–C Amplifier.

Provision is also made for the connection of an external volume indicator meter when desired. The external volume indicator meter will be connected in parallel with the internal volume indicator meter and its calibrating rheostat, and in place of a 5000-ohm resistor normally connected in this position in the amplifier circuits.

The power supply system consists of a filament lighting transformer for the two Radiotrons RCA–1603, and a rectifier Radiotron RCA–25Z5, connected in a voltage doubling circuit to supply plate and grid voltage to all tubes. The filaments of the RCA–25Z5 and RCA–89's being taken off between the first two stages and plate power for the RCA–1603's being taken off between the second and third stages. Each amplifier tube is self-biased. A 180-volt " B " supply for one, two or three Type 41–B microphone pre-amplifiers is taken off across a bleeder resistor following the third filter stage.

Each side of the a.c. line is fused with a 3-ampere fuse, and a double-pole, single-throw toggle switch is connected in series with the a.c. line so as to break both sides of the line.

INSTALLATION AND OPERATION

(*a*) *Installation*—The amplifier should be mounted on the rack and secured in place by six screws on each side of the panel. Remove the tube compartment cover and the rear cover shield. Mount the isolation transformer on the rack upright farthest from the amplifier input circuits, also avoiding any placement which might introduce magnetic coupling with any other amplifier input circuit. If this precaution is not observed, excessive hum may result.

When the Type 40–C amplifier is to operate from a 500-ohm source, such as the output of Type AA–4088 or Type 41–B microphone pre-amplifiers, through a mixing panel having a standard output impedance of 500 ohms, or is to be used as a line terminating amplifier on a 500-ohm line, the input leads should be connected to the first and fifth terminals from the top of the amplifier terminal board. These two terminals are marked " 500."

When the amplifier is to operate from a 250-ohm source, the input leads should be connected to the two terminals marked " 250," the second and fourth terminals from the top of the terminal board. (Only one source may be used at a time.)

The output leads should be connected to the eighth and ninth terminals from the top of the amplifier terminal board. If the amplifier is to feed into a 250-ohm line or load, the connections to terminals 5 and 10 on the output transformer should be transferred to terminals 6 and 9 respectively.

The input and output leads need not be larger than No. 19 A.W.G. and should be a shielded twisted pair insulated for 200 volts.

When an external volume indicator meter is to be used, disconnect the resistor, R–16, at the amplifier terminal board and connect the external volume indicator meter (which should have an internal resistance of 5000 ohms) to the terminals to which the resistor R–16 was connected. The leads to the external volume indicator should be a shielded, twisted pair of No. 19 A. W. G.

If "B" supply for one, two or three Type 41–B microphone pre-amplifiers is to be taken from the Type 40–C amplifier, connections should be made between the "180" and "GND" terminals of the Type 40–C amplifier and corresponding terminals of the Type 41–B amplifiers, using No. 19 A. W. G. rubber-covered, shielded twisted pair insulated for 600 volts. See figure 271.

The amplifier "GND" terminal must be connected directly to a suitable ground. Also make sure that the amplifier chassis, isolation tionsformer case and rack frame are connected to a suitable ground.

With the power switch in its "OFF" position, insert the Radiotrons in their respective sockets as shown in figure 270 and attach the clip leads to the contacts at the tops of the RCA–1603's and RCA–89's.

The tube sockets are made readily accessible by removing the cover plate in the front panel.

(*b*) *Operation*—Before placing the amplifier in normal service, two preliminary checks and adjustments should be made; viz., a check of the plate currents in each of the three amplifier stages and an adjustment of the hum potentiometers. These checks and adjustments are outlined in the two succeeding paragraphs.

The plate current of the first stage Radiotron RCA–1603 should be approximately 1.1 milliamperes, that of the second stage Radiotron RCA–1603, approximately 2 milliamperes, and that of the last stage (including both Radiotrons RCA–89) should be approximately 43 milliamperes. These currents may be measured at the plate current jacks by means of a Type 15–B meter panel, or similar unit using a current patchboard and plug. If the plate current readings vary greatly from the above values, new tubes should be tried in the circuits.

To adjust the hum potentiometer it is necessary to short the input terminals to " MID " tap (ground), connect a radio headset across the output terminals, turn on the amplifier power switch, set the volume control at its maximum position (" 20 ") and adjust the hum potentiometer to the position of minimum hum. The potentiometer may be turned over a certain arc at the center of its travel without introducing appreciable hum in the headset. Therefore, it should be turned in each direction to a position at which the hum is just noticeable and then reset at a point midway between these two positions.

The routine operating procedure is as follows:

1. With the volume control set in its minimum position, and the volume indicator adjustment turned "off," turn the power switch "on."

2. Connect the input to the proper terminals for the opration desired.

3. Set the volume indicator adjustment to the desired output in db. (The volume indicator meter scale bears an auxiliary calibration in db having a " 0 " in the center, " — 2 " and " — 1 " to the left, and " + 1 " and " + 2 " to the right. The output of the amplifier in db is equal to the algebraic sum of the setting of the volume indicator meter. For example: If the volume indicator adjustment is set at 10 db and the peaks of modulation swing the volume indicator needle to read — 1 db, the output of the amplifier is 10 — 1, or 9 db.) The external volume indicator will read the same as that on the amplifier.

4. Set the amplifier volume control so that the peaks of modulation swing the volume indicator needle to " 0 " (or another figure determined in accordance with the information given in the paragraph above) so as to give the desired output from the amplifier.

Caution—Never turn the volume control to an extent which overloads the volume indicator meter.

(*c*) *Maintenance*—If the amplifier should become noisy or have insufficient gain, the Radiotrons should be checked and replaced, where necessary, by removing the access door which is held in place in the front panel by two thumb screws. The tube socket and Radiotron cap contacts should be cleaned with carbon tetrachloride or crocus cloth at least once every three months to insure noiseless operation. The volume control contacts should be cleaned by applying a light grade of machine oil to the contacts, rotating the dial, and, if any dark streaks appear, wiping off the contacts. Repeat this procedure until the contacts are absolutely clean. Then lubricate with a thin film of oil.

Location of Troubles—The following table gives the normal voltages and currents existing at the tube sockets when the amplifier is operated on a power supply of 115 volts. Because of the high resistance values of the plate and grid coupling resistors used, the bias and plate voltage readings of the Radiotrons RCA–1603 and, to a lesser extent, the bias voltage of the Radiotrons RCA–89 will depend largely upon the internal resistance of the measuring voltmeter. The voltmeter used in taking the data given below has an internal resistance of 1000 ohms per volt. The readings were taken with no external load connected. All plate voltages were measured from plate to cathode, using a 250-volt meter scale. All grid bias voltages were measured on a 50-volt meter scale.

Tube	Heater Voltage	Plate Voltage	Bias Voltage	Plate Current in ma.
RCA-1603	6.0	60.0	2.1	1.1
RCA-1603	6.0	110.0	4.1	2.0
2RCA-89's	6.3	195.0	23.0	44.0 Total
RCA-25Z5	25.0	235.0		57.9 Total

If faulty operation develops at any time, the following information is given to simplify the location of the trouble:

(*a*) *Filaments Do Not Light*—If all tubes fail to light, it may generally be supposed that the a.c. power supply circuit is open or defective. Check the setting of all a.c. power switches and the condition of all fuses in this circuit. The amplifier unit fuses are located at the lower left-hand corner of the unit when viewed from the rear. It should be remembered when checking the fuses in the amplifier that they are connected in the a.c. line ahead of the switch and are therfore in a " live " circuit.

If the Radiotrons RCA–89 and RCA–25Z5 fail to light and the Radiotrons RCA–1603 light, the probability is that one of the unlighted tubes is burnt out. If all tubes are in good condition, a defect in the filament circuit wiring of the unlighted tubes is indicated.

If both of the Radiotrons RCA–1603 fail to light, and the Radiotrons RCA–89 and RCA–25Z5 light, check the continuity of the filament lighting transformer and the filament circuit wiring to the RCA–1603's.

If but one of the Radiotrons RCA–1603 fails to light, it is probably burnt out. If a replacement tube also fails to light, check the wiring.

(*b*) *No Plate Current in Any Stage*—If no plate current reading can be obtained in any stage, check the setting of all power supply switches and the condition of all power supply fuses, check and, if necessary, replace the Radiotron RCA–25Z5. If the trouble still persists, check the amplifier wiring for continuity and check the condition of all filter and voltage doubler capacitors.

(*c*) *No Plate Current in One Stage*—If a plate current reading can be obtained in one stage and not in another, replace the tube in the non-operating stage. If this procedure does not remedy the trouble, check the amplifier wiring. Open bias or plate series resistors, defective jack contacts or an open output transformer primary will result in no plate current reading in their respective stages. A defective by-pass capacitor, C–1, C–3 or C–4, will result in excessive plate current in the corresponding tube but will give rise to a low or zero plate current reading at the corresponding jack. A defective by-pass capacitor, C–2, will cause low or zero plate current in the first stage and in jack, J–1.

(*d*) *Low Plate Voltage in All Stages*—If all plate voltages are low it is a general indication that the Radiotron RCA–25Z5 is defective. If the trouble persists after replacing this tube, check the condition of the amplifier wiring and all filter, voltage doubler and by-pass capacitors. See also (*e*) below.

(*e*) *Excessive Plate Current*—Excessive plate current readings may be due to defective tubes; if in jack, J–2, to a defective coupling capacitor, C–5; defective or short-circuited plate loading resistors, R–2, R–3 and R–6, or failure to properly attach the grid caps on the Radiotrons.

An excessive plate current reading in the second stage jack, J–2 and low plate voltage in all other stages may be caused by a defective coupling capacitor, C–14.

(*f*) *No Signals at Output Terminals*—If no signals can be obtained at the output terminals, check the input connections to the terminal board, see that all tubes are lit and that their grid caps are in place, measure the plate current of each stage, and, if necessary, replace the tubes with others known to be in good condition.

If the trouble is not disclosed as a result of the above tests, use a pair of headphones (connected through two 0.5 mfd. capacitors to a pair of test leads) to determine in what part of the circuit the signal is lost. These phones may be connected across the following points in the order given and signals should be heard: Input terminals; primary of the input transformer T–1, terminals "1" and "6" or "2" and "5," depending upon input circuit used; secondary of input transformer T–1, terminals "7" and "10"; grid cap of first tube and ground with volume control set at maximum position; interstage transformer unit, terminals "7" and "2"; across secondary of interstage transformer unit, terminals "3" and "6"; across primary of output transformer, terminals "1" and "4"; and across the secondary of the output transformer, terminals "5" and "10" (or "6" and "9," if 250-ohm output connection is used).

By following the above routine test it should be possible to localize the trouble. It is well to note that trouble arising from the fixed parts of the circuit, excepting transformers, is usually accompanied by changes in plate voltage, bias voltage and plate current, or all three.

(*g*) *Noisy Operation*—Noisy operation is generally traceable to defective tubes or loose or dirty contacts. The contacts of the volume control potentiometer, volume indicator adjustment, the tube sockets and grip clips should be cleaned periodically to insure good contact. See INSTALLATION AND OPERATION (*c*).

The volume control potentiometer and volume indicator adjustment rheostat may be removed through the front of the panel by removing the four screws in the corners of the escutcheon plates.

44. **Western Electric 110–A Program Amplifier**—Ever since the first radio broadcast, an increasingly important problem has been to adapt the fixed volume range of a radio transmitter to the frequently greater volume range of the program material. The volume range of a transmitter lies between those levels which correspond to noise inherent in the equipment and those which correspond to the greatest degree of modulation that can be obtained without objectionable distortion. When this range is exceeded by the program, a monitoring operator attempts to compress the volume range by inserting loss during excessively high passages and removing loss at those passages whose level would be comparable to the noise level. Since the coverage of a transmitter can be increased by increasing the degree of modulation, a similar technique is also employed when the program volume range is less than that of the transmitter. In this case the monitoring operator, by compressing the high level passages, avoids the distortion which would be caused by overmodulation.

The difficulty of inserting exactly the right amount of loss at just the proper time and subsequently removing it, and not affect thereby those levels that would not cause distortion must be painfully familiar to all who have practiced this art. The higher the program level is raised the oftener the peaks will exceed 100 percent modulation and the oftener the monitoring operator must

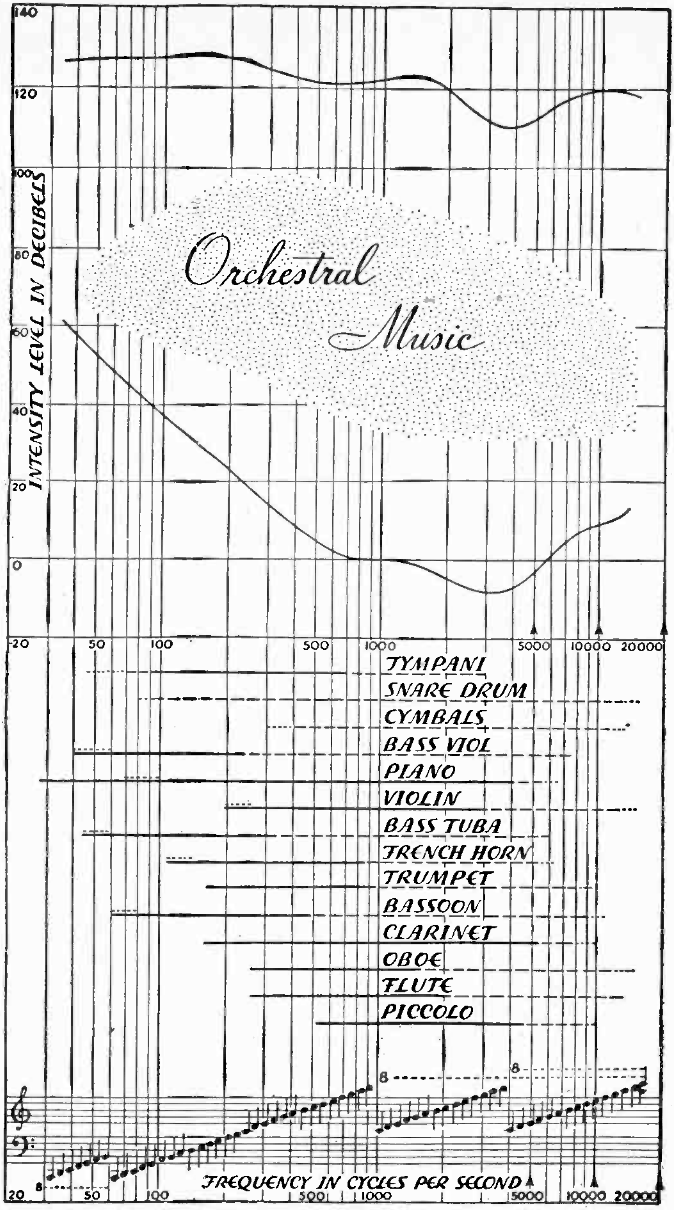

FIG. 272. Frequency Range of Orchestral Music.*

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* From A Fugue in Cycles and Bels, John Mills.

adjust the gain. Also, the more frequently he will fail to make the proper adjustment.

The objective of the monitoring operator is to keep program peaks from causing overmodulation and to do so without affecting these levels which would not cause overmodulation. In other words, if he could do his part to perfection, he would be compressing only those parts of a program which exceeded some predetermined level. The failure to approach perfection is largely due to his inability to interpret the reading of the volume indicator rapidly enough to effect a correction before the need for it has passed. The realization of this inherent weakness in operating technique has brought forth from Bell Telephone Laboratories a new development—the Program Amplifier.

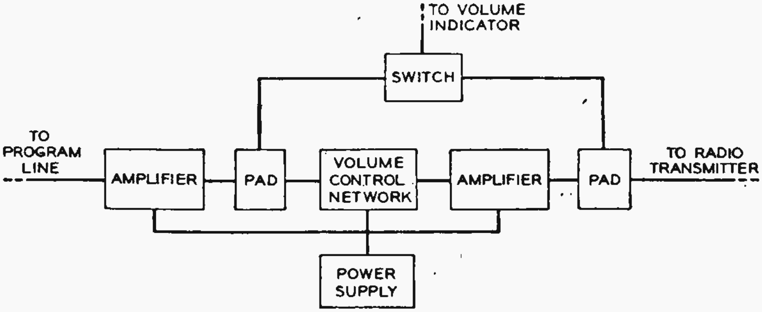

FIG. 273. Box Diagram W. E. 110–A Program Amplifier.

As shown in figure 273 the Program Amplifier is composed of an input amplifier and pad the volume control network, an output amplifier and a pad, a power supply and a switch for connecting an external volume indicator to either the input or to output of the Amplifier. It has been designed as a complete self-contained instrument sufficiently flexible in its terminating facilities to meet a wide range of requirements.

This new instrument will automatically perform many of the functions which the monitoring operator now has to perform manually. Furthermore, it will do so with a degree of perfection which he cannot hope to attain.

Its basis is a variable loss network which is inserted as a part of the program circuit, the loss which it inserts being directly controlled by the program level. A characteristic of such a network is shown in figure 274 which depicts the relationship between the output and input levels for a steady state single frequency. It will be seen that up to the level marked *A* the relationship is linear. For input levels less than *A* the network acts as though it were a small fixed loss and hence will not affect the character of the program. When the level *A* is exceeded the network inserts additional loss in an amount dependent upon the increase in program level, and the volume range beyond the level *A* will therefore be compressed.

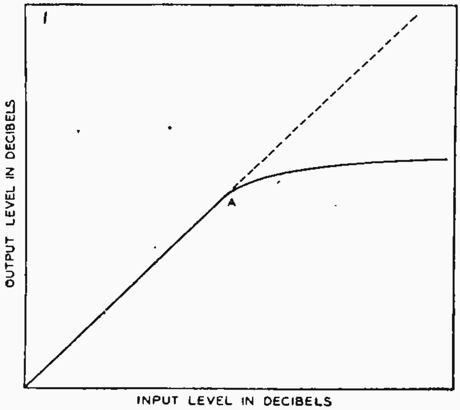

FIG. 274. Relationship between Output and Input Levels for a Steady Single Frequency Using a Variable Loss Network. (Bell Tel. Lab., Inc.)

As an example of its use in connection with a broadcast transmitter, suppose that when the instantaneous program level reaches the level *A* the transmitter is modulated 80 percent. To reach 100 percent modulation of the transmitter, the level at the output of the Amplifier must rise about 2 db, and to effect this increase the level at its input must rise about 5 db. The difference of 3 db represents the amount by which the average program level can be raised through the use of the Program Amplifier. Due to the variable loss characteristic of the amplifier program peaks at the input to the Amplifier which greatly exceed the level *A* will not cause overmodulation. To take an extreme case, an occasional peak which might exceed the level *A* by as much as 10 db would attempt to drive the transmitter to 178 percent modulation if the Amplifier were not in circuit; but with it this excessive input would create only about 108 percent modulation. Such extreme peaks are, of course, infrequent and of short duration but this example serves to illustrate the enormous factor of safety which the Amplifier provides.

When the system is adjusted as in the above example, the average program level will be about 6 db below the level *A*, and there is more than enough margin of safety to prevent accidental shifts in the program level placing it in the compression range. Inasmuch as the relationship between the number and the duration of peaks and the average program level varies widely, means are provided which will indicate by a flashing light whenever the peaks exceed some preselected level. This flashing indicator may be set to operate at any level equal to or greater than the level *A*. If it has been decided to compress only the upper 5 db of the volume range, as in the example, then the indicator would be set to flash at an input level 5 db higher than the level *A*. As long as it flashed only occasionally the operator could feel assured that

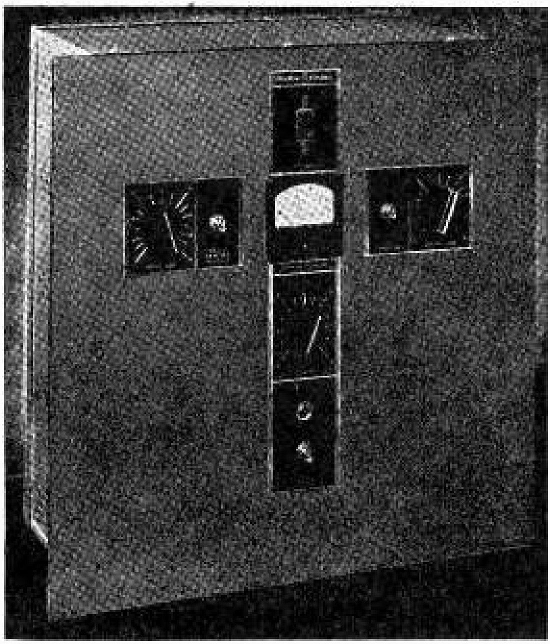

FIG. 275. W.E. 110A Program Amplifier.

the desired operating condition was being maintained. If it flashed frequently, it would be an indication that the normal peaks were being compressed more than the predetermined 5 db and adjustments in level should be made.

Specifications are as follows:

1. Terminating impedance 600 ohms.
2. Input level — 35 to 5 db.
3. Output level up to 20 db.
4. Transmission characteristic flat within 1 db from 30 to 10,000 cycles.
5. Distortion contribution less than 1 percent under normal operating conditions.
6. Relay rack mounting. Approximately 19 1/4 inches of a standard relay rack panel.
7. Front of panel controls.
8. Self-contained power supply completely a.c. operated from 110 volt supply 50–60 cycles. Power consumption less than 100 watts.
9. Nine vacuum tubes are employed. These are: two 6J7G; three 6C5G; one 6F6G; one 6H6G; one 5V4G; one 885.

It is evident then, that the Program Amplifier offers a number of major benefits to the broadcaster. It provides not less than 3 db improvement in average signal level. It compresses the excessive peaks of modulation. It furnishes protection against overmodulation in the case of accidental changes in program level. Freedom from extra band radiation is afforded by the prevention of overmodulation. Also, by means of the flashing light, it provides a continuous indication of the correctness of operating levels.

45. Equalizers—Equalization refers to the introduction of an electrical network, consisting of resistance, inductance or capacity or combinations of any two or all, for the purpose of compensating for defects in the circuit with regard to its frequency characteristics.

Telephone lines possess a certain amount of distributed capacity by virtue of the "condenser effect" between the adjacent wires. Obviously the longer the lines the greater will be the capacity of the condenser thus formed. It has been shown that capacity reactance decreases with increased frequency and capacity; naturally then, when a program is carried over a telephone line the amplitude of the alternating current comprising the voice and musical frequencies will be attenuated and the higher the frequencies and the longer the lines, the greater will be the loss or attenuation factor. Unless some means are provided at the transmitter for reducing the low frequencies to a value comparable to that of the high frequencies marked distortion of the program will result, as the low frequencies will predominate.

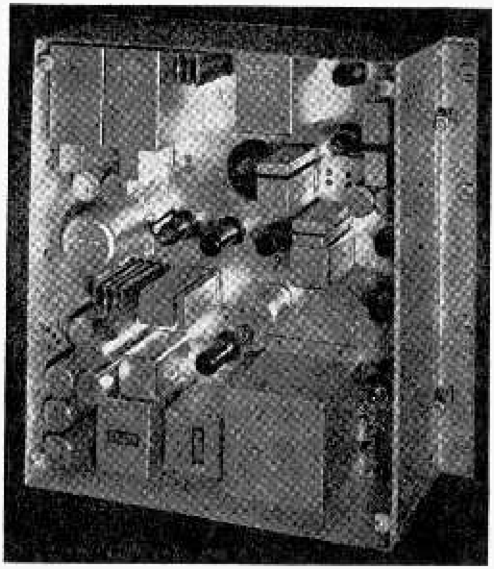

FIG. 276. This Rear View of the 110A Program Amplifier with Cover Removed Reveals How Compact and Comparatively Simple is This New Device. By virtue of its automatic volume limiting ability it effects an appreciable increase in station coverage without requiring increased licensed power. (Courtesy of Western Electric Co.)

It is possible to correct the frequency characteristics of the line by means of an equalizer. This device is composed of a variable resistance connected in series with a parallel circuit of inductance and capacity and the whole network connected across the line to be equalized as shown in figure 277. The operating characteristics of the equalizer are such that it offers a low impedance path to the low frequencies and a high impedance to the high frequencies. By adjusting the resistance of the circuit it is possible to reduce the low frequencies to the same level as that of the high frequencies received over the line. Since the amount of equalization varies with the length of the line it is evident that each particular line must be treated as an individual case, as, for instance, a short line will require very little equalization, whereas a long line would require very careful adjustment of the equalizer in

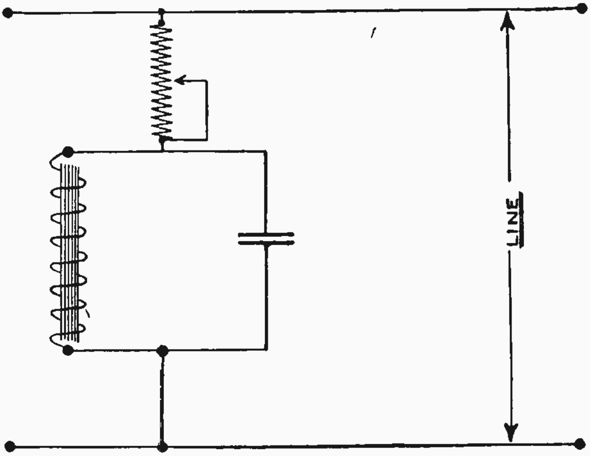

FIG. 277. Equalizer Circuit.

order to obtain a flat frequency transmission characteristic. In fact, several equalizing networks are necessary to properly equalize a long line.

46. Equalizing Procedure—Prior to transmitting a program the lines are equalized by sending out a signal of definite fre-

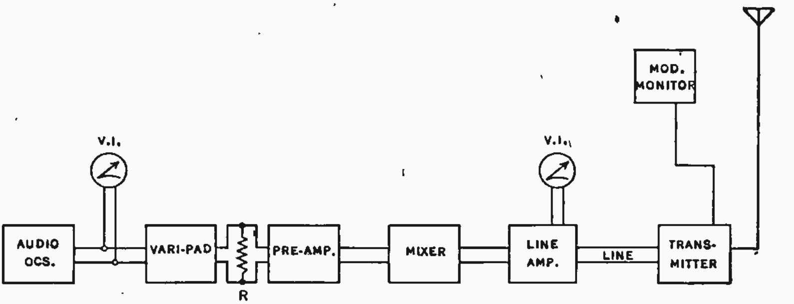

FIG. 278. Setup for a Frequency Run.

quency and known strength. The level is measured at the receiving end by means of the volume indicator. The process is usually started by transmitting a 1000 cycle note and decreasing the frequency at intervals down to the lowest value required, after which the frequency is increased at definite intervals until the highest frequency required for the program has been transmitted. These signals must be received at a predetermined level and all frequencies should be received with almost equal strength. If any undue loss or gain is experienced at any particular frequency or band of frequencies the same can be corrected by the equalizer. Adjustments are made until a flat characteristic curve is obtained, thus ensuring equal transmission of all frequencies throughout the musical range.

A routine method employed to save time consists of sending the highest frequency down the line, as for instance 5000 cycles. The volume indicator ($V1$) reading at the receiving end of the line is noted for reference. Then a low frequency, 100 cycles for example, is transmitted and the equalizer resistance is then adjusted so that the $V1$ reading is the same as it was at the 5000 cycle frequency. The line is then equalized as well as can be accomplished with one equalizer. In general, it is only necessary to make a complete frequency run, throughout the gamut of frequencies required for the program, at definite frequency intervals, if the overall frequency characteristics of the line are desired.

47. Line Amplifiers—Audio frequency amplifiers or repeaters are placed at certain places along the circuit in order to boost the signals due to the loss encountered by the d.c. resistance of the line. These amplifiers amplify all frequencies to an equal degree. The amplification or gain of such amplifiers is adjustable and is carefully measured and regulated.

48. Making a Frequency Run—To insure transmission of a program with a high degree of fidelity it is necessary to know the over-all frequency characteristics of the station including microphone, studio equipment, telephone line and transmitter. The frequency characteristics of a broadcast transmitter designed to meet the requirement of good engineering practice should be substantially flat (that is, within 2 db) from 30 to 10,000 cycles. This is a range which includes all of the audio frequencies that it is practicable to use and a uniformity of response which is within the limits of perception.

When making a frequency run the microphone is omitted from the apparatus set-up, and when considering the over-all frequency characteristics from microphone to antenna the characteristics supplied by the manufacturer of the microphone are used.

The set-up for a frequency run is shown by the box diagram of figure 278. The beat frequency audio oscillator chosen for the signal source should be one of which the harmonic output content is of a very low order. The value of the resistance *R* in figure 278 and the constants of the variable pad are such as to simulate the impedance of the input of the pre-amplifier.

49. Preliminary Tests—Before proceeding with the frequency run it is necessary to test for the presence of regeneration caused by an unbalanced circuit or by radio frequency feed-back picked up by the additional apparatus assembled for the test. To make the first determination, regeneration caused by an unbalanced line, first adjust the transmitter to the normal power output and then with the gain controls and amplifiers set at normal levels, adjust the audio oscillator to 10,000 cycles at a convenient output level. Next disconnect each side of the terminals to the resistance *R* and observe if the volume indicator and modulator meters drop to zero. A zero reading is proof of the absence of regeneration from an unbalanced line.

To test for the presence of radio frequency feed-back, turn off the audio frequency oscillator and observe the volume indicator meter and modulation monitor meter. Radio frequency feed-back is evident by erratic fluctuations or failure of these meters to read zero. If a class *B* modulator system is used, the class *B* static plate current will increase when the program amplifiers are turned on and connected to the input of the modulator, indicating that r.f. is being picked up and rectified by one of the amplifiers and modulating the transmitter with an undesirable signal, frequently above the limits of audibility. Elimination of radio frequency feed-back requires several cut and try methods including the grounding of the metal frames of apparatus.

50. Test Procedure Method No. 1—The procedure about to be described is that generally used when the over-all frequency characteristic is known to be un-uniform and a precise determination is desirable.

A reference frequency and percentage of modulation must be chosen as for example, 1000 cycles and 50 percent positive peak modulation. A low percentage of modulation is chosen so as to make negligible an increased reading of the modulation monitor meter resulting from harmonic distortion generated by the amplifiers and modulators of the transmitter. While it is desirable to record both positive and negative peaks of modulation all computations must be made with reference to the peak chosen for the test. It is assumed that previous adjustments and tests of the transmitter have been made to ensure symmetrical modulation.

The transmitter having been adjusted for the required power output, the audio oscillator is set at 1000 cycles as a reference frequency and adjusted to a convenient output level. The variable pad and gain controls are adjusted until the modulation monitor reads 50 percent positive peak modulation. Since in general a modulation monitor has both a percentage modulation scale and a db scale the reading of the latter is recorded as the reference or zero level. After making these adjustments and recording the readings, no change should be made in any of the controls during the test, except the output of the audio oscillator whose output should always be made equal to the output at the reference frequency as evidenced by the volume indicator meter connected across the oscillator output.

51. Recording Results—Having made all the required adjustments at the reference frequency and recorded the results, the audio oscillator is then adjusted to 500 cycles and the level set at the same value used for 1000 cycles. The reading of the db scale of the modulation monitor is noted and recorded. The same procedure is repeated employing the frequencies in the order shown in the following table.

Frequency Cycles	Volume Indicator Audio Osc.	Volume Indicator Line Amp.	Modulation Monitor db Scale	
			Pos. Peak	Neg. Peak
1,000 (ref.)	60	—	−6	−6
500	60	—	—	—
100	60	—	—	—
60	60	—	—	—
30	60	—	—	—
2,000	60	—	—	—
3,000	60	—	—	—
4,000	60	—	—	—
5,000	60	—	—	—
6,000	60	—	—	—
8,000	60	—	—	—
10,000	60	—	—	—

At the conclusion of the highest frequency run, the audio oscillator should be adjusted to the reference frequency for the purpose of determining that no unusual changes have occurred during the tests. The results obtained from the tests should then be plotted on logarithmic paper as shown in the specimen of figure 279.

52. Method No. 2—A method that can be used to advantage where the over-all frequency characteristic of the transmitter or other piece of apparatus in use does not vary greatly is as follows:

Adjust the 1000 cycle reference tone until the modulation monitor reads some convenient value such as 50 percent modulation. Record the *VI* on the input to the transmitter. Then vary the frequency of the tone through the range specified in the first method, always keeping the modulation monitor meter reading constant by lowering or increasing the input level to the transmitter. The input readings across the *VI* are recorded in the table for use in making the frequency characteristic curve.

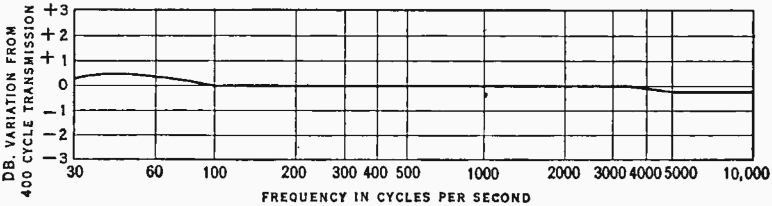

FIG. 279. Frequency Characteristics Plotted on Logarithmic Paper.

If for instance, at some frequency other than the reference frequency, the *VI* indicates 2 db higher than the reference level it indicates that the transmitter is 2 db down at that frequency, on the other hand if the *VI* reads 2 db lower it is of course evident that the transmitter is up at that frequency since it was necessary to reduce the input to the transmitter in order to make the modulation monitor meter read the same as the reference frequency value.

The disadvantage of this last method lies in the fact that it may be necessary, in order to make the modulation monitor read the same for all frequncies, to increase the gain of the amplifiers to the point where distortion becomes excessive and the reading of the modulation monitor meter is the result of modulation frequencies other than the pure fundamental frequency of the tone.

INSTANTANEOUS RECORDING

53. Introduction—Instantaneous recording is a term used to describe a phonograph record or electrical transcription which can be played as soon as it is recorded without damage to the record and without intermediate processes.

The technique and apparatus used have been described by George J. Saliba, Chief Engineer of Presto Recording Corporation in two papers published in Communication and Broadcast Engineering. By courtesy of Communication and Broadcast Engineering and Presto Recording Corporation, material from Mr. Salibas' papers are reprinted with a few minor changes to permit adaptation to this chapter.

54. **High-fidelity Instantaneous Recording**—The progress made in instantaneous recording in the last few years has been remarkable. In 1927 about the only method of making instantaneous records was by means of the acoustic phonograph—and the only medium was the pre-grooved metal disc—which was part aluminum and part zinc. In 1928 feed mechanisms were developed which cut their own grooves as they recorded, but metal was still the only recording medium. It was not until 1931 that the interest in this comparatively new industry began to manifest itself in a desire for some method that could be used to simulate approximately the results that were obtainable in commercial wax recording. This meant that the disc had to be cut and a thread removed.

In metal recording the disc was knurled with a round-nose needle and as a result the metal was distorted. No material was removed, with the consequent result that, although the resulting recording sounded satisfactory enough, it was still a comparatively poor imitation of commercial recording results.

55. **Material**—The problem resolved itself into finding some material that would be soft enough to be cut and at the same time hard enough to be reproduced a reasonable number of times with a steel needle. To reach this happy medium proved to be the biggest problem of all. Gelatin was tried and used for a time, but gelatin is soluble in water, so that extreme care had to be exercised in the handling of the disc. The life of the record was very short, because gelatin, having a high water content, dried out after a short time, leaving the disc quite brittle.

The next material that was found to have the properties satisfactory for recording was celluloid, and for two years it was used extensively. Unfortunately the greatest disadvantage of this latter material, aside from its inflammability, was its flexibility. This necessitated special handling in reproduction.

After intensive research and experimentation the coated disc was finally developed—today this disc is used almost exclusively where high-quality reproduction is required.

56. **Coated Disc**—The coated disc is made by applying a smooth coating of cellulose to both sides of a metal disc, the metal

being used to give the disc rigidity so that it will lie flat on the turntable. The advantages of such a disc are:

1. A steel recording needle can cut it and any medium tone steel neele can reproduce it.
2. It is non-inflammable.
3. It is non-breakable.
4. It possesses a long life.
5. It can be reproduced a great number of times.
6. It can be used to make masters for pressing.

57. **Frequency Response Requirements**—One of the present-day requirements of high fidelity is that all frequencies between 30 and 10,000 cycles be reproduced uniformly. This means that every component part used must be of the highest quality. Further, the shape of the groove, the needle velocity, the wavelength of the modulated groove, the radius of curvature of the groove and the size of the needle point are all factors which must be considered if high fidelity requirements are to be met. These are limiting factors which cannot be changed regardless of the fidelity of the component parts.

The microphones and radio receivers of today, as a source of input into a recording channel, easily meet the 30 to 10,000-cycle requirements (and the same can be said of the audio-amplifiers and loudspeakers), but when it comes to the cutting head a difficult problem presents itself. Here the electrical energy must be converted into mechanical energy without any appreciable loss. Figure 280 shows a frequency characteristic of an average cutter and the deficiencies at both the low frequency and high-frequency ends are quickly noted. The low frequency loss is purposely introduced as will be discussed later, but the high frequency loss is the real difficulty. The popular belief exists that the comparative

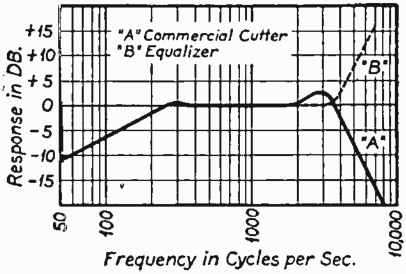

FIG. 280.

hardness of the coated disc with respect to wax is the reason for this loss. To some extent this is true, but the real loss is due to the construction of the cutting head itself. If one were to feed a frequency of 6000 cycles per second to the coil of the cutter one could hear this frequency very plainly, but when the cut is made the 6000-cycle tone is found to be 15 or 20 db below that of 3000 or 4000 cycles.

A great deal of this loss is due to the amount of play between the cutting needle and needle holder, and at the present time the only way this loss can be eliminated is to seal the cutter into the holder. This is easy enough to do in wax where jewel styli are used and where the wear on the stylus is small due to the softness of the wax, but when coated discs are used, the wear on the needle is comparatively great, due to the harder surface. This necessitates the changing of the steel cutting needle about every 30 minutes. It is because of this constant changing of the needle that sealing is not practical. It has been found after thorough investigation and tests that by extreme care and precision in assembly and by using the highest grade materials obtainable cutters can be made to have extremely high frequency response.

57A. Use of Audio Equalizer—Fortunately the use of audio equalizers can compensate for this loss at the high frequency end. Figure 280 shows a curve of a cutter before and after equalization. The equalizer used is of the resonance type. When using an equalizer of this nature it is very important that a high-gain amplifier be used as the equalizer introduces an appreciable loss in gain.

57B. Cutting Characteristics—The cutting head is a constant-velocity device. This means that for a given input voltage to the coil the amplitude of the wave on the disc at a frequency of 250 cycles will be twice as much as the amplitude for 500 cycles and four times as much as the amplitude for 1000 cycles. The depth of the groove on the coated disc is about 0.0015 inch and at a pitch of 96 lines per inch the center-to-center spacing of the grooves is about 0.0044 inch. The width of the groove itself is about 0.006 inch, so that 0.0044 inch of wall thickness is available for lateral motion of the needle. Since the adjacent groove is to be modulated also only one-half of this wall is available for modulation.

Below 300 cycles the cutter is made to have constant amplitude because it is at these lower frequencies that the heaviest waves occur with the consequent danger of overcutting.

At a pitch of 96 lines per inch with a wall space of 0.0044 inch the maximum amplitude to either side is 0.0022 inch. Increasing the pitch decreases the wall space, and the amplitude will have to be decreased in proportion if overcutting and distortion are to be avoided. Obviously the greater the amplitude the greater will be the signal-to-noise ratio—and the reduction of surface noise is one of the requirements of high fidelity.

To obtain a full 15-minute recording on a 16-inch disc at 33 1/3 r.p.m. a pitch of 112 lines per inch would have to be used if reasonably good quality is to be expected at a starting diameter of 6 1/2 inches. The wall space at this pitch is 0.0029 inch. Therefore, the maximum amplitude is about 0.0014 inch at 300 cycles. At 600 cycles the amplitude is 0.0007 inch, at 1200 cycles it is 0.00035 inch, and at 7000 cycles the amplitude is 0.00006 inch. Considerable energy is represented in these high-frequency modulations even though the amplitude is low.

58. Tangential Needle Velocity—At a speed of 33 1/3 r.p.m. and a diameter of 6 1/2 inches the tangential needle velocity is found from the following equation:

$$V = \frac{2\pi RN}{60},$$

where V = Velocity in inches per second; R = Radius in inches; N = Speed in r.p.m.;

$$V = \frac{(2)(3.1416)(3.25)(33.33)}{60} = 11.32 \text{ inches per sec.}$$

On the outside of the disc at a radius of 7.75 inches the needle velocity is V(2) (3.1416) (7.75) (33.33)/60 = 27.0 inches per sec.

59. High Frequency Response Difficulties—Since the needle speed is a function of the radius it follows that the lower the needle speed the shorter will be the total available distance for a given recording. It is because of this fact that the reproducing of the higher frequencies is comparatively difficult at the smaller diameters.

To obtain the wavelength the equation $\lambda = V/F$ is used. Thus, the wavelength of a 7000-cycle note at 33 1/3 r.p.m. and radius of 3 1/4 inches is 0.00162 inch. And at a radius of 7.75 inches = 0.00386 inch.

A few years ago it was the belief that the wavelength determined how high a frequency could be reproduced. It was stated that one-half of the wavelength should be equal to or greater than the diameter of the reproducing needle if that frequency was to be properly reproduced. If a disc is cut with maximum lateral amplitude for a number of single frequencies proceeding from low to high, a frequency will be presently reached for which the wave-length is so small, as compared with the amplitude, that the needle cannot follow such a steep wave front.

The limiting steepness for satisfactory tracking is an angle of about 40° between the direction of the groove at any point and its mean direction.

It is very obvious therefore that the limit of high-frequency response is not so much dependent on wavelength but is governed mostly by the radius of curvature of the modulated groove and the radius of curvature of the needle point. The wavelength determines the radius of curvature of the modulated groove. The highest frequency that can be reproduced at a given radius will be when the radius of curvature of the modulated groove is equal to the radius of curvature of the needle point. As long as the radius of curvature of the groove is greater than the radius of the needle point that frequency will be reproduced.

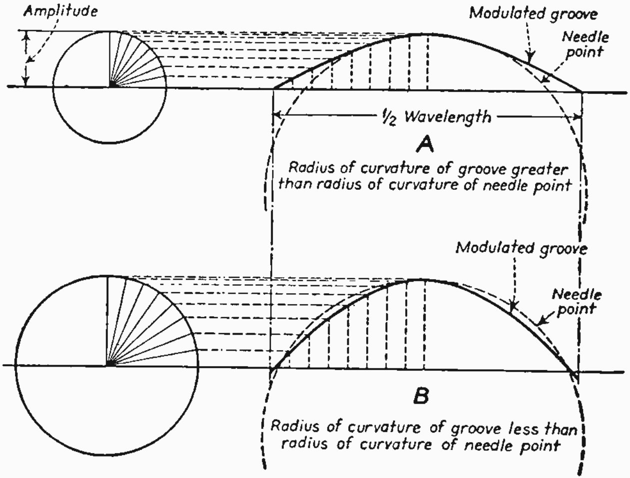

FIG. 281. Diagrams showing that the high-frequency response Is Dependent upon the Radius of Curvature of the Modulated Groove and the Radius of Curvature of the Needle Point.

Figure 281 illustrates this point clearly. The diameter of the point of a steel needle is about 0.003 inch. The wave-length is the same for each condition but the amplitude is varied.

Figure 281A illustrates conditions existing when the radius of curvature of the modulated groove is greater than the raduis of curvature of the needle point. Tracking is possible in this case but impossible as shown in figure 281B where the radius of curvature of the modulated groove is less than the radius of curvature of the needle point.

As stated before the maximum amplitude of a 7000-cycle note using a constant-velocity cutter at a pitch of 112 lines per inch is 0.00006 inch. Now by following the method shown in figure 281 and by using the wavelength curves of figure 282 the different diameters at which this frequency can be reproduced can easily be found. Since the higher frequencies are more difficult to reproduce at the inside diameters, it has been found advisable to start the recording from the inside. When the needle is new its point has the smallest radius of curvature, and it is therefore capable of reproducing comparatively high frequencies. When a needle has played through a 16-inch disc its needle point radius has been increased materially.

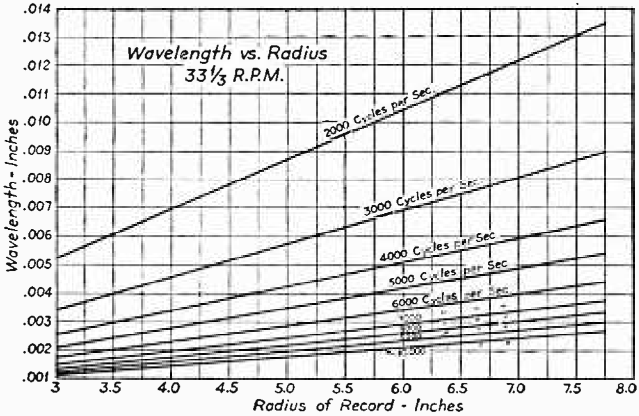

FIG. 282.

The greatest single contributing factor in the advancement of instantaneous recording has been the development of the coated disc. These discs have made possible recordings that are the equal of commercial wax pressings. They have a quality of reproduction that makes them suitable for broadcasting. Another application of these discs is for the making of pressings. They can be processed in the same manner that wax is processed—and this means that any number of duplicates can be made at very low cost.

60. Armature Mounting—The electrical principle involved in the operating of recording heads is the same as that involved in the operation of electric motors. The recording head performs the same function as an electric motor; both take electrical energy and convert it to mechanical energy. The principle involved in either case is the same; namely, that of a wire carrying current in a magnetic field. In recording, alternating current is fed to the coils of the head and the armature vibrates from side to side in direct proportion to the current being fed. In the converted pick-up type of cutter the armature is held in place by a rubber block which also acts as a damping block (figure 285). The arma-

Fig. 283.

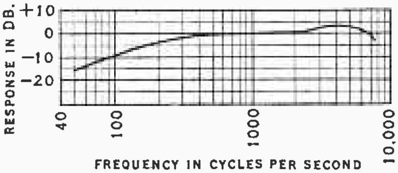

Fig. 284. Frequency Characteristics of the Cutter.

ture is free to vibrate between the polepieces, but all the magnetic action takes place at the top of the polepieces. In the cutter shown in figure 286, the armature is pivoted in the center and action takes place between both the top and the bottom of the polepieces. In the cutter of figure 285 again, the armature is held in place by the pressure of the polepieces which are milled out in semi-circular form to fit the armature. Between the polepieces and the armature is the rubber washer, and, as mentioned previously, it is this rubber washer with its lost motion that plays the biggest part in limiting the high-frequency response.

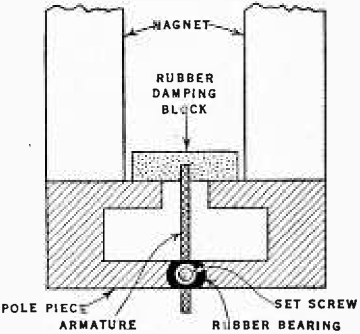

FIG. 285. An Older Type Cutting Head.

In designing the cutter of figure 283 a great deal of thought was devoted to finding a method of mounting the armature which would eliminate all possibility of lost motion. The method finally found to be the most satisfactory is shown in figure 287. This

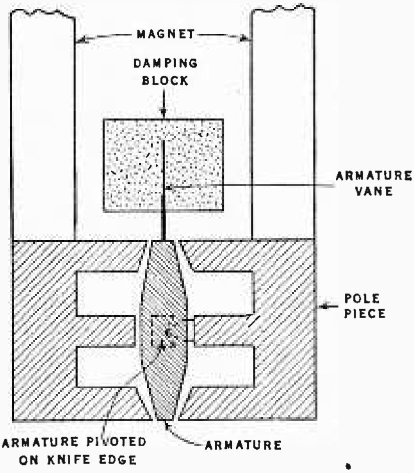

FIG. 286. A Cutter Having the Armature Pivoted at the Center.

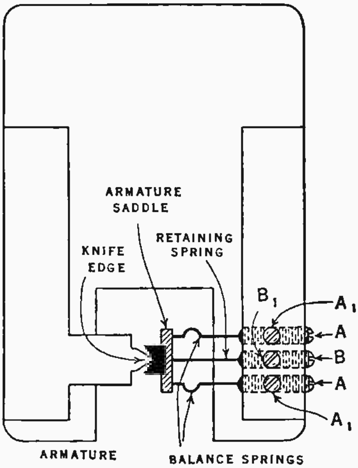

FIG. 287. Rear View of the New Cutter Showing Armature Mounting.

shows a detailed rear view of the armature looking at the back of the cutter. The armature has a *V* bearing milled out along its longitudinal length. In manufacturing, this operation is very carefully carried out so that a perfect *V* is made, the apex of which is a fine line. The armature is mounted with this *V* resting against a knife edge which is also carefully ground and hardened.

The method of keeping the armature tight against the knife edge is unique and at the same time practical. On the right side of the armature is mounted the armature saddle on which are mounted three springs. The center spring is known as the retaining spring and is fastened to screw *B*. Turning screw *B* pushes the armature up against the knife edge. Inspection of the contact area between the knife edge and the *V* of the armature is then made under a powerful microscope. When the proper contact is made *B* is locked with set-screw *B*–1 and sealed. Once this adjustment is made, it need never be tampered with.

The two balance springs are used to center the armature between the polepieces. Each spring is controlled by its own screw *A* and when the position of the armature is definitely set, the screws are locked by set-screw *A*–1. These three screws comprise the entire adjustments on the cutter and, since they are set and adjusted at the factory, the cutter should require very little service and very little adjustment in the field.

61. Damping—In any transmission system a correct terminating impedance is desired and since the cutting head is a transmission system in itself, converting electrical energy to mechanical energy, it also requires a proper terminating impedance.

In commercial wax recording the load imposed by the wax is very small and therefore it is necessary to create a mechanical impedance in the cutter that is relatively large. The mechanical load used as a terminating impedance is a rod of rubber about 10 inches long. Loss of energy along this rubber rod is such that a vibration is substantially dissipated by the time it has travelled down the line and back. Thus the rod constitutes a substantially pure mechanical resistance. In acetate recording the material which is being cut offers a much higher resistance to the cutter than wax does, and, therefore, a built-in large mechanical terminating impedance, such as a long rubber rod, is not required. Hence, the problem of damping is quite different, and the damping block consists of a small piece of absorbent material which successfully dissipates the vibrations without causing them to react again on the armature.

62. Operating Level—This cutter operates at a level of + 16 db which is equivalent of 0.242 watt referred to .006 watt as zero level on a 500-ohm line. At this level the groove in the disc is fully utilized at a pitch of 112 lines per inch and the surface noise is 40 db below the level of the recorded sound. This is 10 db better than the surface noise on a shellac pressing, and about equal to the surface noise on the best acetate transcription disc. A level of + 16 db is comparatively low, and any well-designed recording amplifier having clean power output of at least 2 watts will handle the head very easily.

63. Measurement of Frequency Response—In obtaining a frequency characteristic of a cutting head three methods are commonly used. In the deflection method the cutting head with a recording stylus set in it is clamped tightly in a vise and frequencies are fed to it. Then a polarized beam of light is focused on the needle and by means of calibrated microscope the amount of deflection of the needle point is measured for each frequency. The frequency characteristic of the head is then plotted. This is the true frequency response of the head and the readings give the air velocity of the needle point. This method is satisfactory for measuring wax cutters where the terminating impedance is the disc material itself, and any true frequency response of the head should include the recording material. One method of utilizing the disc material is to record the different frequencies and then measure their amplitudes on the record by means of a calibrated microscope. This method is an excellent one but tedious and long drawn out. An easier way is to record the different frequencies and then reproduce them using a calibrated pick-up, amplifier and vacuum-tube voltmeter. Then by taking into consideration the discrepancies in the pick-up and amplifier the true response of the cutter is found. This is the method used in obtaining the characteristic shown in figure 284.

The development of this high-fidelity cutting head makes possible much wider range instantaneous recordings—but it should be remembered that recording high frequencies requires extreme care besides using the finest equipment. It does not require much to lose the " highs " above 4000 cycles. A loose sapphire in its holder—although not easily detected—is one cause; a needle screw that is not very tight is another reason; and if the needle is too far out of the head the flex in the shank will loose more " highs."

PRESTO PORTABLE RECORDER[3]

The Presto Portable Recorder is designed for the making of instantaneous lateral cut records of the disc type. This recorder can cut acetate, celluloid, gelatin, coated discs (Presto Green Seal) or aluminum discs. Coming in two portable cases it lends itself very readily to any type of recording work, either in the studio or in the field. The Presto is completely a.c. operated and to set it up for recording requires but a few minutes. It is extremely simple in operation, only two controls being required. One is the volume control and the other is the selector switch. This selector switch does away with all unnecessary plugging in of cables when different operations are required. It makes for simplified operation and gives the operator 5 selections. In the first position of the switch the apparatus can be used as a public address system and since the loudspeaker is built into the amplifier case a good-sized room can be filled with sound. The second position is for recording from the microphone. A volume indicator meter located in full view of the operator keeps an accurate check of the volume on the cutter head. This meter enables the operator to cut at the proper volume, thus eliminating the danger of either overcutting or undercutting. The third position is for the playing back of the records. The fourth is for radio recording. A radio receiver or tuner can be furnished when desired. However, all provisions are made for the addition of a receiver at any time. The last

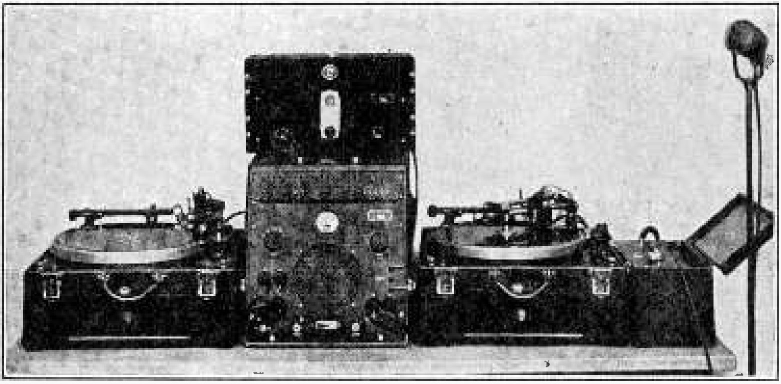

FIG. 288. Presto Portable Recorder.

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[3] Description taken directly from manufacturer's literature.

position is for ordinary radio reception. During recording a pair of phones provide an aural check of everything going to the cutting head.

64. Overhead Feed Mechanism—The feed mechanism, ruggedly constructed, is designed for maximum service with minimum wear. All cast parts are attractively finished in black crystal, while the machined parts are chromium plated. The mechanism is of the overhead feed type, making for easy accessibility.

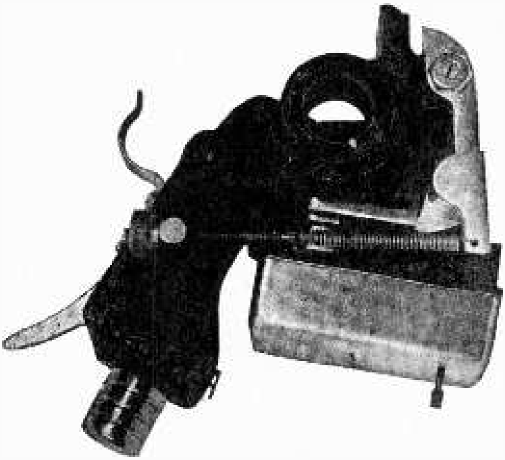


FIG. 289. Presto Cutter.

There are no moving parts under the motor board except the motor. The mechanism is pivoted at the rear of the motor board, and when it is not in the recording position, the front end, which carries the driving flange, rests on a cast shelf. To record, the mechanism is lifted from the shelf by means of the handle on the forward end and swung to the center. The driving flange has 3 holes spaced 120 degrees apart, and this flange fits over the center spindle of the table. The three holes fit over three removable screws set in the turntable, and these three screws drive the flange on whose shaft is mounted an accurately cut steel worm. This worm in turn drives the worm gear mounted on the end of the feed screw. This feed mechanism is mounted on the casting that holds the turntable, motor, and idler mechanism and it is locked in position at the proper distance from the center of the table. Since all the moving parts are mounted on this one casting, there is no danger of temperature changes throwing these different parts out of alignment. These feed mechanisms come in two sizes, one to fit 12 inch turntables, the other to fit 16 inch turntables.

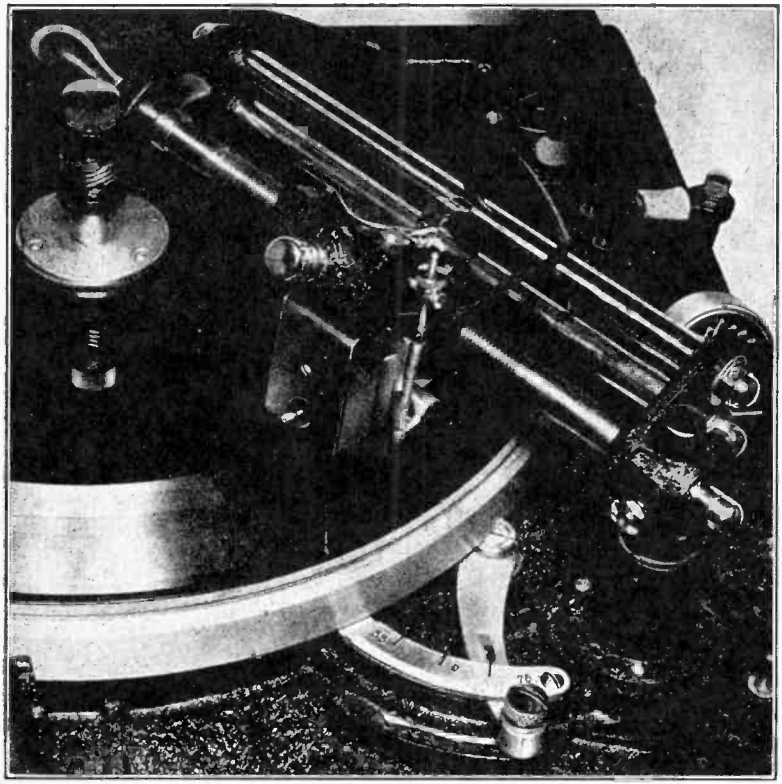


FIG. 290. Presto Overhead Feed Mechanism.

65. Cutting Head Assembly—The Presto Recorder is so constructed that it records on either aluminum or on the softer materials such as acetate and coated discs (Presto Green Seal). In the first case, the disc is knurled and no material is removed, while in the second case, the disc is cut and a thin continuous thread is removed. Presto uses two cutting heads to do the two separate operations; one for the knurling process and the other for the cutting process. This makes for simplicity in operation, assuring that each cutting head is properly adjusted always, and resulting in 100 percent efficient cutting at all times.

The method of driving each cutting head assembly is the same in each case. A chromium-plated feed lever is mounted on top of the casting. This lever is pivoted near the rear and its lower part (lip) is machined so that it fits the buttress thread of the feed screw very snugly. A spring in the casting maintains a constant pressure on the lever. When the latter is on the thread, there is no side-play whatsoever. The cutting head can be moved to any spot on the screw by simply pushing down on the lever with the thumb. This disengages the lip from the screw. This method is known as the positive feed.

66. Cutting Heads—For cutting coated discs such as the Presto Green Seal Disc, the head is very lightly balanced and is so mounted that the needle is almost at right angles with the disc. The pressure is only about 3 ounces and is adjustable by means of the spring located on the right of the head. The angle of cut is also adjustable.

For metal recording (knurling) the head is set in a heavy casting and the angle of cut is fixed. This angle is approximately 45 degrees. The weight on the head is also fixed.

Either one of these heads can be used to cut either inside out or outside in. Each head is interchangeable with the other on the same screw. To set the head in the feed mechanism the feed screw is removed by loosening a knurled screw on the top of the mechanism and the head is slid off the screw. At the rear of each head are two hardened steel bushings set in the casting and these slide over the screw. The fact that these bushings are hardened steel prevents the screw from biting into them. Between these two bushings is a projection which is machined flat to slide under the bottom bar of the feed mechanism. This projection is only necessary when using the lightly balanced head. The casting that carries this head is made top heavy. This fact in conjunction with the projection prevents the screw from lifting the head from the face of the disc during recording. The cutters are of the electromagnetic type and very accurately made. The highest grade steel magnets are used. The pole pieces are made of the finest metal employed for that purpose. They have an impedance of 500 ohms, although this impedance can be anything the customer desires. The cutters have constant velocity from 250 cycles up and constant amplitude below 250 cycles. This is in keeping with the best wax recording practice. Frequency characteristic is uniform to 5000 cycles.

67. **Feed Screws**—Interchangeable feed screws are one of the big features of the Presto Recorder. These feed screws are interchangeable for any pitch and "inside-out" or "outside-in" feed. Each screw is made from stainless steel, turned down to 5/8 in. diameter, accurately machined and chased to within a tolerance of .0005 of an inch. The thread is of the buttress type so that maximum positive driving pressure is maintained at all times on the cutting head assembly. On the end of the screw is mounted a bronze driving worm gear. This gear is carefully pressed into the screw and does not run out even .001 of an inch. All sharp edges on the teeth are carefully removed. There is perfect mesh between the gear teeth and worm. With these screws there is absolutely no periodicity in the grooves—all lines are uniformly spaced.

Good recording practice requires that different pitches be available at all times, so the recording engineer can at any time quickly change to any pitch required. The discriminating engineer will study the sound to be recorded and pick his pitch of screw for maximum results. For example, organ music requires a coarse pitch so that the heavy bass notes can be recorded faithfully without danger of overcutting or distorting, while violin solos can use a finer pitch with result that more sound can be recorded on the disc. It is for this reason the Presto Recorder is made with interchangeable screws. These screws are supplied to feed either from the "outside-in" or "inside-out," and come in the following pitches: 80, 96, 104, 112, 120, 128, 136, and 144 lines per inch.

Feed screws come in two lengths for 12 in. and 16 in. feed mechanisms and are rust proof. Their large diameter and their deep, heavy buttress thread assure long life and continuous work without danger of breakdown. It takes but a fraction of a minute to change feed screws.

68. **Turntable Motor**—One of the major requirements of any recording machine is that the turntable operate at a constant speed so that there be no danger of any wavers or "wows" on any sustained note. It is very important therefore that the driving motor have very good regulation so that any variation in the cutting load will not affect the motor speed. In disc recording the cutting load is continuously variable and is greatest at the outside of the disc. The motor used in the Presto Portable recording equipment is of the constant speed, heavy duty type. It is especially con-

structed for recording and is self starting. It is rated at 1/20 h.p. and operates from the 100 volt a.c. 60 cycle line. The motor is dynamically balanced and the armature runs in precision ball bearings so that vibration is reduced to a minimum. The torque developed by this motor is very large compared to the variation in the cutting load from the center of the disc to the outside, and as a result, constancy of speed is guaranteed at all times. The motor is suspended from the assembly plate by heavy live rubber.

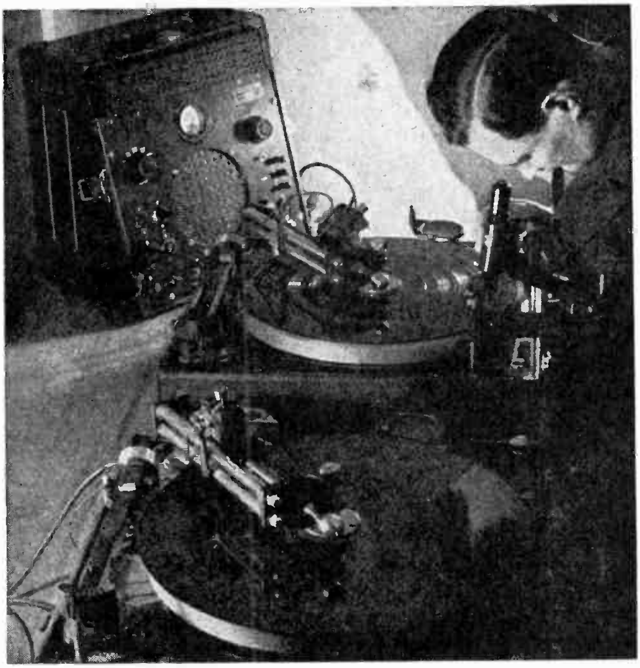


FIG. 291. Engineer Examining Grooves While Recording.

This method of mounting prevents any slight vibrations in the motor from being transmitted to the turntable and cutter. Two oil cups in the bearings are the only points that need attention and about every 3 months a few drops of oil should be added to each cup. No other maintenance is required.

69. Turntable—The turntable is made of heavy cast aluminum and is ribbed on the bottom to eliminate absolutely any danger of warping. The table is accurately turned to .001 of an inch. The rim is made very heavy to obtain a flywheel effect. This guarantees maximum mechanical filtering and is another preventative against "wows" (sudden changes in speed and consequent frequency distortion).

The turntable shaft is of steel and of liberal length so as to obtain a long bearing effect. The bottom of this shaft sits on a steel ball which rests in a conical cup at the bottom of the bearing. This method of construction gives a point pressure between the bearing and the steel ball and the resultant friction is reduced to a minimum. The bearing is of cast bronze and is so precision made that although a running fit is maintained between the shaft and bearing, there is absolutely no side play. The bearing is closed at the bottom, and the shaft is running continuously in a film of oil.

The turntable is driven from the rim through an ingenious idler system. The motor shaft has mounted on it a bronze bushing which drives against a rubber wheel and this wheel in turn drives against the index rim of the table. To change speeds from 78 r.p.m. to 33 1/3 r.p.m. means simply the changing of rubber wheels. These wheels are of live rubber and are molded around a bronze bushing. They are ground to exact proper diameter, to within .0005 of an inch. The rubber wheels in addition to driving the turntable, serve as a filter. Whatever minute vibrations there are in the motor are completely absorbed in the wheels. As a result, the turntable and cutting head are absolutely free from any vibrations whatsoever.

The combination of the heavy duty motor, the heavy rimmed table, the point pressure bearing and the rubber wheels, all contribute to make the table run at constant speed without vibration and waver. These turntables come in 2 sizes: one to accommodate discs up to 12 in. in diameter; the other to accommodate discs up to 16 in. in diameter.

70. **Playback**—The playback pick-up supplied with this equipment is of the highest quality electromagnetic type. It has an impedance of 200 ohms. The armature is so finely balanced that it responds uniformly to frequencies from 40 to 7500 cycles.

The needle pressure is 2 1/2 oz., thus insuring long life to the playback on coated discs. This counterbalancing is accomplished by dead weight at the rear of the arm. No springs are used whatsoever.

71. **The Pre-amplifier**—Two types of pre-amplifiers are

available with Presto Recording Equipment. Each is supplied in a portable case of the same size and is completely shielded.

The Type A pre-amplifier has variable input impedances of 50, 200, and 500 ohms for use with either a dynamic, ribbon or inductor microphone. The output impedance is 200 ohms. This amplifier has two stages of resistance coupling, using two 6c6's as triodes. The frequency response is flat within 2 db from 30 to 12,000 cycles. It has a gain of 40 db. "A" and "B" supply for this amplifier is obtained from the main recording amplifier. Thoroughly filtered, there is absolutely no a.c. hum.

Type B pre-amplifier is identical in all details to Type A except that it has a high impedance input for use with either a crystal or high impedance ribbon microphone.

Since the Presto Recording Corporation does not manufacture microphones, it supplies a choice of microphones. That is the reason two types of pre-amplifiers are manufactured.

72. **Recording Amplifier**—The recording amplifier has three stages of Class A amplification, each stage being in push-pull. It has an input impedance of 200 ohms and an output impedance of 500 ohms. It employs resistance and transformer coupling. All transformers are thoroughly shielded against any stray electrostatic and electromagnetic fields. The gain is 85 db and the undistorted power output is 10 watts. The hum level is —63 db below maximum output. Its frequency response curve is flat from 30 to 12000 cycles within plus or minus 2 db.

This amplifier is made for heavy duty work and the workmanship is of the highest type. Every connection is made mechanically tight before a drop of solder is applied. There is absolutely no danger of any connection falling off. More than sufficient ventilation is provided for the power transformer and tubes, and the amplifier can be operated for hours at a time without danger of overheating.

The tubes used are 2 6C6's, 2 76's, 2 2A3's and 1 5Z3, and are easily accessible when the tube screen on the top is removed.

The amplifier is in an upright position with the front panel sloping back so that all the controls are easily accessible and in full view of the operator.

On the top of the panel in the center is mounted the volume indicator meter manufactured by the Weston Electrical Instrument Company, and is of the copper oxide type.

To the left of this meter is located the selector switch which gives 5 different selections of input and output, as follows:

1. Microphone Public Address.
2. Microphone Recording.
3. Playback.
4. Radio Recording.
5. Radio Reception.

To the right of the volume indicator is located the master gain control which is tapered to give smooth control over its entire range.

Under the selector switch are located four receptacles. Two are 2-prong and two are 5-prong. One 2-prong and one 5-prong receptacle serve one table. The 2-prong is for the 110 volt a.c. turntable motor, while the 5-prong is for the 2 pick-up leads, 2 cutter head leads and ground. If a second table is to be used for continuous recordings, it is plugged into the second set of receptacles.

Underneath the loud speaker is located the change-over switch. When this change-over switch is thrown to the left, the pick-up and recorder leads in receptacle No. 1 are connected to the amplifier and when this switch is thrown to the right, the second set of receptacles are connected. In other words, when a continuous program is being made, transferring from one table to the other requires the flipping over of this switch from one position to the other. The change is instantaneous.

On the right of this switch is located an external speaker jack. This is for use with any standard external speaker with a 500 ohm input. When the speaker plug is inserted into this jack the local speaker is automatically disconnected. The speaker supplied with this unit is located in the center and is a high fidelity 8 in. dynamic speaker. This speaker has sufficient power-handling capacity to fill a good-sized classroom, but if an auditorium type dynamic speaker is plugged into the external speaker jack a hall seating 2000 people can easily be filled. A monitor jack is provided at the left of the selector switch for monitoring during recording by using high impedance phones or a high impedance speaker.

At the lower right-hand corner is located a 4-prong receptacle for use with a radio tuner. Two of these prongs on this socket supply 250 volt d.c. of "B" supply for a tuner while the other 2 prongs are for a standard 200 ohm input impedance.

To the right of this radio socket is located a pre-amplifier socket which supplies 6.3 volts a.c. and 250 volts d.c. to a pre-amplifier.

Above the pre-amplifier socket are located three binding posts for microphone input. The input impedance of these posts is 200 ohms, and the middle post is grounded so that a carbon microphone can be used if desired.

73. **Stationary Equipment**—Where portability is not required or desired, Presto manufactures a special stationary recording machine. This recording machine is designed to cut not only the ordinary acetate or coated disc (Presto Green Seal) and aluminum discs but also wax blanks. It has sufficient weight and rigidity to insure perfect performance, at the same time, however, eliminating unnecessary bulk.

The feed mechanism is heavily constructed and is securely mounted on a heavy cast iron pedestal upon which all other component parts are mounted.

The motor is an integral part of the mechanism and is flexibly mounted to eliminate all vibrations. The countershaft mechanism constitutes a part of the heavy base and contains the drives for the 78 or 33 1/3 pulleys respectively.

A heavily balanced turntable mounted in a substantial bearing guarantees an absolute constancy of speed.

The drive is accomplished by means of flat endless belts of such texture to assure smooth running without vibrations or slippage. These belts are carefully selected for their uniformity and are pre-shrunk and treated so as not to be affected by climatic conditions.

Ample provisions are made for lubrication of all running parts in such a way that such lubrication requires a minimum of attention.

The overhead feed mechanism is driven from the center of the turntable. This method has proved satisfactory in all Presto equipment because it eliminates complex gear mechanisms. It is therefore positive and reliable.

The slide carriage is mounted on heavy ways and contains the carrier for the cutter. Adjustments are provided for raising or lowering the entire cutter mounting to liberal heights to compensate for the varying thickness of waxes. The cutter itself is mounted on a bracket which can be adjusted for angular position. The cutter mounting is carefully counterbalanced and in addition is provided with spring adjustment for very fine pressure adjustment. Advance ball brackets are attached to the cutter mounting for the purpose of adjusting the depth of groove as required in wax. This bracket may be removed when cutting acetate. The advance ball can be adjusted either for "inside-out" or "outside-in" feed.

As in all Presto equipment, the feed screws are removable and interchangeable as heretofore described. No gears or pulleys are required for changing the number of lines per inch.

The base of this equipment is provided with three point suspension leveling screws butting against three flanges. By means of these screws perfect leveling is accomplished.

THE FAIRCHILD-PROCTOR RECORDING SYSTEM

74. **The Duplicating and Playback Processes**—The Fairchild-Proctor Studio Recording System provides for two types of high quality records; the first for duplication and the second for immediate playback. In both cases, a crystal cutting head is used.

The duplication type records are made by recording the program on a metal disc, from which duplicate pressings are subsequently made by the fast molding process used in the Fairchild-Proctor Record Pressing Service. The resulting duplicates can be played with an ordinary shadowgraph steel needle producing a 40 to 8000 cycle response characteristic equal in quality to the customary wax-disc recording.

The metal master can be played back without injury with a fibre or thorn needle while it is being made or immediately after it is finished. This method of playback does not reveal the full quality of the recording, because of the necessity of using a fibre needle, and it is not recommended that the metal master be played back except for checking purposes. When high quality instantaneous playback is required, the original recording should be done on black acetate-coated discs.

The black acetate-coated discs are intended for playback purposes only, and cannot be duplicated unless "dubbed" back on a metal master. For playback use they give higher quality than the metal master, although they cannot equal the extremely high quality of duplicates made from the master. These discs give results entirely satisfactory for rehearsals and for delayed broadcasting.

75. **Recording Head**—The Fairchild-Proctor Crystal Recording Head was developed following long experience with the piezo electric crystals which resulted in the Fairchild-Proctor Crystal Pick-up.

Fairchild-Proctor claims that the Crystal Recording Head is more efficient than a magnetic device in the conversion of electrical energy into mechanical energy. This, they state, is due to the inherent characteristics of the crystal itself and the fact that the movement of the crystal is transmitted directly to the stylus without loss of motion. In the magnetic type, most of the movement of the stylus is absorbed by the rubber damping, the loss of motion being particularly great at higher-frequencies. Because of its greater efficiency it is possible to cut deeper grooves.

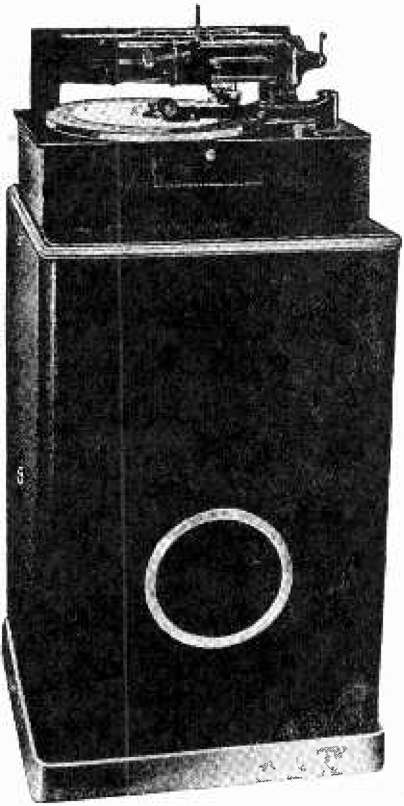


FIG. 291, A. The Fairchild-Proctor Studio Recorder.

Another important characteristic of the piezo electric crystal is that it has a constant amplitude characteristic, thus producing a relation between high and low notes which is substantially the same regardless of the volume level. This particular characteristic is extremely important, in that it minimizes the possibility of over-cutting into adjacent grooves, which frequently occurs when using a magnetic recording head, especially on low notes. Furthermore, with a constant amplitude recorder, records can be cut at a much higher overall volume level, which is highly desirable in order to maintain a satisfactory signal-to-surface-noise ratio.

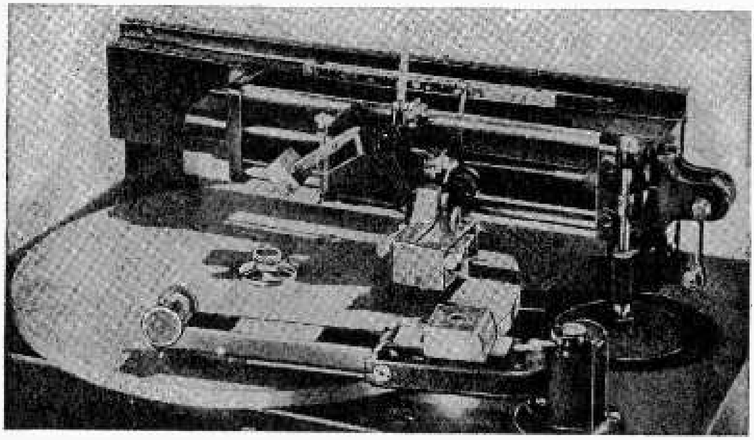


FIG. 291, B. Fairchild-Proctor Recorder Mechanism.

The stylus holder is equipped with two openings for insertion of cutting styli. One hole is intended for steel or sapphire cutting needles used in cutting acetate, celluloid, or coated discs, and holds the needle at an angle of 6°. The other opening is used with a diamond stylus when recording on metal discs and holds the stylus at a 19° angle. By means of this feature, exclusive with Fairchild-Proctor, it is possible to record on acetate or metal discs, without the necessity of changing recording heads.

The angle of the stylus with reference to the recorder is adjustable by means of an adjusting screw knob, located on the left side of the recording head. Clockwise rotation decreases the angle. By means of this adjustment, the needle angle can be varied if desired in either direction from the normal position maintained by the hole in the stylus holder, another exclusive Fairchild-Proctor feature.

The depth of the groove when cutting acetate coated discs is controlled by means of a screw knob on the right side of the Recording Head. This knob adjustment raises or lowers a spring balanced "advance ball" which rides on the surface of the disc immediately ahead of the cutting stylus.

76. Pantograph Recording Head Carriage—The recording carriage which supports the crystal cutting head is a unique patented pantographic device carried on a 3-point suspension. The pantograph limits the recording head to only an up and down true vertical travel so that the angle of attack of the cutting stylus on the recording surface is held constant, irrespective of variations in the thickness of the record disc. The pantograph movement takes place on hardened steel balls with adjustable seats to take up wear. A handle on the top of this assembly frees the pantograph when the recording head is to be lowered to contact with the recording surface.

This three point suspension pantograph support is free to roll smoothly across the turntable on the guide rods which are made of stainless steel. The entire weight of the assembly is carried on two vertically mounted pulleys riding on the lower rod. The side thrust of the unit is carried through the horizontally mounted pulley riding behind the upper guide rod. This side thrust pulley is maintained in close engagement with the upper guide rods under all conditions because of the large forward weight moment on the cutter. The spring pivoted pulley applies pressure to the front of the guide rod and prevents any possible rocking during operation. The recording head carriage assembly is engaged to the stainless steel feed screw with a self-aligning clutch which moves the carriage assembly horizontally across the turntable. The feed screw is supported on steel balls with an end thrust spring to insure constant pitch and is driven by a seamless belt from the turntable. Stepped pulleys on the turntable provide for a pitch of 100, 110, 120 lines per inch. Special pulleys can be supplied for any pitch required. The exact position of the feed screw can be varied, by a cam-lever system, permitting the making of pre-starting grooves and making possible separately engraved sections with blank portions between. A scale marked in tenths of an inch and a pointer show the length of the recording at any time. The entire recording head and feed mechanism is supported on U-channels, which can be adjusted up or down to accomodate different thicknesses of recording materials.

77. Turntable and Motor Drive—The turntable proper is a seasoned, 25 pound casting, 16 inches in diameter, completed machined and dynamically balanced. The top surface is linoleum, which can be readily cleaned and does not wear or become uneven, as does felt. A clamping nut secures the recording blank to the table, preventing slippage.

The turntable is driven by a 100 watt, 110 volt, 60 cycle capacitor type, synchronous motor, mounted on a three point vibration-absorbing support to a rigid base assembly which rests on the floor independent of the general turntable-mechanism structure.

The turntable may be driven at either 33 1/3 or 78 r.p.m. At 33 1/3 r.p.m., the drive is direct from the motor through an accurately machine gear and worm reduction unit. The change to 78 r.p.m. is accomplished by movement of a lever on the motor drive base assembly which brings into action an ingenious adhesion drive speed changing mechanism between the 33 1/3 r.p.m. motor shaft and the turntable. The smooth rolling action between the balls and the cone surface of the adhesion drive assures constant turntable speed. As a further precaution against "wows" a fifty pound flywheel is mounted directly above the adhesion drive. A flexible coupling joins the flywheel to the turntable shaft providing additional vibration filtering and allows for any misalignment between the motor drive assembly and the turntable.

78. **Pick-up and Playback Facilities**—The Fairchild-Proctor Studio Recorder is equipped for simultaneous playback. A Fairchild-Proctor Crystal Pick-up is mounted beside the turntable, and can be set in the groove following the recording stylus. In this manner, the recording can be monitored with headphones or loudspeaker while it is being made. Such monitoring is usually very helpful as an adjunct to volume level meter-indications.

79. **Technical Characteristics of Equipment**—A description of the technical characteristics of several of the important items follows:

Recording Playback Amplifier and Control Equipment for High Quality Direct Recording—(*Note:* Used in special "built to order" installations for recording studios and sound studios. Each installation has a Unit 218 drawing number assigned which calls for all Unit 218 group numbers and accessories that may be needed for the job.)

Unit 218 Group A Recording Amplifier—Recording or Playback Amplifier suitable for either rack or panel mounting or shelf mounting. This power amplifier may be used for operating the unit 214 cutterhead on either Unit 199, 215, or 220 Recording Mechanisms for making direct lateral recording on aluminum discs or acetate coated aluminum discs. It can be used for playing back records of any type in connection with the Unit 209 Pick-up matching transformer. It will operate any dynamic loudspeaker with a transformer or voice coil impedance specified under "Output Impedance" below. It is used to drive the intermediate air column speaker on Unit 224 Multi-Channel Speaker Assembly or the single air column speaker E218–A11 Gain 80 decibels. Power output 33 decibels with two percent total harmonic distortion at 400 cycles (referred to .006 watts as zero level). Noise level—50 db below zero level. Frequency response—minus 2 db at 30 cycles; plus 1 db at 10,000 cycles. Push-pull 6C5—transformer coupled into push-pull 6C5—transformer coupled into push-pull parallel class *AB* type 45 power amplifier tubes. Amertran Precision DeLuxe Transformers used throughout.

Unit 218 Group B Power Supply for Recording Amplifier—A separate power supply unit for producing d.c. plate voltage, bias voltage, and heater voltage to above power amplifier (E218–A11).

Unit 218 Group C Control Panel for Direct Lateral Recording—The control panel for direct lateral recording is designed for rack panel mounting.

A 500 ohm "T" pad is provided for control of recording amplifier input level.

A 500 ohm "T" pad is provided for control of playback amplifier input level.

A power level indicator with decibel scale is provided for monitoring the recording output level. The power level indicator is provided with a multiplier so that the zero reading of db meter corresponds to power levels of 10, 15, 20, 25, 30 and 35 decibels.

A pick-up selector switch permits instantaneous switching of either of the two pick-up circuits to input of playback amplifier.

A cutterhead selector switch permits instantaneous switching of either of two recording cutterheads to output of recording amplifier.

A Monitor Comparing switch permits comparing the incoming line program with the recording of said line program.

A selector input switch permits instantaneous switching to either of two incoming line programs.

The equipment is mounted on an engraved panel finished in black General Radio type crackle lacquer. All leads are brought to a terminal board in the back of the panel for short convenient connection to patch cord panel E218–A4.

Unit 218 Group E Recording Equalizer Panel—The recording equalizer panel is used for providing audio compensation at the bass and high frequency end of the recording amplifier channel to obtain the desired frequency response on the record.

A bass equalizer control is provided for compensation at 60 cycles in two decibel steps up to 15 decibels.

A high frequency control is provided for compensation at 5500 cycles in two decibel steps up to 15 decibels.

A band elimination filter control is provided for reducing the peak characteristic of the crystal cutterhead over the range of 2700 to 4000 cycles by 15 decibels.

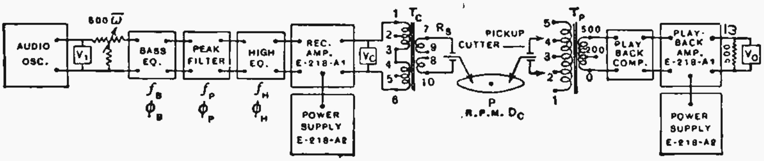


FIG. 291, C. Test Setup for Measurement of Overall Recording Playback Frequency Response. (Fairchild Aerial Camera Corp.)

f_B = Bass Compensation Frequency-Cycles Per Second
f_P = Cutter Head Peak Compensation Frequency-Cycles Per Second
f_H = High Compensation Frequency-Cycles Per Second
ϕ_B = Bass Compensation in Plus Decibels
ϕ_P = Cutter Head Peak Compensation in Minus Decibels
ϕ_H = High Compensation in Plus Decibels
T_C = Cutter Head Matching Transformer—Fairchild No. B-209-45
T_P = Pickup Matching Transformer—Fairchild No. B-209-27
Z_C = Impedance Ratio—Primary to Secondary of Transformer T_C in Ohms
Z_P = Impedance Ratio—Primary to Secondary of Transformer T_P in Ohms
V_C = Input Level in Decibels Across Cutter Head Transformer T_C
V_O = Output Level in Decibels Across Playback Amplifier 500 Ohm Load
P = Cutting Pitch in Lines/Inch
R.P.M. = Turntable Speed in Revolutions Per Minute
D_C = Direction of Cut—"Inside to Out" or "Outside to In"

The input and output impedance of the equalizer is 500 ohms and it should be used in the input circuit of the amplifier or at levels below "0" decibels.

Unit 218 Group F Playback Equalizer Panel—The Playback Equalizer Panel is for providing bass audio compensation in the playback amplifier channel, standard practice in recording results in the 60 cycle response being about minus 17 decibels down referred to 1000 cycle reference level. The function of the playback equalizer is to compensate for this lack of low response. The Unit 209 crystal pick-up provides about 8 decibels plus equalization so that the bass compensation is necessary to provide the additional 11 db equalization.

A bass equalizer control is provided for compensation at 60 cycles in two decibels steps up to plus 15 decibels.

The input and output impedance is 500 ohms.

Unit 218 Group G Mixer Panel—The Mixer Panel is for mixing three microphones into a common input channel to a pre-amplifier.

An individual "T" pad level control is supplied for each microphone circuit and an individual "off-on" key permits each microphone channel to be instantly and completely cut-off. A master

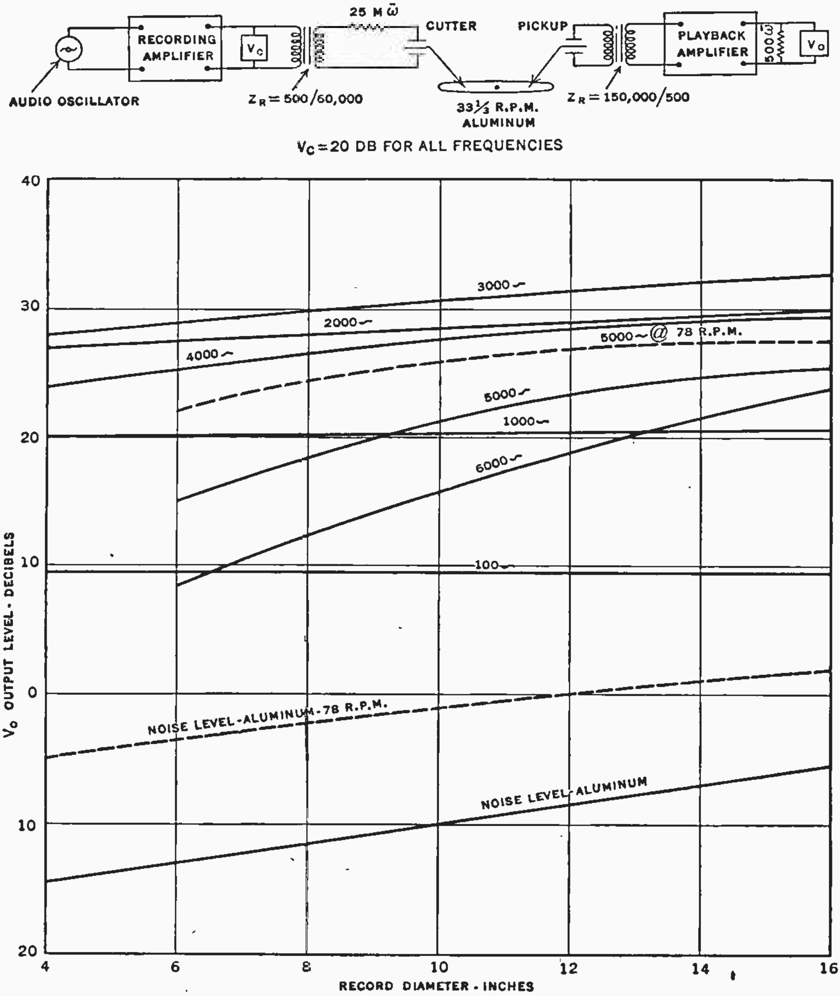


FIG. 291, D. Frequency Response and Noise vs. Record Diameter. (Fairchild Aerial Camera Corp.)

control "T" pad is provided for controlling the overall level of the three mixed microphone channels. An "off-on" key permits the master circuit to be entirely cut-off instantly.

The mixer is intended for use on low level circuits at power levels below zero decibel power level.

The input impedance for each individual microphone channels 1, 2 and 3 can be supplied in the following impedances subject to customers' specifications (30, 50, 200, and 500 ohms). Any other impedance can be supplied on special order.

The output impedance is 500 ohms.

Unit 218 Group H Pre-Amplifier Panel—The Pre-Amplifier Panel is a two stage amplifier suitable for either rack panel mounting or shelf mounting. Gain 50 decibels. Maximum Power Output 0 decibels with five percent total harmonic distortion. Noise Level—minus 85 db below "0" level. Frequency response—minus 2 db at 30 cycles; plus 1.0 db at 10,000 cycles. Input transformer to 6C5 tube, resistance coupled to 6C5 tube, transformer coupled by output transformer to 500 ohm line.

Unit 218 Group I Pre-Amplifier Power Supply—A separate power supply unit providing 200 volts d.c. plate voltage and 6.3 volts—.6 amperes heater voltage for above pre-amplifier (E218-A9).

Unit 218 Group K Bass/High Amplifier—The Bass/High Amplifier is used in conjunction with Recording Amplifier Group A for driving a Unit 224 Multi-Channel Speaker system.

The Group A Recording Amplifier drives the intermediate channel speaker. A bridging circuit across the output of the recording amplifier is used to drive the Bass/High Amplifier.

There are two separate power amplifier circuits on the Bass/High amplifier for driving the bass speaker and the high frequency speaker respectively at power levels above the output level maintained in the intermediate channel. There is a bass control provided at the input of the bass amplifier and a high frequency control provided on the input to the high frequency amplifier.

The bass response at 40 cycles can be raised 13 db above the 1000 reference level in the bass channel.

The high frequency channel cuts off below 3000 cycles, passing frequencies only above 3000 cycles in the high frequency speaker. The output tubes in the bass amplifier are 45 tubes in parallel push-pull. The output tube in the high frequency channel is a type 6F6.

Output impedance of bass channel—500, 125, 15, 7.5, 5, 3.75, 1.25 ohms. Output impedance of high channel—15 ohms.

Input impedance—bridging circuits 20,000 ohms across plate to plate of E218–A1 recording amplifier.

The Bass/High Amplifier is operated by Power Supply E218–A2 under Group B of Unit 218.

80. Duties of the Control Room Operator—The control operator generally is required to arrive at the control room one-half to three-quarters of an hour preceding the broadcast day. Each studio channel and associated power equipment is inspected and tested and repairs and replacements made if necessary.

Continuity tests are made on each studio and announcers, microphone circuit, transcription equipment, remote pick-ups and network positions.

A frequency run is made on the program line running from the control room to the transmitter and characteristics of the line checked and equalization provided where required.

When the program begins he operates the control gain and mixing panels, makes the necessary switching to announcers, studios, pick-ups and chain networks; operates transcription machines and controls and handles chain program orders by telegraph or teletype. He is required to keep a program log showing the nature of the program the time each station and call announcement is made, the time the program commences and stops. At the end of the day he is required to close down all the equipment, place storage batteries, if any on charge, and inspect and clean the equipment.

CHAPTER 8

RADIO AND AUDIO FREQUENCY MEASUREMENTS AND FREQUENCY MONITORS

1. **Introduction**—Rule 206 of the Federal Communications Comission reads as follows:

> 206. The licensee of each station, except amateur, shall provide for measurement of the station frequency and establish procedure for checking it regularly. These measurements of station frequency shall be made by means independent of the frequency control of the transmitter and shall be of such an accuracy that the limit of error is within the frequency tolerance allowed the station.

To meet this requirement several services have established a frequency measuring service of their own while others contract with a commercial company rendering such service for periodical measurements.

The number of measurements within a given period of time varies with the nature of the service and the frequency of operation. Recently the Commission advised the licensees of commercial and itinerant aircraft that measurements would be required as follows.

> As a result of inspections it appears that certain itinerant aircraft operators have not made arrangements for the measurement of their station frequencies as required by Rule 206. For your information the following schedule is believed satisfactory:
>
> 1. Aircraft equipment having high quality frequency control operating on chain frequencies, monthly.
> 2. Aircraft equipment of the master oscillator type operating on chain frequencies, previous to each trip on which chain frequencies are to be used.
> 3. Aircraft having high quality frequency control equipment and using itinerant frequencies only, quarterly.
> 4. Aircraft having master oscillator power amplifier equipment and using itinerant aircraft frequencies only, monthly.

In addition to the privately and commercially owned frequency measuring services, several branches of the federal government operate frequency monitoring stations for the purpose of measurement of frequencies of their own stations, as well as those of other services which are off-frequency and causing them interference.

The Federal Communications Commission also operates seven monitoring stations located at strategical receiving points in the United States where the frequencies of all stations of the world are measured.

The National Bureau of Standards in Washington maintains a radio frequency standard from which there are transmitted on schedule standard radio and audio frequency signals. The interception of these signals permits comparison with working standards utilized by commercial companies and government agencies.

In order to assist the student and operator interested in frequency measurements the author has chosen to describe a working standard of frequency and associated interpolating apparatus manufactured by The General Radio Company whose standards are used extensively in this country and other parts of the world. By permission of the Company the following material is taken directly from their instruction book.

GENERAL RADIO CLASS C–21–H STANDARD FREQUENCY ASSEMBLY

The designation "Class C–21–H" classifies this assembly in a general way, but for a complete specification the type numbers of the individual instruments are required.

The assembly consists of the following components. There are two possible types of power-supply equipment and this book applies to both:

Type 693–A	Syncro-Clock and Amplifiers
Type 692–A	Multivibrator (1-kc.)
Type 692–A	Multivibrator (10-kc.)
Type 692–A	Multivibrator (50-kc.)
Type 691–B	Temperature-Control Unit
Type 690–B	Piezo-Electric Oscillator
Type 676–A	50-kc. Quartz Bar and Holder
Type 694–B	Crystal Oscillator Control Panel

Complete a.c. Operation—When intended for operation without batteries from the 60-cycle line a Type 696–A Power Supply is used.

2. Fundamental Principles—*Purpose:* The standard-frequency assembly is designed to supply for laboratory use a large number of standard frequencies, each of which is known with an accuracy of five parts in ten million or better. It provides frequencies over the entire communication spectrum, all of which are derived from and controlled by a single high precision standard of frequency.

Description—Since frequency is measured in cycles per second, the element of time enters directly into the determination of frequency. In the final analysis, the exact measurement of frequency consists of counting a number of operations of a given type and dividing by the exact time interval in which they occur. An oscillator or generator may be as uniquely defined in terms of its periods (time) as by its frequency, the relation between them being $f = 1/T$. The element of time, therefore, is of fundamental importance in the precision determination of frequency. A primary standard of frequency is defined as one whose frequency is determined directly by comparison with mean solar time. The General Radio Class C–21–H Standard-Frequency Assembly comes under this classification.

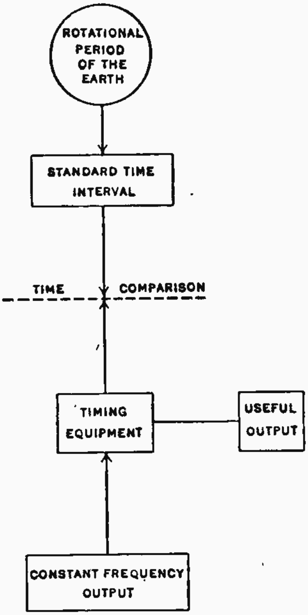


FIG. 292. Basic Principle of a Primary Standard of Frequency.

Figure 292 is an outline chart which shows without confusing detail the basic principles of this standard-frequency assembly. A source of radio-frequency voltage is first established, the frequency of which is nearly enough constant to justify the statement that its instantaneous frequency deviates from its mean frequency by a negligibly small amount. Apparatus is next provided for counting the number of oscillations executed by this frequency standard during a standard time interval, which, for convenience, may take the form of a clock. The time interval usually chosen for measurement is the mean solar day. The total number of oscillations executed by the standard in one mean solar day, divided by the number of seconds in the day, gives its mean frequency in cycles per second.

In order that we may secure the output frequencies needed for use in measurements, we utilize the conversion equipment which is necessary for the reduction of the frequency of the working standard to the value employed in operating a synchronous motor-driven clock. This equipment merely derives the desired frequencies (which may be expressed as harmonics and subharmonics of the frequency of the working standard) by frequency multiplication and division.

Functional Arrangement—Figure 293 shows in more detail the actual standard-frequency assembly. The *working standard* is a temperature-controlled piezo-electric quartz-crystal oscillator. The frequency of the working standard is chosen as 50 kilocycles. For special work, other frequencies may be more suitable. Both the *timing* and *conversion* functions are performed by two *multivibrators* operating as frequency dividers, at fundamental frequencies of 10 kc. and 1 kc., respectively, under the direct and absolute control of the working standard oscillator. The 1-kc. output voltage of the second multivibrator is amplified to operate a synchronous-motor-driven clock which is so geared that when the driving voltage has a frequency of exactly 1 kc. the clock keeps correct time. A means of comparing the indicated clock time with standard time as given by radio or other time signals completes the timing sequence.

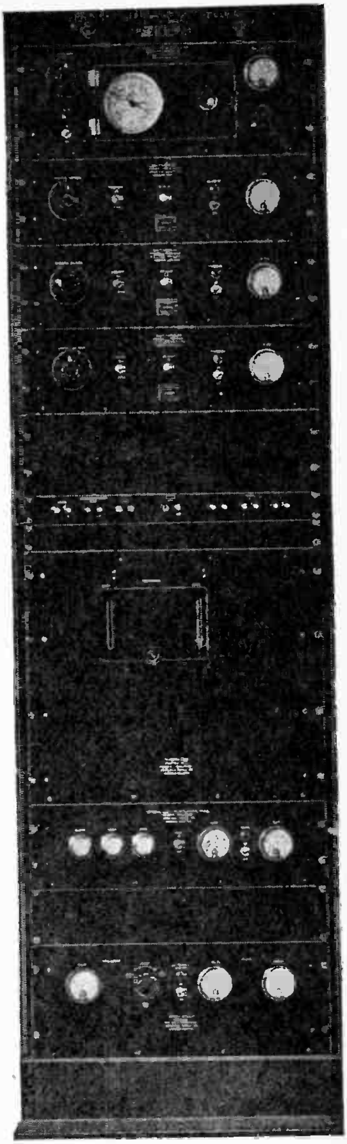


FIG. 293. Class C-21-H Standard-Frequency Equipment.

The "useful output" is derived from the harmonics of the 10-kc. and 1-kc. multivibrators as well as from the harmonics of a third multivibrator which may be operated at a fundamental frequency equal to that of the working-standard oscillator. Since each of the "useful output" frequencies is derived from the working standard by harmonic frequency multiplication and division, each is known with the same percentage accuracy as that with which the frequency of the working standard is known.

The assembly contains, in addition to the units mentioned above, a crystal-oscillator control panel, a temperature-control unit and a power-supply unit.

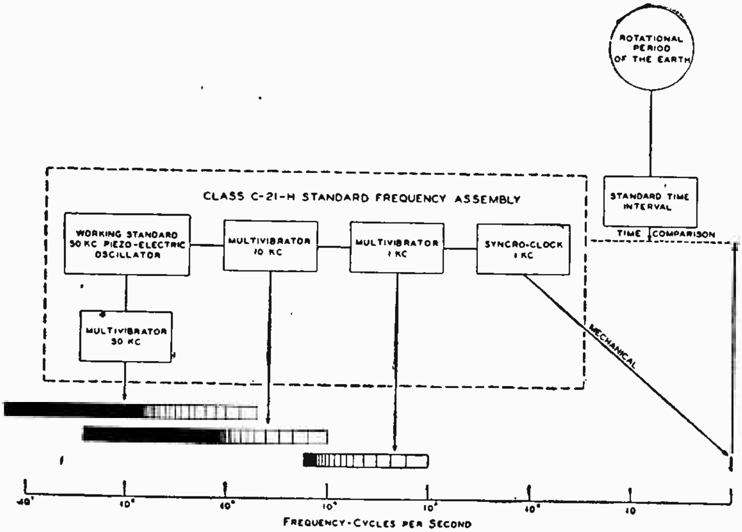


FIG. 294. Schematic Representation of a Class C–21–H Standard-Frequency Assembly Showing the Frequency Distribution of the Standard Harmonics It Makes Available for Frequency Measurements."

3. **Type 694–B Crystal Oscillator Control Panel**—On the Type 694–B Crystal Oscillator Control Panel is mounted the necessary meters and controls for both the oscillator and the temperature-control unit. The wiring for both these pieces of apparatus should be studied in connection with the wiring diagram for the crystal oscillator control panel.

4. **Type 691–B Temperature-Control Unit**—This unit is the temperature control for both the quartz plate and the oscillator circuit elements. The unit consists of two temperature-control boxes, one inside the other.

The two temperature-control boxes are identical in construction, differing only in size. Each box consists of:

(1) A balsa insulating layer.
(2) A layer of distributed heaters.
(3) An aluminum distributing layer.
(4) An asbestos pressboard attenuating layer.
(5) A second aluminum distributing layer.

(6) A second asbestos pressboard attenuating layer.
(7) A third aluminum distributing layer.

It should be pointed out that the use of a two-stage unit makes possible a very precise control of temperature. The inner unit has to operate against only the temperature fluctuations remaining from the operation of the outer unit. If the outer unit reduces the fluctuation in room temperature by a factor, *n*, then in the inner unit the total reduction is of the order of n^2.

The temperature of the inner box of the temperature-control unit fluctuates less than 0.01° C. for changes in room temperature from —.5 to 43.5° C. (20° to 110° F.). This is an important factor in determining the ultimate frequency stability of the system. The outer unit controls to better than 0.1° C.

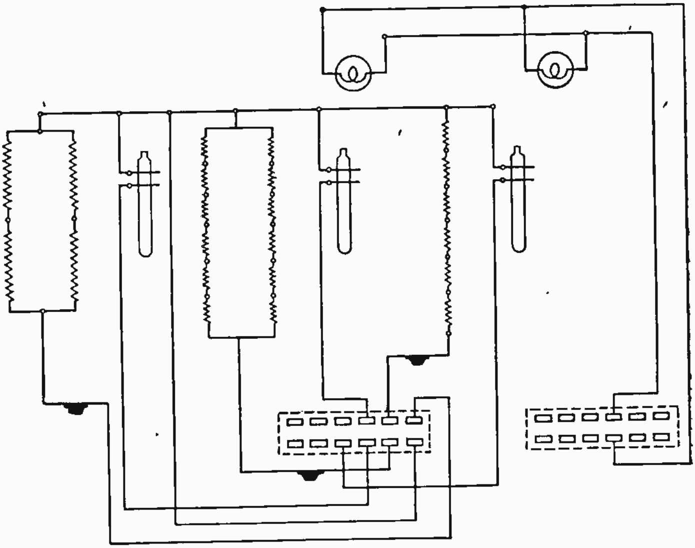


Fig. 295. Wiring Diagram for Type 690–B and Type 691–B Temperature-Control Boxes.

A diagram of the heat-control circuits is shown in figures 295 and 296. Briefly, the system operates as follows:

When the temperature is below its operating value, the end of the mercury column in the thermostat is below the upper contact, the winding of the relay is energized, the armature of the relay is closed, and current is supplied to the heaters. Under this condition, the heat indicator lamp is lighted.

When the temperature rises to such a value that the mercury column reaches the upper contact, the winding of the relay is short circuited, and the armature circuit opens, breaking the circuit to the heaters, turning off the heat indicator lamp. When the temperature at the thermostat drops slightly, the relay again closes, and the cycle is repeated.

Fusible links are placed in the inner, outer and crystal oscillator heater circuits as a protection against damage to the temperature-control unit or its contents should the heat-control circuit fail. If the temperature should ever reach about 65° C., the links melt and open the heater circuits.

5. **Type 690–B Piezo-Electric Oscillator**—This unit consists of a piezo-electric oscillator with automatic amplitude control and an isolating output amplifier. The oscillator employs a circuit developed by the General Radio Company in which the crystal is operated at, or extremely near to, its series resonant frequency.

The complete circuit diagram is given in figure 296. The oscillator circuit employs a modified Colpitts circuit, the oscillating circuit elements being all mounted on the quartz crystal mounting base. The inductor L (General Radio Part No. 676–31) is mounted on the upper clamp and the two fixed condensers C–3 and C–4 are the two Type 505 Mica Condensers mounted underneath the base.

It will be found that the frquency of the crystal oscillator is influenced by any changes in the following factors:

(1) Air-gap distance to baffles
(2) Temperature
(3) Capacitance of circuit
(4) Inductance of circuit
(5) Tubes
(6) Tube voltage

1. The baffles (see next section) being adjusted for quarter-wave resonance, the change in frequency with the distance from the end of the quartz bar is least. This change is roughly five parts per million per millimeter *at the operating adjustment.* As the baffles are quite rigidly mounted, the changes in distance are small and changes in frequency from this cause appear to be so small as to be very difficult of detection. It should also be noticed that with the air columns in resonance, the effects of air pressure variations are considerably reduced.

2. The temperature coefficient of the crystal oscillator is —2 to —5 parts per million per degree centigrade.

3. The capacitance of the circuit is 275 uuf., of which 50 uuf. is made variable for regulation of the frequency. The total variation thus obtained is approximately ± 3 parts per million.

4. The inductance in series with the crystal tunes with the circuit capacitance so that the system oscillates at very nearly 50 kc. in the absence of the crystal. With the crystal in circuit the frequency variation is about one part per million for ten turns change in the inductor.

5. Changes in tubes produce changes in frequency which are almost entirely due to the variations in capacitance of the circuit. Since the circuit capacitances are large compared to the tube capacitances these changes are very small and compensation can easily be made by means of the frequency adjusting condenser.

6. Changes in frequency produced by changes in tube operating voltages have been practically overcome through the use of automatic amplitude control. The oscillator amplitude is held at a relatively low and sensibly constant value by means of a bias voltage obtained from a diode rectifier.

Under normal operating conditions, oscillators of this type have held to better than one part in ten million over considerable periods of time.

6. **Type 676–A Quartz Bar and Mounting**—This quartz bar and its mounting are the result of considerable study and research in the General Radio laboratories. The design of the holder is such that maximum stability and freedom from external effects is obtained. The bar vibrates along its longest dimension in a direction perpendicular to its electric axis. Under these conditions, the point of minimum motion is at the geometrical center of the largest faces, and the bar is clamped at these points.

The two plates or "bafflles" near the end of the bar are designed to minimize the effect of air waves radiated from the ends. These air waves are reflected from nearby surfaces, and, if the reflected waves are not in phase with the motion of the bar, an appreciable reactive component is introduced in the crystal impedance as well as an increase in its damping factor.

The baffles are set at the point which results in maximum crystal amplitude which is the point where quarter-wave air resonance occurs. Under this condition, the operation of the bar is greatly improved, and the effect of changes in atmospheric pressure is minimized.

The air-gap usually existing between the electrodes and the

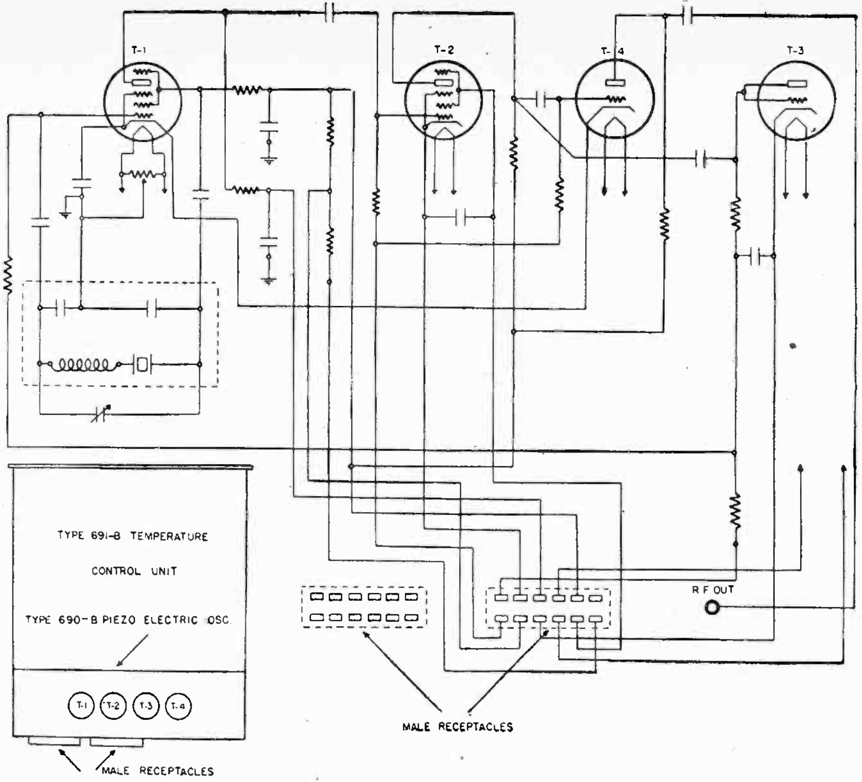


FIG. 296. Wiring Diagrams for Type 690–B Piezo-Electric Oscillator and Type 676–A Quartz-Bar Mounting.

quartz bar is avoided by forming the electrodes directly on the quartz. This not only avoids the frequency variations caused by variations in air-gap (which are very appreciable in most air-gap type mountings) but results also in much improved electrical performance.

7. Type 692–A Multivibrators—The Type 692–A Multivibrator is provided with a switch by means of which the control voltage may be applied to one or both multivibrator tubes. The two positions of this switch are engraved ODD and EVEN respectively.

Control from a source whose frequency is a subharmonic of the multivibrator fundamental is, in general, difficult to realize. When, however, the controlling frequency contains an appreciable harmonic whose frequency corresponds to that of the multivibrator fundamental, this harmonic may be filtered and amplified and used as a controlling voltage.

In the Type 692–A multivibrator an input amplifier is provided, through which the controlling voltage is introduced. This is done so that not only may the input impedance of the unit be high but the reaction of the multivibrator on the controlling source may be kept small. Two output amplifiers are provided, either or both of which may be used as required. One, marked CONTROL OUTPUT, is primarily intended for use when several multivibrators are operated in cascade as frequency dividers. The output waveform, while by no means sinusoidal, contains a very strong component of fundamental frequency. The other, marked HARMONIC OUTPUT, is purposely arranged to accentuate the higher harmonics of the multivibrator frequency in order that these may be used in frequency measurements.

In the Class C–21–H Standard-Frequency Assembly three multivibrators are employed. A 50-kc. unit (which may be turned on and off as desired) is used to obtain a large number of harmonics of the crystal frequency; a 10-kc. unit divides the crystal frequency by five and provides a large number of harmonics at multiples of 10 kc., and the 1-kc. unit divides the 10-kc. frequency by ten to obtain an output frequency (1 kc.) which is 1/50th of the crystal frequency for operation of the syncro-clock.

The wiring diagram of the Type 692–A Multivibrators is given in figure 297. The units are mechanically identical for the frequencies used and differ electrically only in the constants.

8. Type 693–A Syncro-Clock and Amplifiers—In this unit the necessary amplifying equipment is provided for the running of the syncro-clock on the output voltage available from the

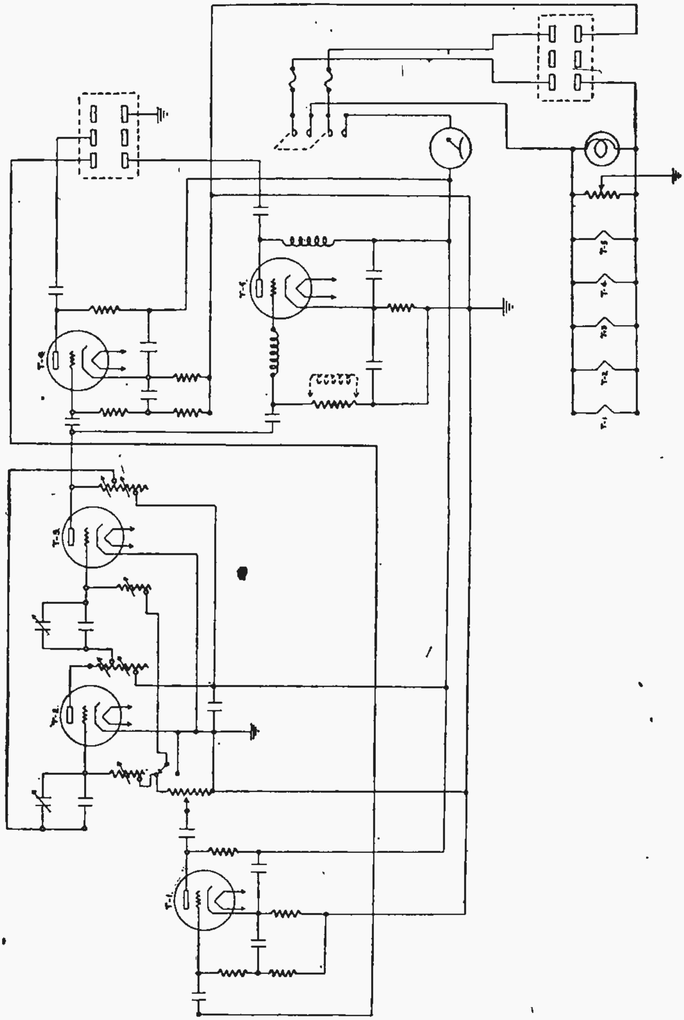


Fig. 297. Wiring Diagram for Type 692-A Multivibrators (1-kc., 10-kc., 50-kc.).

multivibrator assemblies. A circuit diagram is given in figure 298.

The voltage available for driving the clock is generally considerably in excess of the amount required for satisfactory operation, and for this reason a voltage divider is provided, for regulating the voltage on the grid of the clock amplifier tube. The output circuits of these tubes are separate, one serving to drive the clock, while the other is connected through a transformer to the terminals marked on the terminal strip 1-KC. OUTPUT.

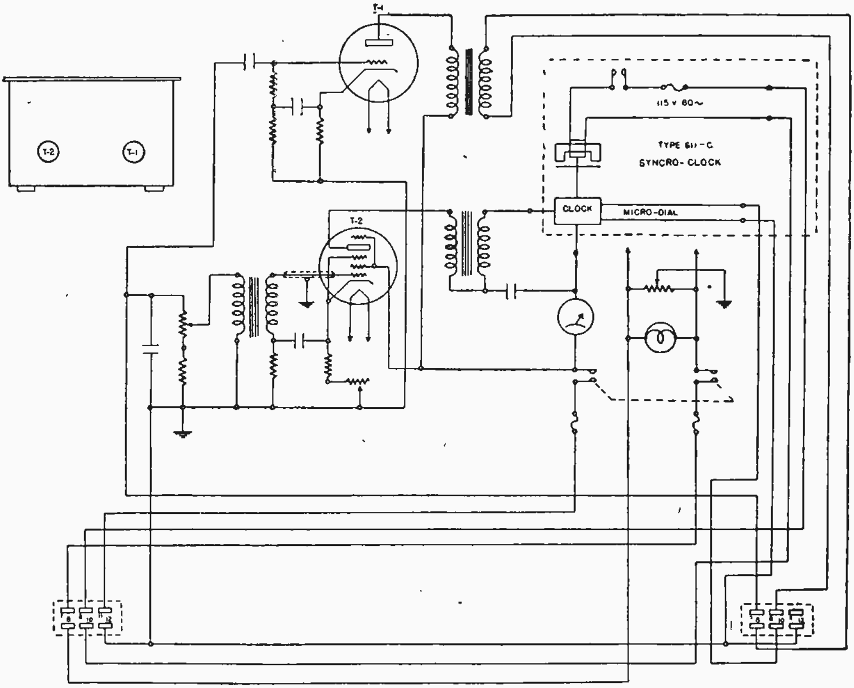


FIG. 298. Type 693–A Syncro-Clock and Amplifier.

The syncro-clock is designed and constructed so that when it is operated from a supply frequency of 1 kc. it keeps true time. The number of teeth on the rotor disc is 100; the disc, therefore, makes 10 revolutions per second. The rotation of the disc is stepped down through worm gearing to a countershaft which rotates one revolution per second. This countershaft drives the clock train through a worm and differential gearing giving a reduction of 60 to 1, so that the main shaft of the clock mechanism proper turns at 1 revolution per minute.

Interposed between the driving mechanism and the clock train is a set of planetary differential gears which are normally locked so that the driven shaft rotates at exactly the same speed as the driving shaft.

By means of the small knob to the left and above the clock face, the differential train may be unlocked and shifted in either direction with respect to the driving shaft. The knob carries a gear and a stop-spring engaging the teeth of this gear, so that the position of the shaft on which the knob is mounted may be advanced or retarded by definite steps. Each notch of the gear corresponds to a change in position of the second hand of the clock of one-half a second. If the knob is rotated one tooth to the right, the second hand of the clock will be advanced one-half second. In this manner it is possible to set the clock while running, to within plus or minus one quarter second of any desired time, without slipping the hands.

To the right of the clock face is mounted the micro-dial, by means of which the time indicated by the clock may be accurately compared with time signals. The contact is driven at one revolution per second as it is mounted on the main countershaft. The contact is closed for about 0.95 of each second. The instant at which the contacts close may be adjusted by turning the knurled wheel projecting through the clock face. If the contacts are connected across the telephones or loud-speaker of a time signal receiver (from which any direct current in the output has been filtered) the operation of the cam may be adjusted so as to short-circuit all but the *beginning* of each pulse of the time signal. The reading of the micro dial then gives the fraction of a second that the clock differs from the time signal. Each division equals 0.01 second. The micro-dial contacts may be utilized for transmission of second's pulses for laboratory purposes.

9. Instructions for Operating Complete a.c. Assembly—The following paragraphs give all the information necessary for starting up an assembly in which power is derived from a Type 696–A Power Supply.

In placing the equipment in operation, the temperature control should be started at least twelve and preferably twenty-four hours before the apparatus is to be used. It is recommended, even though the equipment as a whole may not be operated continuously, that the temperature control be left on at all times.

The temperature-control circuits are turned on and off by the HEAT switch mounted at the left on the Type 694–B Crystal Oscillator Control Panel. Leave the MASTER switch on the Type 696–A Power Supply in the OFF position.

On first closing the HEAT switch, both "inner" and "outer" relays should operate, and both heat-indicator lamps should light. The thermostats will not operate until the heat has been applied for roughly one-half to one hour. The temperature in the crystal compartment does not reach its final value until a period of six to twelve hours has elapsed.

The final inner temperature should be 55° C. within 0.5° and it should remain constant to within 0.01° C. The outer thermometer should read approximately 51.8° C. The circuit thermometer should read 62° C.

To place the assembly in operation, proceed as follows:

1. Throw MASTER SWITCH on Type 696–A Power Supply to ON. Pilot should light the FILAMENT and PLATE meters should read. Set ADJUST control to give 6.3 volts on filament voltmeter.

2. Throw FIL-PL switch on Type 694–B Crystal Oscillator Control Panel to ON. Pilot should light. After a few moments PLATE and DIODE meters should read. If DIODE meter reads zero or a very small amount while PLATE meter reads about 0.5 milliampere, it indicates the crystal is not oscillating. When crystal is oscillating, the DIODE meter should read 80 to 110 microamperes and PLATE meter 0.15 to 0.25 milliampere. Set the FREQUENCY ADJUST dial (on rear panel) on the temperature control unit to setting given in test data for the individual device in use. See this data also for actual meter readings.

3. Throw FILAMENT switch on the 50-kc. Type 692–A Multivibrator to ON. Pilot should light and after a few moments PLATE meter should read. Throw CONTROL switch to the position and set CONTROL VOLTAGE adjustment at setting given in test data.

4. Repeat (3) for 10-kc. Multivibrator.

5. Repeat (3) for 1-kc. Multivibrator.

6. Throw FIL-PL switch on Type 693–A Syncro-Clock and Amplifiers to ON. Pilot should light and after a few moments PLATE meter should read.

Note: PLATE meter indicates plate current of clock amplifier *only;* total plate current meter consequently reads higher than the sum of the readings of the individual plate current meters.

7. Readjust voltage control on power-supply unit to give 6.3 volts on FILAMENT voltmeter. PLATE voltmeter should read from 175 to 186 volts.

8. Adjust BIAS and CLOCK INPUT controls on the syncro-clock to values given in test data.

9. Unless adjustments have been disturbed in shipment, the multivibrators should be operating at the correct frequencies and be in control. Details on checking the multivibrators are given below.

10. To start the clock motor, press the switch on the clock face, thus turning on the 60-cycle supply to the starting motor. Due to the pull of the steady plate current the motor will not turn until the FIL-PL switch is thrown to OFF *momentarily*. Return this switch to ON immediately. The clock rotor will now turn and pick up speed.

The motor reaches synchronous speed in about two seconds as indicated on the clock face. In most cases the 1000-cycle motor will take hold and prevent the 60-cycle motor from any further increase in speed. The switch on the clock face may then be released. If the 60-cycle motor carries the rotor through synchronous speed, simply release the switch. The 1000-cycle motor may fall into step while coasting. If not, simply press the starting motor switch and bring the 1000-cycle motor up to synchronous speed again.

10. Operating Suggestions—After the assembly has been installed and put in operation a check upon the various adjustments is desirable.

1. *Crystal Oscillator:* If the crystal oscillator does not oscillate, most probably the quartz bar has been displaced in the mounting during shipment. The bar should be in alignment in the holder, with the baffles parallel to the ends. The two air-gaps should be equal. The crystal should be clamped firmly enough so that shaking the holder does not cause any displacement of the bar. The clamping points should be at the geometric centers of the two large faces.

Caution: Handle crystal with great care so as not to break off the connecting leads.

2. *Multivibrators:* The Type 692-A multivibrators should operate at very nearly their rated frequency when no control voltage is applied, that is, when the control voltage adjustment is set at zero. If this control is advanced slightly, the multivibrator should go into control and remain at the controlled frequency as the control voltage is increasing over quite a range. If sufficient control voltage is applied, the multivibration frequency may be pulled up to the next higher value. Set the control voltage adjustment at about 80 percent of the value where this jump occurs.

If only a very small control voltage is used, it will be found that as the MV ADJUST condenser is varied (by removing the snap cover on the panel and adjusting the condenser with a screw driver) control may be obtained over roughly plus or minus one-half turn. Set the condenser in the middle of this range. If changes have resulted in bringing this condenser to one end or the other of its range, a similar condenser will be found inside of the unit which may be readjusted to bring the operating point into the range of the panel condenser.

If the multivibrators require entire readjustment, proceed as follows:

Use a heterodyne receiver or heterodyne-frequency meter covering a range of preferably 100 kc. to 150 kc. (any 50-kc. interval covering two crystal harmonics can be used, but it should be taken at as low a frequency as possible).

First, identify the settings for two crystal harmonics, such as 100 kc. and 150 kc. by coupling the receiver to the crystal oscillator RF OUTPUT terminal at the rear of the temperature-control unit.

Next, turn on the 50-kc. multivibrator. The settings where beats are heard should agree with those previously obtained, and the beat tones should be as clear and steady as when listening to the crystal oscillator directly. Control should be obtained from 0.5 to practically full-scale on the CONTROL-VOLTAGE adjustment. Turn off the multivibrator.

Turn on the 10-kc multivibrator, using the settings given in test data. Starting at 100 kc. count the zero beat points found on the receiver between this point and the second crystal harmonic. If the first point, 100 kc., is called zero, then the last point should be five. The multivibrator is then operating at 50/5—10 kc. If the count gives four, the frequency is 50/4—12.5 kc., etc. If the multivibrator frequency is too low, reduce the multivibrator capacitance until the proper frequency is obtained. If the frequency is too high, increase the capacitance. Make the final setting by reducing the control voltage to a small value and adjusting the condenser to the middle of the control range. These adjustments are best made when listening to a multivibrator harmonic which is not a crystal harmonic, such as 110 kc., 120 kc., etc.

To check the 1-kc. multivibrator, compare the output frequency with a calibrated audio-frequency oscillator, tuning fork, etc., of 1 kc. If none are available start the clock and compare with a watch. If the clock keeps time, the frequency is 1 kc. If it gains or loses by about 10 percent the multivibrator frequency must be readjusted. Obtain the final setting of the condenser by reducing the control voltage and setting the condenser in the middle of the control range.

11. Determination and Adjustment of Crystal Frequency—The frequency of the system is self-determining and can be corrected for errors and deviations. The timing equipment provides a means for counting the number of cycles executed by the crystal, so, to determine the average frequency over any time interval, we have only to divide the number of cycles occurring during that interval by the length of the interval in seconds. The reading of the clock on the syncro-clock unit is a measure of the number of cycles executed by the crystal, so if we set the clock to standard time, and, after an appreciable interval (say 24 hours) we compare its reading with standard time, the amount by which its reading differs from the standard times is a measure of the deviation of the crystal frequency from its assigned value. In practice this can be applied as follows:

Suppose we compare the clock with standard time signals as transmitted by radio and find the clock to be 0.12 seconds fast. The next day (24 hours later) the clock is found to be 0.46 second fast. Then the time interval read on the clock is 24 hours plus (0.46–0.12) second and the frequency of the crystal oscillator is

$$\frac{86{,}400 + (0.46 - 0.12)}{86{,}400} \times 50{,}000,$$

or 50,000.20 cycles per second.

It is generally more convenient to consider the *deviation* of the frequency from its assigned value, expressed in parts per million, or other convenient percentage terms. Since there are 86,400 seconds in one day, one part in a million deviation in the average frequency means that the clock will gain or lose 0.0864 seconds in twenty-four hours. If, then, the seconds gained or lost by the clock per 24 hours are divided by 0.0864, the deviation of the average frequency is obtained, expressed in parts per million. *This figure is convenient since its applies to any and all of the frequencies derived from the assembly.*

Obviously, the accurate determination of the frequency depends on the time signals being correct. Acutally there are small errors in the transmission, and correction for these will be supplied on request to the observatory or transmitting station.

12. Comparison of Clock with Time Signals—The following instructions for making comparisons between time kept by the assembly and time signals are based on the transmissions of the U. S. Naval Observatory through **NAA** and **NSS.** There are at present eight different frequencies used for transmissions at various times during 24 hours, and although occasional changes are made, there are probably few, if any, places where one or more transmissions cannot be received satisfactorily. It is suggested that, if possible, these transmissions be used until the operating engineer has become thoroughly familiar with the operation of the assembly.

To the right of the clock face is mounted the micro-dial, by means of which the time indicated by the clock may be accurately compared with time signals. The contact is driven at 1 revolution per second by the main countershaft. The contacts are connected to the output terminals on the terminal strip marked MICRO-DIAL. The contacts are closed for about 0.95 second. The instant at which the contacts close may be adjusted by turning the knurled wheel projecting through the clock face. If the contacts are connected across the telephones or loudspeaker of a time receiver (from which any direct current in the output has been filtered) the operation of the cam may be adjusted so as to short-circuit all but the beginning of each pulse of the time signal as transmitted by the U. S. Naval Observatory. This adjustment is made by advancing the knurled wheel from " zero " on the scale *toward higher readings* until just a very short pulse remains of each transmitted time dot. This adjustment may generally be made to better than 0.01 second. The arrangement requires if the readings are to be taken directly from the figures on the scale, that fractions of a second be expressed as *positive increments* from the last whole second. For example, if the clock were 0.30 seconds slow, the reading would be 11 h. 59 m. 59.70 seconds on the clock-face and micro-dial scales. Each division on the micro-dial scale corresponds to 0.01 second.

The micro-dial contacts may be utilized for transmission of second's pulses for laboratory purposes. This is helpful, for instance, if time kept by the assembly is to be compared with time signals from a station using the so-called rhythmic type of transmission in which 61 pulses or dots are sent out in 60 seconds. This requires that the method of coincidences be used. It is thus merely necessary to compare, by aural or other means, the seconds pulses from the standard with the pulses of the transmission.

Greater Precision—Where the reliability of the time signals is great enough to justify a closer comparison than the 0.01 second provided by the micro-dial, the General Radio Company is prepared to furnish a clock that can be compared with time signals to better than 0.001 second. Stroboscopic means are utilized.

13. Adjustment of Frequency—After the frequency of the system has been determined by means of time signals for several days, readjustments may be made to bring the frequency to exactly 50 kilocycles. If the adjustment to be made is small, the ADJUST dial on the panel of the temperature-control unit may be used. If the amount by which the frequency needs to be changed is greater than can be obtained on this dial (— 3 parts per million over the entire 180 of the dial), the number of turns on the crystal coil may be changed, 10 turns varying the frequency by about 1 part per million. *Increasing* the number of turns *decreases* the frequency and vice-versa.

General Radio Interpolation and Auxiliary Equipment

GENERAL DESCRIPTION OF COMPONENT INSTRUMENTS

14. Type 612 Coupling Panel—This unit is a centralized switching panel to which the standard and unknown sources and connections to the various instruments tabulated above are made. All of the arrangements and rearrangements of these units required in different cases may be made by operating the switches and controls on this panel. Through the use of the panel, permanent interconnecting wiring may be made among the various units, without losing flexibility of control (no power supply required).

14a. Type 614 Selective Amplifier (Optional)—This unit is designed for the production and selection of the first ten harmonics from an input of 1 kc. In particular, it is intended for use on the 1-kc. output of the Class C–21–H Standard-Frequency Assembly, but it can be used on any 1-kc. supply of accurate frequency. The equipment consists of an input control, harmonic producing tube, amplifier, selector circuits, and an output amplifier. Regeneration is employed to improve the selectivity (power supply: 115 volts, 60 cycles.

15. Type 616 Heterodyne-Frequency Meter—This unit is designed to be used as a general-purpose heterodyne-frequency meter, for which service a detector and audio-frequency amplifier are provided in the instrument. When used with the other equipment of this assembly, it is generally more satisfactory to obtain the beats in the Type 619 Heterodyne Detector. The frequency range of the frequency meter is 100 kc. to 5000 kc. covered in sixteen steps. Provision is made in the output circuits for obtaining voltages of fundamental or harmonic frequencies. Sufficient harmonic output is obtainable to produce beats in a high-frequency receiver operating at 30,000 kc. The instrument is fitted with an auxiliary dial for direct interpolation between known frequencies. Temperature control is provided, which greatly reduces the variations in frequency caused by changes in room temperature. The stability of the instrument over long periods has been improved through the use of a new design of variable condenser (Power supply: 115 volts, 60 cycles).

16. **Type 617 Interpolation Oscillator**—This instrument is designed particularly for use in determining the frequency difference between an unknown frequency and the nearest harmonic of a 10-kc. series. In this case the unknown is never more than 5 kc. away from a known frequency.

The oscillator, consequently, has a frequency range up to 5 kc. The dial has 5000 divisions, so that each division represents one cycle very closely. For most work the error of the instrument is small enough so that the dial reading may be taken as the frequency. A correction table is furnished for use if more accurate results are required.

Provision is made for rapid checking of the oscillator against the 1-kc. output of the standard-frequency assembly and for rapidly matching an unknown frequency. Volume controls for the unknown or standard input and for oscillator output are provided so that beats of large amplitude may easily be obtained. An output meter provides a visual indication of the beat between unknown and the oscillator, or between the oscillator and the standard. A control is also provided for utilizing the beat indicator in matching an oscillator under test to integral multiples of 1 kc. (Power supply: 115 volts, 60 cycles.)

17. **Type 619 Heterodyne Detector**—In principle, this unit is a heterodyne detector and two-stage audio-frequency amplifier. The circuit employs plug-in indicators covering a frequency range from 90 kc. to 6000 kc. with twelve inductors. Nine more inductors covering up to 25 Mc. are available on special order. The instrument is almost indispensible in making measurements with this assembly, being used as the third oscillator in obtaining zero-beat adjustments and for obtaining the difference frequency between known and unknown frequencies in direct beating (power supply: 115 volts, 60 cycles).

18. **Methods of Frequency Measurement**—*Introductory*—Before proceeding to the details of manipulation of the equipment, a brief discussion of the function of the Class C–21–H Standard-Frequency Assembly should be given. This is most quickly done

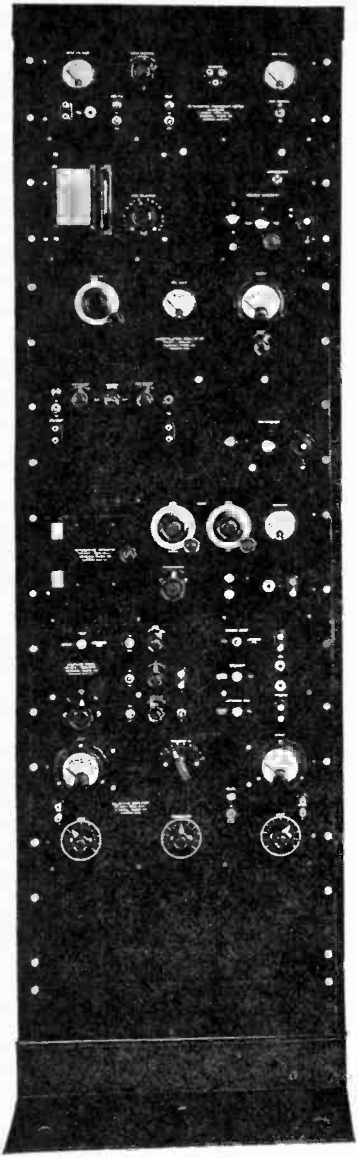


FIG. 299. Interpolation and Auxiliary Equipment for Class C-21-H Primary Standard of Frequency.

by reference to figure 299. In the figure, the working standard is at the upper left and the successive divisions of its frequency of 50 kc. to 10 kc. and 1 kc. are indicated. The 1-kc. output operates the syncro-clock, the mechanism of which performs a further frequency division (mechanically) to 1 cycle per second.

The average frequency of the working standard is determined by comparison of the time of the syncro-clock with standard time, as indicated on the right of figure 3. When the working standard is exactly 50 kc., then the clock keeps true time.

The output voltages of the multivibrators contain many harmonics useful in frequency measurements. The extent of the useful ranges is roughly indicated by the spectra shown in the lower part of the figure against the scale of frequency. It must be appreciated that the upper limit of frequency, at which harmonics of a multivibrator may be used, depends greatly upon the type and sensitivity of the receiver and the method of coupling employed. The equipment as furnished provides no tuning of the multivibrator output, in the interests of greatest simplicity of operation, but at some sacrifice in the strength of harmonics at the higher frequencies. For special work, the coupling system may be changed as necessary.

The Problem—The problem of determining the value of an unknown radio frequency may be reduced to that (illustrated in figure 300) of measuring the difference between the unknown f_x and a known frequency comparatively near to f_x. The known frequencies are the harmonics of a multivibrator fundamental frequency controlled by the standard crystal oscillator, so each harmonic frequency is known with the same percentage accuracy as the frequency of the standard. The interval between successive harmonics is equal to the fundamental frequency. The frequency of any harmonic is known when its harmonic number is known, and the harmonic number may be readily determined.

If the harmonics of the 10-kc. multivibrator are used, the difference (A) between the unknown frequency and the harmonic just below, or the difference (B) between it and the harmonic next above, is always less than 5 kc.

If either of these differences lies between (roughly) 100 and 5000 cycles, the difference is easily determined by matching this beat frequency with the Type 617 Interpolation Oscillator.

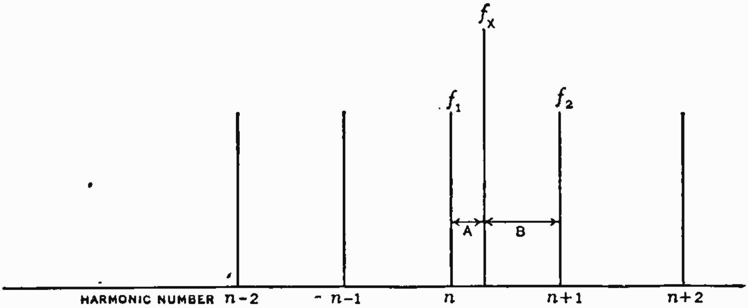


FIG. 300. The Problem of Measuring a Frequency Lying between Two Known Frequencies f_1 and f_2 is One of Determining the Frequency Interval A or B.

If the beat frequency lies below 100 cycles but above 20 cycles, the matching may still be made if the intensity is sufficiently great.

Because of the general loss of sensitivity in amplifiers, at very low frequencies, a somewhat different procedure is advantageous. Use is made of the Type 616 Heterodyne-Frequency Meter to step from the unknown frequency to a lower frequency (which is an integral submultiple of the unknown). The difference between the fundamental frequency and the nearest standard harmonic frequency is then measured. By choice of the submultiple employed, the beat difference which is measured may be made to fall in the range of audio frequencies where matching Oscillator is quickly and easily done.

A word is in order as to the relative ranges over which the unknown frequency is measured by one method or another. If the unknown lies (roughly) between 100 kc. and 3500 kc., the difference between the unknown and the nearest harmonic may be taken by direct beating in the Type 619 Heterodyne Detector or a radio receiver. For lower frequencies, below (roughly) 100 kc., better accuracy is obtainable if a harmonic of the unknown is measured against the standard frequency nearest to it instead of using the fundamental frequency. For higher frequencies, the Type 616 Heterodyne-Frequency Meter is employed to divide the unknown frequency by an integer so that the fundamental of the heterodyne-frequency meter falls below (roughly) 3500 kc., where it may be easily measured.

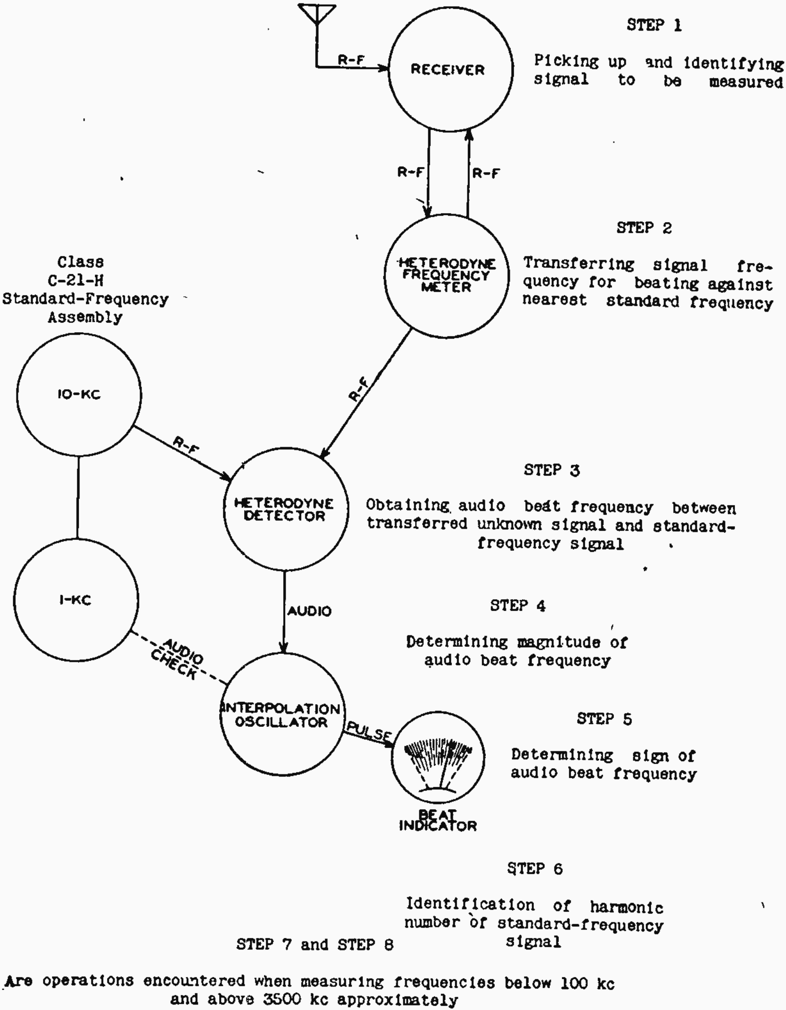
19. Making Measurements: Summary—*General Statement*—The procedure to be followed in making frequency measurements with this equipment will be understood by reference to figure 301. In the diagram, it is assumed that the frequency to be measured is that of a distant transmitter. In such cases, the procedure consists of setting a local oscillator (Type 616 Heterodyne-Frequency Meter) to zero beat with the received signal frequency (or a multiple or sub-multiple thereof) and measuring the audio frequency or a harmonic of the local oscillator and the nearest 10-kc. standard-frequency range of the local oscillator and the useful range over which 10-kc. harmonics may be used are both limited, harmonic methods must be used for *low* and *high* frequency measurements.

The Six Steps—In certain cases, the procedure may be simplified and in other cases intermediate steps are required. In an assembly as complex as this it is not feasible to give general instructions covering all cases, which are clear enough to be helpful. The procedure is consequently divided into sections, depending upon the frequency being measured and the method and apparatus employed.

Six steps are *in general* taken in all frequency measurements as indicated in the following summary:

Step 1—Picking up and identifying the signal to be measured, for transfer to and comparison with, the standard. This step is very simple in the case of a local transmitter; it may be quite complicated in the case of a distant transmitter. This transfer may be at the signal frequency or, for various reasons, may be at a multiple or sub-multiple of the signal frequency. This step, in general form, is indicated in the upper part of figure 301.

Step 2—Transferring the signal frequency for beating against



STEP 1

Picking up and identifying signal to be measured

STEP 2

Transferring signal frequency for beating against nearest standard frequency

STEP 3

Obtaining audio beat frequency between transferred unknown signal and standard-frequency signal

STEP 4

Determining magnitude of audio beat frequency

STEP 5

Determining sign of audio beat frequency

STEP 6

Identification of harmonic number of standard-frequency signal

STEP 7 and STEP 8

Are operations encountered when measuring frequencies below 100 kc and above 3500 kc approximately

FIG. 301. Basic Outline Drawing for a Frequency Measurement.

the nearest standard frequency and obtaining an audio-frequency output of *useful frequency.* This latter requirement sometimes demands a change in frequency in STEP 1, when otherwise the signal frequency would be transferred without change.

Step 3—Obtaining the audio beat frequency difference between standard and the transferred unknown frequency. In general, this is done by using the Type 619 Heterodyne Detector, although a receiver may be used in many cases.

Step 4—Determination of the value of the beat frequency difference, obtained in STEP 3.

Step 5—The determination of the sign of the beat frequency difference is the fifth step.

Step 6—The identification of the standard-frequency harmonic used in obtaining the beat frequency.

In the measurement of frequencies below (roughly) 100 kc. or above (roughly) 3500 kc. additional steps may be required as follows:

Step 7—Identification of the harmonic of an unknown frequency used in measurements of frequencies below 100 kc.

Step 8—Identification of the harmonic of the heterodyne-frequency meter used in measurements of frequencies above 3500 kc.

In many cases, some of the steps are eliminated or are made simultaneously with other steps. This is particularly true in cases where routine measurements of stations operating on assigned frequencies are made. In such cases, all settings are known closely in advance, and the determinations under STEP 5, STEP 6, STEP 7, and STEP 8 above may often be eliminated.

In carrying out these steps, the arrangement of the apparatus and the details of adjustment vary considerably, depending upon the frequency being measured and the apparatus employed.

20. Making Measurements—Procedure.

STEP 1. PICKING UP AND IDENTIFYING THE UNKNOWN SIGNAL

1A. USING A RECEIVER

1A–1. Selection and Installation of Receiver—This item is intended to indicate the use of a receiver *external* to the frequency measuring equipment. The Type 619 Heterodyne Detector can function as a receiver for picking up local transmitters. In cases where measurements of frequencies of distant transmitters are frequently required, receivers of suitable sensitivity and selectivity should be provided.

Such a receiver should be installed, for convenience, near the frequency standard, but some precautions are necessary: The antenna system should connect to the receiver either by a shielded lead-in for low frequencies or by a transposed tranmission line for high frequencies. This arrangement, with moderate shielding of the receiver, prevents pick-up of the harmonic frequencies from the frequency standard and also prevents the introduction of interfering signals into the interpolating equipment from the antenna.

1B. USING THE TYPE 619 HETERODYNE DETECTOR

1B–1. Tuned to the Fundamental of the Unknown Frequency—In a large number of measurements the heterodyne detector is tuned to the fundamental of the unknown frequency. This is accomplished through the use of plug-in inductors and a two-section variable condenser. The inductor plugs are arranged to pick up the larger section of the variable condenser for low frequencies and the smaller section for high frequencies. In both cases the variable condenser is controlled by the "COARSE TUNING" dial. The "FINE TUNING" dial controls a small vernier condenser for fine adjustment. By reference to the coil range-table, or the calibration data, the heterodyne detector may be quickly set in the region of any desired frequency.

1B–2. Tuned to a Harmonic of the Unknown Frequency—Particularly in the measurement of frequencies below, roughly 100 kc., it is often necessary to measure the frequency of a *harmonic* of the unknown frequency. Primarily this is due to the low-frequency limits of range of the measuring equipment, but secondarily this is due to accuracy requirements. For example, if the accuracy of measurement is one cycle, and a direct measurement of a 30-kc. frequency is made, the best accuracy of measurement is 1 in 30,000. If a harmonic, say the fifth, is used in the measurement, then the accuracy is 1 in 150,000.

In obtaining a strong harmonic of the unknown frequency, the desired signal should be tuned in on a receiver, preferable of the type employing tuned radio-frequency amplification and a regenerative detector. If the *radio-frequency* output of the detector is coupled to the measuring equipment, as by connecting a coupling wire to the "high side" of the "X" terminals on the Type 612 Coupling Panel, the harmonic signal may be introduced into the Type 619 Heterodyne Detector through the "X" switch and volume control.

In picking up a harmonic of a local transmitter, it is generally sufficient to couple to the "X" terminals of the coupling panel and introduce a fairly strong signal into the heterodyne detector.

STEP 2. TRANSFERRING THE UNKNOWN FREQUENCY IN PREPARATION FOR COMPARISON WITH THE STANDARD

2A. USING TYPE 616 HETERODYNE-FREQUENCY METER WITH A RECEIVER

2A–1. Matching Fundamental of Heterodyne-Frequency Meter to Fundamental of Unknown Frequency—In many cases it is desirable to transfer the unknown frequency to the heterodyne-frequency meter to avoid confusion from interfering signals, from fading or from keying of the transmitter. This transfer is readily accomplished as follows:

(*a*) Tune in desired signal on receiver; set receiver to zero audible beat with signal.

(*b*) Couple output of heterodyne-frequency meter to receiver by means of a coupling wire connected to the high terminal of the HET DET INPUT-3 connections on the Type 612 Coupling Panel.

(*c*) Start the heterodyne-frequency meter; adjust it near the desired frequency by reference to calibration; adjust volume of the frequency meter signal in the receiver to be about that of the signal to be measured, by use of the HET. F.M. controls of the coupling panel. Bring the frequency meter into zero audible beat with the receiver.

(*d*) Next adjust the heterodyne-frequency meter to zero beat with the desired signal, using the three-oscillator method (see note on this method in Par. A, Part IX), the receiver being the third oscillator.

Some practice is necessary to match the frequency meter to the desired signal in cases where the desired signal is keyed or where much interference or fading occurs, but the necessary familiarity with the adjustments is readily obtained.

2A–2. Matching a Harmonic of the Heterodyne-Frequency Meter to the Fundamental of the Unknown Frequency—This adjustment is desired when a direct comparison of the unknown and standard frequencies results in a beat frequency difference which is too low to be matched satisfactorily by means of the Type 617 Interpolation Oscillator, or where the unknown frequency lies above 3500 kc. The adjustment is made exactly as in Par. 2A–1 above, except that the fundamental frequency of the heterodyne-frequency meter is a sub-multiple of the desired frequency. The steps are given in detail below:

(*a*) Tune in desired signal on receiver; set receiver to zero audible beat with signal.

(*b*) Couple the output of the heterodyne-frequency meter to the receiver by means of a coupling wire connected to the high terminal of the HET DET INPUT-3 connections on the Type 612 Coupling Panel.

(*c*) Start the heterodyne-frequency meter; adjust it near a sub-multiple of the desired frequency by reference to the calibration; adjust the volume of the heterodyne-frequency meter signal in the receiver to be about that of the signal to be measured by use of the HET. F.M. controls on the coupling panel. Bring the harmonic of the heterodyne-frequency meter into zero audible beat with receiver.

(*d*) Next adjust the harmonic of the heterodyne-frequency meter into zero beat with the desired signal, using the three-oscillator method, the receiver being the third oscillator.

As in Par. 2A–1 above, some practice is necessary to match the frequency of the harmonic of the heterodyne-frequency meter to the desired signal in cases where the desired signal is keyed, or where much interference or fading occurs, but the necessary familiarity with the adjustments is readily obtained.

2A–3. Matching the Fundamental of the Heterodyne-Frequency Meter to a Harmonic of the Unknown Frequency—In the measurement of frequencies below 100 kc., particularly, it is desirable to utilize a harmonic of the unknown frequency because of the appreciable increase in accuracy of measurement; it is necessary here because of the limitation in range of the equipment.

(*a*) Tune in desired signal on receiver; increase amplification so as to produce strong harmonics in the detector radio-frequency output.

(*b*) Couple the detector radio-frequency output to the measuring equipment by means of a coupling wire connected to the high terminal of the "X" terminals on the Type 612 Coupling Panel.

(*c*) Pick up the harmonic frequency of the desired signal in the Type 619 Heterodyne Detector. The volume of the signal may be controlled by the "X" controls on the coupling panel. Set the heterodyne detector into zero audible beat with the harmonic.

(*d*) Using the Type 616 Heterodyne-Frequency Meter, adjust frequency to approximate value of unknown harmonic frequency by reference to calibration; control volume of signal in heterodyne detector by means of the HET. F.M. controls; regulate volume to be about that of the unknown harmonic signal; bring heterodyne-frequency meter into zero audible beat with heterodyne detector.

(*e*) Adjust heterodyne-frequency meter fundamental frequency into zero beat with the harmonic of the unknown frequency by the three-oscillator method, the Type 619 Heterodyne Detector being the third oscillator.

2A–4. **Matching a Harmonic of the Heterodyne-Frequency Meter to a Harmonic of the Unknown Frequency**—In the measurement of frequencies below 100 kc., cases arise where the use of a harmonic of the unknown frequency alone will not result in a beat frequency difference against the standard which is high enough for convenient matching with the interpolation oscillator. For example, if the unknown lies very near to a multiple of 10 kc., then all the harmonics lie near multiples of 10 kc. and, unless a very high harmonic is used, the beat frequency differences will all be small. By setting a *harmonic* of the heterodyne-frequency meter to a harmonic of the unknown frequency convenient beat differences may be obtained between the fundamental (or a harmonic) of the frequency meter and the standard.

(*a*) Tune in desired signal on receiver; increase amplification to produce strong harmonics in the detector radio-frequency output.

(*b*) Couple the detector radio-frequency-output to the measuring equipment by means of a coupling wire connected to the high terminal of the "X" terminals on the Type 612 Coupling Panel.

(*c*) Pick up the harmonic frequency of the desired signal in the Type 619 Heterodyne Detector. The volume of the signal may be controlled by the "X" controls on the coupling panel. Set the heterodyne detector into zero audible beat with the harmonic frequency.

(*d*) Start the Type 616 Heterodyne-Frequency Meter; adjust the frequency to approximate value of a sub-multiple of the harmonic frequency to which the heterodyne detector is tuned. This is readily done by reference to the calibrations of the heterodyne detector and heterodyne-frequency meter. The volume of the signal in the heterodyne detector may be controlled by the HET. F. M. controls; regulate volume to be about that of the harmonic of the desired frequency; bring the heterodyne-frequency meter harmonic into zero audible beat with the heterodyne detector.

(*e*) Adjust the heterodyne-frequency meter harmonic into zero beat with the signal harmonic by the three-oscillator method, the Type 619 Heterodyne Detector being the third oscillator.

Note—The condition to be met in obtaining a usable beat difference is that the unknown harmonic frequency divided by the number of the frequency meter harmonic shall not give a frequency meter fundamental frequency very near a frequency ending in 0 or 5 (in kc.).

Example: The 6th harmonic of an unknown frequency lies very near 420 kc. The usable harmonics of the heterodyne-frequency meter, i.e., the 2nd, 3rd, and 4th give fundamental frequencies very near 210, 140 and 105 kc. respectively, none of these giving a usable beat difference against the standard. By choosing the next higher harmonic of the unknown, the 7th, lying very near 490 kc. and using either the 3rd or 4th harmonic of the frequency meter to match it; frequency meter fundamental frequencies very near 163.333 or 122.500 kc. result, either of which gives a useful beat difference against the standard.

2B. USING A RECEIVER

2B–1. Introducing the Standard Harmonic Frequencies into the Receiver—In some cases it is desirable to introduce standard harmonic frequencies into a receiver, the beat frequency difference btween an unknown and the standard frequency then being obtained in the receiver output. This is accomplished as follows:

(*a*) Couple the standard to the receiver by means of a coupling wire connected to the high terminal of the HET DET INPUT-I terminals of the Type 612 Coupling Panel.

(*b*) The standard harmonic series thus introduced into the receiver may be selected by the STD selector, and the volume of the standard series controlled by the STD controls on the coupling panel.

(*c*) If the beat frequency difference between unknown and standard is to be matched by means of the Type 617–A Interpolation Oscillator, connect the receiver output to the STD input terminals of the interpolating oscillator. Throw the INTERP INPUT switch to LISTENING OSC (after checking against 1-kc. standard); throw LISTENING OSC switch to TEL. This leaves the input terminals of the interpolation oscillator free for the beat frequency from the receiver.

2C. USING TYPE 619 HETERODYNE DETECTOR

2C–1. Introducing Standard Harmonic Frequencies into Heterodyne Detector—As the Type 619 Heterodyne Detector is used a great deal in making measurements with this measuring equipment, provision has been made for introducing the standard harmonic frequencies into the detector at will without the necessity of special coupling wires.

(*a*) The STD selector and volume controls on the Type 612 Coupling Panel are operated to give the desired standard harmonic series and to control the volume of signal. Throwing the STD ON-SWITCH to OFF cuts out the standard signal.

STEP 3. OBTAINING THE BEAT FREQUENCY DIFFERENCE BETWEEN STANDARD AND UNKNOWN FREQUENCY

3A. USING TYPE 619 HETERODYNE DETECTOR, NON OSCILLATING

3A–1. Difference between Standard and Fundamental of Type 616 Heterodyne-Frequency Meter—This adjustment is frequently carried out in making measurements. No special connections are required. The various steps are as follows:

(*a*) Having matched the heterodyne-frequency meter to the unknown frequency, pick up the fundamental frequency of the heterodyne-frequency meter, using the Type 619 Heterodyne Detector in the oscillating condition. The approximate setting of the detector is easily obtained by reference to the frequency meter calibration of the detector. Set the detector into zero audible beat with the heterodyne-frequency meter.

(*b*) Introduces the standard harmonic frequencies into the detector by operation of the STD controls on the Type 612 Coupling Panel. On introducing the standard harmonic frequencies into the detector a beat tone will be heard which is approximately equal to the beat difference between the unknown and standard frequencies.

(*c*) Decrease regeneration in the heterodyne detector until the detector just stops oscillating, retuning as necessary to obtain the best beat frequency output. Change of tuning of the detector over a small range should alter only the amplitude and *not* the frequency of the beat tone heard.

(*d*) The amplitude of the fundamental heterodyne-frequency meter signal may be controlled by the HET. F. M. controls on the coupling panel. The amplitude of the standard signal is controlled by the STD controls. Both should be adjusted as necessary to give the best frequency output.

3A–2. Difference between Standard and Unknown Frequencies—This adjustment is also frequently used. The detailed steps are as given in the following paragraphs:

(*a*) Tune the Type 619 Heterodyne Detector to the unknown frequency, using the detector in the oscillating condition and introducing the unknown frequency through the "X" terminals and controls of the Type 612 Coupling Panel.

(*b*) Bring heterodyne detector into zero audible beat with the unknown frequency.

(*c*) Introduce the standard harmonic frequencies by operation of the STD selector and controls on the coupling panel. On introduction of the standard frequencies a beat tone will be heard which is approximately the beat difference between the standard and unknown frequencies.

(*d*) Reduce regeneration until the heterodyne detector just stops oscillating, retuning as necessary to obtain maximum output at the beat frequency. Change of tuning of the heterodyne detector over a small range should alter only the amplitude and *not* the frequency of the beat tone heard.

3A–3. Difference between Standard and a Harmonic of the Unknown Frequency—This adjustment may frequently be used in cases where a large number of routine frequency measurements are made on stations operating below 100 kc. The adjustments and coupling arrangements required for producing the harmonic of the unknown frequency and introducing it into the heterodyne detector are given under Par. 2A–3 above, sub-paragraphs (*a*), (*b*), and (*c*).

Having set the Type 619 Heterodyne Detector into zero audible beat with the harmonic of the unknown frequency, proceed as follows:

(*a*) Introduce the standard harmonic frequencies into the heterodyne detector by operation of the STD controls on the Type 612 Coupling Panel. On introduction of the standard, a beat tone will be heard which is approximately equal to the beat difference between the standard and the unknown.

(*b*) Decrease regeneration in the heterodyne detector until the detector just stops oscillating, retuning as necessary to obtain maximum output at the beat frequency. Change of tuning of the heterodyne detector over a small range should alter only the amplitude and *not* the frequency of the beat tone heard.

(*c*) If the harmonic of the unknown is not of sufficiently large amplitude, the resulting beat difference may not be strong enough to give satisfactory matching in the Type 617 Interpolation Oscillator. In this case it is necessary to match the fundamental, or a harmonic, frequency of the Type 616 Heterodyne-Frequency Meter to the harmonic of the unknown frequency as described in Par. 2A–3 and obtain the beat difference between this fundamental and the standard.

3A–4. Difference between Standard and a Harmonic of the Type 616 Heterodyne-Frequency Meter—This adjustment is not often used, but occurs occasionally in measurements on frequencies, below 100 kc., when the unknown lies near a multiple of 10 kc. In this case a harmonic of the unknown also lies near a multiple of 10 kc. and, unless a very high harmonic is used, may be too near the standard frequency to give a beat difference which is satisfactory for matching.

The adjustments and coupling arrangements required for producing the harmonic of the unknown frequency and introducing it into the heterodyne detector are given in Par. 2A–3 above, subparagraphs (*a*), (*b*), and (*c*). Having set the heterodyne detector into zero audible beat with the harmonic of the unknown frequency, proceed as follows:

(*a*) Start Type 616 Heterodyne-Frequency Meter and adjust it to a frequency which is a sub-multiple of the unknown harmonic frequency. This is readily done by reference to the calibrations of the detector and frequency meter. Adjust the frequency meter so that the *harmonic* chosen comes into zero audible beat with the heterodyne detector. Then set this harmonic of the frequency meter into zero beat with the harmonic of the unknown frequency by the three-oscillator method, the heterodyne detector being the third oscillator.

(*b*) After this matching is completed, the tuning of the heterodyne detector is altered to pick up the fundamental or any desired harmonic of the heterodyne-frequency meter.

(*c*) Set the heterodyne detector to zero audible beat with this chosen harmonic. Introduce the standard harmonic frequencies into the detector by operation of the STD controls on the coupling panel. The beat tone heard is approximately equal to the beat difference between the heterodyne-frequency meter harmonic and the standard.

(*d*) Reduce regeneration in the heterodyne detector until the detector justs stops oscillating, retuning as necessary to obtain the maximum output at the beat frequency. Change of tuning of the detector over a small range should alter only the amplitude and *not* the frequency of the beat heard. The final beat tone is the beat difference between the standard and the harmonic of the heterodyne-frequency meter.

3B. USING TYPE 619 HETERODYNE DETECTOR, OR A RECEIVER, OSCILLATING

3B–1. Difference between Standard and Unknown Frequencies in a Few Cycles—In cases where the unknown is only a few cycles different from the standard, the most convenient method for determining the beat difference is to make use of the heterodyne detector, or a receiver, in the oscillating condition, and obtain the beat as in the three-oscillator method. The beat is evaluated by counting or recording the number of beats in a given time. The procedure is as follows:

(*a*) When using the heterodyne detector, pick up the unknown frequency and set the detector into zero audible beat with the unknown. The unknown frequency is introduced through the "X" terminals and controls of the Type 612 Coupling Panel. The standard harmonic frequencies are then introduced by operation of the STD controls.

(*b*) Keeping the detector in the oscillating condition, alter its frequency by a kilocycle or so. This beat tone will then be found to wax and wane at a rate equal to the difference between the standard and unknown frequencies. Adjustment of the beat tone heard, by variation of the frequency of the detector, will *not* alter the rate of the waxing and waning. The standard and unknown signals should be regulated to approximately the same intensity to give the maximum waxing and waning effect. If the beat difference thus obtained is too fast for counting or recording, use must be made of the Type 616 Heterodyne-Frequency Meter. Proceed as in Par. 2A–2.

(*c*) When using a receiver the process of obtaining the slow beat is exactly the same as outlined above in sub-paragraphs (*a*) and (*b*), except that the standard harmonic frequencies must be introduced into the receiver by a coupling wire connected to the high HET DET INPUT-1 terminal on the Type 612 Coupling Panel, as fully described in Par. 2B–1.

3C. USING A RECEIVER

3C–1. Difference between Standard and Unknown—In routine measurements of many frequencies of distant transmitters it is convenient to utilize the receiver employed in picking up the desired signal in making the measurement. The procedure is as follows:

(*a*) Having picked up and identified the desired signal, set receiver into zero audible beat with the unknown frequency. Introduce the standard harmonic frequencies by coupling the rceiver to the high terminal of the HET DET INPUT-1 terminals on the Type 612 Coupling Panel. The beat tone heard on introducing the standard frequency is approximately the beat difference between the standard and the unknown. If this beat tone is suitable for matching with the Type 617 Interpolation Oscillator, continue as outlined below; if beat tone is too low for matching, use must be made of the Type 616 Heterodyne-Frequency Meter where a harmonic of the frequency meter is matched to the unknown frequency.

(*b*) Having a beat tone of suitable frequency for matching, reduce the regeneration of the receiver until it just stops oscillating, retuning as necessary to obtain the maximum output at the beat frequency. Control of the amplitude of the standard harmonic frequencies is obtained through the STD control of the coupling panel.

(*c*) The beat frequency of the receiver output is then transferred to the STD input terminals of the Type 617 Interpolation Oscillator for matching.

STEP 4. EVALUATING THE BEAT-FREQUENCY DIFFERENCE BETWEEN THE STANDARD AND THE TRANSFERRED UNKNOWN FREQUENCY

4A. USING TYPE 617 INTERPOLATION OSCILLATOR

4A-1. To Match Beat Frequency Output of Type 619 Heterodyne Detector—As this operation is very frequently carried out, provision is made on the Type 612 Coupling Panel for all necessary circuit changes for checking and using the Type 617 Interpolation Oscillator. Procedure is as follows:

(*a*) Having obtained the beat difference between the standard and the transferred unknown frequency in the heterodyne detector, first check the interpolation oscillator against the standard 1 kc. by throwing the INTERP INPUT switch on the coupling panel to "1 KC" and throwing the CHECK switch to CHECK on the interpolation oscillator panel.

(*b*) Having checked the oscillator, switch the output of the heterodyne detector to the STD INPUT terminals of the interpolation oscillator by throwing the INTERP INPUT switch to LISTENING OSC and the LISTENING OSC output switch from TEL to INTERP INPUT on the coupling panel. The CHECK switch of the interpolation oscillator remains on CHECK. The output of the interpolation oscillator is transferred to the SPEAKER terminals by throwing the SPEAKER SWITCH to INTERP OUTPUT. Either speaker or telephones may be connected to these terminals. Adjust the frequency of the interpolation oscillator into approximate aggrement with the beat frequency being matched; adjust the relative amplitudes of the beat frequency and the oscillator to obtain the beat difference amplitude as indicated by the telephones or by the output meter of the interpolation oscillator. Make final adjustment of oscillator to a very slow beat on the meter. Read frequency from interpolation oscillator dial; apply correction if necessary.

4A–2. To Match Beat Frequency Output of a Receiver—This operation may be frequently used in a given installation. The procedure is as follows:

(*a*) Having obtained the beat frequency difference between the standard and the transferred unknown frequency in the receiver, first check the interpolation oscillator against the standard 1 kc by throwing the INTERP INPUT switch to "1 KC" on the coupling panel; throw the CHECK switch on the interpolation oscillator to CHECK on the oscillator panel.

(*b*) Having checked the oscillator, throw the INTERP INPUT switch to LISTENING OSC and the LISTENING OSC output switch to TEL. This leaves the STD INPUT terminals of the interpolation oscillator open and the receiver output should be connected to them. The output of the interpolation oscillator may be transferred to the SPEAKER terminals of the coupling panel by throwing the SPEAKER switch to INTERP OUTPUT. Either speaker or telephones may be connected to these terminals. The balance of the process is identical with the last part of Par. 4A–1b above.

4B. COUNTING BEATS IN A GIVEN TIME

4B–1. Using a Receiver, or Type 619 Heterodyne Detector in Oscillating Condition—When the standard and the transferred unknown frequencies are within a few cycles, the beat difference is readily determined by counting or recording the beats in a given time. The method of obtaining the beats is covered in Par. 3B–1 above. In counting the beats a manually operated counter is convenient. The time interval may be determined from the clock of the standard-frequency assembly. The beats may be transferred to a chronograph or tape recorder if desired.

STEP 5. DETERMINING THE SIGN OF THE BEAT DIFFERENCE BETWEEN THE STANDARD AND THE TRANSFERRED UNKNOWN FREQUENCY

(See also Step 6)

5A. BY MOMENTARY ALTERATION OF STANDARD FREQUENCY

If the frequency standard may be momentarily altered in a known direction, the change in beat frequency between the standard and the transferred unknown will indicate whether the unknown is above or below the standard. For example, if the standard frequency be *lowered,* the beat frequency will *increase* if the unknown is above the standard. The beat frequency will decrease if the unknown is *below* the standard.

Unfortunately, devices, such as a condenser operated by a push-button switch, alter the standard frequency by a fixed *percentage,* so that the actual change in beat frequency in cycles varies widely through the range of harmonic frequencies of the standard.

In many cases it is not desirable to alter the standard frequency even momentarily, as the stability of the standard is being determined in terms of continuous timing.

5B. USING TYPE 616 HETERODYNE-FREQUENCY METER

In measurements where the heterodyne-frequency meter is employed, the determination of the sign of the beat frequency difference is easily made just after the beat frequency has been measured.

In these cases, the beat between the fundamental (or a harmonic) frequency of the heterodyne-frequency meter and the standard is being obtained in the Type 619 Heterodyne Detector, non-oscillating. After measurement of this beat frequency, alter the heterodyne-frequency meter toward *higher* frequencies, i.e., toward higher dial readings. If the beat frequency *increases,* the unknown is *above* the standard; if the beat frequency *decreases,* the unknown is *below* the standard.

5C. USING THE TYPE 619 HETERODYNE DETECTOR OR A RECEIVER

In cases where the beat difference is being obtained in the heterodyne detector (or a receiver), the sign of the beat difference is readily determined. First cut off the standard frequency and set the detector or receiver into oscillation; adjust for zero audible beat against the unknown frequency. Next turn on the standard and turn off the unknown signal. Now adjust the heterodyne detector, or receiver, toward *higher* frequencies. If the beat note heard *increases,* the unknown is *above* the standard; if the beat note *decreases,* the unknown is *below* the standard. If the three-oscillator method (Part IX) is used, the sign of the beat may be determined when the difference of the two frequencies is very small. The heterodyne-frequency meter may be used as the third oscillator, the heterodyne detector being used oscillating and matched to either the standard or the unknown.

STEP 6. IDENTIFYING THE STANDARD HARMONIC FREQUENCY

6A. USING CALIBRATION OF TYPE 619 HETERODYNE DETECTOR, OR A CALIBRATED RECEIVER

6A–1. Details—When the Type 619 Heterodyne Detector or a receiver has been used in a measurement, it is generally most convenient to make use of this instrument in identifying the standard harmonic frequency. The detailed procedure is outlined below; it will be found that experience in handling the equipment will make the operations much simpler than would appear from these instructions.

(*a*) Having used the heterodyne detector or receiver for obtaining the beat frequency difference between the standard and the transferred unknown frequency, first cut off the standard frequency by means of the STD ON-OFF switch on the Type 612 Coupling Panel.

(*b*) Throw the detector or receiver into oscillation and adjust it for zero audible beat with the unknown frequency. Then cut off the unknown frequency and turn on the standard. A beat tone will be heard which is approximately the beat difference between the standard and the transferred unknown frequency.

(*c*) Now adjust the frequency of the heterodyne detector, or receiver, toward *higher* frequencies. If the beat is *increased,* then the unknown is *above* the standard. If the beat frequency is *decreased,* then the unknown is *below* the standard.

(*d*) Bring the heterodyne detector into zero audible beat with the standard harmonic frequency. Reference to the detector calibration should now permit the frequency of the standard harmonic to be determined. If any doubt exists, or if the heterodyne detector or receiver is not calibrated closely enough at this setting, follow Par. 6B or 6C below. In most cases Par. 6C will answer. If differences are small, use three-oscillator method throughout.

6B. USING CALIBRATION OF TYPE 616 HETERODYNE-FREQUENCY METER

When the Type 616 Heterodyne-Frequency Meter has been used in the course of a measurement, it is generally most convenient to utilize it for identifying the standard harmonic frequency. In some cases it is necessary to refer to this instrument because of its more open scale and better stability of calibration.

6B–1. Direct Use of Heterodyne Frequency Meter—The simplest procedure, and the most rapid, follows; in cases where uncertainties are encountered, recourse must be made to methods such as those outlined in the two following sections:

(*a*) If the heterodyne-frequency meter has been used in a measurement, it generally has been matched to the unknown signal frequency. If not, bring the heterodyne-frequency meter fundamental frequency into zero audible beat with the transferred unknown frequency, listening in a receiver or in the Type 619 Heterodyne Detector.

(*b*) Cut off the unknown frequency and turn on the standard harmonic frequencies by the "X" and STD controls on the Type 612 Coupling Panel.

(*c*) Vary the frequency of the heterodyne-frequency meter toward *higher* frequencies. If the beat frequency *increases,* then the unknown frequency is *above* the standard. If the beat frequency *decreases,* then the unknown is *below* the standard.

(*d*) Bring the heterodyne-frequency meter into zero audible beat with the standard. (If differences are small, the three-oscillator method may be necessary). The calibration of the heterodyne-frequency meter should now identify the standard harmonic frequency for 10-kc. harmonics. If any doubt exists, bring the heterodyne-frequency meter into zero audible beat with a 50-kc. harmonic and identify it; then count the number of 10-kc. intervals between this 50-kc. harmonic and the desired 10-kc. harmonic. See Par. 6C below.

6B–2. Submultiple Check with Heterodyne-Frequency Meter—At the higher frequencies, particularly, where the scale interval for 10 kc. on the heterodyne-frequency meter is small, and comparatively small changes in the calibration may cause ambiguity, the following method may be used.

(*a*) First adjust the heterodyne-frequency meter to zero audible beat with the standard harmonic frequency and check its value from the calibration, listening in a receiver or in the Type 619 Heterodyne Detector as, in Par. 6B–1 above.

(*b*) Leaving the receiver or heterodyne detector tuned to the 10-kc. harmonic frequency used in the measurements, adjust the heterodyne-frequency meter to a *submultiple* of the standard frequency found in (*a*). A beat note should be heard in receiver or detector and when the heterodyne-frequency meter is set to the submultiple, zero beat should again be obtained. By choice of the submultiple, the new setting may always be made to fall on a 10-kc. multiple, so that any error in the heterodyne-frequency meter calibration is automatically compensated.

(*c*) If no beat is heard, as the heterodyne-frequency meter is brought to the submultiple of the standard frequency found in (*a*), either the original value was incorrectly determined or a serious error has crept into the frequency meter calibration.

6C. Identifying 50-kc. Harmonics from Calibrations; Identifying 10-kc. Harmonics by Counting from 50-kc. Points—At the higher frequencies, calibrations of the heterodyne detector or heterodyne-frequency meter which are not accurate enough to identify 10-kc. harmonics without ambiguity may be entirely satisfactory in identifying 50-kc. standard harmonics. It is often more convenient to make use of the 50-kc. multiples in this way than to make separate checks as outlined in Par. 6A–1 and Par. 6B–1 above.

(*a*) If the heterodyne detector is being used, set it to zero audible beat with the 10-kc. standard harmonic frequency used in the measurement. Note the dial reading on the FINE tuning dial.

(*b*) Cut off the 10-kc. harmonics and turn on the 50-kc. harmonics from the standard. Vary the FINE tuning dial in either direction to pick up a 50-kc. harmonic. Identify this harmonic from the heterodyne detector calibration.

(*c*) Return to the 10-kc. harmonics and vary the heterodyne detector tuning on the FINE tuning dial *toward the original setting,* observed in (*a*) above. Count the number of zero beat points passed over in going from the 50-kc. multiple to the setting used in the measurements, as noted in (*a*). Starting with the 50-kc. point as zero, then the successive 10-kc. points, 1, 2, 3, etc. up to and including the desired setting, indicate that the desired 10-kc. harmonic is 10, 20, 30, etc. kc. above or below the identified 50-kc. point. If the heterodyne detector is adjusted to *higher* frequencies in approaching the desired 10-kc. harmonic, the desired harmonic is *above* the reference 50-kc. harmonic, and vice-versa.

STEP 7. IDENTIFICATION OF THE HARMONIC OF AN UNKNOWN FREQUENCY USED IN MEASUREMENTS BELOW 100 KC.

7A. USING A RECEIVER, OR HETERODYNE DETECTOR AND TYPE 616 HETERODYNE-FREQUENCY METER CALIBRATION

In the measurement of low radio frequencies, a harmonic of the unknown frequency being compared with the standard, it is necessary to know which harmonic of the unknown is used. In many cases, knowledge of the approximate value of the unknown and observation of the frequency of measurement determines immediately which harmonic is used. If a definite check is necessary, proceed as follows:

(*a*) In the measurement, the Type 616 Heterodyne-Frequency

Meter has been matched to a harmonic of the unknown. The calibration gives the frequency of this harmonic.

(*b*) After completing the measurement, adjust the Type 619 Heterodyne Detector, or receiver, to pick up *the next higher harmonic of the unknown,* and set to zero audible beat against this harmonic.

(*c*) Increase the frequency of the heterodyne-frequency meter until zero audible beat is obtained against this higher harmonic. The frequency meter calibration gives the frequency of this higher harmonic.

(*d*) The difference of the two frequencies read from the heterodyne-frequency meter calibration gives approximately the fundamental frequency of the unknown. If this approximate value be divided into the frequency of the harmonic used in the measurement as in (*a*), the resulting quotient is the number of this harmonic.

Thus:

$$f_1 = Nf_x,$$

$$f_2 = (N + 1)f_x,$$

$$N = \frac{f_1}{f_2 - f_1},$$

where f_2 is higher than f_1.

Due to experimental error, the result may not be exactly an integer but will differ only slightly from the integral value which is correct; the nearest integer should be used as the final result. For example, if the experimental results give a quotient of 7.04, the seventh harmonic was used.

7B. USING THE TYPE 619 HETERODYNE DETECTOR, OR RECEIVER CALIBRATION

In the measurement of local transmitters or oscillators the calibration of the Type 619 Heterodyne Detector may often be used to determine which harmonic of a low radio-frequency unknown has been used in a measurement. In the measurement, the heterodyne detector or receiver is set to zero beat with the harmonic of the unknown frequency to be used in the measurement. At this point, note the setting and determine the approximate frequency of the harmonic from the calibration of the heterodyne detector or receiver.

(*a*) After completing the measurement, cut off the standard harmonic frequencies and set the heterodyne detector or receiver to the *next higher harmonic of the unknown frequency* and determine the approximate frequency from the calibration of the detector or receiver.

(*b*) The difference of the two harmonic frequencies thus determined is the approximate value of the fundamental of the unknown frequency. The number of the harmonic may then be determined as in Par. 7A above.

STEP 8. IDENTIFYING THE HARMONIC OF THE HETERODYNE-FREQUENCY METER

8A. USING CALIBRATION OF TYPE 616 HETERODYNE-FREQUENCY METER

8A–1. For Frequency Measurements Above 3500 kc.—In the measurement of high radio frequencies, some harmonic of the heterodyne-frequency meter is matched to the unknown frequency and it is necessary to know which harmonic used. When the value of the unknown frequency is roughly known, the number of the harmonic is known when the value of the heterodyne-frequency meter fundamental frequency is determined in the measurement, or if this value is approximately determined by reference to the calibration of the frequency meter. If a more definite check is required, proceed as follows:

(*a*) Having determined the value of heterodyne-frequency meter fundamental frequency corresponding to the harmonic used in matching the high frequency under measurement, cut off the standard harmonic frequencies from the Type 619 Heterodyne Detector or receiver used to pick the signal frequency.

(*b*) Using the heterodyne detector, or the high-frequency receiver, match *the next higher harmonic of the heterodyne-frequency meter* to the unknown frequency, by *reducing* the frequency of the frequent meter. Determine the approximate value of the fundamental frequency of the heterodyne-frequency meter, corresponding to this higher harmonic by reference to the calibration.

(*c*) The difference of these two fundamental frequencies, divided into the value of the *second* gives the number of the harmonic used in the *first* measurement. Thus:

$$nf_1 = (n + 1)f_2 = f_x,$$

$$n = \frac{f_2}{f_1 - f_2},$$

where f_2 is *lower* than f_1.

8A-2. In Measurements of Frequencies Below 100 kc. Where Harmonic of Heterodyne-Frequency Meter Is Matched to Harmonic of Unknown—In cases where the beat difference between a harmonic of the unknown frequency and the standard is too low for satisfactory matching, recourse must be made to setting a harmonic (n) of the heterodyne-frequency meter to the harmonic (N) of the unknown frequency. The beat difference between the fundamental, or some other harmonic (n') of the heterodyne-frequency meter and the standard is then matched with the interpolation oscillator. In the case of the heterodyne fundamental frequency being used, the two harmonics n and N must be identified; in the case of the use of a harmonic of the heterodyne-frequency meter for obtaining the beat difference, the harmonic n' must also be identified. While the process seems complicated, the identifications are generally easily made from the calibrations of the heterodyne detector and the heterodyne-frequency meter. This process is also only occasionally used, in the measurement of low radio frequencies.

In tuning in the harmonic, N, of the unknown frequency, the approximate value of this harmonic frequency is easily determined from the detector calibration. When the heterodyne-frequency meter harmonic, n, has been matched to this harmonic frequency of the unknown (Nf_x), the harmonic frequency of the heterodyne-frequency meter is of course the same as that just determined from the detector calibration. The calibration of the heterodyne-frequency meter then gives the approximate fundamental frequency of the frequency meter, which, divided into the harmonic frequency read from the detector calibration gives immediately the harmonic n of the heterodyne-frequency meter used in the matching. If some harmonic n' of the frequency meter is used in taking the beat difference against the standard, the approximate frequency is given by the heterodyne detector setting and this frequency divided by the frequency meter fundamental gives n'. The harmonic, N, of the unknown is determined from the detector calibration as given in Par. 7B. The unknown frequency is

$$f_x = \frac{nf_h}{N} = \frac{n(f_s \pm f_b)}{N},$$

when the beat is taken between heterodyne-frequency meter fundamental and the standard, and

$$f_x = \frac{n(n'f_h)}{n'N} = \frac{n(f_s \pm f_b)}{n'N},$$

when the beat is taken between the harmonic n' of the heterodyne-frequency meter and the standard.

8A–3. For Measurements Where the Direct Beat Difference between Standard and Unknown Is too Low for Satisfactory Matching—In those cases where the unknown frequency is within 100 cycles or so of the standard frequency, satisfactory matching may not be obtained. A harmonic of the heterodyne-frequency meter is then matched to the unknown by the three-oscillator method and the determination of the beat difference is transferred to the fundamental, or some other harmonic frequency of the frequency meter. The setting of the receiver or heterodyne detector should give the approximate value of the unknown frequency, which is also the frequency of harmonic n of the frequency meter. The value of the frequency meter fundamental is known from the measurements. The frequency of the nth harmonic, divided by the fundamental frequency gives the value of n. This is all that is required, if the beat difference is measured by using the heterodyne-frequency meter fundamental frequency. If a harmonic is used instead, the number n' of this harmonic must be found from the frequency (as determined by receiver or heterodyne detector calibration) divided by the fundamental frequency previously obtained. The unknown frequency is then

$$f_x = nf_h = n(f_s \pm f_b)$$

when the beat difference is taken against the frequency meter fundamental, and

$$f_x = \frac{n(n'f_h)}{n'} = \frac{n(f_s \pm f_b)}{n'}$$

when the beat difference is taken against harmonic n' of the heterodyne-frequency meter.

21. General Information—

A. Three-Oscillator Method—The three-oscillator method has been in use for a number of years, yet there are still numbers of people engaged in making frequency measurements who are not acquainted with it. It allows two radio-frequency oscillators to be set to zero beat within one cycle or less without any auxiliary equipment except an oscillating detector.

Suppose a continuous wave signal is picked up in an oscillating receiver, and it is desired to bring a heterodyne-frequency meter into zero beat with the signal. The receiver is adjusted to give zero audible beat with the signal and then the heterodyne-frequency meter is also brought into zero audible beat. The precision of the zero-beat setting is limited by the fact that the range of zero audibility is several cycles wide.

If, however, the frequency of the oscillating receiver is then moved away from the zero audible beat setting until an audible beat tone of, say, 1000 cycles is heard, the difference frequency between the signal and the heterodyne-frequency meter will be heard in the form of a waxing and waning of the audio-frequency tone. If the frequency of the receiver is varied somewhat, thereby changing the audio frequency, *no change in the rate of waxing and waning occurs,* showing that the slow beat is between the signal and the heterodyne-frequency meter. If the waxing and waning rate *does change* when the receiver frequency is varied, *the beat is between the wrong pair of oscillators and the adjustments should be made again with more care.*

To obtain the maximum waxing and waning effect, the amplitudes of the two signals which are to be brought into zero beat should be about equal at the detector, and these amplitudes should not be so great as to "block" or "drag" the oscillations of the detector. One of the strongest points in favor of this method is that two frequencies may be matched accurately when the amplitudes are so small as to give a just audible signal in the heterodyne detector.

After the waxing and waning beat is heard, the heterodyne-frequency meter may be readjusted to bring the rate of waxing and waning to one, or less, cycles per second after which the two frequencies will be matched to within a cycle.

The example of the radio signal and the heterodyne-frequency meter is given merely for purposes of illustration. Obviously, any two oscillators can be set to zero beat by this method, if a third oscillator and a detector are available. The third oscillator and detector may be a simple regenerative detector. Note: The beat frequency oscillator incorporated in a communication receiver may be used in lieu of a separate oscillator. *It is generally most satisfactory to listen in the third oscillator.*

B. When Beat Differences Are Very nearly Multiples of 1 kc.—When a frequency is to be adjusted to an exact multiple of 1 kc., the precision of adjustment is greatly increased through the use of the Type 614 Selective Amplifier. While the amplifier is arranged for selection of the first ten harmonics of the 1 kc. supplied by the standard, only the first five are required in this measurement.

In making the adjustment, the beat between the nearest 10-kc.

standard harmonic and the frequency under adjustment is picked up in a receiver or in the Type 619 Heterodyne Detector. The selective amplifier is set to the desired multiple of 1 kc., the output being connected to the SPEAKER terminals of the control panel. Comparison of the beat frequency with the 1-kc. multiple is easily made by listening to the two simultaneously. Adjustment of these two frequencies to zero brings the frequency under adjustment exactly to the desired multiple of 1 kc.

The beat indicator of the Type 617 Interpolation Oscillator may be used conveniently for this adjustment by throwing the "AMPLIFIER INPUT" switch to the "1 KC. HARMONIC" position, which connects the beat indicator to the output of the Type 614 Harmonic Amplifier. After setting the harmonic amplifier for the desired 1-kc. multiple, the frequency under adjustment may be brought to this value exactly by obtaining zero beat on the beat indicator.

C. Coupling Arrangements—While particular coupling arrangements have been indicated in the preceding instructions, at the point where the arrangements are used, a more general statement may prove helpful in making the apparatus more flexible in meeting special requirements.

C–1. To Couple Standard Harmonic Output to an External Receiver or Circuit—The standard harmonic output passes from the selector switch through the STD switch and volume control. The output of these controls passes to the HET DET INPUT-1 terminals of the Type 612 Coupling Panel. By connecting these terminals to the external circuit, the standard harmonic frequencies may be passed to the external circuit, control being maintained by the "STD" controls of the coupling panel.

In many cases capacitance coupling is all that is required. If so, a wire, connected to the "high" terminal of the HET DET INPUT-1 terminals, and taken near the receiver input, or connected thereto through a very small capacitance, will serve.

In some cases the control features may not be desired; it is then only necessary to couple the required standard harmonic output to the external circuit by plugging in at the appropriate terminals of the terminal strip in the Class C–21–H Assembly.

C–2. To Couple Heterodyne-Frequency Meter to an External Receiver or Circuit—The output of the heterodyne-frequency meter passes from the instrument to the "HET F. M." switches and volume control on the Type 612 Coupling Panel. These controls provide for turning the output on and off, selecting either the OUTPUT-1 (fundamental) or OUTPUT-2 (harmonic) outputs and for regulating the output level. From the controls, the output passes to the HET DET INPUT-3 terminals. By connecting these terminals to the external circuit, the heterodyne-frequency meter output may be passed to the external circuit, control being maintained by the HET F. M. controls on the coupling panel.

In many cases capacitance coupling is all that is required. If so, a wire, connected to the "high" terminal of the HET DET INPUT-3 terminals, and taken near the receiver input, or connected thereto through a very small capacitance, will serve.

In cases where the control features are not desired, it is only necessary to couple the external circuit to the required output terminals (front or rear) of the Type 616 Heterodyne-Frequency Meter.

C–3. To Couple Heterodyne Detector to an External Circuit—As this arrangement is frequently used, provision has been made for all necessary connections on the Type 612 Coupling Panel. Connecting the "x" terminals (front or rear) of the coupling panel to the external frequency source provides the necessary coupling, via the "X" switches and controls on the panel.

C–4. To Utilize the Interpolation Oscillator for Matching Frequency of an External Source—To check the calibration of the interpolation oscillator against the 1-kc. standard frequency, throw the INTERP INPUT switch on the coupling panel to "1–KC."; throw the CHECK switch on the oscillator to CHECK (See also, Type 617 Instruction Book).

Having checked the oscillator calibration, throw the INTERP INPUT switch on the coupling panel to LISTENING OSC and the LISTENING OSC output switch to TEL. The external source may then be connected to the STD INPUT terminals of the interpolation oscillator for matching.

C–5. To Utilize Output of Interpolation Oscillator in an External Circuit—The interpolation oscillator output may be utilized in an external circuit by throwing the SPEAKER switch on the coupling panel to INTERP OUTPUT and connecting the external circuit to the SPEAKER terminals. If a speaker is permanently connected to these terminals, throw the SPEAKER switch to "1-KC." (and cut off the 1-kc. by throwing the "1-KC." switch to LISTENING OSC); then connect the external circuit to the TEL terminals on the interpolation oscillator. Check the oscillator calibration as previously described and then throw CHECK switch to RUN.

22. Radio Transmitter Frequency Monitoring Equipment—Federal Communications Commission rule 33.13 applicable to broadcasting stations read as follows: The licensee of each standard broadcast station shall have in operation at the transmitter a frequency monitor independent of the frequency control of the transmitter. The frequency monitor shall be approved by the Commission. It shall have a stability and accuracy of at least 5 parts per million.

The frequency monitors about to be described provide the operator with a visual indication of the difference in frequency between the quartz crystal oscillator in the monitor and that of the transmitter provided the difference is within the scale reading of the indicating meter. If the difference in frequency is beyond the maximum reading of scale of the meter the needle may read zero deviation, therefore, means are provided whereby the operator may make aural observations of the beat frequency.

In the General Radio type of instrument the crystal oscillator is set to operate 1000 cycles above or below the assigned frequency of the station whereas in the Western Electric instrument the crystal is ground to operate at the same frequency as that of the transmitter.

WESTERN ELECTRIC FREQUENCY MONITORING UNIT No. 1B

23. Introduction—The No. 1B Frequency Monitoring Unit provides a means for checking the operating frequency of a radio broadcasting station by comparing the frequency of the transmitter with that of a stable crystal-controlled oscillator. This reference oscillator is an integral part of the monitoring unit and is accurately adjusted to the assigned frequency of the station. In addition to the crystal-controlled oscillator, the monitoring unit contains temperature control equipment for the oscillator, two screen-grid radio frequency amplifiers, a detector, a visual frequency difference indicator, and complete power equipment. The power equipment is arranged for operation from a 110-volt, 50 to 60-cycle a.c. power supply. The unit can be modified for operation from a 220-volt, 50 to 60-cycle power source.

The radio frequency voltage to be checked can be obtained from any stage of the radio transmitter, from an antenna near the transmitter, or from a radio receiver tuned to the transmitter frequency.

24. General Description—The circuit diagram is shown in simplified form as figure 302 and in complete form as figure 303. The principle of operation is as follows: The output of the oscillator in the monitoring unit and the radio frequency voltage from the transmitter are each amplified by one of the two tetrode radio frequency amplifiers ($V4$ and $V2$ respectively) which are coupled to a triode detector ($V3$). A condenser ($C7$) in series with a rectifier (*X*1) and a milliammeter (*M*3) is connected in the plate circuit of the detector. The current through the condenser and meter is directly proportional to the beat frequency between the two radio frequencies when the voltage of the beat note is maintained at a constant value. A switch (*D*4) is provided for connecting the rectifier and meter as a voltmeter so that the voltage of the beat note may be adjusted to the proper value.

The reference oscillator (No. D-95100 Oscillator) is calibrated as a unit to the assigned carrier frequency of the station. A control on the side of the oscillator, which is set at zero on the scale at the time of calibration, permits limited frequency adjustment. The setting of this control should not be changed unless it is desired to make a small frequency adjustment when measurement by a recognized authority indicates the desirability of so doing. The dial has an arbitrary scale for reference purpose and a careful readjustment to zero should restore the original setting of the oscillator frequency.

The quartz crystal in the oscillator is maintained at a constant temperature by a heater supplied with power through a three-element rectifier tube (*V*1) acting as a relay. The grid voltage of this tube is in phase with the plate voltage when the oscillator temperature is low and current flows into the heater. When the crystal temperature reaches the proper value, the contacts of a mercury thermostat close applying an out-of-phase grid voltage to the rectifier tube, preventing the flow of current into the heater.

One transformer (*T*3) supplies the necessary power for the oscillator and amplifier tubes and another (*T*1) supplies the power for the heater control tube. A full-wave rectifier (*V*5) with a suitable filter furnishes the required screen, plate and grid voltages.

Access to the tubes, heater supply switches, and fuses is through a rear door which may be opened at any time without affecting the operation of the unit. There is no live wiring or fuses exposed in this compartment which would endanger the operator, therefore, no switch on the door is provided.

25. Installation—The No. 1B Frequency Monitoring Unit can be installed on a desk or table or mounted on a standard rack. For rack mounting the No. D-95314 Shelf is used and the assembly requires 15 3/4 inches of rack space.

When the unit is furnished for operation from a 110-volt, 50 to 60-cycle a.c. power supply, the primaries of the transformers are connected in parallel and the resistance of the rheostat is approximately 50 ohms. When furnished for 220-volt, 50 to 60-cycle a.c. operation, the primaries of the transformers are connected in series and the resistance of the rheostat is approximately 200 ohms. These rheostats permit the unit to be operated on a power supply voltage range from 105 to 135 or 210 to 270 volts.

The power consumption of the unit is approximately as follows:

Voltage	Watts, Heater On	Watts, Heater Off
105 or 210	105	85
120 or 240	130	100
135 or 270	155	115

The power consumption may be reduced to less than 40 watts (heater on) when no readings are desired by operating the power switch to the "Off" position. This does not disturb the temperature of the crystal.

Cords terminated in plugs are provided to connect the unit with the a.c. power source and the radio frequency input. The power supply cord is furnished with a non-polarizing plug. A standard receptacle that will not accept the polarized radio frequency plug should be used in the power supply outlet. The receptacle for the radio frequency plug should be a General Electric polarity plug receptacle, Graybar Catalog No. GE–996 or a similar outlet.

Caution—Care should be exercised that the power supply is never connected to the radio frequency input as excess voltage will damage the circuit.

A radio frequency transmission line from the transmitter to the radio frequency outlet may be run in conduit or exposed as desired. A single shielded conductor similar to the Belden Manufacturing Company's No. 16 Cord, code word "Airduct," should be used as the transmission line. The copper shield should be grounded and connected to the wide contact on the receptacle. This transmission line should be connected to a source of suitable radio frequency voltage either by direct connection or by use of a coupling coil. This coil may consist of approximately 10 turns of wire on 3-inch diameter tubing. The coupling should be adjusted to provide two volts or more to assure proper operation of the frequency monitoring unit. When the monitoring unit is installed where the field strength is high, the radio frequency input may be obtained from a small antenna wired through an opening in the base of the monitoring unit and connected to terminal No. 5. When the unit is operating from an antenna, the red bus wire connecting condenser "*C9*" and resistance "*R17*" should be disconnected. To disconnect this lead the front compartment must be opened by removing the screws at the corners of the panel and the knob on the input control.

The No. 1B Frequency Monitoring Unit can be operated at a distance from the radio transmitter in conjunction with a tuned radio frequency type of receiver. When the Monitoring Unit is operated in this manner, the red wire connecting condenser "*C*9" and resistance "*R*17" should be disconnected, and a lead connected from terminal No. 5 to the grid of the detector tube in the radio receiver. This lead should be as short and direct as possible to prevent detuning of the preceding radio frequency circuit in the receiver.

The indicating lamp should be inserted in the proper socket with all power switches in the "Off" position. Unscrew the cap terminal No. 9 on the No. D–95100 Oscillator, replace the top nut on terminal No. 8 with the tapped stud supplied with the Monitoring Unit, and insert the oscillator in the mounting provided, following carefully the directions on the card attached to it. When the oscillator is in position, the spring contacts in the unit should make firm connections to terminals 8 and 9.

To place the temperature control circuit in operation for the first time, operate the switch (*D*1) designated "Primary" to the "On" position and heat the cathode of the three element heater supply rectifier tube (*V*1) for fifteen minutes with the plate voltage off to vaporize any particles of mercury adhering to the tube elements. When this preliminary heating is complete operate the switch (*D*2) designated "Plate" to the "On" position. The tube (*V*1) will then glow and the crystal heater indicator lamp (*E*1) will light. After about one hour the thermostat will reach the operating temperature and its contacts will close applying a voltage to the grid of the rectifier tube (*V*1) which is of opposite phase to that on the plate, thus preventing the flow of current through the heater and the indicator lamp (*E*1). After this the thermostat and indicator lamp (*E*1) will operate at intervals of about one minute. A period of three hours should elapse after the temperature control circuit is placed in operation (i.e. after closing the "Plate" switch *D*2) before any frequency readings are taken. The preliminary heating is not necessary for subsequent occasional starting unless a new tube (*V*1) has been installed or the unit has been moved while cold. However, if the unit is turned off at the end of each day's use, the filament should be allowed to warm the tube for 15 seconds before applying plate voltage by closing the "Plate" switch (*D*2).

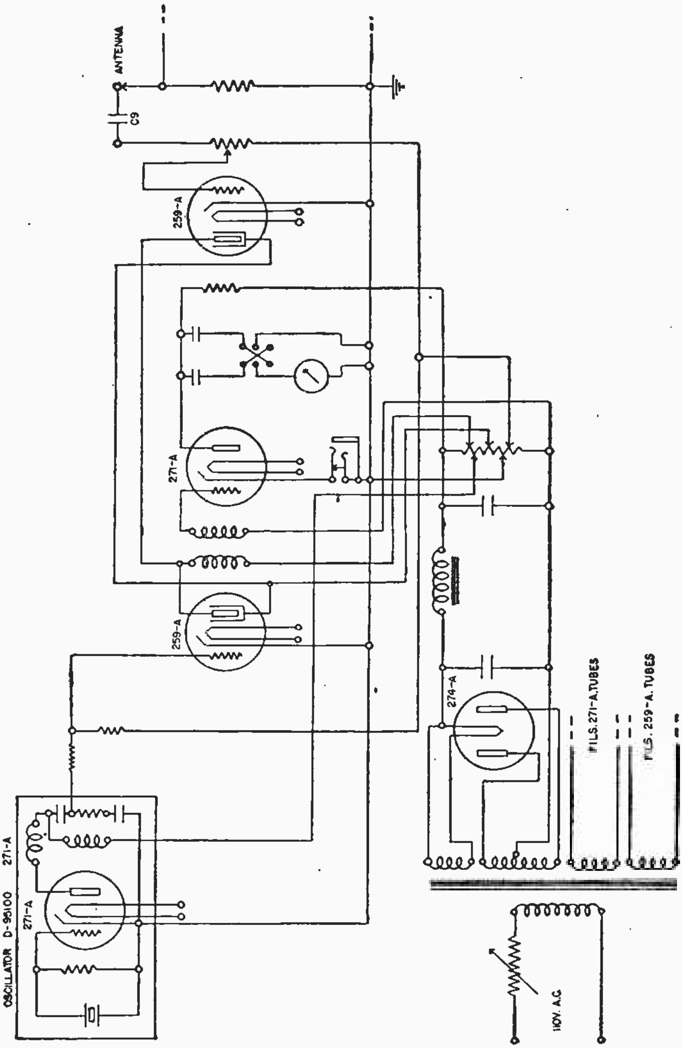


FIG. 302. Simplified Schematic of No. 1B Frequency Monitoring Unit.

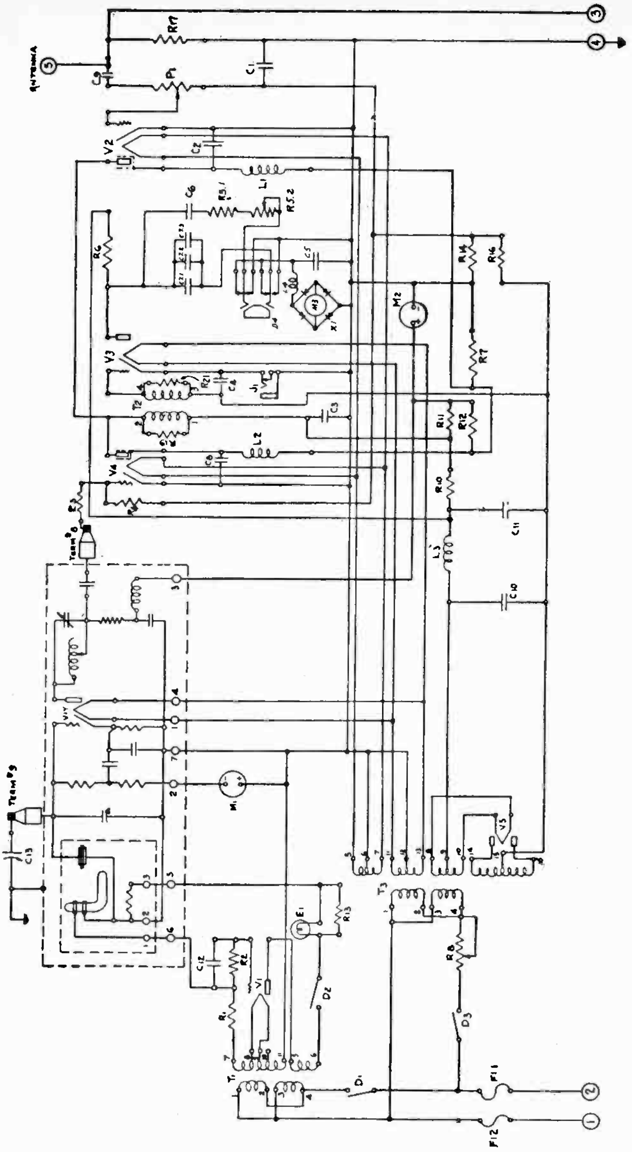


Fig. 303. Wiring Diagram of No. 1B Frequency Monitoring Unit.

To operate the unit, place the power switch (*D*3) lever on the front panel in the "on" position and allow the tube cathodes to warm up for about one minute. Adjust the control (*R*8) marked "Voltage" until the "Oscillator Plate Voltage" voltmeter (*M*2) indicates 130 volts. The "Oscillator Grid Current" meter (*M*1) should indicate between 0.05 and 0.08 milliamperes, showing that the oscillator is operating.

With the radio transmitter in operation press the "Calibrate" button (*D*4) and adjust the potentiometer control (*P*1) marked "Input" until the "Frequency Difference" meter (*M*3) shows a deflection to the red mark at 350 on the scale. With this setting the beat note voltage is correct for making "Frequency Difference" measurements. Releasing the calibrate button (*D*4) will cause the meter (*M*) to indicate directly the deviation of the transmitter from the assigned frequency. The calibration of the "Frequency Difference" meter (*M*3) and the adjustment of the potentiometer control (*P*1) should be checked at intervals, particularly just before taking a reading for record.

When the "Direction" button (*C*13) is pressed a small capacity is added to the oscillator circuit thereby lowering its frequency. By observing the effect of this change on the frequency difference in accordance with instructions on the meter (*M*3) face the direction of the deviation of the transmitter from its assigned frequency is determined.

Aural observation of the difference frequency may be made by plugging head phones into jack (*J*1) provided for that purpose. In cases where the frequency monitoring unit is used to observe the operation of a non-crystal controlled transmitter where the difference frequency may be observable but high, the transmitter frequency can be adjusted until the frequency of the sound in the head phones is estimated to be within the range of the frequency difference meter. The head phones should then be removed from the circuit, as they disturb the calibration of the frequency difference indicator.

26. Measurements—When the monitoring unit has been placed in operation, measurements may be made as follows: (If the radio frequency voltage for the operation of this device is obtained from a point where the carrier is modulated measurements should be made only when there is no modulation present).

1. Depress the push button (*D*4) marked "Calibrate" and adjust the "Input" control (*P*1) until the "Frequency Difference" meter indication (*M*3) is at the red mark corresponding to

a scale reading of 350 cycles. Release the button and read the frequency deviation on the meter.

2. Depress the "Direction" button ($C13$) slowly and observe the change in the reading of the "Frequency Difference" meter.

The first operation will give the frequency difference. If the second operation decreases this difference, the transmitter frequency is low. If this operation increases the frequency difference, the transmitter frequency is high. Care must be taken in interpreting this rule when the change in frequency produced by the "Direction" button is greater than the "Frequency Difference" observed in the first operation. If the button is depressed slowly and the "Frequency Difference" meter ($M3$) is carefully observed at the same time there should be no difficulty in interpreting the rule.

In using a frequency monitoring unit greater benefit will usually be obtained by periodically reading and recording the frequency difference than by making frequent small adjustments of the transmitter frequency to make it agree with that of the monitoring unit. The statistical records thus obtained will show the normal variations of the system so that steps can be taken to correct the abnormal performance of an individual element before serious trouble develops. Graph paper similar to the No. 4117 made by the Codex Book Co. of Norwood, Mass., will be found satisfactory for plotting the frequency deviations. This paper has arbitrary ordinates which may be marked in cycles and the abscissae are labeled in months of the year.

When the carrier frequency of the transmitter is measured by a recognized authority and an error in the reference oscillator is indicated, the frequency may be reset by adjusting the control on the Monitoring Unit (reference) oscillator until the "Frequency Difference" meter registers the measured deviation. To make such an adjustment unscrew the plug in the side of the Monitoring Unit and insert a screw driver in the slot provided.

At times when no readings are desired the amplifier-modulator tubes ($V2$, $V3$ and $V4$) may be turned off by operating the power switch ($D3$) to the "Off" position without disturbing the temperature of the crystal. When readings are required they may be taken within one minute after operating the power switch ($D3$) to the "On" position.

27. Maintenance—Being precision equipment, the No. 1B Frequency Monitoring Unit should be handled with care and it should be observed at regular intervals to make certain that the operation is normal. The "Oscillator Grid Current" ($M1$)

should be observed regularly and if it decreases materially, the oscillator tube should be replaced. The temperature control circuit will require occasional replacements of the three element rectifier tube (*V*1) and indicator lamp (*E*1) which are in service continuously. This tube (*V*1) serves as a relay operating in connection with the mercury contacts of the thermostat and passes the entire crystal heater current through its plate circuit. Improper operation of this tube will affect the temperature of the crystal oscillator used as a reference and seriously impair the accuracy of the readings, therefore it should be checked frequently for regularity in its periodic flashing and replaced if there is reason to doubt its performance.

The Monitoring Unit should be cleaned periodically with a jet of compressed air or a soft clean rag to prevent an accumulation of dust or dirt.

28. Location of Trouble—Failure to obtain adjustment to 130 volts on the "Oscillator Plate Voltage" voltmeter (*M*2) may be due to failure of the rectifier tube or to excessive voltage variation in the power supply.

The temperature control indicator lamp (*E*1) will not light if the relay tube (*V*1) fails. If the relay tube appears to be operating normally and the lamp does not light, the lamp may be burned out and should be replaced. Flickering of the relay tube is not an abnormal condition.

If there is reason to suspect that the readings on the "Frequency Difference" meter (*M*3) are in error they may be checked by applying a known audio frequency voltage (60 cycles may be used) to the grid of the detector tube (*V*3) through a condenser to avoid disturbing the grid bias voltage, calibrating with the oscillator output control to the red mark at 350, and reading the known frequency on the meter. If the reading is found in error the adjustment of resistance "*R*5" has probably been disturbed and should be corrected as follows: Set an oscillator at 350 cycles per second using a reliable calibration chart and adjust its voltage output so that 350 cycles per second are read on the "Frequency Difference" meter. With the oscillator set as above depress the "Calibrate" key (*D*4) and adjust resistance "*R*5" until a deflection to the red mark at 350 is again obtained. The meter (*M*3) should now read correctly (within 5 percent) at all other frequencies on its scale, if not there may be contact trouble in the key (*D*4) or the varistor (*X*1) may have been damaged and require replacement.

The following table lists the voltages used on the vacuum tubes in the Monitoring Unit:

Vacuum Tube	D.C. Plate Voltage		D.C. Screen Voltage		D.C. Grid Bias Voltage		Filament Voltage
V1Y	130	2	—		—		5AC
V2	174	9	69	6	− 4.2	0.3	2AC
V3	260	10*	—		−22	2	5AC
V4	174	9	69	6	− 4.2	0.3	2AC

* Applied through a series resistance (R6) of 12,000 ohms. (Subtract voltage drop through resistance R6 from 260 V. to obtain voltage on plate.)

General Radio Type 475-A Frequency Monitor

30. Purpose—The Type 475-A Frequency Monitor is designed for use in monitoring the frequency of radio transmitters. When used with Type 376-J and Type 376-K Quartz Plates, transmitters can be monitored against the fundamental frequency up to 4000 kilocycles. Higher frequency transmitters can be monitored by utilizing harmonics of the oscillator frequency.

31. Principle of Operation—Monitoring of the transmitter is accomplished by using the difference frequency between the transmitter and the crystal oscillator in the monitor. This difference frequency is available at the output terminals of the monitor and can be used to give an audible indication of the frequency difference on a loud speaker or a pair of head telephones. It can also be used to operate a frequency deviation indicator to furnish a visual indication.

The present tolerances on high frequency channels are such that if the beat difference is held to low audible values by adjustment of the transmitter carrier frequency against the monitor (assuming the monitoring crystal is ground to the assigned frequency of the transmitter), the requirements are met. This method of monitoring is recommended for police broadcast transmitters and other stations engaged in a limited class of service at frequencies above the normal broadcast band.

For monitoring the frequency of a radio broadcasting station where the frequency tolerance is 50 cycles, the Type 681-A Frequency Deviation Meter should be used. When used with a Type 681-A Frequency Deviation Meter the crystal in the monitor is adjusted to differ from that of the assigned transmitter frequency by 1000 cycles. The indicator in the frequency deviation meter

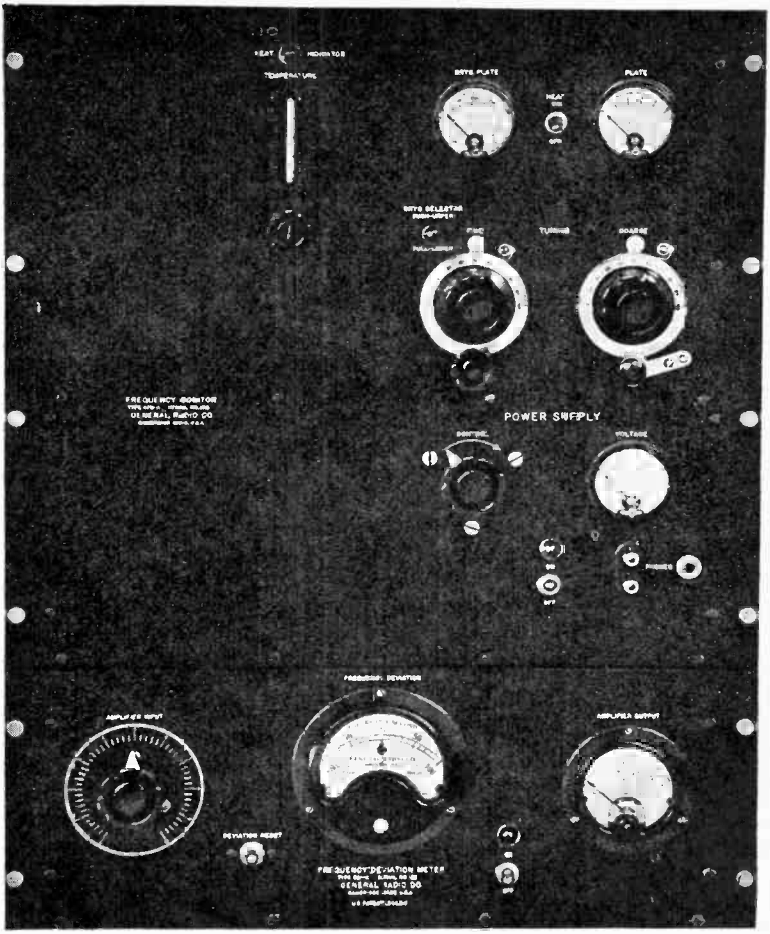


FIG. 304. General Radio Type 475–A Frequency Monitor and Type 681–A Frequency Deviation Meter.

is adjusted to read zero when this difference frequency is exactly 1000 cycles.

Other methods of obtaining a quantitative measure of the frequency deviation can be used. Among these are the Type 434–B Audio-Frequency Meter and various types of electronic frequency meters.

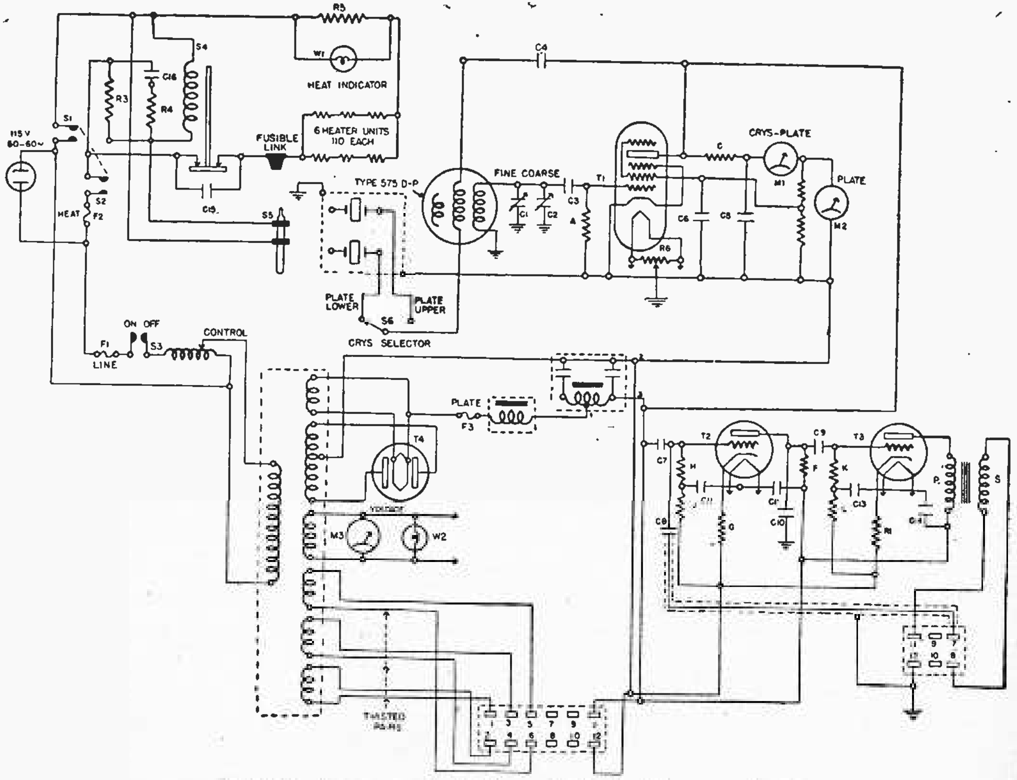


Fig. 305. Circuit Arrangement of General Radio Type 475-A Frequency Monitor.

32. **Description**—The monitor consists of a temperature-controlled crystal oscillator, a detector and a single stage audio amplifier. The oscillator is loosely coupled to the grid of the detector and provision is made for introducing a signal from the transmitter to be monitored. The detector and amplifier are resistance coupled to give satisfactory performance at low beat frequencies.

33. **Oscillator**—The oscillator circuit is of the tuned-grid magnetic feed-back type, in which the crystal is operated at very near its true resonant frequency. The system is a free oscillator and no difficulty is encountered in starting oscillation. A particular advantage is that the proper adjustment of the tuning condenser is indicated by a minimum plate current, so that the oscillator circuit need not be calibrated with each crystal used. Both FINE and COARSE tuning controls are provided for easy adjustment, particularly at the higher frequencies.

34. **Power Supply**—The Type 475-A Frequency Monitor is completely a.c. operated from 115-volt, 50–60 cycle mains. The internal power supply provides for three filament circuits and a 180-volt plate supply for external equipment operated with the oscillator.

35. **Temperature Control**—A terminal plate carrying two sets of jacks for Type 376 Quartz Plates is provided in the temperature-controlled space. Choice of the quartz plate which is in circuit is made by a panel switch. Within the metal case are placed a balsa wood insulating wall, distributed heaters (on all six faces of the inner assembly), a cast aluminum distributing layer, an asbestos attenuation layer, and a second heavy cast aluminum distributing layer which forms the wall of the temperature-controlled space. A thermometer, graduated in 0.5° C. steps from 40° to 60° C., is mounted behind a removable cover plate on the panel and is illuminated by the heat control signal lamp. The thermometer indicates the air temperature of the inner space. The temperature control system is completely a.c. operated.

36. **Mounting**—The monitor should be installed as far distant as possible from the power amplifier stages of the transmitter. The relay rack should be grounded. If no rack is used, ground the frame of the monitor.

Quartz Plate—Plug the quartz plate or plates into the jack mountings inside the temperature-control box.

Thermostat and Thermometer—Place the thermostat in the mounting block on the rear face of the aluminum temperature-control box. Connect the leads to the terminals on the block just above the thermostat mounting. If shipped in place, check the connections.

Install the thermometer in its mounting behind the removable cover plate on the panel.

Inductor—Plug in the crystal oscillator inductor in the coil mounting on the upper shelf.

Vacuum Tubes—Install tubes as follows:

Type	*Location*
77	Top Shelf
76	5-Prong sockets on lower shelf
523	4-Prong socket on lower shelf

Be sure the clip is connected to the grid terminal at the top of the 77 tube.

37. **Coupling to Transmitter**—A voltage of the transmitter frequency can be introduced through the small multipoint connector at the rear of the instrument. A short length of wire connected to terminal 7 will be sufficient with transmitters of appreciable power. A larger voltage, if necessary, can be obtained by connecting a small coil of a few turns of wire between terminals 7 and 12. This coil should then be placed in the field of one of the tuned circuits of the transmitter, preferably the master oscillator.

OPERATION

38. **Temperature Control**—Having placed the unit in operating condition as described above, throw the HEAT ON-OFF Switch to ON. The HEAT INDICATOR bull's-eye should light immediately.

To test the operation of the heat control circuit short circuit the thermostat temporarily. The relay should open and the heat indicator lamp go out. A fusible link is provided which melts and opens the heater circuit if the temperature becomes excessively high due to relay or thermostat failure. The heat will remain on for about one-half hour, before the thermostat begins to operate. After about one hour the thermostat will operate so that heat is on (indicator lamp lighted) about 20 seconds and heat off (indicator lamp out) about 95 seconds at ordinary room temperatures. A period of about four hours is required before the inner temperature reaches its final value.

39. **Crystal Oscillator**—Throw the POWER SUPPLY ON-OFF Switch to ON; adjust the supply voltage CONTROL until a filament voltage of 6 volts is indicated on the filament voltmeter. The

plate voltmeter will indicate about 200 volts until the tubes begin to draw plate current, after which the voltage will drop somewhat. The crystal oscillator plate current meter will read slightly off scale when the crystal is not oscillating. Throw the CRYSTAL SELECTOR switch to select the desired crystal. Adjust the FINE TUNING dial to 50 divisions, then adjust the COARSE TUNING dial slowly until the crystal begins to oscillate, indicated by a sudden drop in crystal oscillator plate current. Adjust for the minimum plate current and lock the COARSE TUNING dial in this position. Then adjust the FINE TUNING dial to give the minimum plate current.

39a. Monitoring—When monitoring by the audio beat method, adjust the frequency of the transmitter until the frequency of the beat heard in the head telephones or loudspeaker is well below the tolerance allowed by government regulations. If possible, adjust to zero audible beat. If the transmitter frequency lies within a few cycles of that of the crystal oscillator, a "flutter" corresponding to the beat frequency will be heard which is produced by a modulation of circuit noise by the beat.

If an audio-frequency meter is used to determine the beat frequency, this can be connected directly to the output of the monitor. Instructions for connecting the Type 681–A Frequency Deviation Meter will be found in the instruction book for that instrument.

40. Precautions—A check should be made to see that an undue amount of radio frequency is not picked up in the oscillator circuits. If the oscillator is placed in operation with the transmitter carrier *off* and the oscillator plate current noted, no appreciable change in plate current should be observed when the transmitter carrier is *on*.

A more sensitive test may be made by operating the crystal oscillator in the non-oscillating condition (which results from throwing the CRYSTAL SELECTOR switch to the empty crystal position when only one crystal is used, or temporarily removing the crystal from the plug mounting). With the transmitter carrier off, the oscillator plate current meter will read roughly 5 milliamperes. If this reading drops appreciably when the carrier is, on, it is an indication of considerable pick-up.

In certain transmitter installations, particularly those where a long ground lead is used, it may be found that if the monitoring oscillator is grounded to the transmitter frame, excessive pick-up results. In such cases the oscillator must be grounded separately, or must be operated without ground.

SPECIFICATIONS

41. **Fundamental Frequency Range**—The fundamental frequency range is 100–4000 kc. using Type 376 Quartz Plates.

Accuracy—The guaranteed absolute accuracy is 20 parts in a million (0.002 percent) using Type 376–J Quartz Plates and 30 parts in a million (0.0003 percent) using Type 376–K Quartz Plates.

42. **Stability**—The frequency stability is 5 parts per million (0.0005 percent) over long periods of time.

43. **Quartz Plate**—Quartz plates are not furnished with the instrument, which is intended for use only with the Type 376 Quartz Plate. No crystal oscillator circuit elements are mounted with the quartz plate.

44. **Accuracy of Temperature Control**—The unit will control the temperature of the inner space to within 0.1° C. for room temperatures of 16° C.

Operating Temperature—Normally 50° C., but thermostats for other temperatures can be supplied on special order.

45. **Thermostat**—Fixed, or non-adjustable, mercury-type, accuracy of working-point 0.1° C. Sensitivity 0.05° C.

Inductor—One Type 575–DP Inductor for the crystal oscillator circuit is furnished with one quartz plate. If two quartz plates are used, and the second is outside of the frequency range of the coil used with the first, an additional coil at extra cost is required.

46. **Output Level**—The audio-frequency output level is sufficient to operate either head telephones or a small loud speaker. The output impedance is approximately 10,000 ohms.

47. **Power Supply**—115-volts 50–60 cycles. Provision is made through a multipoint connector for obtaining power supply (both filament and plate) for external devices, such as detectors, amplifiers or frequency deviation indicators used with the oscillator. Three filament windings (6 volts a.c.) and 180 volts (50 milliamperes d.c.) are available.

48. **Power Input**—120 watts with heaters on; 45 watts with heaters off and no external devices connected to the power supply.

49. **Controls**—Power supply ON-OFF switch; HEAT ON-OFF switch; crystal selector switch; crystal oscillator tuning condensers (fine and coarse tuning); line input voltage control.

50. **Meters**—Filament and plate voltage; crystal oscillator plate current.

51. **Tubes**—Supplied with instrument.

1 Type 77 Crystal Oscillator
1 Type 76 Amplifier
1 Type 76 Detector
1 Type 5Z3 Rectifier

GENERAL RADIO TYPE 681–A FREQUENCY DEVIATION METER

52. **Purpose**—The Type 681–A Frequency-Deviation Meter (Fig. 307) is designed for use with the Type 475–A Frequency Monitor to enable the radio broadcasting station to maintain its frequency within the tolerance specified by the Federal Communications Commission and by similar commissions in other countries.

53. **Advantages**—The instrument indicates the deviation of the station carrier frequency from its assigned value on a pointer-type meter. The scale is graduated in 10-cycle steps, from — 100 cycles to + 100 cycles, and a change of one cycle is readily discernible. As the indicator has a zero-center scale, the reading of the instrument shows automatically whether the station frequency is high or low. Power supply is obtained from the Type 475–A Frequency Monitor. Cables for connecting the deviation meter and the frequency monitor are furnished.

54. **Principle of Operation**—The Type 681–A Frequency Deviation Meter is designed to operate by means of a beat tone of approximately 1000 cycles which is present in the output of the Type 475–A Frequency Monitor when the piezo-electric crystal in the monitor is set off from the frequency of the assigned channel by 1000 cycles. It is essential that the transmitter be of the master oscillator type in which the master oscillator itself is not modulated. The voltage from the transmitter which produces the beat with the crystal oscillator in a Type 475–A Frequency Monitor must be derived from the unmodulated master oscillator since otherwise spurious indications will be obtained which are caused by the varying side band frequencies of the transmitter.

Figure 306 is a functional block diagram showing the operation of the monitor. Briefly, the system operates as follows: The frequency of the type 475–A Frequency Monitor is set at exactly 1000 cycles above (or below) the assigned frequency of the transmitter. Voltages of this frequency and that of the transmitter carrier frequency are applied to a vacuum-tube detector and the resulting 1000-cycle beat is passed through an audio amplifier to a frequency meter which reads zero at 1000 cycles and indicates the number of cycles above and below 1000. For instance, if the transmitter frequency is 50 cycles higher than its assigned value, the beat between it and the monitoring oscillator will be 950 cycles and the meter will indicate 50 cycles on the high side of zero. Similarly, if the transmitter is 50 cycles low, a reading of 50 cycles on the low side will be obtained. The monitoring oscillator may be either 1000 cycles higher or lower than the assigned transmitter frequency, *since reversing the leads to the indicating meter will reverse its reading.*

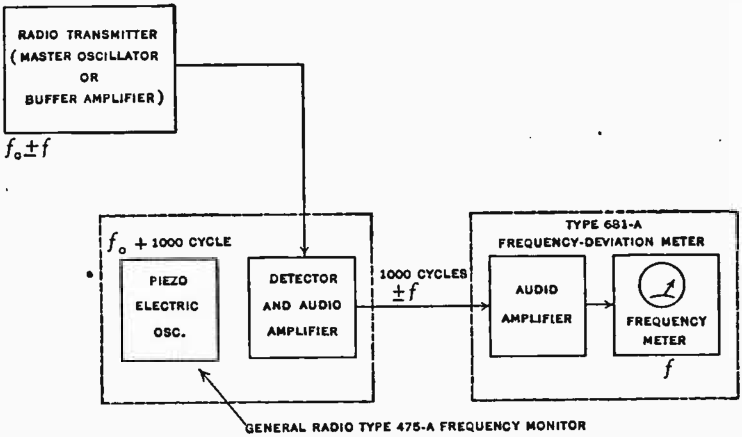


FIG. 306. Block Diagram Type 681–A Frequency-Deviation Meter.

The Type 681–A Frequency-Deviation Meter consists of an audio amplifier and a frequency meter. The circuit diagram of the instrument is shown in figure 307. The circuit L_1, C_1, R is resonant above 1000 cycles, and the circuit L_2, C_2, R_2, R below 1000 cycles. The voltages across the condensers are applied to linear vacuum-tube rectifiers (V_1, V_2) and the difference of the currents from the two rectifiers is indicated by the meter M_2.

At 1000 cycles, the current difference is zero and the meter is at mid-scale. The meter M_2 is a direct-current micro-ammeter that is made to read directly in cycles per second by adjusting the resistance R_2 until one cycle change in frequency produces a change of one microampere in the meter circuit. This adjustment is made at the factory. The accuracy of the indication then depends on keeping constant the output voltage of the amplifier. An alternating-current voltmeter M_1 and a volume control R_1 are provided for this purpose.

While the Type 681–A Frequency-Deviation Meter will function with any monitoring oscillator associated detector and audio-frequency amplifier, the frequency of which differs from the assigned station frequency by exactly 1000 cycles, *the requirements which must be met impose rigid restrictions on the frequency stability of the monitoring oscillator.* Because of these restrictions, an improved type of monitoring standard, the Type 475–A Frequency Monitor, has been developed especially for use with the deviation meter.

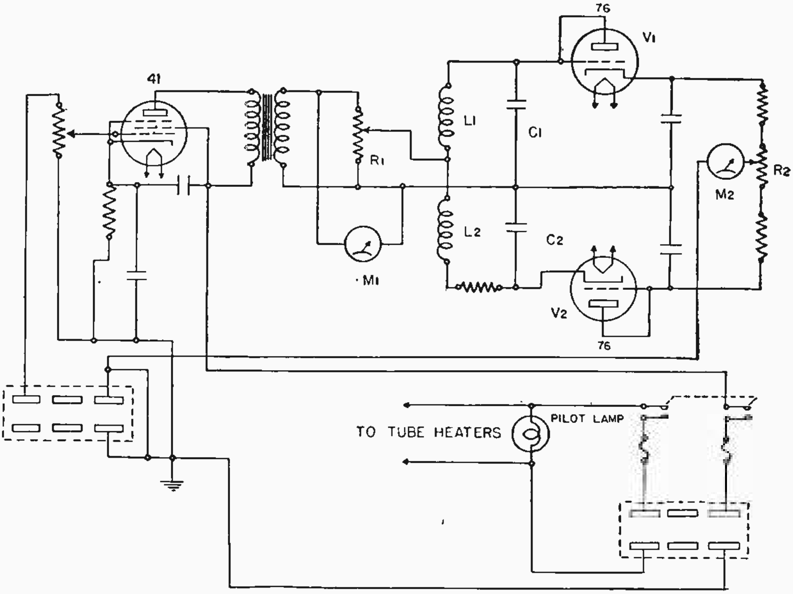


FIG. 307. General Radio Type 681–A Frequency Deviation Meter Circuit Diagram.

Accuracy—The Type 681–A Frequency Deviation Meter will indicate to within ± 5 cycles the beat between the transmitter and monitoring standard. The 1000-cycle difference does not appear on the meter scale, that is, 1050 cycles is indicated as 50 cycles high (or low) and 950 cycles as 50 cycles low (or high).

55. Installation—*Accessories*—With each Type 681–A Frequency-Deviation Meter are supplied the following accessories and spares:

1 RCA-41 Vacuum Tube
2 RCA-76 Vacuum Tubes (These two tubes have been selected for use with this particular instrument)
1 Cable for making connections to Type 475-A Frequency Monitor
1 Box 0-1-a Bussman 7AG fuses
1 Box 5.0-a Bussman 7AG fuses
1 Mazda 41 lamp (pilot)

Location—Both the deviation meter and the frequency monitor should be located in the transmitting room. Both units are designed for 19-inch relay-rack mounting. Mount the Type 681-A Frequency Deviation Meter below the Type 475-A Frequency Monitor.

Connections—1. Connect the deviation meter to the Type 475-A Frequency Monitor by means of the cable furnished.

2. Run the coupling lead from the multi-point connector of the Type 457-A Frequency Monitor to the transmitter and place the end of this lead in the field of the tuning inductance of either the buffer amplifier or the master oscillator of the transmitter. *This lead must be coupled to the transmitter at a point where the carrier is unmodulated. The Type 681-A Frequency-Deviation Meter will not function properly on a modulated signal.*

3. Provision is made for connecting an external indicating meter if desired. The meter should be connected to terminals 11 and 12 on the multi-point connector at the right (looking at rear) of the Type 681-A Frequency-Deviation Meter. Remove the jumper between these terminals when making the meter connections.

56. Operation—With connections made as outlined in the preceding section, proceed as follows:

1. Turn on the Type 475-A Frequency Monitor and adjust for proper operation. Directions are given in the instruction book for that instrument.

2. Turn on the Type 681-A Frequency Deviation Meter.

3. Set AMPLIFIER INPUT control at 7.

4. Note reading of amplifier output meter. If reading is over 15 volts (off scale) move coupling lead away from the coupling point of the transmitter until a reading of 15 volts is obtained. If the reading is below 15 volts, increase the coupling until this reading is obtained.

5. Adjust AMPLIFIER INPUT control to obtain a reading of 13.0 volts. This is the standard output voltage, and this voltage should always be maintained (by adjustment of the AMPLIFIER INPUT

CONTROL) when-ever accurate readings of the frequency deviation are to be made.

6. If the transmitter frequency is within 100 cycles of its assigned value, the meter will indicate the frequency difference. If the transmitter is more than 100 and less than about 200 cycles off frequency, the meter pointer will be off scale. If the station is more than 200 cycles off its channel, the meter may read on scale, but the indications will be false. *The station should be adjusted as closely as possible before using the deviation meter.* If there is any doubt as to whether or not the station is approximately correct, i.e., within 100 cycles, plug in a pair of telephones or a loudspeaker at the terminals provided on the panel of the Type 475–A Frequency Monitor. The tone heard should be approximately 1000 cycles. If necessary, this tone may be matched against a 1000-cycles tuning fork or a calibrated audio oscillator, by varying the transmitter frequency.

7. When the reading varies with modulation, it indicates the presence of one of two conditions. Either the modulated voltage is picked up on the leads from the transmitter to the deviation meter, or the output stages of the transmitter are reacting on the frequency control system. Usually the former effect is the cause of the trouble.

8. A deviation reset device consisting of a potentiometer is mounted on the panel of the Type 681–A Frequency-Deviation Meter. By means of this the point of zero frequency deviation, as indicated by the meter, can be varied over a range of ± 20 cycles per second. The normal position is with the arm in the center of the winding.

It is recognized that slight differences between operating and calibrating temperatures, rough handling in shipment, or slight aging effects may shift the operating frequency of the quartz crystal in the monitoring oscillator. The deviation adjusting device permits the operator to bring the indication into exact agreement with measurements made by government or commercial monitoring stations.

57. **Example of Use**—Suppose the average of a number of measurements indicates that the station frequency is 10 cycles high. The setting of the potentiometer is adjusted until the indicator reads 10 cycles high, which makes the monitor *agree* exactly with the measurements. If the monitor equipment is then left alone, *and the station frequency adjusted until the deviation meter reads zero,* the station will be exactly on frequency as determined by the agency making the measurements.

Routine Operation—When the transmitter is shut down, both the crystal oscillator and the frequency-deviation meter should be turned off. The heat-control system on the crystal oscillator should be kept in constant operation. The heater supply is controlled by a separate switch and is not affected when the oscillator is turned off at its filament-plate switch.

58. **Maintenance**—The following suggestions should be followed in order to secure the most satisfactory operation:

1. *Accuracy*—When the monitoring apparatus is first placed in operation, the transmitter should be operated at such a frequency that the frequency indicator reads zero. At this point, the transmitter should be well within the 50-cycle limit. If a closer check is desired, the value of frequency given by monitoring stations may be compared with the indicator reading, thus giving a correction factor for the indication. This error may then be compensated for by means of the deviation adjustment.

2. *Output Voltmeter*—The voltmeter reading on the Type 681–A Frequency-Deviation Meter should be held at 13 volts, readjusting whenever necessary by use of the AMPLIFIER INPUT control.

3. *Replacement of Tubes*—When it is necessary to replace the two frequency meter tubes, a test should be made to be sure that the replacements are matched and are of the proper sensitivity. These tubes can be supplied by the General Radio Company, or, if the user so desires, he may select his own tubes. To make this test, proceed as follows:

a. Short-circuit both of the wooden form coils in the Type 681–A Frequency-Deviation Meter. A wire connected across each pair of coil binding posts will be sufficient.

b. With the unit operating normally, i.e., with both transmitter and monitoring oscillator connected and operating, change the volume control setting until the voltmeter reads 13.0 volts.

c. Remove the two frequency meter tubes from their sockets. These are the two immediately in front of the wooden coil forms (as seen from rear of instrument).

d. Into one socket (either one) plug successively the tubes to be tested. The frequency indicator scale reading should be between 48 and 52 divisions. Select a pair of tubes falling in this range whose individual readings do not differ by more than 4. These are satisfactory for use in the frequency meter. Normal tubes of the specified type are usually satisfactory.

Note—If the deviation reset is not in the center of the range, the readings obtained for a given tube will be different in the two sockets. To avoid changing the deviation reset, plug the tubes first in one socket, then in the other, making certain the heaters have time to come to final temperature. Then use the average of the two readings obtained for each tube, and choose tubes whose average readings fall between 48 and 52.

Note—The guarantees made on the instrument are valid only if the adjustments made at the factory are not changed, and provided the instrument has not been mishandled or subjected to abuse.

COMMERCIAL RADIO EQUIPMENT CO. FREQUENCY MONITOR

59. Audible Heterodyne Frequency Monitor—The following is a description of the type FM-1A Frequency Monitor of the audible heterodyne type marketed by the Commercial Radio Equipment Company. This instrument is intended for use by police, aeronautical and other similar services, other than broadcasting, so as to permit compliance with Sec. 23.05 of the Federal Communications Commission. It is designed for operation on frequencies between 100 and 5000 kilocycles. External connections permit connections to a visual frequency meter. The description and principle of operation are quoted directly from the instruction book furnished with the instrument by the Commercial Radio Equipment Company.

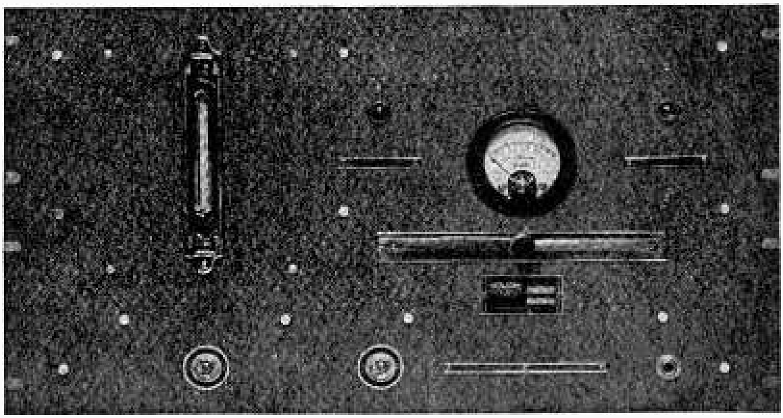


FIG. 308. FM-1A Frequency Monitors—Commercial Radio Equipment Co.

COMMERCIAL RADIO EQUIPMENT CO.

FM–IA FREQUENCY MONITOR INSTALLATION INSTRUCTIONS

60. 110 V. a.c. Connections—The unit is designed for operation on a supply source of 110 v. a.c. 60 cycles and is completely a.c. operated, including relay. The method of connecting the 110 v. source to the unit is as follows: In the rear of the unit, lower than the relay and slightly to the right is a four prong socket. The two 110 v. leads are brought up to the two filament prongs of the socket (the two larger holes). To the left of this socket and below the relay will be found the fuse block for the unit. This fuse should be of at least a 3 ampere rating.

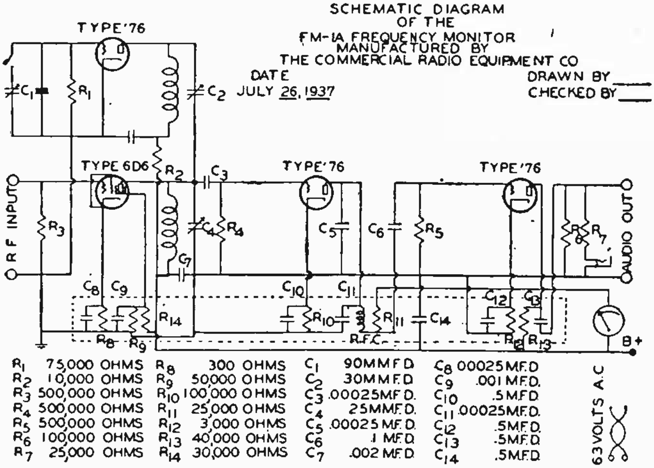


FIG. 309. FM–1A Frequency Monitor Schematic Diagram.

61. R.F. Pick-up Coil—To the left of the fuse block just mentioned will be found two stand-through insulators. These are the two connections to the external r.f. pick-up coil which introduces the transmitter voltage into the frequency monitor. The external coil should consist of a few turns of wire on a form having a diameter of from 1 to 3 inches which should be inductively coupled (loosely) to either the crystal oscillator plate tank circuit or the tank of the first buffer stage. Under no conditions can this coil be coupled to the modulated stage or any linear amplifier stage following modulation as modulation will destroy the audio heterodyne beat note which is heard in the headphones when operating properly and coupled to some stage prior to modulation. The number of turns on the r.f. pick-up coil as well as the proper degree of inductive coupling will vary with individual operating conditions. Just enough coupling should be had to provide a comfortably loud signal in the headphones. The two leads from the r.f. pick-up coil to the r.f. input connections should be encased in shielded cable that is well grounded. The milliammeter should read just about the same with the transmitter input coupled into the unit as when the crystal is oscillating by itself—that is, a little over half scale.

62. **Headphones**—The jack located on the lower right hand side of the front panel is the jack connected for headphones. Any standard high impedance headphone set can be used.

63. **Controls**—There are two toggle switches located on the front of the panel. The switch located under the thermometer guard is in the heater circuit of the oven. It should be left on continuously. The second switch is located just to the right of this heater switch directly under the green pilot light. This switch controls the filament and B supply for the crystal oscillator, r.f. buffer, detector and amplifier tubes of the unit and should only be in the " On " position when the unit is being used to check a station. Thus the green pilot light when on indicates that the unit is ready for making a measurement. The red pilot light to the right of the meter is the indicator for the operation of the heaters and thermostat. It will operate intermittently when the oven in functioning properly. The milliammeter is in the cathode circuit of the detector and reads plate current of the detector tube. Without the crystal oscillating (the crystal within the unit itself) this value will be quite low, between .1 and .2 ma., but with the crystal oscillating it will rise to about half scale.

64. **Operating Temperature**—The normal operating temperature of the oven is approximately 50 degrees centigrade although this will vary somewhat with each oven as the individual thermostats, because of their fixed temperature adjustment are not set exactly to 50 degrees. The normal operating temperature of any of the ovens will lie somewhere between plus-minus 2 degrees centigrade of 50 degrees. Each oven will hold its normal operating temperature to within plus-minus one degree centigrade, even under extreme changes of ambient temperature and where the room temperature will not change widely the operating temperature of the ovens will remain within a few tenths of a degree of the mean operating temperature.

65. Instructions for Operation—The unit is simple to operate when installed properly and the input voltage from the r.f. stage prior to modulation is properly balanced with the input voltage from the crystal oscillator within the unit. This is accomplished by proper choice of r.f. external pick-up coil size and coupling.

With the 110 v. a.c. connections properly made and the switch under the thermometer to the "On" position the red pilot light will operate, indicating that the heaters in the oven are operating. When first turning on the oven the red pilot light will remain on for about one-half hour and thereafter the "heat cycle" of the oven will be about one minute on and one minute off, although this will vary somewhat with ambient room temperature.

If the operation of the thermostat is erratic, and the temperature of the oven does not settle within plus-minus two degrees of the 50 degree centigrade reading on the thermometer it is quite probable that either the thermostat or the thermometer has an air bubble in the capillary, which of course must be removed. It is best to thoroughly inspect each before installation for such troubles as vibration in shipping is apt to cause the formation of these air bubbles.

Evidence of crystal oscillation of the crystal in the unit can be noted by observing the reading of the milliammeter which is in the cathode of the detector circuit. Shorting the grid terminals of the crystal holder to the aluminum framework will cause the meter reading to drop if the crystal is oscillating as this stops oscillation of the crystal and reduces the input voltage from the crystal oscillator circuit to zero. This test should be done without the transmitter in operation or coupled to the unit while in operation.

The FM–1A Frequency Monitor operates on the principle of heterodyne action. The r.f. voltage from the oscillator in the unit is mixed with the r.f. voltage from the transmitter carrier at the grid of the detector in the unit and an audio beat note is created, the frequency of which is the difference in frequency between the monitor crystal frequency and the transmitter crystal frequency. Thus an audio beat note is heard in the head-phones if the difference or beat-note frequency lies between 16 and 10,000 cycles, the upper and lower limits of audibility; when the heterodyne is less than 16 c.p.s. no distinct tone can be heard in the headphones—down to about nine c.p.s. the sound in the headphones is an audio "flutter," below nine c.p.s. the sound in the headphones can hardly be heard, but pronounced swinging of the milliammeter will occur and these beats of the meter can be counted up to about six c.p.s.

Since the audio note occurring in the headphones is only the difference frequency and will exist whether the transmitter frequency is higher or lower than the monitor's crystal some means must be determined to ascertain whether the transmitter frequency is higher or lower than the monitor's frequency. This is tested by switching in the condenser C_1. This is accomplished by means of the non-locking push switch located on the chromium plated strip just under the meter. The monitor has been calibrated with this switch in its normally undisturbed position. By pressing in on the switch the frequency of the monitor is automatically lowered about 100 c.p.s., and consequently a change in the frequency of the beat note will be heard. By this means the operator can tell whether the transmitter is higher or lower than the monitor frequency. If, on pressing the push-button switch, the audio beat note is increased to a higher tone then the transmitter frequency is *higher than the station's assigned frequency,* and if, instead the frequency of the audio beat note is lowered then the transmitter frequency is *lower than the station's assigned frequency.* Since the frequency stability of the monitor is far within the limits required of the Federal Communications Commission for this type of service, if the transmitter is held to within a very low beat note value of the order of 100 to 200 c.p.s. then assurance is had that the station is operating within the limits specified by the Commission.

Should it be desired to know the exact deviation in c.p.s. of the transmitter frequency the audio beat note in the headphones can be compared with the output of a calibrated audio oscillator or to tones of a piano, the frequencies of which are known quite accurately.

65. General Radio Type 775-A Frequency-Limit Monitor—A functional diagram of the Type 775-A Frequency-Limit Monitor is shown in figure 310-*A*. The instrument consists of a highly stable quartz-controlled monitoring oscillator which produces a voltage rich in harmonics, a detector which mixes the transmitter frequency and a harmonic of the local monitoring frequency to produce a low-frequency beat note, and a frequency-discriminating circuit which lights a warning lamp when the beat frequency departs from a value of 6.5 kc. by more than a predetermined amount.

Provision is made for the use of four separate crystals to monitor four different frequencies. The quartz plates are of the low-temperature-coefficient type and are protected against large changes in ambient temperature by a simple temperature-control system which maintains the compartment temperature at 50° C. ± 3° C. An individual tuning condenser for each crystal is mounted on the panel and a selector switch on the panel simultaneously switches the quartz plate, tuning condenser, and input circuit when different transmitter frequencies are to be monitored.

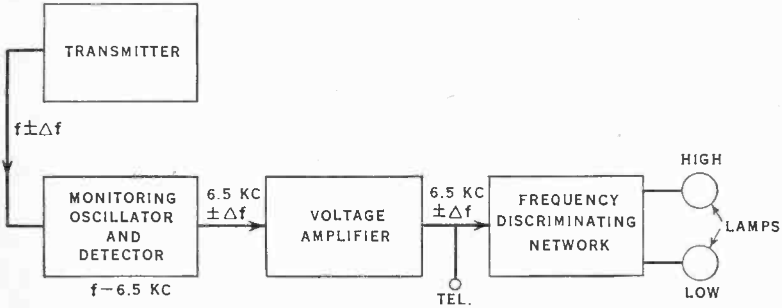


Fig. 310, A. Functional Diagram Showing the Operation of the Frequency-Limit Monitor.

An electron-ray tube is used to indicate when the local monitoring oscillator is correctly adjusted. By means of a switch mounted on the panel, it may also be connected to indicate when the correct input from the transmitter is obtained. The accuracy of the instrument is not critically affected by either local oscillator adjustment or input voltage.

The dial on the panel used to set the accuracy limits is engraved for frequency deviations from ± 500 cycles to ± 3000 cycles.

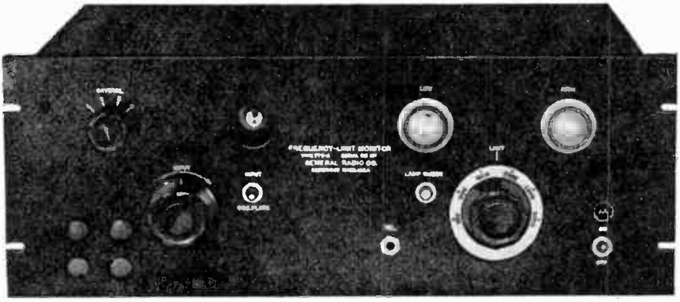


Fig. 310, B. General Radio Frequency-Limit Monitor.

With this span of adjustment the frequency range of the instrument is as indicated in the following specifications:

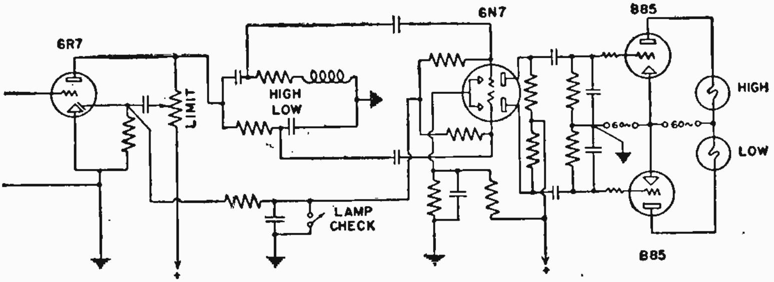


FIG. 310–*C*. Schematic Wiring Diagram of the Limit-indicating Section of the Frequency-limit Monitor.

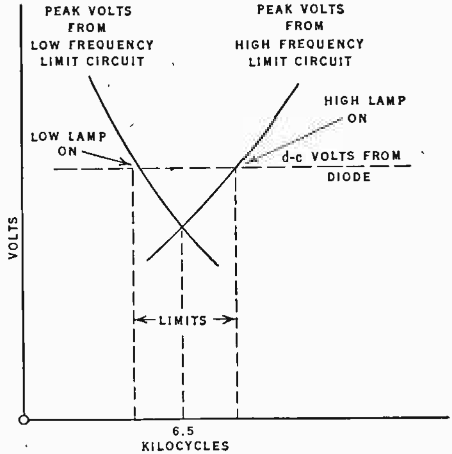


FIG. 310, D. Voltage-Frequency Characteristic of the Frequency Discriminating Circuits.

Frequency Range—

For limits of 0.10%: 1500–3000 kc.
For limits of 0.05%: 1500–6000 kc.
For limits of 0.04%: 1500–7500 kc.
For limits of 0.03%: 1700–10,000 kc.
For limits of 0.03%: 2500–15,000 kc.
For limits of 0.01%: 5000–30,000 kc.

Accuracy of Monitoring Frequency—The absolute accuracy is 0.003 percent when using Type 376–M Quartz Plate.

Stability of Monitoring Frequency—The frequency stability is 0.001 percent over long periods of time.

Quartz Plate—Type 376–M Quartz Plates are to be used with this instrument and must be ordered separately.

Accuracy of Frequency Discriminating Network—When operated at proper input voltage, the warning lamps will light at frequencies which are within 200 cycles 10 per cent of the LIMIT dial reading.

A simple push-button switch on the panel is provided for routine checking of the instrument under operating conditions. Once installed and put in proper operation, no further adjustments are necessary except for changing the LIMIT dial when switching from one frequency to another.

The instrument is entirely self-contained. It may be operated from any 110–120 volt, 40–60 cycle line.

The beat-frequency voltage obtained from the detector is impressed upon the grid of the 6R7 duplex-diode-triode. The a.c. plate voltage of the 6R7 is developed across the frequency-discriminating circuit, the characteristics of which are shown in figure 310–*D*. The voltage obtained from each branch of this circuit is fed to a grid of the 6N7 dual triode, which is biased to cut-off. Each plate of the 6N7 feeds a gas triode which has a warning lamp in its plate circuit. In shunt with the frequency-discriminating circuit is a potentiometer which is used to obtain a fraction of the total a.c. plate voltage. This voltage is rectified by one of the 6R7 diodes and used to bias the grids of the 6N7 beyond their normal cut-off voltage. The d.c. bias, controlled by the setting of the LIMIT dial, determines the frequency at which the lamps will light. When an a.c. voltage on either grid exceeds this bias, plate current flows, tripping one of the 885's and lighting a warning lamp. So long as the transmitter frequency remains within the assigned limits, both lamps remain dark. If the transmitter frequency increases beyond the assigned accuracy limit, one warning lamp lights. If the transmitter frequency decreases beyond the assigned accuracy limit, the other lamp lights.

CHAPTER 9

ANTENNA RESISTANCE AND FIELD STRENGTH MEASUREMENTS

1. Antenna Resistance Measurements—If the antenna resistance is known it is helpful in determining the efficiency of the transmitter. Antenna resistance comprises three distinct resistances which are measured in ohms. They are radiation, ohmic and dielectric absorption.

Radiation resistance is the most useful. Energy lost by this resistance is instrumental in producing the signal at a distant station. Therefore, it is this quantity multiplied by the square of the antenna current that determines the power of the radiated waves.

The power delivered to an antenna is equal to the square of the antenna current multiplied by the effective resistance. The resistance must be measured at the same part of the antenna as the current. Thus it can be seen that by comparisons of the power delivered to an antenna to the power that is actively radiated it is possible to determine the efficiency of the radiating system.

Radiation resistance of an antenna depends upon its effective height, shape and the frequency at which it operates. It is at a maximum at the fundamental and decreases rapidly as the antenna is loaded.

Ohmic resistance is not useful. It is due to heat losses by the current flowing in the antenna wires, ground wires, and condensers comprising the open circuit. The value of this resistance remains practically constant over the whole range.

Dielectric absorption also represents another power loss. It is due to imperfect dielectrics within the field of the antenna such as masts, guys, trees and if on shipboard the smoke stack of the vessel. The value of this resistance increases in proportion as the antenna is loaded.

For the practical purpose of securing the power input to the antenna the three resistances are combined and called the total antenna resistance.

Figure 311 shows how the different resistances are distributed for an antenna having a fundamental wavelength of 300 meters.

The curves represent: (1) Radiation resistance, (2) ohmic resistance, (3) dielectric absorption, (4) total or effective resistance. However, measured curves often differ greatly from curve 1 and may be difficult to analyze into the components 2, 3 and 4.

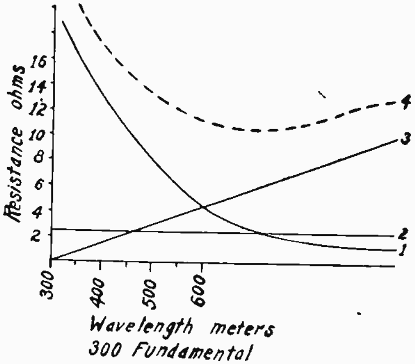


FIG. 311. Antenna Resistance Curves.

2. The Variation Method—The variation method of antenna resistance measurement is accomplished by inserting a standard or known value of non-inductive resistance in series with the antenna and ground and noting the change in the antenna current ammeter. The circuit arrangement for such a measurement is shown in figure 312. It will be noted that the antenna coupling and loading inductance (if used) are in the circuit also a variable condenser so as to permit measurements above as well as below the fundamental frequency of the antenna. The shielded terminal of the condenser should be connected to the ground.

In order to measure the resistance at the fundamental frequency of the antenna the natural period of the antenna system must be found. This is done by connecting the antenna directly to the ground or counterpoise. If a grid current milliammeter is included in the driver circuit a pronounced dip of the needle will be indicated when the driver is in resonance with the natural frequency of the antenna system. If an antenna milliammeter is included in the antenna circuit it should indicate its maximum deflection when the grid meter makes its lowest dip. The deflection of the grid meter should be gradual as resonance is approached on either side. A very sharp dip of the needle with a sudden turn to its normal position indicates too close coupling between driver and antenna circuit. The coupling should be still further loosened until there is absolutely no reaction between the two circuits. A powerful driver separated by several feet from the antenna is necessary if accuracy is desired.

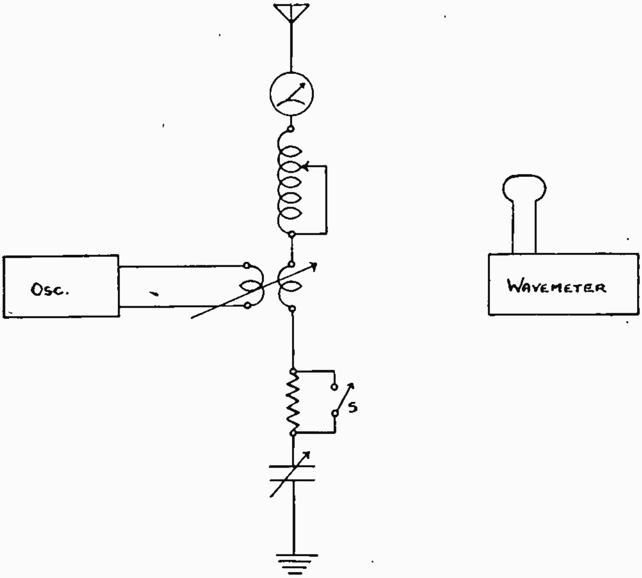


Fig. 312. Arrangement for Antenna Resistance Measurement by the Variation Method.

After determining the fundamental frequency of the antenna its resistance at this frequency can be measured.

The antenna current at resonance is noted and then the known resistance is put in series with the circuit and the antenna current read again. The power output of the oscillator should not be disturbed when the known resistance is inserted in the circuit. The antenna resistance in ohms is obtained from the formula,

$$R_a = \left(\frac{I_k}{I_a - I_k}\right) R_k,$$

where I_a is the antenna current with R_k the known resistance short-circuited or out of the circuit, and I_k is the antenna current with R_k in the circuit.

Having determined the resistance of the antenna at its fundamental or natural period the loading and coupling inductors and tuning condenser should be tied-in and a measurement made at the operating frequency. Measurements should be made at 5 kilocycle intervals, 30 kilocycles above and below the operating frequency. A curve should then be plotted as shown in figure 311. Humps in the curve are indicative of resonance circuits within the field of the antenna.

Extreme care should be exercised to prevent energizing the antenna at points other than at the coupling coil such as might happen if the oscillator is improperly shielded or if stray capacities exist between the coupling link and the antenna circuit.

Laport has described a variation resistance measurement procedure[1] which permits of a high degree of accuracy and permits the operator to determine if stray capacity exists between the measuring circuit and ground. The circuit arrangement is shown in figure 313.

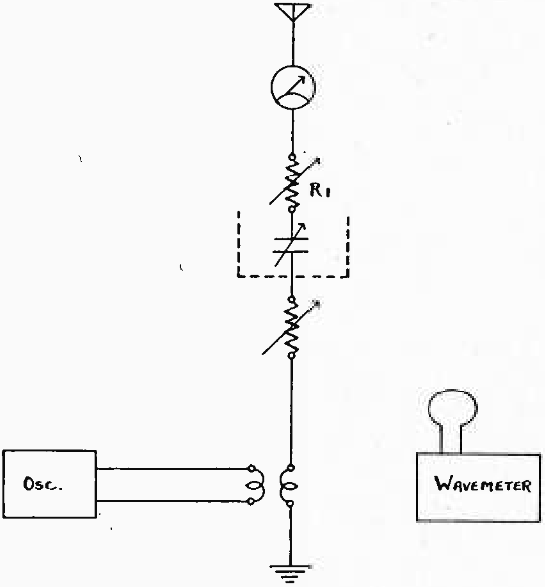


Fig. 313. Two Resistor Method of Antenna Resistance Measurement.

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[1] Laport, Influence of Stray Capacitance. Proceedings I. R. E., May, 1934.

3. **Alternate Variation Method**—Two standard resistors are required. The tuning condenser should be a precision calibrated condenser for reactance measurements as per Federal Communications Commission's requirements. The shielded terminal of the condenser should be connected to R_2. Measurements are made as follows: R_1 and R_2 are set at zero resistance. The circuit is tuned to resonance by the condenser C_1 as evidenced by maximum antenna current. Some adjustment of the exciting voltage may be necessary to obtain a convenient deflection of the ammeter. When exact resonance is found, known values of resistance R_1 are cut in and the antenna current noted and the resistance computed from the formula shown in the description of the first method. Then R_1 is set at zero resistance and similar measurements made using R. If there is no appreciable stray capacitance between the measuring circuit and ground the resistance values given by R_2 will agree with those obtained using R_1, but if there is an appreciable amount of stray capacitance, the two sets of measurements will not agree. The arrangement of the instruments should then be changed and measurements made until the two are in substantial agreement.

The truest results will always be obtained by using resistance R_1 and the final measurements made with this resistance.

The reactance of the circuit at the point where the resistance was measured can be determined from the calibration of the condenser at the resonance setting or

$$X_c = \frac{1}{2\pi fc},$$

where f = resonance frequency and c the capacity of the condenser at resonance.

When an inductance is also used in the measuring circuit, the net resultant reactance of the tuning elements will be equal to the antenna reactance.

Considerable care is necessary when making measurements of high impedance antennas, especially those close to a half wave.

4. **Substitution Method**—Measurements of an antenna resistance by the substitution method as the name implies consists of the substituting for the antenna an artificial antenna, comprising inductance or capacity and resistance. The inductance employed to couple to the transmission line or final amplifier and any inductance necessary for loading should be used in the antenna circuit, thereby permitting a more accurate determination of the total antenna resistance. It is assumed that the antenna is resonant

at the working frequency. Since at resonance the reactance has been made equal to zero by use of the antenna tuning means, only resistance remains and therefore the dummy circuit may also consist of a pure resistance.

A radio frequency generator variable in frequency and with at least 50 watts output is required to drive or energize the dummy

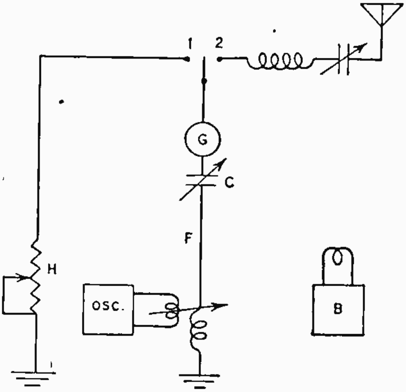

FIG. 314. Arrangement for Antenna Resistance Measurement by Substitution Method (see text).

circuit. The circuit arrangement of apparatus is shown in figure 314.

It is imperative when making measurements that the apparatus be arranged so that no energy is coupled into the antenna circuit by stray capacities, otherwise, erroneous results will be obtained. In particular the oscillator must be well shielded so that stray coupling between the antenna and oscillator tank circuit is small as compared with the direct coupling employed to energize the antenna. The antenna energizing current should be as high as practicable for a given oscillator. This precaution is particularly important if the oscillator does not possess adequate shielding.

It will be noted in the requirements stipulated by the Federal Communications Commission that a wavemeter is required having an accuracy of 0.25 percent. The wavemeter, either of the absorption or heterodyne frequency type is required to adjust the driving oscillator to the operating frequency and the other frequencies both above and below the operating frequency, at which additional measurements are required.

The resistance at the operating frequency is determined by adjusting the oscillator or driver to the operating frequency and coupling the output to the antenna circuit and recording the antenna current as I_a. The antenna and ground are disconnected and the antenna inductances connected to the calibrated variable condenser C and resistance H. The output of the oscillator is kept constant and the condenser adjusted until the dummy circuit is resonant at the operating frequency as determined by the wavemeter. The resistance H is then varied until the ammeter current is the same value as that when the antenna and ground were connected. The value of the resistance is then equal to the antenna resistance and the reactance of the antenna is equal to the dummy condenser reactance.

5. **Other Use of Dummy Antenna**—The dummy antenna circuit is also useful for testing purposes without the necessity of radiating a carrier wave. To find out what antenna current to expect when 500 watts of power was delivered to an antenna having a resistance of 10 ohms. Substituting in the formula

$$I^a = \sqrt{\frac{P}{R_a}},$$

or

$$I^a = \sqrt{\frac{500}{10}} \quad \text{or} \quad I^a = 7.07 \text{ amperes,}$$

P = Desired antenna power,
R_a = Antenna resistance,
I^a = Antenna current.

Another example of the use of these values is as follows: Suppose it was desired to adjust the same transmitter to 750 watts output at the same wavelength. The transmitter should be adjusted until the dummy antenna current is 8.66 amperes.

$$I^a = \sqrt{\frac{P}{R_a}} \quad \text{or} \quad \sqrt{\frac{750}{10}} \quad \text{or} \quad I^a = 8.66 \text{ amperes.}$$

Proof:
Watts in antenna = $I^2 \times R$,
Watts in antenna = $8.66^2 \times 10$,
Watts in antenna = 749.9.

If 750 watts were put into the antenna and 450 watts were shown as energy lost by radiation the remaining 300 watts would be lost in heating the wires, ground connection, dielectric absorption, surrounding the wires and by eddy currents induced in nearby wires and metal masts.

The artificial or dummy antenna built-in modern broadcast transmitters is also useful for making modulation tests and frequency runs.

FIELD STRENGTH MEASUREMENTS

6. Purpose—The measurement of radio field intensity enables one to determine the distribution of the field in various directions from the antenna system of a given transmitting station. In the case of a broadcasting station it shows the service area of broadcasting stations. It also shows the effects produced by locating stations in cities on or near large steel structures and the effects produced by locating stations in the open country away from steel structures or electrical networks. From the results of such measurements one may choose a desirable location for a transmitter in order to serve a certain area. This can be done in conjunction with a portable transmitter and field strength measuring apparatus.

7. Unit of Measurement—There are several different methods and types of apparatus employed in field strength measurements. The universally adopted unit of measurement is "volt per meter." The unit volt per meter is a large one, and for ordinary purposes it is more convenient to use "millivolts per meter" or "microvolts per meter."

Meter-amperes—The regulations of the International Radiotelegraph Convention require that the normal radiated power of a transmitter be expressed in meter-amperes; or lacking this, the height of the antenna and intensity of the current at the base of the antenna.

The expression meter-ampere is the unit of antenna current moment and is found by multiplying the antenna current by the effective height of the antenna in meters. The effective height is generally about 60 percent of the mean height of the flat top above ground.

8. Derivation of "Millivolt Per Meter"—When oscillations are set up in an antenna there is created an electro-magnetic field surrounding the antenna. This field consists of two distinct parts: First, there is the field of electro-magnetic induction which rapidly dies out and usually cannot be detected at more than a distance of one wavelength or so from the transmitter; second, there is the field due to radiation which represents the energy of wave propagation.

As has been described in the previous chapter, this electro-magnetic field travels with the speed of light. The value of the field strength at moderate distances from the transmitter is given by the formula:

$$E = \frac{188\,hI}{\lambda r} \text{ millivolts per meter,}$$

where h = effective height of antenna in meters,
I = current in antenna in amperes,
λ = wavelength in meters,
r = distance in kilometers.

The effective height is defined as the height of a vertical single wire having the same amount of current throughout its whole length, and giving the same field strengths at given distances. In the case of a transmitting antenna with one end grounded the current is unevenly distributed being at a maximum at the base and decreasing with height and reaching a minimum at the extremity. By keeping the effective height as high as possible a more even distribution of current is obtained and results in a maximum of radiation and therefore more millivolts per meter at a given distance. From the above the actual field strength from a transmitter at any given distance can be computed, provided there is no absorption of energy nor interference by waves bent back to earth from an ionized layer.

Actually there is absorption of the ground wave and a factor must be introduced depending on the wavelength, and on the nature of the ground and what is on it over which the wave travels. In the case of absorption the radiated energy is conducted to ground and therefore lost as far as being of any practical use is concerned.

A field strength of 1 millivolt per meter means that the potential difference due to the field between two points a meter apart on the same line of electric force is 1 millivolt. Consequently if a 1-kilowatt transmitter has a field strength of 20 millivolts per meter at a distance of five miles and a broadcast receiving antenna is erected having an effective height of 5 meters, there will be 100 millivolts of energy available for the receiver. The more sensitive the receiver, the greater will be the volume delivered by the loud speaker for a given signal strength.

9. **Apparatus and Methods of Measurement**—As previously mentioned, there are several different methods of measuring the strength of radio signals. Usually, the actual voltage across a given antenna is measured by the substitution method, which consists of substituting for the received signal a known locally-generated signal identical in frequency to the signal and of such magnitude as to produce the same receiver output as that

resulting from the received signal. Under these simulated conditions, the known locally-generated e.m.f. is equal to the voltage induced in the antenna by the signal. Usually, a loop antenna is employed with a superheterodyne receiver. The field strength is obtained by dividing the induced voltage by the effective height of the loop. (The effective height of a loop is defined as the height of an equivalent vertical wire having the same induced voltage.)

The magnitude of the locally-generated e.m.f. is usually obtained by passing a known current through a known impedance inserted at the loop center. The known impedance must be non-inductive so as to be independent of frequency and its value kept as small as possible. The minute known currents are obtained by attenuating measurable currents by known amounts through the use of suitable circuits. This system requires separate and thorough shielding between the local oscillator and the attenuating circuit in order to eliminate "pick-up" comparable in signal strength to the small induced voltage.

As shown by Friis and Bruce, in their paper entitled "A radio field-strength measuring system for frequencies up to forty megacycles," Proceedings of Institute of Radio Engineers, Volume 14, August, 1926, considerable advantage is obtained if a voltage of sufficient magnitude measurable by means of a tube voltmeter, is induced into the loop from the local oscillator. In conjunction with this, a voltage attenuator could be located elsewhere in the receiver proper. This would eliminate the undesirable "pick-up" from the local oscillator by the attenuator circuit and minimize the necessity of elaborate shielding of the oscillator.

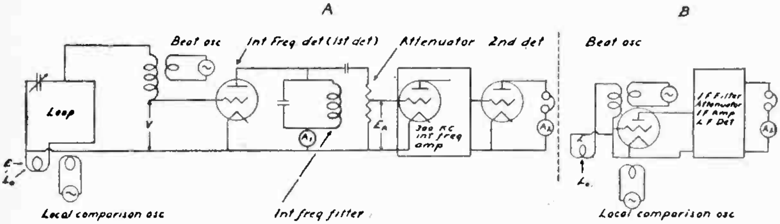

FIG. 315. Diagram of Field Strength Measuring Apparatus.

This paper says, "furthermore, the search for an appropriate location for the voltage attenuator, beyond the loop, revealed the desirability of placing it on the output of the intermediate-frequency detector of a double-detection (super-heterodyne) scheme, with due regard for the limits of overloading of this tube. The importance of this arrangement should be emphasized. It means that the attenuator need operate at only the fixed intermediate frequency. Since this frequency has been selected as 300 kilocycles, great accuracy is possible without elaborate attenuator design, regardless of the signal frequency."

The intermediate frequency detector also serves a tube voltmeter actuating the d.c. plate circuit meter. The gain control or voltage attenuator is calibrated directly in voltage ratios; thus, a reading of 10,000 indicates that the input voltage to the attenuator is 10,000 times larger than the output voltage.

The procedure of operation of the apparatus shown in figure 315 is as follows:

TABLE OF PROCEDURE

		Attenuation Ratio of Attenuator
I.	The receiving set is tuned to the incoming signal. The attenuator is adjusted until a convenient output deflection is obtained. This deflection is noted.	a_1
II.	(1) The local comparison oscillator is started and tuned to resonance with the receiving set.	
	(2) The attenuator is adjusted to make the output the same as in *I*.	a_2
	(3) The input V to the grid of the intermediate frequency detector is determined (beating oscillator is off during this measurement).	
III.	(1) The grid of the intermediate frequency detector is connected through L_0 to the local oscillator input.	
	(2) The attenuator is readjusted to make output the same as in case I.	a_3

From this table we have

Voltage across half of the loop due to incoming signal $= \dfrac{V}{\dfrac{a_2}{a_1}}$ volts.

Loop voltage step-up (the ratio of half of the loop terminal voltage to the induced voltage) $= B^* = \dfrac{a_2}{a}$

Voltage induced in loop by comparison oscillator $= E = \dfrac{V}{B}$ volts.

Voltage induced in loop by incoming signal $= \dfrac{V}{\dfrac{a_2}{a_1} B}$ volts.

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* $B =$ magnetic flux density.

It should be noted here that it is entirely unnecessary for the transmitter of the incoming signal to stop while measurements are being made.

As the paper progresses the authors discuss some refinements in the accurate measurement of the voltage set-up B of the loop.

The following is a description of a commercial field strength meter.

R.C.A. TYPE TMV–75–B FIELD METER

The Field-Intensity Meter, Type TMV–75–B, is capable of measuring field strengths throughout an intensity range of from 20 to 5,000,000 microvolts per meter at any frequency within the limits of 515 and 20,000 kilocycles. An independent calibration standard forms an integral part of this instrument, insuring results of the greatest possible accuracy. Field intensity measurements properly performed will be accurate to within five percent over the entire frequency range. The frequency calibration of the instrument is not permitted to deviate more than five percent in the factory alignment process.

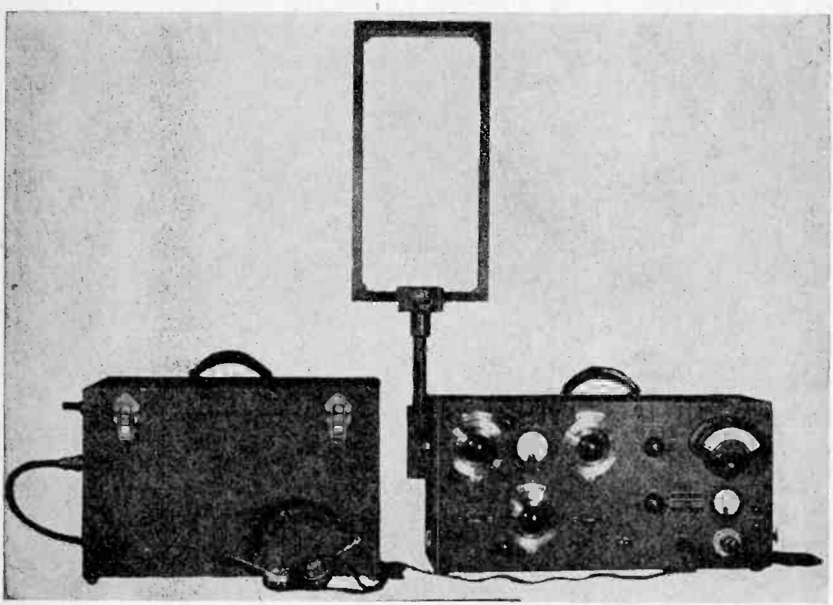

FIG. 316. RCA Type TMV–75–B Field Intensity Meter.

10. Theory of Operation—The theory of the superheterodyne receiver is well known and so will not be discussed here except as involved in deriving the formula for computation of field intensities from readings of the instrument.

When a loop antenna is placed in a magnetic field, a voltage is induced in its circuit. The magnitude of this voltage is dependent upon the strength of the field, the effective height of the loop and the angle between the field and the loop. When the loop is directed so as to give maximum induced voltage, this induced voltage may be expressed by the formula:

$$e = F \cdot h, \tag{1}$$

where e = induced voltage in microvolts,
F = field intensity in microvolts per meter,
h = effective height of the loop antenna in meters.

If a variable capacitor is placed across the loop antenna and the circuit tuned to resonance with the frequency of the field, a voltage will appear across the loop antenna and condenser greater than the induced voltage by an amount termed here the "step up" of the loop, and expressed by the symbol Q. The voltage (E) across the loop antenna in the magnetic field thus may be expressed by the formula:

$$E = Q \cdot e = Q \cdot F \cdot h \tag{2}$$

Since the loop must be balanced to ground in order to prevent antenna effects, only one-half of the actual voltage (or $E/2$) is impressed on the grid of the first detector and thence combined with the heterodyne oscillator. There will now appear across the plate load of the first detector a voltage of intermediate frequency (300 kc.) whose amplitude is dependent both on the voltage $E/2$ and a constant (the conversion conductance of the first detector tube) designed as M_d. The circuits associated with the first detector are so designed as to make this quantity (M_d) constant for any input voltage ($E/2$) over the range of the instrument at any given frequency, and as nearly constant as possible for all frequencies without overloading any of the associated tubes.

The voltage (E_d) fed to the intermediate-frequency amplifier is, therefore:

$$E_d = \frac{E}{2} \cdot M_d = \frac{Q \cdot F \cdot h \cdot M_d}{2}. \tag{3}$$

The voltage (E_d) is impressed across a resistance attenuator network where it may be attenuated by any amount up to 50,000 (in steps of 4 and 5) such that the attenuation factors are 1, 5, 20, 100, 500, 2000, 10,000 and 50,000. The attenuated voltage is impressed on the grid circuit of the first tube of the three-stage intermediate-frequency amplifier. The gain of this amplifier may be varied by means of a potentiometer type control between rather wide limits. The gain at any constant setting will be designated by M_a and the setting of the attenuator will be designated by A_1, A_2, etc. The output voltage of the i.f. amplifier is measured by means of a d.c. microammeter and a diode rectifier. Because of the fact that the diode rectifier is not a true linear device, the meter scale is calibrated so that its readings are directly proportional to the output voltage. The output of the i.f. amplifier will be designated as R_1, R_2, etc.

Thus, $R = \dfrac{E_d \cdot M_a}{A}$ and from (3),

$$R = \frac{F \cdot h \cdot Q \cdot M_d \cdot M_a}{2 \cdot A} \tag{4}$$

or

$$F = \frac{2 \cdot R \cdot A}{h \cdot Q \cdot M_d \cdot M_a}. \tag{4a}$$

In order to calculate the field intensity giving the reading R, it is necessary to know the values of "h," "Q," "M_d," and "M_a." To find these values, it is necessary to calibrate the instrument. If a known voltage "V" is induced in the loop circuit, it will be possible to calculate a value which will include all of these constants with the exception of "h" which is known from the physical dimensions of the loop. This voltage is introduced in the loop circuit by means of a mutual-inductance attenuator.

The mutual-inductance attenuator consists of two self-inductances, inductively coupled to each other and shielded to prevent any capacitive coupling. The primary or larger inductance is fed with current from the calibrating oscillator and the voltage across the coil is measured by means of a thermocouple voltmeter. The secondary or smaller coil is connected in series with the loop antenna, the loops being opened at their electrical center so that one side of the secondary (as well as one side of the primary) of the mutual inductance will be at ground. The secondary voltage (V) is proportional to the primary current and the mutual inductance between the two coils, being expressed by the equation:

$$V = 2 \cdot \pi \cdot f \cdot I_p \cdot L_m \tag{5}$$

and since the primary voltage

$$(E_p) = 2 \cdot \pi \cdot f \cdot I_p \cdot L_p \qquad \text{or} \qquad I_p = \frac{E_p}{2 \cdot \pi \cdot f \cdot L_p}, \tag{6}$$

then

$$V = \frac{E_p}{L_p} \cdot L_m. \tag{7}$$

Since L_m and L_p are constants, it follows that if E_p is held constant, the secondary voltage (V) also will be constant irrespective of frequency. We thus have a known constant voltage source as long as the primary voltage is held constant by means of the thermocouple voltmeter across the primary coil.

With the voltage "V" introduced in the loop circuit as outlined above, there will be impressed on the grid of the first detector a voltage equal to $VQ/2$ which will produce an output reading (R) proportional to "M_d," "M_a," and "A." Thus,

$$R = \frac{V \cdot Q \cdot M_d \cdot M_a}{2 \cdot A}. \tag{8}$$

To calibrate the instrument, we will choose certain calibrating values as follows:

$$R = R_1,$$
$$V = V_1,$$
$$A = A_1,$$

and will adjust "M_a" so that these conditions may be met at this frequency. Then, from (8):

$$R_1 = \frac{V_1 \cdot Q \cdot M_d \cdot M_{a1}}{2 \cdot A_1}$$

or

$$\frac{2 \cdot A_1 \cdot R_1}{V_1} = Q \cdot M_d \cdot M_{a1}. \tag{9}$$

If now we place the loop of the instrument in an unknown field of field strength "F" and allow the gain of the i.f. amplifier to remain "M_{a1}," but vary the attenuator setting to A_2, the output reading will be some value R_2; from (4a), therefore:

$$F = \frac{2 \cdot R_2 \cdot A_2}{h \cdot Q \cdot M_d \cdot M_{a1}} \tag{10}$$

and substituting (9) in (10):

$$F = \frac{2 \cdot R_2 \cdot A_2 \cdot V_1}{2 \cdot h \cdot A_1 \cdot R_1}, \qquad (11)$$

from which the field strength may be calculated since all quantities except " F " are known.

By collecting the terms of the calibrating conditions, this formula may be simplified to the form:

$$F = \frac{R_2 \cdot A_2 \cdot K}{h}, \qquad (12)$$

where

$$K = \frac{V_1}{A_1 \cdot R_1}.$$

This formula can be simplified still further by substituting therein the formula for the effective height of a loop antenna:

$$h = 2 \cdot \pi \cdot f \cdot S \cdot N \cdot A$$

where S = a constant,
N = number of turns,
A = area enclosed by the loop.

For any given loop, this becomes

$$h = S'f \qquad (13)$$

and substituting (13) in (12):

$$F = \frac{R_2 \cdot A_2 \cdot C}{f} \qquad (14)$$

where

$$C = \frac{K}{S}.$$

The value " C " is calculated for each loop so that calculation of field intensities from " R_2 " and " A_2 " are very simple, " f " being a known and constant quantity for any measurements such as when making a station survey or recording fading. It must be remembered that the quantities " Q " and " M_d " are not constants with respect to frequency so that the instrument must be recalibrated for each different frequency if the frequency difference is greater than a few percent. Frequency changes up to five percent do not affect these quantities appreciably.

In order that the higher field intensities may be measured, it is necessary first to attenuate the voltage across the loop to prevent overloading of the first detector. This is accomplished by placing a capacitance attenuator in the grid circuit of the first detector. This attenuator may be placed in or out of the circuit as desired. No attempt has been made to keep the attenuation ratio of this unit constant with respect to frequency so that when making measurements with this unit in the circuit, it will also be necessary to calibrate under like conditions.

When calibrating with the input attenuator in the circuit (position L), the i.f. attenuator must be set on a different position than when the input attenuator is disconnected (position H). The field strength calculated by (14) therefore must be multiplied by the ratio of the previous i.f. attenuator setting for calibration to the new i.f. attenuator calibration setting.

11. **Operation**—*Set-up*—The field-intensity meter should be set up for operation in the following manner:

1. Connect the instrument to the batteries in the carrying case by means of the battery cable.

Note—To conserve the batteries, it is recommended that this cable be shortened by the customer to a length consistent with practical requirements, thereby minimizing the inherent voltage drop.

2. Insert the plug-in coils and loop antenna which are designed for the frequency of the signal to be measured.

In special cases where it is necessary to mount the loop antenna at a distance from the field-intensity meter (as for measurements in an automobile), the installation should be referred to the Engineering Department, RCA Victor Co., Inc., Camden, N. J.

Procedure—The complete procedure for measurement consists of three steps as follows:

(1) *Adjustment of Receiver to Frequency*—Turn the power "on" and tune the receiver to the signal to be measured by means of the loop (LOOP TUNE) and heterodyne-oscillator (HET. TUNE) tuning controls. Headphones may be employed to expedite this procedure, using the phone jack (PHONES) on the panel. After the desired signal is located and the receiver accurately tuned, rotate the loop until the signal is at a minimum, then turn the calibrating oscillator (CAL. TUNE) "on" and adjust that oscillator to the frequency for which the receiver is tuned.

Note—The loop tuning range switch (see figure 3) should be set "inward" when using loop A or loop B and "outward" when using loop C or loop D.

(2) *Calibration of the Receiver*—Adjust the (CAL.) knob to a setting where the calibration meter (INPUT) reads "200." With the i.f. attenuator set at "50,000" and the input attenuator switch (SENS) turned clockwise (*H*), adjust the gain of the i.f. amplifier with the (GAIN) control until the OUTPUT meter reads "150."

Note—Since the battery voltages decrease slowly with age, it may be necessary at some time to take measurements with the calibration meter (INPUT) at a lower than prescribed setting. Under such conditions, the OUTPUT meter setting naturally will be lower also but not by the same amount. It will be advisable therefore, at the time new batteries are installed, to obtain several INPUT versus OUTPUT meter readings. Corresponding values may be determined by first performing the normal calibration procedure, then setting the INPUT meter by means of the (CAL) knob at various points and noting the OUTPUT meter readings, making *no* adjustment of the (GAIN) control.

(3) *Measurement of Field Intensity*—Turn the calibrating oscillator "off" and rotate the loop until the signal is again received, then adjust the i.f. attenuator until the output meter reads a convenient value. The field strength is equal to the product of the output meter reading, the attenuator multiplier ratio, and a constant derived from the loop constants, all divided by the frequency in kilocycles at which the measurement is made, as shown by the following formula:

$$\begin{array}{c}\text{Field Strength}\\ \text{(microvolts per meter)}\end{array} = \frac{\begin{array}{c}\text{Meter Attenuator}\\ \text{Reading}\cdot\text{Setting}\cdot C\end{array}}{\text{Frequency (kc)}},$$

$$\begin{aligned}\text{with “}C\text{”} &= 144.3 \text{ for loop } A,\\ &= 532.0 \text{ for loop } B,\\ &= 1687.0 \text{ for loop } C,\\ &= 7617.0 \text{ for loop } D,\end{aligned}$$

Note—When using the instrument with (SENS) control on "*L*," calibrate with the i.f. attenuator set at 2000; to calculate the field intensity under such conditions, multiply the measured results by 25.

In actual practice, it will not be necessary to repeat steps (1) and (2) for measurements at a single frequency when the elapsed time between measurements is short. Where extremely accurate results are not required, field intensities greater than five volts per meter may be measured.

Errors—Errors in the instrument may occur from several different sources and will be discussed in conjunction with measurements made on the component parts of one of these instruments. Perhaps the most serious error possible is that incurred through variation of the calibrating voltage. If any appreciable amount of capacitive coupling exists between the primary and secondary coils or if the secondary coil should resonate within the frequency range of the instrument, the calibrating voltage will not remain constant.

With the coupling adjusted to the proper value, the secondary voltage at various frequencies was compared with a voltage at corresponding frequencies emitted by a standard (Type TMV–18) signal generator. This test indicated that the calibrating voltage is constant (within the limits of normal errors in measurement) over the frequency range of 500 to 20,000 kc. Subsequent measurements of a more exacting nature on similar types of mutual-inductance attenuators enable interpretation of these results to assure an accuracy of at least ± 1 percent, including visual errors in reading the voltmeter.

Next in the order of importance is the error caused by non-linearity of the first detector over a wide range of input voltages. A curve of input voltage versus output voltage starting with an input of a few microvolts and continuing up to 5 volts input shows non-linearity of less than 2 percent; in other words, M_d varies less than ± 1 percent from calibrating to measuring conditions.

Another source of error is found in the attenuation factor of the i.f. attenuator. Measurements of the attenuation ratios show a maximum error of ± 1.5 percent.

An error also may occur in marking or reading the output meter; this, however, will not be greater than one part in 50, 50 being the lowest point on the output meter scale which the operator will be required to read. Thus an error of ± 2 percent may occur at this point in the equipment, and since the errors in marking and reading the scale may be in the same direction, it will be possible to obtain a total error of ± 4 percent. At the point of calibration, however, the error in reading the output meter will be less than ± 1.5 percent, including the calibration error.

Thus through percentage errors of ± 1.5 percent in the output meter, ± 1 percent in the calibrating voltage, and ± 1 percent because of non-linearity in the detector, the gain of the i-f amplifier may be incorrect by 3.5 percent. After calibrating the instrument and while making a measurement, an error of ± 4 percent may occur in the output meter and one of ± 1.5 in the F. attenuator. Thus the maximum error, excluding that produced by improper tuning, is ± 9 percent. The probability, however, that all of these errors will occur in the same direction is extremely small and the average error should be well within ± 5 percent. This fact is borne out by measurements of overall gain made between 15 microvolts and 2 volts input by means of the previously mentioned (Type TMV-18) signal generator. These measurements which include any errors which may occur in the first detector and i-f attenuator (as well as errors in reading the output meter) showed total errors of less than ± 1 percent where in the above calculations we have allowed errors of ± 3.5 percent. Using these measurements as a basis for computing the overall error, the maximum probable error of the instrument will be within ± 2 percent.

Any errors resulting from improper tuning may be eliminated during calibration by adjusting the calibrating oscillator to " zero-beat " with the signal being measured.

F. C. C. Requirements for Direct Measurements of Power by Standard Broadcast Stations[3]

Sec. 3.54 * states that the antenna input power determined by direct measurement is the square of the antenna current times the antenna resistance at the point where the current is measured and at the operating frequency, and sets forth certain requirements relative to the determination of the resistance and measurement of the antenna current.

The Commission does not specify any particular method of making antenna resistance measurements. Measurements made by any standard method will be accepted provided satisfactory evidence is submitted in accordance with the following as to the procedure used, accuracy of the instruments and qualifications of the engineer conducting the measurements.

The resistance variation method, substitution method and bridge method are acceptable methods for measuring the total antenna resistance and the following general instructions are given as a guide.

The apparatus required is as follows:

(*a*) Radio frequency generator to cover the frequency range necessary, power 50 watts or required power when using bridge method.

(*b*) Wavemeter for broadcasting frequency, accuracy 0.25 percent.

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[3] Extracted from the F. C. C. Standards of Good Engineering Practice for Standard Broadcast Stations.

* Rules Governing Standard Broadcast Stations.

(*c*) Decade resistor having steps of units, tens and hundreds ohms resistance, or equivalent, accuracy 1.0 percent.
(*d*) Radio frequency galvanometer or milliammeter of approved type, accuracy 2.0 percent.
(*e*) Approved tuning condenser of approximately 0.001 M.F.D. capacity and tuning inductance of approximately 60 MH.
(f) Or suitable bridge if this method is used.

The broadcast transmitter is not usually satisfactory for use as the source of radio frequencies. The maximum power dissipated in the antenna while making measurements should not be over 10 percent of the power available from the radio frequency generator.

An accurate determination of the antenna resistance can only be made by taking a series of measurements each for a different frequency. From 10 to 12 resistance measurements covering a band 50 to 60 kc. wide with the operating frequency near the middle of the band must be made to give data from which accurate results may be obtained. The values measured should be plotted with frequency as abscissa and resistance in ohms as ordinate and a smooth curve drawn. The point on the ordinate where this curve intersects the operating frequency gives the value of the antenna resistance.

In order to comply with the provisions of Sec. 3.54 the following data should be submitted in duplicate to the Commission in affidavit form, accompanied by duplicate copies of F. C. C. Form 306 properly executed:

1. Complete data taken.
2. The graph drawn.
3. Description of method used to take readings (include schematic circuit diagrams of the measurement circuit and of the antenna system showing point of measurement).
4. Manufacturer's name of each calibrated instrument used and manufacturer's rated accuracy.
5. Accuracy, date and by whom each instrument was last calibrated.
6. Qualifications of engineer making measurements.

Licensees of broadcast stations authorized to employ directional antenna systems desiring to determine the operating power by direct measurement of the antenna power must determine the resistance by one of the following methods:

1. Measure the resistance of each element of the antenna system

with the other element or elements detuned following the procedure specified above.

(*a*) The operating power is determined as the sum of the power in each element, that is, the sum of the square of the current times the resistance of each element (the accuracy of this method is only approximate in any case and in many cases unsatisfactory depending on the operating conditions of the directional antenna).

(*b*) The data and curve on each element must be submitted.

(*c*) A permanently installed antenna ammeter shall be placed in each element of the system with remote reading ammeters[4] located in the transmitter room. The application for authority to determine the power by the direct method shall specify the current in each element at the point of resistance measurements for the authorized input power (I^2R in accordance with Rule 3.54) and the resistance of each element when adjusted for the required pattern and for the authorized operating power as determined above.

2. Measure the resistance at the point of common radio frequency input to the directional antenna system. The following conditions and procedure shall obtain:

(*a*) The antenna shall be finally adjusted for the required pattern.

(*b*) The reactance at the operating frequency and at the point of measurement shall be adjusted to zero or as near thereto as practical.

(*c*) Suitable radio frequency bridge or other method shall be employed to determine the resistance at the point of common radio frequency input in the same manner as set forth above for a single antenna.

(*d*) Ten to twelve resistance and reactance measurements in a band 20 kilocycles wide with the operating frequency near the middle of the band shall be made. The values measured shall be plotted and the resistance at the operating frequency determined in the same manner as for a single element antenna.

(*e*) A permanently installed antenna ammeter shall be placed in each element of the system as well as at the point of measurement of resistance with the remote reading ammeters[5] located in the transmitter room. The application for authority to determine

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[4] In all cases regular antenna ammeters and remote antenna ammeters shall comply with the requirements of Sec. 3.58 and "Indicating Instruments Pursuant to Sec. 3.58."

[5] In all cases regular antenna ammeters and remote antenna ammeters shall comply with the requirements of Sec. 3.58 and "Indicating Instruments Pursuant to Sec. 3.58."

power by the direct method shall specify not only the current at the point of resistance measurement for the authorized input power (I^2R in accordance with Rule 33.6), but also the current of each element of the system when adjusted for the required pattern and for the authorized operating power as determined above.

*Determination of Operating Power by Radiated Power Computed from Field Intensity Measurements[6]

Rule 33.7 requires that applicants for authority to determine the operating power of a standard broadcast station by the radiated power computed from field intensity measurements, shall take and submit sufficient measurements of the field intensity to insure accuracy and shall submit an analysis of the relative distribution of the radiation (i.e. ground and sky wave radiation) including data on the antenna resistance, complete description of the antenna system, method of taking field intensity measurements and method of relating measurements to the operating power.

In compliance with these requirements, the following shall be submitted:

1. Complete description of antenna system.
    - *a.* Type of antenna.
    - *b.* Manufacturer's name and type of tower or towers (i.e. guyed or self-supporting, triangular or square, uniform cross-section or tapered, etc.).
    - *c.* If top loaded, give details.
    - *d.* Height of vertical lead —— feet. (Height above base insulator or base, if grounded.)
    - *e.* Overall height —— feet.
    - *f.* Details of ground system (for each element if directional). (Length and number of radials, dimensions of ground screen if used and depth buried.)
    - *g.* Schematic sketch and description of means of supplying power to antenna, including coupling equipment and antenna ammeter connections.
    - *h.* Antenna current for operation at authorized power determining power by (give for each element if directional):
        1. Direct method.
        2. Radiated power.

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[6] Extracted from F. C. C. Standards of Good Engineering Practice for Standard Broadcast Stations.

* This method of determining operating power is no longer authorized by the F. C. C.

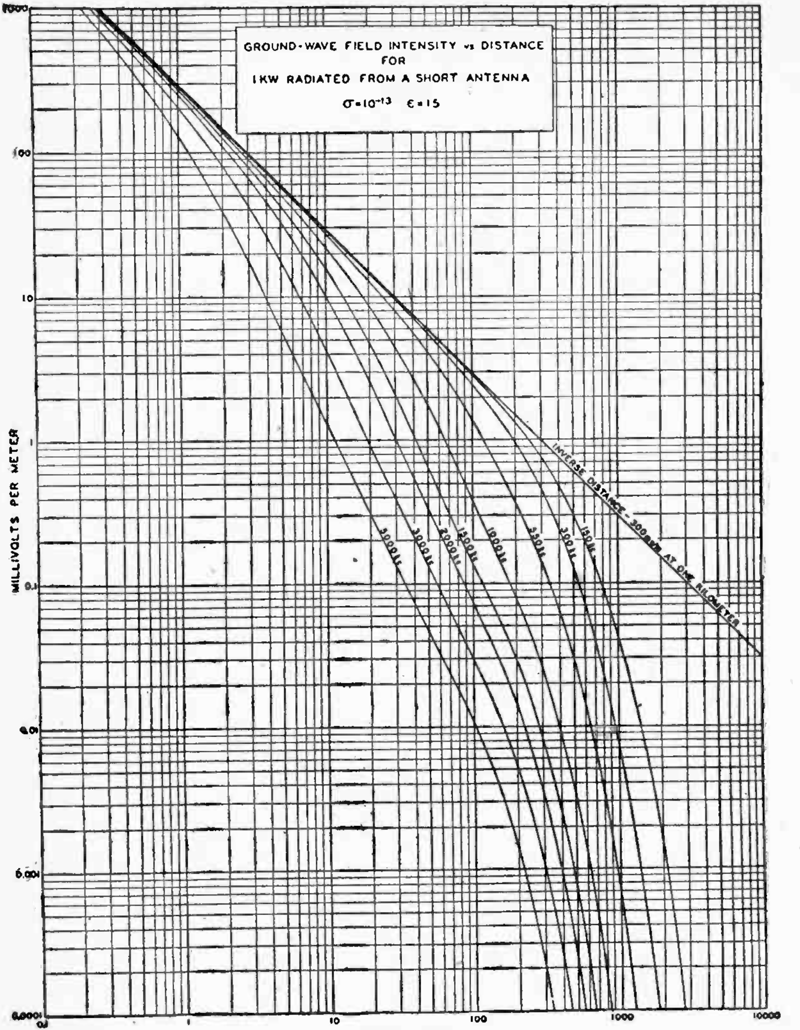
GROUND-WAVE FIELD INTENSITY vs DISTANCE
FOR
1KW RADIATED FROM A SHORT ANTENNA
σ=10⁻¹³ ε=15
1000
100
10
1
0.1
0.01
0.001
0.0001
MILLIVOLTS PER METER
0.1
1
10
100
1000
10000
KILOMETERS
5000kc
3000kc
2000kc
1500kc
1000kc
550kc
300kc
150kc
INVERSE DISTANCE - 300 mv AT ONE KILOMETER

FIG. 317.

- *i.* If not fully described above, give complete details and sketches if needed.
- *j.* Full description of painting and lighting installed.

2. Horizontal field intensity patterns for each power involved showing:
   - *a.* Unabsorbed field intensity contour at one mile determined by actual field intensity measurements and plotted in accordance with Section A (also determine r.m.s. field intensity). In the case of a directional antenna, additional measurements shall be made in accordance with Section B.
   - *b.* Map having scale not less than one inch to the mile preferably Geological Survey Quadrangle Sheet, if available, for the particular area involved) showing location at each point of measurement properly keyed to the tabulation sheet required below.
   - *c.* Complete tabulation of all data used in plotting the above pattern, showing, among other things, the location where measurement was made, the actual field intensity measured, field intensity times distance and any pertinent remarks relative thereto.
   - *d.* Any other pertinent information.
3. Calculated vertical field intensity patterns for each power involved showing (should be supported by measurements if possible):
   - *a.* Field intensity contour at one mile from the antenna determined theoretically for angles from 0° to 90° above the ground plane in the directions of each of the radials on which measurements were made for 2 (*a*) above.
   - *b.* Complete tabulation of data, formula, calculations, assumptions and measurements used in determining the vertical patterns.
   - *c.* Any other pertinent information.
4. Complete data on determination of the antenna resistance and input power by the direct method as required in Commission release "Further Requirements for Determination of Power by Direct Measurement of Antenna Power."
5. Complete explanation of method of relating field intensity measurements to the operating power.
6. A monitoring point shall be specified for two radials (approximately 90° apart) on which measurements were taken with

a description of how reached and the actual field intensities at such points for each power concerned.

7. Manufacturer's name of each calibrated instrument used, and manufacturer's rated accuracy.
8. Accuracy, date and by whom each instrument was last calibrated.
9. Name, address and qualifications of the engineer making measurement and of the engineer calculating and relating the measurements to the operating power.

FIELD INTENSITY MEASUREMENTS IN ALLOCATION[7]

A. Field Intensity Measurements to Establish Effective Field Intensity at One Mile

Sec. 3.45 provides that certain minimum field intensities are acceptable in lieu of the required minimum physical vertical heights of the antennas proper. Also in other allocation problems, it is necessary to determine the effective field at one mile. The following requirements shall govern the taking and submission of data on the field intensity produced:

Beginning as near to the antenna as possible without including the induction field (not less than one wavelength), measurements shall be made on eight or more radials, at intervals of one-tenth mile more or less up to two miles, at intervals of approximately one-half mile from two miles to six miles, and a few additional measurements, if needed, at greater distances from the antenna. Where the antenna is rurally located and unobstructed measurements can be made, there shall be as many as eighteen or twenty measurements on each radial. However, where the antenna is located in a city or where unobstructed measurements are difficult to make, measurements shall be made on each radial at much closer intervals, particularly within two miles of the antenna.[8]

Points on each radial should be plotted from these data on logarithmic co-ordinate paper with the field intensity times distance as ordinate, and distance as abscissa. Through these points draw a smooth curve following the general curvature. A straight line on semi-logarithmic paper showing a substantially larger value of field at zero miles than at one mile, very likely such value does not

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[7] Extracted from F. C. C. Standards of Good Engineering Practice for Standard Broadcast Stations.

[8] It is suggested that "Wave Tilt" measurements may be made to determine and compare locations for taking field intensity measurements, particularly to determine that there are no abrupt changes in ground conductivity or that reflected waves are not causing abnormal intensities.

represent the actual effective field. The curve should bend generally with the points and the value at two wavelengths shall determine the effective field at one mile.

When all radials have been analyzed in this manner, a curve shall be plotted on polar co-ordinate paper from the unabsorbed values obtained, which gives the unabsorbed field pattern at one mile. The radius of a circle, the area of which is equal to the area bounded by this pattern, is the effective unabsorbed field intensity at one mile.

While making the field intensity survey, the output power of the station shall be maintained at the licensed power as determined by the direct method. To do this it is necessary to determine accurately the total antenna resistance (the resistance variation method, the substitution method or bridge method is acceptable) and to measure the antenna current by means of an ammeter of acceptable accuracy.

The following data shall be submitted to the Commission in affidavit form:

1. Complete data taken for field intensity measurement, including a map showing each point of measurement numbered to agree with the tabulated data and for the antenna resistance measurement.
2. The graphs drawn for each radial, the unattenuated field pattern and the antenna resistance curve.
3. Description of methods used to take readings for field intensity and antenna resistance measurements.
4. Manufacturer's name of each calibrated instrument used, and manufacturer's rated accuracy.
5. Accuracy, date and by whom each instrument was last calibrated.
6. Name, address and qualifications of engineer making measurements.

B. Field Intensity Measurements to Establish Performance of Directional Antennas

Sec. 3.33 (*b*) requires that proof of performance of directional antenna systems be submitted before any authorization during the regular broadcast day may be permitted. These data shall be taken upon proper request and authorization therefore during the experimental period and shall show that the pattern obtained is essentially the same as that predicted by the application and required by terms of the authorization and that any specific requirements set out are fully met.

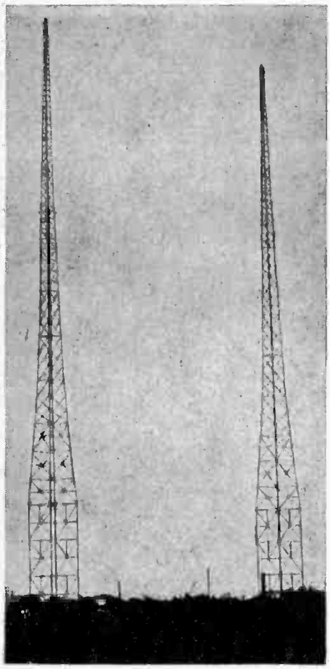

FIG. 318. Directional Antenna System of WEAN, Providence, R. I. Feed System Is Shown in Fig. 319. Tower Height 325 feet. (Courtesy the Blau Knox Co.)

To establish this performance measurements shall be made in accordance with the preceding Section A along sufficient number of radials to establish the effective field intensity at one mile from the antenna system. In the case of a relatively simple directional antenna pattern, approximately eight radials in addition to the radials in the directions the field intensity as specified by the authorization are sufficient. However, when more complicated patterns are involved, that is, patterns having several or sharp lobes or nulls, measurements shall be taken along as many additional radials as necessary to definitely establish the pattern.

In cases where the authorization requires a showing that absorbed field intensities of specified values be obtained in the various portions of the service area, sufficient actual measurements throughout these areas shall be made to show that at least the values specified are obtained.

In either of the above cases the following information shall be submitted in triplicate even through such information was submitted with the original application:

1. Complete description of antenna array.
    - *a.* Number of elements.
    - *b.* Manufacturer's name and type of each element (i.e., guyed or self-supporting, triangular or square, uniform cross-section or tapered, etc.).
    - *c.* If top loaded, give details.

d. Height of vertical lead of each element in feet (height above base insulator or base, if grounded).

e. Overall height in feet of each element.

f. Orientation of array with respect to true north and time (specify degrees leading or lagging) and space phasing of elements. (Space phasing should be given in feet as well as in degrees.)

g. Details of ground system for each element (length and number of radials, dimensions of ground screen, if used, and depth buried).

h. Current in each element (at point where antenna ammeter is located).

i. Schematic sketch and description of method of feeding power to elements, including phasing and coupling equipment and locations of antenna ammeters (both regular and remote) in the circuits.

j. If not fully described above, give complete details and sketches if needed.

k. Full description of painting and lighting installed on each elment.

2. Horizontal field intensity patterns for each power involved showing:

a. Unabsorbed directional field intensity at one mile and equivalent unabsorbed non-directional (r.m.s.) field intensity at one mile from the antenna determined by actual field intensity measurements as set forth above.

b. Direction true north shall be shown at zero azimuth.

c. Direction of each station or city specified in the instrument of authorization in which direction a limiting field was specified and the actual unabsorbed field intensity obtained in each of such directions (all directions shall be determined by accurate calculation or from Lambert Conformal Conic Projection Map such as U. S. Coast and Geodetic Survey Map No. 3060 a, and all distances shall be determined by accurate calculation or from U. S. Albers Equal Area Projection Map, Scale 1/2,500,000 or map of equal accuracy. These may be obtained from the United States Department of Interior, Geological Survey, for the sums of fifty cents and one dollar, respectively).

d. Measured field intensity contours for 25, 10, 5 and 2 mv./m. and any other contours specified by the instrument of authorization on a map having the largest practical scale.

3. Complete tabulation of all data used in plotting the above patterns.
4. Any other pertinent information.

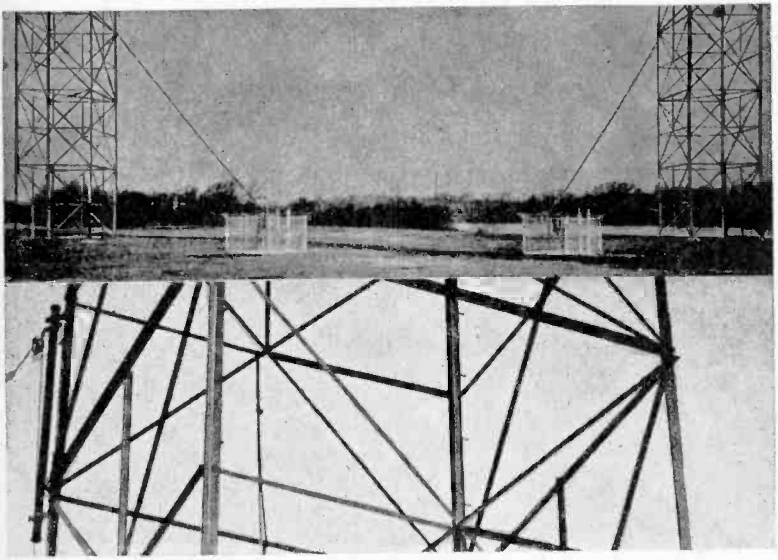

FIG. 319. Shunt Excitation System for Fig. 318. A Tuned Circuit in Each Fenced Enclosure Supplies R.F. Current to a Triangular Loop Consisting of the Ground, the Slanting Wire and the Lower Part of the Tower.

5. Plotting of field intensity patterns:
   a. All patterns shall be plotted on standard letter size polar co-ordinate paper (main engraving approximately 7″ x 10″).
   b. All patterns shall be plotted to the largest scale possible on the paper specified in (*a*) above using divisions and sub-divisions having values of 1, 2, 2.5 or 5 times 10^x. (No other values shall be used.)
   c. All values of field intensity less than 10 percent of the r.m.s. field intensity of the pattern shall be shown

on an enlarged scale in accordance with (*a* and *b*) above.

As a check on the shape of the unabsorbed field intensity pattern obtained in accordance with the above it is suggested that measurements be taken on each of the radials at approximately one mile from the antenna system for operation, both directional and non-directional and the ratios of these values plotted on polar co-ordinate paper in accordance with the above specifications.

C. Measurement of the Field Intensity of Broadcast Stations for Presentation in Support of Applications or Evidence at Hearings before the Commission

Sec. 3.24 requires that among other things an application for a new standard broadcast station or increase in facilities of an existing station make a satisfactory showing that objectionable interference will not be caused to an existing station or stations.

In the determination of such interference in accordance with Sec. 3.28 actual measurements will take precedence over theoretical values provided such measurements are properly taken and presented.

When measurements of either ground wave signal intensity or sky wave signal intensity are presented in evidence, they shall be supported by a field intensity survey of the station observed, which survey should be sufficiently complete in accordance with Sections *A* and *B* above to determine the effective field at one mile in the pertinent directions for that station.

When measurements are made on sky wave signal intensity (either service or interference) they shall be graphic recordings as follows:

1. Recordings shall be made on 10 or more nights for sufficient periods each night to obtain reasonable average values.
2. Observations shall be made on other stations to determine whether sky wave transmission conditions are of propagation.
3. Scales on the graphic paper shall be such as to permit easy reading of both time and field intensity and calibrations shall be clearly indicated.
4. Pertinent notes such as predominance of signal of a certain station when recording composite signals shall be made on the recording.

5. Full description shall be given the point where recordings were made (geographically as well as field intensity of the station to which interference is being determined).

6. Full explanation of to what extent signals from other stations on the same channel affected the accuracy of the recordings and what steps, if any, were taken to eliminate or compensate for such signals.

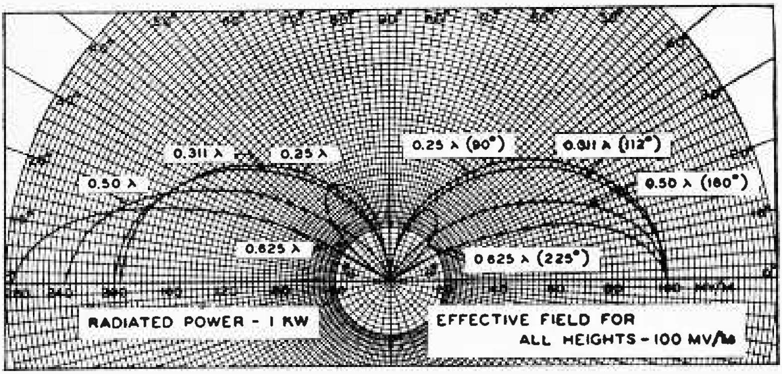

FIG. 320. Vertical Radiation Patterns for Different Heights of Vertical Wire Antennas (Sinusoidal Current Distribution). F. C. C., May 4, 1938.

If the observed station is owned or controlled by the party on whose behalf the measurements are made, then, in addition to the above, detailed reports on the measurement of the antenna resistance and on the amount of power actually radiated (as determined by the direct method) during the course of the field intensity measurements shall be presented. The applicant (or participant) shall also furnish a complete description of the antenna and ground system in use at the transmitting station during the period of observations and a statement as to whether or not this is the identical equipment regularly used by the station.

When measurements of both the "desired" and "undesired" station are made in one area to determine the point where objectionable interference from ground wave signals occurs, several measurements of each station shall be made within a few miles of the point where the ratio of signals is that selected as the appropriate ratio for the determination of objectionable interference.

All information on the above, including description and accuracy of equipment used, when and by whom last calibrated, and the name and qualifications of the engineer making the measurements, when filed with an application, shall be in affidavit form. At the time of the hearing on applications involving such observations. the applicant should be prepared to present, as sworn testimony, complete data on the above

CHAPTER 10

BROADCAST TRANSMITTERS

Introduction—Stimulated by competition as well as by higher standards as to performance required by both the Federal Communications Commission and the industry, manufacturers of broadcasting equipment are now supplying transmitters possessing vastly superior characteristics to those obtainable two years ago. In general, marked progress has been made in increasing the stability of frequency, extending the over-all frequency characteristics into the high fidelity regions and the reduction of audio distortion, carrier noise and radio frequency harmonics. Other improvements consist of reduction in the cost of operation, addition of automatic safety devices to protect the operating personnel and equipment, adaptability to power changes, centralized controls, reliability of operation, accessibility of parts for maintenance and service and modernistic trends in appearance.

The transmitters described in this chapter are typical of those designed to include all of these features. In order to give the student and operator an insight into present-day radio broadcasting it has been thought best to describe one of the many transmitters of two manufacturers whose equipment is used extensively in the United States. The descriptions of the apparatus, the adjustments and maintenance instructions are taken verbatim from the instruction books supplied with the equipment. The type number of all the apparatus and the peculiar language of the art have been left in the text so that the student or operator may have a better opportunity to read his way into current practice.

One must not assume that the manufacturers whose apparatus is described herein, are the *only* ones manufacturing broadcast equipment in keeping with good engineering practice. There are others, but obviously space would not permit a description of each.

The student preparing for an examination for a radiotelephone operator's license of any grade is advised to study the material in this chapter, particularly the power adjustments and maintenance instructions.

RCA TYPES 100–H AND 250–D RADIO BROADCAST TRANSMITTERS

1. Introduction—The Types 100–H and 250–D Broadcast Transmitters are high-grade units designed to satisfy requirements of high fidelity, low distortion, low carrier noise and reliability of operation. Their respective designs are so similar that they may be regarded as one equipment. *Differences are to be found only in the tube complements required and in minor wiring changes and either transmitter may be converted readily to the other type.* Instructions for such conversion will be found in the section entitled "Installation and Operation." The appearance of the transmitter in the 250–D form is shown by figure 321.

When connected as Type 100–H, the transmitter is capable of continuous operation at a carrier output of 100 watts. The Type 250–D form permits interchangeable operation at 100 or 250 watts as desired and the equipment is normally wired in this arrangement at the factory. For 100/250-watt (250–D) operation, the carrier output changeover is effected by means of the toggle switch on the control panel (marked "LOW-HIGH") which energizes a relay whereby series resistors in the plate-voltage supply are short-circuited for the higher output. The latter switch operates other relays also which maintain the audio-frequency input level and the output voltage substantially constant under proper conditions of modulation.

Both transmitters utilize the same tube complement in the oscillator and buffer stages. The Type 100–H utilizes one RCA–838 tube in the intermediate power amplifier, two RCA–838 tubes in the power amplifier, and four RCA–845 tubes (operated "Class A") as the modulator with 1050-volt plate potential. The Type 250–D utilizes one RCA–805 tube in the intermediate power amplifier, two RCA–805 tubes in the power amplifier, two RCA–805 tubes (operated "Class B") as modulators and two RCA–845 tubes (operated "Class A") as modulator drivers with 1320-volt plate potential.

(No changes in sockets are necessary nor are the r.f. circuits changed in any way when converting type 100–H to type 250–D, except only that a lead must be run to the top cap plate connection of the 805 tubes replacing the 838 tubes. The class *B* audio 805 modulators require the same connection but the plate resistors and modulation transformer No. 228 remain unchanged. The jumpers between grids and plates are removed and the remaining pair of 845 tubes is coupled to the 805 pair through a new transformer No. 221. Since the fixed bias from the power supply now reaches only the class *B* tubes a new bias is provided for the driver tube by unshorting the autobias resistors 216 and 217.)

Either transmitter may be operated on any frequency between 550 and 1600 kc., requiring only the connection of the antenna, ground, power supply and audio input circuits. It will deliver rated power into a 70 to 600-ohm transmission line or into any

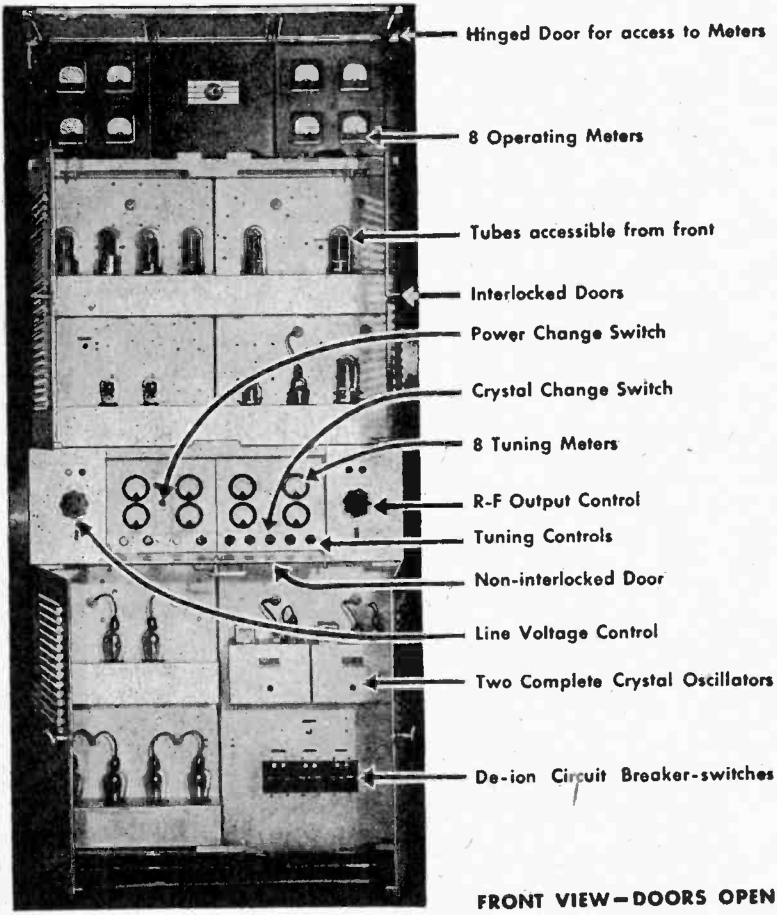

FIG. 321. Front View 250-D. Doors Open.

type antenna normally used with broadcast transmitters. In unusual cases, it may be necessary to substitute an antenna ammeter with a different scale range. Suitably arranged terminals are provided to supply energy for operation of modulation and frequency monitors and for audio monitoring.

Using a constant tone source (12.5-milliwatt reference level) the audio-input level for the Type 250–D (100/250 watt) transmitter is approximately —6 db at 100 percent modulation with no input attenuation. The Type 100–H (100 watt) transmitter input level is approximately —2 db at 100 percent modulation with no input attenuation. With average program modulation, the power input is approximately 1400 watts for the Type 100–H transmitter and 1700 watts for the Type 250–D.

The transmitter incorporates two Type UL–4292 crystal oscillators, either of which may be selected for operation by means of a switch on the control panel. Each oscillator unit is equipped with a "V" cut crystal mounted in a Type TMV–129–B temperature-controlled holder which is of "plug-in" construction. Either crystal when properly adjusted will maintain the operating frequency of the transmitter constant within ± 10 cycles.

The Type UL–4292 crystal oscillator is a completely shielded unit developed for broadcast application. No tuned circuits are used and the output circuit is electron coupled to the oscillator. A vernier capacitor, controlled from the front, is provided to adjust the crystal frequency to the desired value.

Viewed from the front, the transmitter is divided vertically into two sections—an r.f. unit on the right and an audio unit on the left. Referring to the front-view (figure 321), it will be observed that the four lower tubes on the left-hand (audio) side are the high-voltage rectifier tubes. Directly above these (on the second shelf) are the two low-voltage rectifier tubes. The first audio-frequency amplifier tubes are located on the third shelf, while the fourth or top shelf supports the modulator tubes in the Type 100–H transmitter or the driver and modulator tubes in the Type 250–D. Meters for indicating the line voltage, the power amplifier plate voltage and the modulator plate current are located on the top meter panel of the audio section. Meters for indicating the plate currents of the first and second audio tubes are located on the control subpanel together with the potentiometers for adjusting the bias of the audio system. The line voltage adjustment and filament control switches are mounted on the main control panel. Directly above the first audio tubes is a hum compensator adjustment which may be reached through the grille bars by means of a bakelite rod with one end cut similar to a screw-driver.

At the bottom of the right-hand (r.f.) unit are located the combination over-load and line switches with the two crystal oscillator units directly above. The oscillator plate voltage rectifier, the buffer and the IPA tubes are mounted on the first shelf and the power amplifier tubes on the second shelf. The control subpanel on this side contains the meters for indicating the grid currents of IPA and PA tubes and plate currents of the buffer and IPA tubes in addition to the crystal oscillator selector switch and tuning controls for the buffer, IPA, PA and antenna tuning capacitors. Mounted on the main control panel are the r.f. power output control and the plate voltage control switch. The top meter panel contains the meters for indicating the oscillator plate voltage and plate current, power amplifier plate current and antenna current. The neutralizing capacitors for the PA and IPA stages are adjustable through the grille bars.

2. Circuits—Figures 322 and 323 show the schematic circuit diagrams of the Types 100–H and 250–D transmitters, respectively. It should be observed at this point that these diagrams are identical except for the tube complements and associated circuit changes in the audio system. The individual circuit components each bear an identifying "Item" number, these numbers being referred to for purposes of convenience in the subsequent text. Since the "Item" numbers are repeated on the connection diagrams and insofar as possible on the photographs also, the position of any given component in the equipment should be relatively easy to determine. All terminal numbers which appear in the schematic diagrams correspond to actual markings adjacent to the respective terminals provided in the transmitter.

The crystal oscillator utilizes an RCA–802 tube with the crystal connected between the control and screen grids. The plate circuit provides for selection of four chokes, 011, in covering the total frequency range as follows:

Coil No.	Frequency Band
4	550– 700 kc.
3	700–1150 kc.
2	1150–1400 kc.
1	1400–1600 kc.

The crystal is tested and adjusted in a similar oscillator before shipment. At installation, therefore, it is only necessary to select

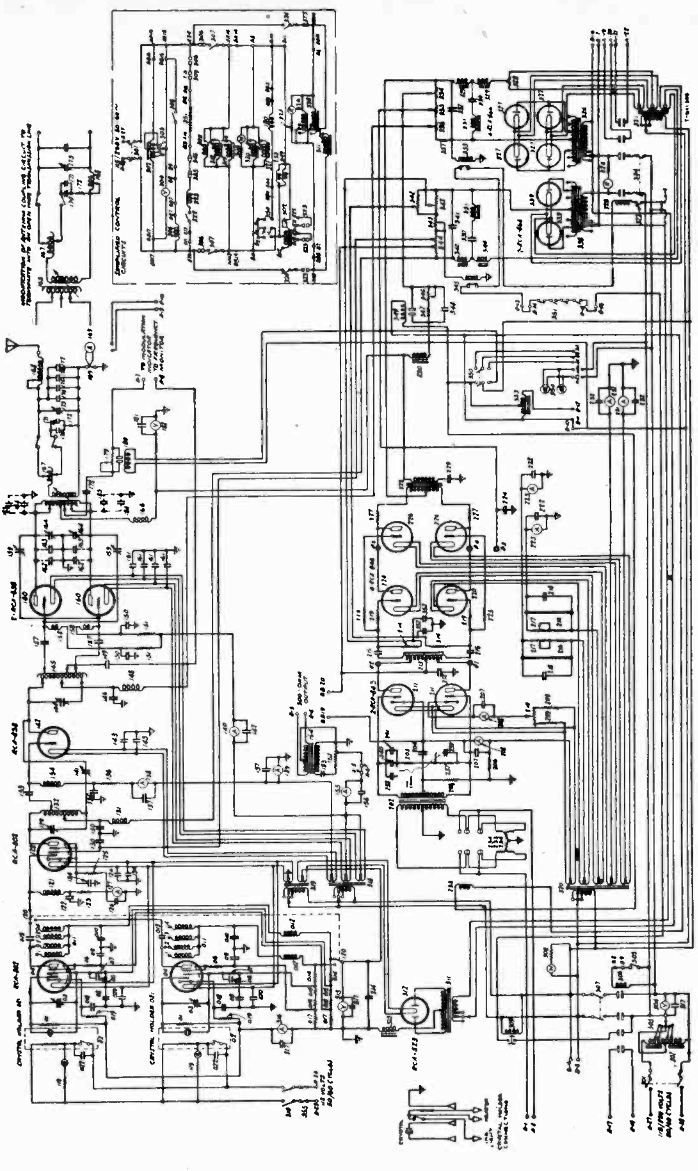

FIG. 322. Schematic Circuit Diagram for Type 100-H Transmitter. This is the 100 watt form using a Class A modulator comprising 4 type 845 tubes in push-pull-parallel.

the proper coil connection and adjust the circuit with the vernier condenser, .03, to " zero beat " as indicated by a frequency monitor.

The crystal oscillator plate and grid voltages are obtained from the single-phase, full-wave rectifier which utilizes an RCA–5Z3 tube. No plate voltage is applied to the spare oscillator.

Terminals " A–25 " and " A–26 " are provided for connection of a separate 115-volt supply to the heater units in the crystal holders so that both crystals will be maintained at the proper operating temperature at all times. The signal lights, 119, indicate proper operation of the heater circuits. The meters, 315 and 316, denote the plate voltage and the combined plate and screen-grid currents of the operating oscillator.

The buffer amplifier utilizes an RCA–802 tube and the tank circuit is arranged to provide grid exciting and neutralizing voltages for the intermediate power amplifier. The tank circuit will tune over the frequency range without changing coil taps. All plate and screen voltages are obtained from the low voltage rectifier.

The intermediate power amplifier utilizes an RCA–805 tube in the Type 250–D and an RCA–838 tube in the Type 100–H transmitter. It is only necessary to change coil taps once in order to tune over the frequency range. Taps are provided on the tank coil to obtain voltages for the frequency monitor. The plate voltage for this stage is obtained from the high voltage rectifier.

The power amplifier embodies two RCA–805 tubes in the Type 250–D and two RCA–838 tubes in the Type 100–H transmitter. This stage is cross-neutralized and taps are provided on the associated tank coil to obtain voltages for the modulation indicator. Meters 182 and 155 respectively, indicate the plate voltage and the total plate current of the power amplifier tubes. Meter, 169, indicates the antenna current and is provided with a special expanded scale (0 to 5 amperes) which can be readily used to indicate currents as low as 1 ampere. Use of this type meter for measurement of antenna currents down to one-fifth of the maximum scale reading has been approved by the Federal Communications Commission.

The output circuit is inductively coupled to the power amplifier tank by means of a variable coupling coil, the position of which is controlled from the main control panel. The variable coupling coil is designed to work into an impedance of approximately 70 ohms. The output circuit incorporates a " T " network which is used when the transmitter is connected to an antenna or to an open-wire transmission line. When a concentric line is used, the coupling coil is connected directly.

Type 100–H Audio System—The audio system of the Type 100–H transmitter utilizes two RCA–843 tubes (operated "Class A") in the first audio stage and four RCA–845 tubes (operated "Class A") as modulators. Separate meters, 208, 223 and 231, are provided for indicating the plate current of each tube.

The bias voltage of the modulators is supplied by the low voltage rectifier and the bias of each pair of tubes may be adjusted by means of the potentiometers, 342, located on the control sub-panel.

Type 250–D Audio System—The audio system of the Type 250–D transmitter employs two RCA–843 tubes (operated "Class A") in the first stage, two RCA–845 tubes (operated "Class A") as drivers and two RCA–805 tubes (operated "Class B") as modulators.

The first audio stage is self-biased and the plate voltage is supplied by the low voltage rectifier. Milliammeters, 208, for reading the plate current of each tube are provided in the respective cathode circuits.

The second audio stage is also self-biased and the bias of each tube may be adjusted separately by means of potentiometers located on the control sub-panel, 217. The plate voltage is supplied by the high voltage rectifier and a milliammeter, 233, is provided in the plate circuit of each tube to denote the respective plate currents.

The bias voltage of the modulator tubes is supplied by the low voltage rectifier and the bias of each tube may be adjusted by means of potentiometers, 342, located on the control sub-panel. The plate voltage for this stage is supplied by the high voltage rectifier.

Input—The input level of the Type 100–H transmitter is approximately —2 db and that of the Type 250–D transmitter is approximately —6 db. The required input level of the audio system may be increased 14 db (in 2 db steps) by means of the fixed pads, 234, 235 and 236. The audio-monitor transformer, 154, delivers an output of approximately zero level into a 500-ohm impedance load at 100 percent modulation (250 watts output).

Rectifiers—The low voltage rectifier utilizes two RCA–866 tubes in a single-phase, full-wave circuit and supplies both plate voltage for the low-power r.f. stages and grid bias for the modulator tubes.

The high voltage rectifier embodies four RCA–866 tubes in a single-phase, full-wave circuit and supplies plate voltages for power amplifier, intermediate power amplifier, modulator driver and modulator stages.

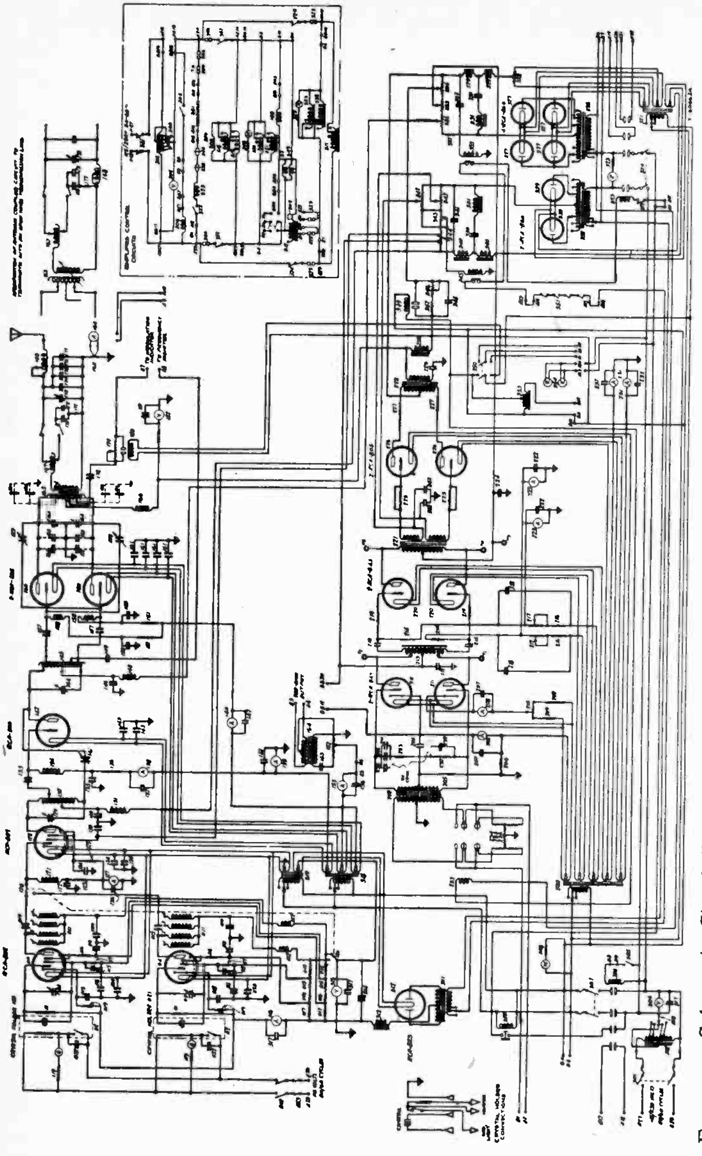

FIG. 323. Schematic Circuit Diagram for Type 250-D Transmitter. This is the 250 watt form. One pair of 845 tubes is retained to drive a Class B pair of type 805 modulators. The r.f. 838 tubes are replaced by type 805.

Both rectifiers are equipped with two-section filters to reduce the ripple to a minimum and afford a regulation of less than 5 percent.

Control Circuits—The overload switch, 301, controls the power supply to the entire transmitter and also protects the equipment in case of a short-circuit in the power-supply line inside of the transmitter. The transmitter is started by means of the master-control switch, 305, marked "FILAMENT," located on the main control panel. By operating this switch, the filament contactor, 306, is energized and upon closing applies power to the time-delay relay, 309, and to all of the filament transformers. The time-delay relay contacts are in series with the plate contactor coil, 323, the plate switch, 322, and the door "interlock" switches, 351, and close at the end of 30 seconds. By closing the doors and operating the switch, 322, marked "PLATE," the plate contactor operates and energizes the oscillator plate voltage rectifier and the low and high voltage rectifiers. If, for any reason, the low and high voltage rectifiers are overloaded, the overload relays, 345 and 333, will operate and de-energize the plate contactor.

The line voltage may be controlled within close limits by means of the auto-transformer, 302, which is adjustable through the tap switch, 303, located on the main control panel and marked "LINE VOLTAGE."

The crystal heater circuit is protected by the fuses, 355.

3. Installation and Operation—The location of the transmitter should be carefully selected in order to make the antenna lead-in and ground connections as short as possible. There should be sufficient air circulation so that the internal temperature will not exceed a maximum of 110° F. The transmitter should be accessible at the sides and rear to facilitate maintenance.

Three coils, 165, 167 and 168, and the power amplifier tank capacitor, 164, of the equipment are packed separately for shipment. When making the installation, these parts may be readily assembled as follows:

(*a*) The variable tank capacitor, 164, should be mounted on the r.f. chassis, at the upper left-hand side as viewed from the rear, with its flexible coupling towards the rear of the transmitter.

(*b*) The coils also are mounted on the upper portion of the r.f. chassis. Coil, 168, mounts horizontally at the top of the chassis above the square hole located behind the meter panel. Coil, 167, mounts horizontally on the side of the chassis above the power amplifier tank capacitors. Coil, 165, mounts with its axis vertical on the front part of the chassis behind the power amplifier tubes.

Mounting holes are properly positioned in the chassis and mounting screws, nuts and washers are packed with the coils. The permanent connections to the units are tagged in duplicate showing their proper locations. Adjustable taps should be connected in accordance with the tables showing "Typical Settings for the Tank Circuits" on pages 635 and 636. The flexible shaft should be attached to the insulating coupling on the rotor of coil, 165, by means of the set screw provided and the shaft casing secured to its supporting post.

The buffer and IPA shielded tank coils, 134 and 145, are clamped to the chassis by wooden blocks during shipment. These block and their supporting studs should be removed at installation.

The large shield which encloses the upper portion of the r.f. chassis also is shipped separately. It is easily assembled in its correct location by slipping the notched edges over the mounting studs provided on the turned over edges of the chassis. One set of the studs is located centrally in the equipment on the front flange of the chassis. The other set is located on the side flange of the chassis at the rear of the unit.

The conduits for external connection leads should be installed according to the external connection diagram shown in figure 9 on page 20.

The antenna tuning and coupling circuits within the transmitter unit are terminated at the two stand-off insulators located on the side of the r.f. chassis near the top. The antenna lead-in should be arranged for connection to the terminal toward the front of the unit. Copper tubing (3/8″ O.D.) is recommended for this purpose. The station equipment should include lightning protection switch or horn type safety gap which should be arranged to ground the antenna when the transmitter is not operating. Connection to the terminal toward the rear of the unit depends on the arrangement used for connecting the transmitter to the antenna system. The thermocouple for the antenna ammeter is normally connected between this terminal and the chassis. The transmitter chassis and frame should be well grounded. One or more of the bolts used for securing the chassis to the frame may be used for the main ground connection. The bolt located at the bottom rear section of the chassis below the terminal board "B" is suitably arranged for this purpose. All paint or lacquer should be removed to insure a good connection.

Direct Antenna and Ground Connections—1. Remove the "N" wires, thus disconnecting the following items:

(*a*) Antenna terminal from antenna coupling capacitor, 173—1 wire.
(*b*) Dummy antenna, 172, from antenna coupling capacitor, 173—1 wire.
(*c*) Antenna coil, 168, from dummy antenna, 172—1 wire.

2. Connect the " P " wires, thus linking together the following items:

(*a*) Antenna coil, 168, to antenna coupling capacitor, 173—1 wire.
(*b*) Antenna coil, 168, to link switch on dummy antenna, 172—1 wire.
(*c*) Dummy antenna, 172, to antenna coupling capacitor, 173—1 wire.

Open Wire Transmission Line—Reverse the connections described in the foregoing paragraph, removing the " P " wires and connecting the " N " wires. Also remove the normal connections to the thermocouple. If the line current is to be indicated, connect the " X " wire from the variable coupling capacitor, 173, and the wire between the antenna coil, 168, and the rear antenna terminal to one terminal of the thermocouple instead of to the antenna terminal. The opposite terminal of the thermocouple should then connect to the rear antenna terminal.

Concentric Transmission Line—Connect both terminals of the variable coupling coil, 165, to the antenna circuit terminals and connect the rear terminal to the frame of the transmitter.[1] If the line current is to be indicated, the rear terminal should not be grounded but instead should be connected to one terminal of the antenna meter thermocouple, and the other terminal of the thermocouple should be grounded. The inner conductor of the transmission line should be connected to the front antenna terminal and the outer conductor to the rear antenna terminal.

A 115- or 230-volt, 50- to 60-cycle, single-phase power supply, having a regulation of 5 percent or better, should be connected to transmitter terminals " A–27 " and " A–28," using No. 12 B&S gauge, insulated wire. It is recommended, and usually required by local authorities, that a fused line switch be provided.

The auto-transformer, 302, should be connected correctly for the supply voltage used. The center tap is used for 115 volts and the outside tap for 230 volts. Make certain that the main overload switch, 301, is open before the power leads are connected.

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[1] To obtain proper loading, it may be necessary to insert capacitance 174–177.

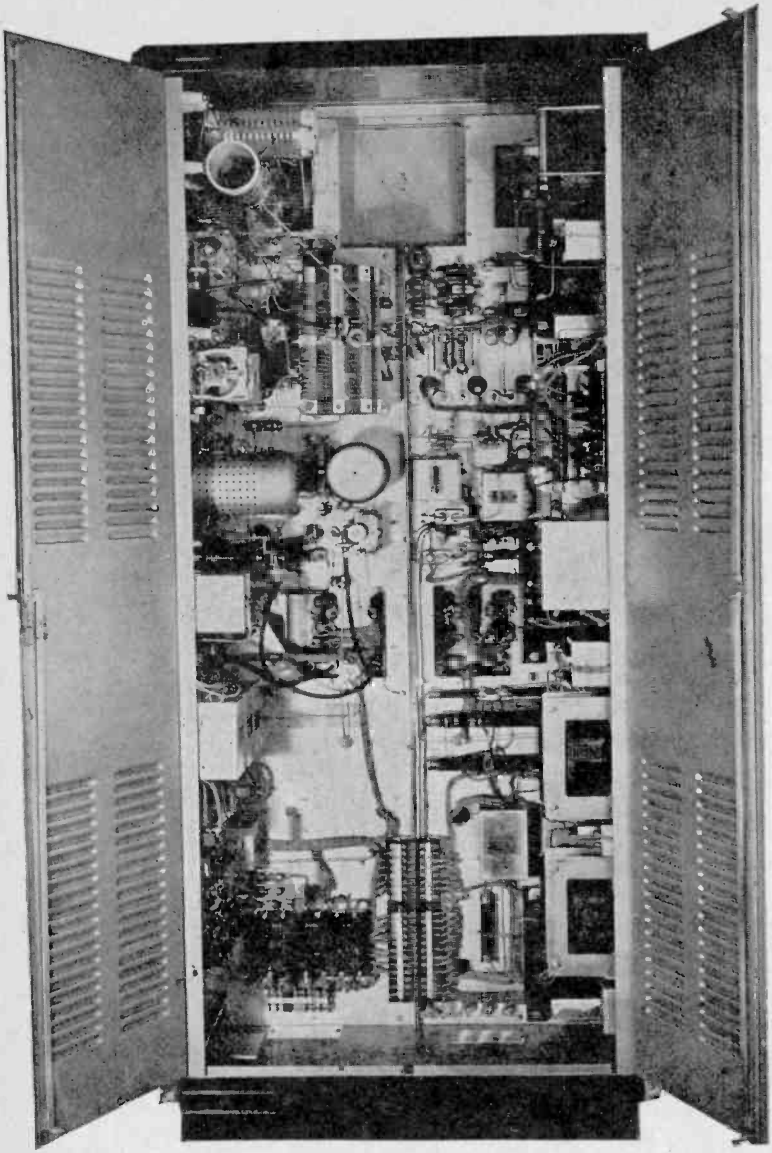


FIG. 324. Rear View of 250-D Transmitter.

Separate 115-volt, single-phase supply leads should be connected to terminals " A–25 " and " A–26 " for supplying power to the crystal heaters. The heater circuits require approximately 30 watts from the a.c. supply.

For all external audio connections, No. 19 twisted pair, rubber covered and lead sheathed wire or its equivalent should be used.

The audio-input leads should be connected to terminals " A–1 " and " A–2 " and the audio-monitor leads to terminals " A–3 " and " A–4."

The frequency-monitor connections should be made to terminal " A–8 " and the modulation indicator connection to terminal " A–7," using low-capacity shielded cable.

The Type 100–H and Type 250–D transmitters use different audio systems. The equipment is normally shipped with connections in place for operation as a Type 250–D unit. For operation as either Type 100–H or Type 250–D equipment, refer to figure 11 on page 24 which shows the diagram for the audio-unit and arrange the circuit connections on the audio chassis (as indicated by the note at the top of the diagram) to suit the required operation.

Audio Connections for Type 100–H Transmitter—1. Remove the " R " and " S " wires, thus detaching the short-circuiting connections from resistors, 227 and 206—3 wires.

2. Remove the " U " wires, thus disconnecting the first audio plate terminals, 211, from high voltage terminals " 1 " and " 2 "—2 wires.

3. Remove the " V " wires, thus disconnecting the positive terminals of meters, 223, from resistors, 214—2 wires.

4. Remove the " W " wires, thus disconnecting the bushed plate terminals of sockets, 220 and 226, from the stand-off insulators directly above—2 wires.

5. Connect the " X " wires, thus linking together the following items:

(*a*) Grid resistors, 219, to grid resistors, 225—2 wires.
(*b*) Resistors, 214, to capacitors, 352—2 wires.
(*c*) Bushed plate terminals of sockets, 220, to bushed plate terminals of sockets, 226—2 wires.
(*d*) Capacitors, 218, short-circuited—2 wires.

6. Remove the " Y " wires, thus disconnecting the following items:

(*a*) Short-circuiting connections from resistors, 225—2 wires.

(*b*) Terminals "1," "3," "4" and "7" of transformer, 221, from resistors, 225, and from bushed plate terminals of sockets, 220—4 wires.

(*c*) Short-circuiting connection from resistor, 343—1 wire.

7. Connect the "Z" wires, thus linking together the bushed plate terminals of sockets, 226, and resistors, 227—2 wires.

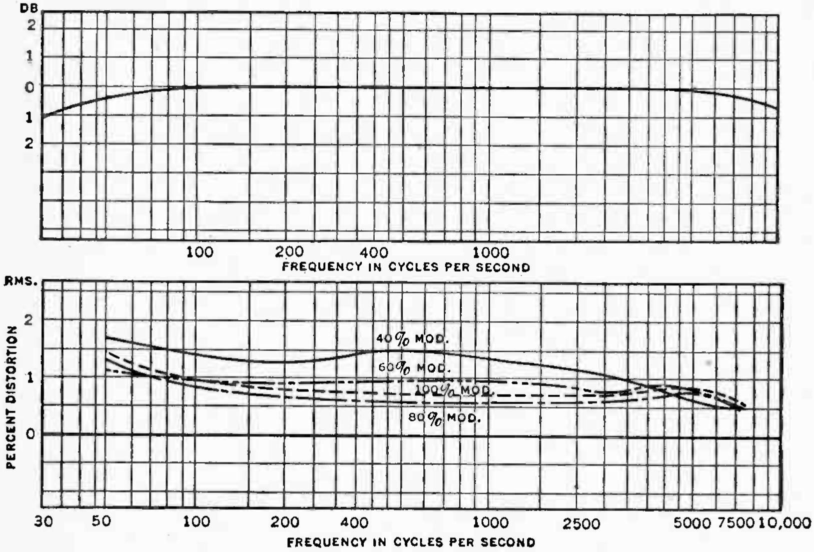


FIG. 325. Frequency Response (above) and Percent Harmonic Distortion (below) for the 100–H Transmitter.

Audio Connections for Type 250–D Transmitter—1. Remove the "R" and "S" wires, thus detaching the short-circuiting connections from resistors, 227 and 206—3 wires.

2. Remove the "U" wires, thus disconnecting the first audio plate terminals, 211, from high voltage terminals "1" and "2"—2 wires.

3. Connect the "V" wires, thus attaching the positive terminals of meters, 223, to resistors, 214—2 wires.

4. Remove the "W" wires, thus disconnecting the bushed plate terminals of sockets, 220 and 226, from the stand-off insulators directly above—2 wires.

5. Remove the "X" wires, thus disconnecting the following items:

(*a*) Grid resistors, 219, from grid resistors, 225—2 wires.
(*b*) Resistors, 214, from capacitors, 352—2 wires.
(*c*) Bushed plate terminals of socket, 220, from bushed plate terminals of socket, 226—2 wires.
(*d*) Short-circuiting connections from capacitors, 218—2 wires.

6. Connect the "Y" wires, thus giving circuit conditions as follows:

(*a*) Resistors, 225, short-circuited—2 wires.
(*b*) Terminals "1," "3," "4" and "7" of the driver transformer, 221, connected to resistors, 225, and to bushed plate terminals of sockets, 220—4 wires.
(*c*) Resistor, 343, short-circuited—1 wire.

7. Connect the "Z" wires, thus linking together the bushed plate terminals of sockets, 226, and resistors, 227—2 wires.

If station requirements should include control of the equipment from a remote point, the filament and plate voltages may be so controlled by connecting switches between terminals "B–8" and "B–9" and between terminals "A–11" and "A–12," removing the respective jumper wires which normally short-circuit these terminals.

The dashpot of the time-delay relay, 309, should be filled with oil and adjusted so that its contacts close approximately 30 seconds after its coil has been energized. The operating time may be varied by adjusting the stroke of the plunger or by turning the disc located in the bottom of the plunger cup for varying the effective number and size of holes in the cup.

The stroke of the plungers in the overload relays should be adjusted to the following values:

Transmitter	Relay, 333	Relay, 345
Type 100-H	1.7 amperes	0.8 ampere
Type 250-D	1.4 amperes	0.8 ampere

The secondary connections of the high and low voltage plate transformers should be made as follows:

Transmitter	Transformer, 326	Transformer, 338
Type 100-H	Terminals 3 and 3	Terminals for 1620 volts
Type 250-D	Terminals 2 and 2	Terminals for 1290 volts

The short-circuiting jumper on the resistor, 343, should be connected in the Type 100–H transmitter so that the total resistance is 580 ohms. By using the 540 or 620–ohm tap, the bias voltage may be changed by approximately ± 10 volts.

Check the crystal oscillator to make certain that the proper plate coil is used for the particular frequency as specified in the tabulation given under "*circuits*." It is necessary to remove the output terminal nuts as well as the cover screws in order to remove the cover.

Open the switch, 324, in order that no plate voltage will be applied and remove the plate caps from all tubes. Close the line voltage switch, 301, and adjust the voltage by means of the switch, 303, until the voltmeter, 304, reads 115 volts. Close the filament switch, 307, and the filament contactor switch, 305, and check all filament voltages; these voltages should be within 2 percent of their rated values. Before applying plate voltage, the filaments of the RCA–866 rectifier tubes should be allowed to heat for 30 minutes (on initial operation) in order to prolong their life.

Check the operation of the crystal oscillators by replacing the oscillator tube plate caps and then applying plate voltage by closing the rectifier overload switch, 324, and the "PLATE" switch, 322. Closing of the "PLATE" switch, 322, will operate the plate contactor, 323, providing the door-interlocking switches, 351, and contacts of the overload and time-delay relays are closed. The voltmeter, 315, should indicate 330 ± 10 volts. Set the oscillator selector switch, 120, to each position in turn and make the necessary adjustments to ascertain that each crystal oscillator unit is operating properly. The oscillator plate current should be within the limits specified in the table of "Typical Meter Readings" (see Part IV, page 642).

Check the operation of the door-interlock switches, 351, by opening and closing the doors and open the "PLATE" switch, 322, before reaching into or making any adjustments inside of the transmitter.

Replace the tube caps on the low voltage rectifier tubes, 339, and buffer tube, 128. Operation of the "PLATE" switch should supply plate and screen voltages to the buffer tube and plate voltage to the first audio stage.

Resonate the RCA–802 buffer stage by adjusting the variable capacitor to obtain a minimum indication on the plate current meter, 127. As a precaution, start tuning at maximum value of the variable capacitor in order to avoid tuning to a harmonic of the operating frequency. Check the screen voltage of this stage, limiting it to 230 volts by adjusting the screen voltage connection to the 1250 or 1450-ohm tap on the resistor, 344. Also adjust the plate voltage of the first audio tube for 400–425 volts by selecting a suitable tap on resistor, 344.

Typical tap settings for the IPA tank coil are as follows:

	550–850 kc.	850–1150 kc.	1150–1600 kc.
IPA capacitor taps	P1 – P1	P1 – P1	P2 – P2
PA grid taps (from frame out)	G2 – G1	G2 – G2	G2 – G2
Center tap	C3	C3	C1

The taps "C_1" and "C_3" are slightly off center and used to balance the power amplifier tubes in order that the grid currents may be equalized in cases where these currents are out of balance by 10 percent or more.

Replace the high voltage rectifier and IPA tube caps and resonate the IPA tank circuit by adjusting the variable capacitor, 144, for a minimum indication on the plate current meter, 139. As a precaution, start tuning with a maximum value of the variable capacitor in order to avoid tuning to a harmonic of the operating frequency. Adjust the plate voltage for approximately 800 volts by changing the connection on the resistor, 336.

Neutralize the IPA stage by adjusting the neutralizing capacitor, 141, for a minimum or for zero grid current in the power amplifier. At the higher broadcast frequencies, the IPA may neutralize better by selecting taps "C1" and "G1" instead of taps "C1" and "G2" as normally used.

The proper voltage for the frequency monitor may be obtained from either tap "T1" or "T2."

Replace the tube caps on the power amplifier and modulator tubes. Adjust the vario-coupler in the power amplifier plate tank coil for minimum coupling to the antenna (coupling coil and power amplifier tank coil at right angles). To avoid excessive plate current, operate the power change switch in the "LOW" position for preliminary adjustments.

Typical settings for the power amplifier tank circuit are as follows:

Frequency (kc.)	Coil Active Turns/Section (From Center)	Tank Capacitors (Center Grounded)
550–600	34	Parallel circuit comprising the variable capacitor, 164, the two fixed .0002 mfd. capacitors, 163, in series and the two fixed .00015 mfd. capacitors, 162, in series.
600–650	33	
650–700	32	Parallel circuit comprising the variable capacitor, 164, and the two fixed .00015 mfd. capacitors, 162, in series.
700–750	30	
750–800	28	
800–900	26	
900–1,000	24	
1,000–1,100	22	
1,100–1,200	20	
1,200–1,300	19	The variable capacitor alone.
1,300–1,400	16	
1,400–1,600	14	

Apply plate voltage and resonate the tank circuit by adjusting the variable capacitor, 164, for a minimum indication on the plate current meter, 155.

The power amplifier may be neutralized by connecting a 0–115 milliampere thermo-galvanometer or a low reading r-f milliammeter in the tank circuit, removing the plate voltage, tuning the variable tank capacitor for a maximum indication of the tank-current meter and then adjusting the neutralizing capacitor for a minimum indication on the latter meter.

After the transmitter has been entirely adjusted, the power amplifier may be reneutralized by modulating over 100 percent as indicated by a cathode-ray oscilloscope and then adjusting the neutralizing capacitor until the valley of the modulation envelope is narrowest.

With minimum coupling to the antenna, the plate current of the power amplifier tubes should be low since the tubes are unloaded. As the antenna circuit is closer coupled to the power amplifier tank coil, increased power is drawn from it and a resultant increase in the amplifier plate current will occur.

The variable coupling is designed to terminate into approximately 70 ohms and it is necessary to adjust the "T" network for this impedance. Electrically, the "T" network consists of a low-pass filter. The series arms, 167 and 168, are inductive and the parallel section, 173–177, is capacitive.

The selection of the coupling capacitors, 173–177, will depend upon the resistance and reactance of the antenna and on the operating frequency. The correct value may be obtained from the curves shown in figure 326. In these curves, the following symbols are used:

R_a = antenna resistance (ohms),
X_a = antenna reactance (ohms),
X_1 = coupling capacitor reactance (ohms),
Z_0 = input impedance of network (ohms).

The antenna circuit which includes the coil, 168, should always be inductive. If the antenna used is capacitive or only slightly inductive, the coil, 168, should be included in the circuit. If the antenna has a high inductive reactance (200 ohms or more), the latter coil should be short-circuited.

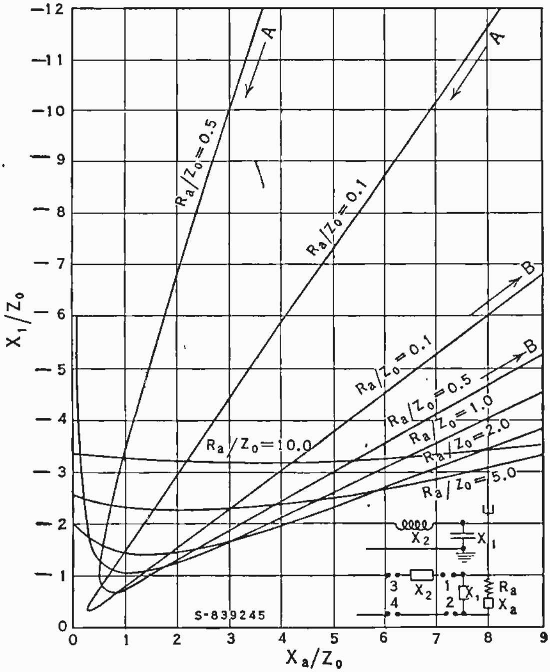


FIG. 326. Curves for Antenna-Matching Network.

In determining X_1/Z_0 from the curves, a ratio of 3 (compromise value) will be used for X_a/Z_0, provided the coil, 168, is necessary. If the antenna has an inductive reactance of 200 ohms or more, the correct radio of X_a/Z_0 should be used.

FIG. 327. 891-R Tube.

Example—Given

$X_a = 50$ ohms (inductive),
$R_0 = 35$ ohms,
$Z_0 = 70$ ohms.

It will be necessary to add turns to the coil, 168, to provide 210 ohms inductance reactance.

$$X_a/Z_0 = 3, \; R_a/Z_0 = 0.5.$$

From the curves we find two values of X_1/Z_0, namely:

$$X_1/Z_0 = -1.7 \text{ and } X_1/Z_0 = -10.0.$$

If the ratio R_a/Z_0 does not coincide with a curve, the value may be interpolated. The smaller value should always be selected; then $X_1 = -1.7 \cdot Z_0 = -119$ ohms capacitive reactance.

The value of the coupling capacitors may be found as follows:

$$C \text{ (mfd.)} = \frac{10^3}{6.28 \cdot F \cdot X_1},$$

where

F = operating frequency in kc.

assuming $F = 1000$, then

$$C = \frac{10^3}{6.28 \cdot 1000 \cdot 119} = .001 \text{ mfd. (approximately).}$$

The .001 mfd. coupling capacitor should be used with the variable capacitor, 173, which should be operated near a medium value when the network is properly terminated.

Parallel or series combinations of the fixed coupling capacitors, 174–177, may be used to obtain the proper value. The variable capacitor has a maximum value of .00044 mfd. The .0005 mfd. coupling capacitor, comprising 170 and 171, should always be used in parallel with the other capacitors. If it is determined from the curves that a .0005 mfd. coupling capacitor is necessary, a series combination of the .001 mfd. capacitor, 175, and the .002 mfd. capacitors, 176 and 177, together with variable capacitors should be used.

If a 500 ohm, open-wire transmission line is used, the ratio X_a/Z_0 is zero and X_1/Z_0 is approximately -2.75 or $X_1 = -192$ ohms.

To adjust the network, connect a 0–3 ampere r-f meter to indicate the coupling coil current. Increase the coupling between coupling coil and power amplifier tank coil until a reading is obtained by means of the "R-F OUTPUT" control on the control panel. Select turns at random in the antenna coil, 168, and then tune by adjusting the turns of coil, 167, for maximum antenna current (maximum line current when an open wire transmission line is used) until the coupling coil current is within ± 10 percent of the value indicated by the equation:

$$I_L = \sqrt{\frac{P}{Z_0}},$$

where

I_L = coupling coil current at expected power output (amperes),
P = power output (watts),
Z_0 = input impedance of network (70 ohms).

The network should be adjusted with the variable capacitor in mid-position in order that it may be used to properly tune the network when climatic conditions have changed the antenna characteristics. It will be necessary to retune the power amplifier tank circuit slightly when the antenna circuit is coupled due to reactions between the two circuits.

The power amplifier tubes should be loaded to the proper plate current with the correct plate voltage in order to determine correctly the coupling coil and antenna currents.

After the power amplifier tank and antenna coupling circuits have been tuned and loaded, adjust the plate voltages on the intermediate power amplifier and audio tubes for the correct value. Also adjust the bias control potentiometers for the proper value of plate current in the audio tubes and then readjust the power amplifier plate voltage.

With the power change switch, 350, in the "LOW" (100 watt) position adjust the tap connection on the resistor, 346, until the following meter readings are obtained:

PA Plate Voltage (volts)	780–790
PA Plate Current (ma)	215–212
PA Input (watts)	167.5

In the Type 100–H transmitter, the power change switch, 350, should be left in the "HIGH" position except when making tuning adjustments. In the Type 250–D, operation at either 100 or 250 watts is then obtained by simply throwing the power change switch to the proper position.

The input power to the power amplifier may be kept constant by regulation of the "R-F OUTPUT" control, 165, if for any reason the antenna resistance varies and changes the transmitter load or if the power amplifier plate voltage does not remain constant.

The correct voltage to the modulation indicator for the Type 250–D transmitter should be selected by adjusting the taps on the power amplifier tank coil with the power change switch in the "LOW" (100 watt) position. Then throw the power change switch to the "HIGH" (250 watt) position and adjust the resistor, 179, until the modulation indicator input voltage is the same as before.

The hum level of the transmitter can be adjusted to a very low value by means of the hum adjusting potentiometer, 210. A harmonic analyzer or indicator should be used and tuned or adjusted to the fundamental hum frequency (50 or 60 cycles). Then adjust the hum potentiometer for a minimum indication.

If a line amplifier is used with the transmitter, it may be desirable to add audio-input attenuation at the transmitter by connecting one or more of the attenuator pads, 234, 235 and 236, in series with the audio line, thus permitting operation at a higher level of amplifier output which in turn will improve the signal-to-noise ratio of the amplifier.

When the transmitter is operated as Type 250–D (100/250 watts), the audio input level required for 100-watt operation is approximately 2 db below that for 250-watt operation. In order to keep the audio input at a proper level when changing power, the 2 db attenuator pad, 234, is arranged so that it will be connected or disconnected by the relay, 233, which is controlled by the power change switch.

To keep the distortion at a minimum in the Type 250–D transmitter, select two modulator tubes which have nearly equal plate currents with zero bias voltage. In general, the audio second harmonic can be reduced to a minimum by adjusting the bias voltage of the modulator-driver stage. Adjusting the bias voltage of the modulator tubes will decrease the audio third harmonic.

The dummy antenna may be connected by means of the link switch provided on the stand-off insulators on the dummy antenna panel. First remove the link for connecting the antenna circuit and then connect the capacitors, 170 and 171, as follows:

Frequency (kc.)	Capacitor Connection
550–850	Items 170 and 171 in parallel
850–1,150	Item 170 only (.0003 mfd.)
1,150–1,500	Item 171 only (.0002 mfd.)
1,500–1,600	Items 170 and 171 in series

Adjust the tap connection on the coil, 167, until the circuit consisting of that coil, the antenna coupling coil, 165, and capacitors, 170 and 171, is tuned. As the dummy antenna resistance is approximately 70 ohms, the power amplifier plate current should be the same as with the "T" network connected, provided that the position of the coupling coil remains fixed.

After the transmitter has been properly adjusted, connect an r-f ammeter in the tank circuit and measure the tank current. For the Type 250–D transmitter, the proper value should be between 1.25 and 1.5 amperes approximately. Adjust the turns on the power amplifier tank coil, retuning after each adjustment, until the tank current is within the limit specified. The IPA plate voltage also should be adjusted, if necessary, in order to obtain the proper power amplifier grid current.

4. **Maintenance**—With ordinary care, little attention will be required to keep the transmitter in operation. The adjustments and meter readings of the transmitter should be checked prior to each broadcasting period to assure proper operation. The operation of both crystals also should be checked.

To secure continuous and reliable operation, it is recommended that a definite maintenance schedule be arranged. It is important that the transmitter be kept free from dust and for this purpose a small blower may be used advantageously. The transmitter should be inspected periodically for loosened connections. As far as possible, tube failures should be anticipated by keeping a log and replacements made in advance of the actual occurrence.

The contacts of all relays and contactors should be cleaned periodically.

It is important that antenna insulators be kept clean to avoid high resistance ground leaks which would decrease the radiation efficiency of the station. Also, clean the lightning protection switch contacts and tighten all ground and antenna connections.

TYPICAL METER READINGS*

	Type 250-D		Type 100-H
	100 W	250 W	100 W
Line Voltage (volts)	115	115	115
Oscillator Plate Voltage (volts)	330 (±10)	330 (±10)	330 (±10)
Oscillator Plate Current (amperes)	20 (±5)	20 (±5)	20 (±5)
Buffer Plate Voltage (volts)	480	480	480
Buffer Plate Current (amperes)	45–55	45–55	45–55
Buffer Screen Voltage (volts)	200–230	200–230	200–230
IPA Plate Voltage (volts)	700–900	700–900	700–900
IPA Plate Current (amperes)	75–110	75–110	75–110
IPA Grid Current (amperes)	30–40	30–40	30–40
PA Grid Current (amperes)	110–130	110–130	110–130
PA Plate Current (amperes)	210–215	335–340	200
PA Plate Voltage (volts)	780–790	1250	1000
1st Audio Plate Voltage (volts)	415–420	415–420	415–420
1st Audio Plate Current per tube (amperes)	20–25	20–25	20–25
2nd Audio Plate Voltage (volts)	1225	1225	
2nd Audio Plate Current (amperes)			
Left	50–55	50–55	
Right	50–55	50–55	
Modulator Plate Current (amperes)			
Left (no mod.)	35–45	35–45	65 (per tube)
Right (no mod.)	35–45	35–45	65 (per tube)
Modulator Plate Voltage (volts)	1320	1320	1050

* In the table the current values are in milliamperes.

RCA 5-D RADIO BROADCAST TRANSMITTER—AN AIR COOLED 5 KW. TRANSMITTER

The elimination of water cooling has been attained in the 5-D transmitter and at the same time untried or experimental tubes have been avoided. The large tubes are standard metal anode types which have been used in service for a considerable period and whose life is known to be long and satisfactory. These

Tube Complement

Type 100-H Transmitter (100 Watts Output)

Oscillators	2—RCA-802
Buffer	1—RCA-802
Intermediate Power Amplifier	1—RCA-838
Power Amplifier	2—RCA-838
Speech Amplifier	2—RCA-843
Class "A" Modulators	4—RCA-845
High Voltage Rectifier	4-RCA-866
High Voltage Rectifier	4—RCA-866
Low Voltage Rectifier	2—RCA-866
Oscillator Plate Voltage Rectifier	1—RCA-5Z3

Type 250-D Transmitter (100/250 Watts Output)

Oscillators	2—RCA-802
Buffer	1—RCA-802
Intermediate Power Amplifier	1—RCA-805
Power Amplifier	2—RCA-805
Speech Amplifier	2—RCA-843
Class "A" Drivers	2—RCA-845
Class "B" Modulators	2—RCA-805
High Voltage Rectifier	4—RCA-866
Low Voltage Rectifier	2—RCA-866
Oscillator Plate Voltage Rectifier	1—RCA-5Z3

tubes are mounted in sockets provided with copper radiating fins over which a stream of air is blown by silent Sirocco blowers (see figure 329). Because of the high efficiency circuits, the amount of heat liberated from the tubes is of the same order as that from many 1000 watt transmitters. Since air to the blowers is supplied through a dust filter at the bottom of the cabinet and since there is no other air-entry, components will have more circulation of air, equipment will run cooler and apparatus will require less cleaning than formerly. Air cooling of metal anode tubes, such as the 891–R modulator tube shown in figure 328, provides considerably better tube operation which will be apparent when it is considered that not only the metal anode, but the glass seal and press are air-cooled. Since no scale can form nor can boiling take place, there will be no hot spots on the anode—tubes will operate cooler and life expectancy will be longer.

The high plate efficiency is attained by the use of high level, Class *B* modulation. This efficiency is more than double that of

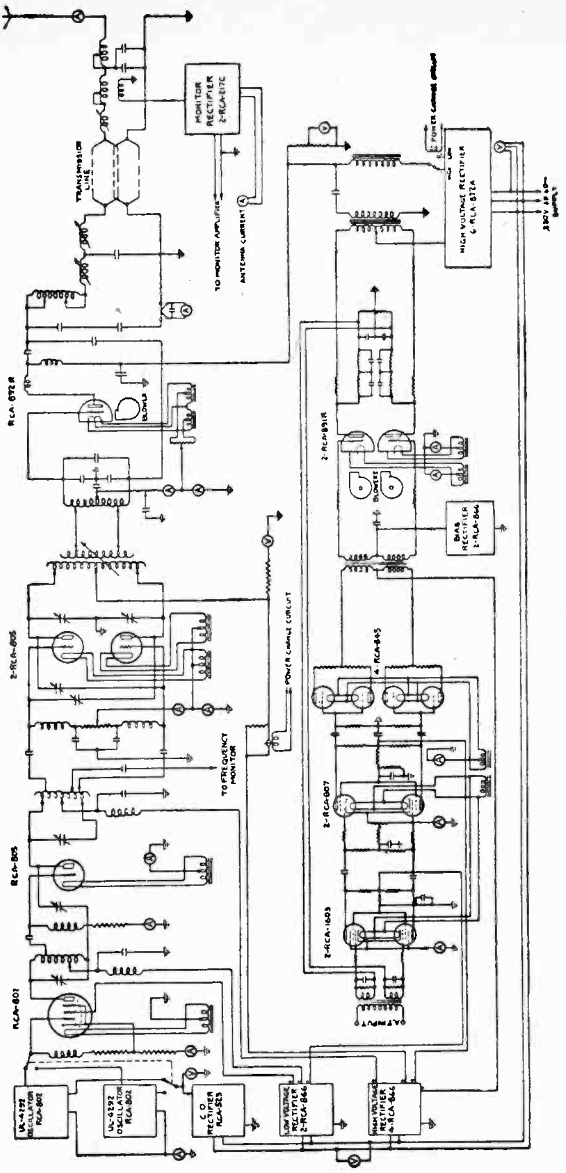


FIG. 328. Schematic Diagram of 5-D Transmitter.

any previous 5 kw. transmitter. This means lowered power costs and because less power is dissipated, operation of tubes will be less severe and the life longer. In addition, tuning and adjustment of such a circuit is considerably simpler than for a low level amplifier.

5. **Fidelity**—The frequency response and noise level characteristics have been tested under many different conditions to preclude any possibility of unnatural reproduction. Distortion measurements at 400 cycles, as often taken, give no indication of distortion at other important frequencies. In the case of the 5–D, distortion is low over the entire audio range (less than 3 percent r.m.s.). Frequency response is uniform over the range under all normal conditions of use. Hum level with 1 kw. or 5 kw. output will be minus 60 db unweighted (or more) below the 100 percent modulation level.

6. **Equalizer Feedback**—A fundamentally high quality audio system is used in the 5–D transmitter combined with a push-pull feedback circuit permitting stable operation with 30 db of degenerative feedback or more. The feedback circuit requires no adjustment, covers a wider band of frequencies, is non-critical and independent of tubes and a change in power from 1 to 5 kw. requires no alterations of setting. The feedback acts from the audio input of the transmitter up to the primary of the modulation transformer. However, with a high level modulation system, the feedback device will compensate for distortion or ripple taking place in the class *C*, r.f. amplifier and also tends to compensate the modulating voltage of the class *C* stage. At the same time, since there is no r.f. rectification, there is no possibility of change in coupling, variation of feedback with power output or other difficulties apt to be experienced with such a method. Thus the advantages of feedback have been adapted to the transmitter without the limitations of less stable feedback methods.

7. **Control Circuits**—A transmitter of 5 kw. power or over requires rather elaborate control equipment for proper operation. This is needed for automatic starting, for protective purposes and for changing power. The 5–D transmitter is provided with a separate power control panel on which all of the relays, breakers and control apparatus are mounted. Changes in timing of relays or other adjustments can be made easily. This power panel is wired in accordance with switchboard standards. Automatic starting is, of course, provided. A resetting device operating from any overload relay will remove or interrupt the plate power quickly and return it again automatically, performing this func-

tion three times before the power is finally taken off. This resetting system also operates from the antenna power rectifier, so that if an arc-over in the antenna circuit should take place, due to lightning or static charges, the arc will be broken and the transmitter returned to the air without an appreciable break. High grade overload and supervisory relays are employed. De-ion circuit breakers are employed extensively to assure a rapid break of the circuit without arcs as well as a convenient switching method. Fuses are limited practically to meter circuits.

Automatic air blast interlocks are used in the transmitter to prevent application of filament or plate power without proper cooling. The air blast continues automatically after the transmitter has been closed down, even though tubes will not be damaged (as in the case of water cooling) without circulation. If a.c. power fails, the transmitter will be automatically restored to the air when power resumes, the restoring time being proportional, within limits, to the time of failure. Thus on a short break, less time will be lost off the air since the full starting cycle time is not required.

Controls are provided on the power panel for adjusting the line voltage to the power amplifier and modulator units. Separate filament voltage controls are also included there for each high power tube together with arrangements for reading the actual filament voltages. Thus the heating voltage can be adjusted accurately according to the tube demand and life of tubes can be improved.

A tube hour meter has been included on the panel for indicating the number of hours of operation and aiding in keeping logs.

Power changes are accomplished easily and efficiently for stations operating with 1000 watts at night, 5000 watts day. A reduced voltage tap is provided on the plate supply transformers and only a small vernier adjustment resistance is in the circuit. Thus no great amount of power is dissipated in the power reducing system and efficient 1000 watt operation with low power costs is provided. At the same time that power is reduced, the input to the modulation monitor is maintained at a constant level. Power changes may be made without a program interruption and the slight switching click on the carrier is audible, only under exception conditions.

In starting, the plate voltage applied to the tubes rises smoothly and rapidly from zero at the instant the plate rectifier contactor closes to full voltage approximately a second after closure of the breaker. Excessive peak currents through the rectifier tubes are prevented by charging the filter capacitors through a current limiting resistor which is automatically short circuited when the capacitors are fully charged. Thus arc backs are minimized, and the life of the rectifier tubes prolonged.

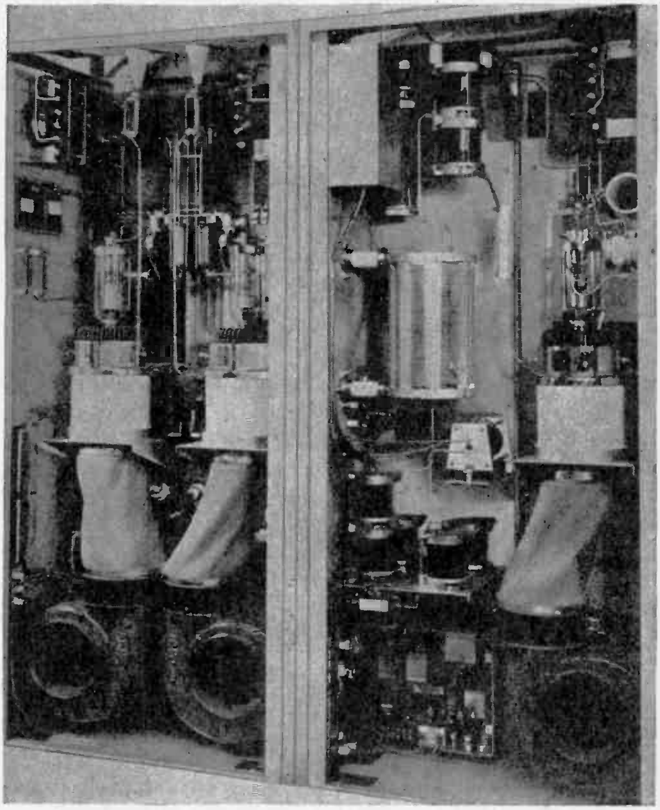


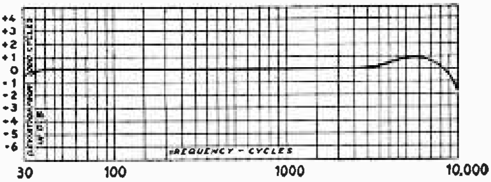
FIG. 329. Rear View Photograph of the RCA 5-D Transmitter.

8. Transmitter Circuits—The transmitter, as shown by figure 328, consists essentially of the 250-F exciter (this is the 250-D transmitter described on previous pages of this Chapter used for excitation purposes) with the addition of a high level modulated class *C* stage and rectifiers.

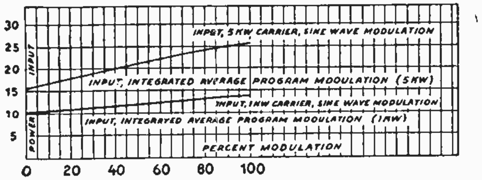
In the exciter unit, two crystal oscillators are supplied with a changeover switch, each oscillator employing a new electron coupled circuit without tuned circuits. Thus operation will be more stable and less subject to variation from voltage changes than more conventional circuits. RCA V-cut crystals with low temperature coefficient are used. The oscillator tube (and the spare oscillator) is an RCA–802 and this is followed by a buffer stage also using an RCA–802. The output of this stage feeds a stage using one RCA–805 which drives the final stage in the exciter, two RCA–805's in push-pull. The RCA–805 tubes were specially developed for this unit and the small number of different types in the exciter simplifies the problem of keeping spares on hand. The output of the exciter feeds into a grid tank in the power amplifier unit. The power amplifier tube is an RCA–892–R, this being the designation for the standard metal anode type tube used in the air cooled mounting. The plate tank is notable in that, together with the output coupling, it forms a low pass filter. By this arrangement harmonics are excluded from the line to the antenna and field intensity measurements have demonstrated the great effectiveness of this type circuit in preventing harmonic radiation. Tuning is by means of a variable inductor in a portion of the filter circuit which may be used for small adjustments of power output, if desired, since circuit efficiency or operation does not change appreciably over its range. The transmitter is designed for use with a concentric line or grounded four wire line and an antenna coupling unit is supplied as standard equipment. This may be used with any normal antenna and is arranged for outdoor mounting without a tuning house. In addition to the coupling circuits it includes a tube rectifier unit to operate a remote antenna current indicator at the station, to operate an audio monitoring circuit, and for operating the notching mechanism in the event of an arc-over in the radiating system.

The audio and modulation circuits have been specially designed and a new low power audio amplifier, especially adapted for feedback is included in the power amplifier unit. This is push-pull throughout and is intended to operate from a zero level signal. The input stage employs a pair of RCA–1603's followed by two RCA–807's. The stage before the modulators consists of four RCA–845's in multiple. The modulators are air-cooled, metal anode RCA–891–R tubes operated class *B*, push-pull. The modulation transformer has also been especially designed for this service. The feedback system is entirely unique in that it operates from a push-pull circuit. All of the audio stages up to the modulator are resistance-capacity coupled, without transformers, and so phase turnover points have been avoided throughout the audio range.

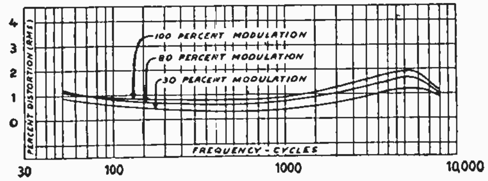
The main rectifier employs RCA–872–A tubes in a three phase, full wave circuit with an unusually adequate filter. The exciter unit is equipped with separate rectifiers using RCA–866 tubes and a crystal oscillator rectifier with a 5–Z–3. Bias for the modulators obtained from a separate rectifier employing two RCA–866 tubes. Bias for the power amplifier is by means of grid leak, and circuits



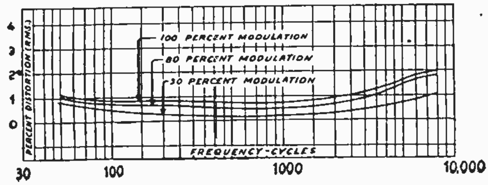
Frequency Characteristic Type 5–D Transmitter



Type 5–D Transmitter Power Input 230 V—3 Phase



Distortion Characteristic Type 5–D Transmitter Input, Modulated Amp. 1.54 KW. (1 KW. Operation)



Distortion Characteristic Type 5–D Transmitter Input, Modulated Amp. 7.7 KW. (5 KW. Operation)

FIG. 330.

are arranged so that the tube can draw only normal plate current in the event of failure of excitation.

Neutralization of the power amplifier is of the fixed type and is not critical.

The r.f. power amplifier tank has been designed for a low k.v.a. ratio so that circulating current losses are low and sideband cutting is prevented at low carrier frequencies. The plate circuit efficiency of the power amplifier is phenomenally high, a fact which assures full power output in the antenna, even with line losses, by the use of plate power measurements. It is thus unnecessary to operate by direct power measurements.

SPECIFICATIONS

Carrier Power Output	5000 w. or 5000/1000 watts
Carrier Frequency Range	550–1600 kc.
Carrier Frequency Stability	Within ± 10 cycles
Modulation Capability	100%
Audio Distortion	Less than 3 per cent r.m.s. 0–95 per cent modulation, 50–7500 cycles
Audio Frequency Response	Uniform within ± 1½ db, 30–10,000 cycles
Carrier and Hum Level	Better than 60 db below 100 per cent modulation, unweighted
Power Input (Total)	5 kw., 16½ kw. without modulation 18½ kw. with average modulation 1 kw., 10½ kw. without modulation 11 kw. with average modulation
Power Data	Power factor approximately 88 per cent, 230 volts, 3 phase, 60 cycles
Antenna and Line	For use with concentric or grounded 4 wire line antennas of 20 to 200 ohms resistance
Audio Input Level	Zero level (12.5 m.w.) at 500 ohms for 100 per cent modulation
Tubes	3—802 2—891-R 1—5-Z-3 4—845 3—805 1—892-R 2—1603 2—217-C 8—866 6—872-A 2—807

WESTERN ELECTRIC 5 KILOWATT RADIOTELEPHONE BROADCASTING EQUIPMENT (CONVERTIBLE TO 15 KILOWATT)

9. Stabilized Feedback—The Western Electric Company's new system for the reduction of harmonic distortion and noise provides high fidelity performance.

Uniform Frequency Response—The audio frequency transmission characteristic is uniform within 1/2 db from 30 to 10,000 cycles per second at all percentages of modulation.

10. Low Distortion—The r.m.s. value of the distortion introduced by the transmitter is less than 5 percent at 100 percent modulation and less than 2 percent at average program level.

Low Noise Level—Approximately 60 db unweighted below the signal at 100 percent modulation and approximately 70 db weighted below the signal at 100 percent modulation as measured with a program noise meter.

11. **Low Harmonic Radiation**—On any multiple of the carrier frequency, harmonic radiation is at least 70 db below the carrier (equivalent to .032 percent).

12. **Flexibility of Power Output and Operation**—Full or reduced power obtained by throwing one switch.

13. **Centralized Control**—Operation is fully automatic; a single switch energizes all circuits in proper sequence.

14. **All a.c. Operation**—Including filament heating of the power amplifier tubes.

15. **Quartz Crystal Frequency Control**—Amply meets all requirements of the Federal Comm. Commission.

16. **Compact Assembly**—Cabinet type construction; adaptable and easy to install, particular attention having been given to accessibility for servicing.

17. **Complete Protection**—Dead front cabinets, circuit breakers, automatic disconnect switches protect operating personnel.

18. **Low Maintenance Cost**—Quality of workmanship and material, proper design of circuits, engineering foresight insure low maintenance and protect owner against depreciation and early obsolescence.

GENERAL INFORMATION

19. **High Fidelity**—A high quality of radiated signal has become one of the important requirements that modern broadcast transmitters must meet. This new transmitter is one of the first to make use of stabilized feedback, an achievement of Bell System pioneering, which effects a high fidelity of performance more than meeting present day standards. Stabilized feedback involves the introduction of a portion of the output of an amplifier into the input in such a manner as to cancel the major part of the distortion and noise products introduced by the amplifier.

All a.c. Operation—Stabilized feedback makes possible the use of alternating current for all supplies, including filament heating of the power amplifier tubes. The only moving parts are in the water-circulating pump and in the water-cooling radiator fan, thus eliminating the care and maintenance of motor generators.

Stabilized feedback operates automatically, requiring no maintenance or adjustment by the operator. Changes in power regulation, phase rotation of voltage or magnitude of harmonic components present in the power supply are recognized and the variation in noise resulting therefrom is automatically compensated. Feedback action depends only on the mode of operation of the circuit and not upon the accuracy with which apparatus can be built and maintained. The only adjustment required is the initial one made during the installation of the equipment.

20. Flexible Power Output—Many stations which are licensed to operate at 5 kw. or 2.5 kw. in the daytime, operate at 1 kw. during the night. A magnetic switching arrangement, which changes the excitation, plate and bias voltages of the final amplifier, permits automatic and practically instantaneous change-over from 5 kw. or 2.5 kw. to 1 kw. and back by the operation of a single push button. The equipment also can be operated at any power output between 1 and 5 kw. by decreasing the radio frequency input to the final amplifier stage when the direct method of measurement is used.

The equipment has been conservatively designed for 5 kw. operation so that it can readily be expanded to a maximum of 15 kw. carrier output, 100 percent modulated, by the addition of an intermediate driving unit and certain tuning condensers, the replacement of the rectifier tubes, two power amplifier tubes, the plate supply transformers, high voltage filter equipment and other accessories.

21. Centralized Control—Operation of the transmitter is fully automatic; a single switch energizes the entire circuit in proper sequence. Semi-manual control is available for use at the discretion of the operator.

Control is further simplified by having the meters for measuring the plate, filament, bias voltages and leakage current of the power amplifier, together with signal lamps, mounted in a single unit.

22. Compact Assembly—The major components of the new 5 kw. transmitting equipment are assembled in compact, attractive metal cabinets which may be readily adapted to a number of arrangements to meet individual requirements and which are easy to install and occupy comparatively little floor space. The unusual compactness has been attained without sacrificing accessibility.

23. Complete Accessibility—Special attention was given in the design of this transmitter to facilitating inspection and thorough maintenance. Four grilled doors in each of the four main cabinets provide easy access to the circuit components. Signal lamps grouped together on the control panel, instantly indicate and facilitate the identification of a trouble condition.

24. Protective Features—The cabinets are "dead front" and circuit breakers cut off all high voltages when the doors are opened. A manual disconnect and grounding switch, interlocked with the doors of the power amplifier cabinet, automatically de-energizes and grounds the high voltage rectifier.

25. Circuit Arrangement—A simplified schematic diagram of the transmitter is shown in figure 331. A quartz crystal controlled oscillator operates into buffer amplifiers which drive a modulating amplifier. The modulating amplifier furnishes excitation for the power amplifier. A program input level of 4 db or a single tone input level of 10 db is required for 100 percent modulation. Both the modulating amplifier and the power amplifier are push-pull combinations, and the tube capacities are such that with full 100 percent modulation of the carrier, the distortion is well within the tentative limits set by the Federal Communications Commission for high fidelity operation.

The plate and grid bias voltages are supplied by mercury vapor tube rectifiers. All filaments are supplied with alternating current.

Description of Units

26. Oscillator Modulator Unit—The oscillator, buffer amplifiers, modulating amplifier, and feedback amplifier, together with their associated power supply equipment are compactly assembled in one cabinet.

The oscillator is quartz crystal controlled and provides a frequency stability which amply meets all the requirements of the Federal Comm. Commission. The oscillator unit is calibrated at the factory and needs no further adjustment. The crystal is contained in a temperature controlled chamber and the temperature control circuit is maintained in continuous operation independently of the operation of the transmitter.

The vacuum tubes used in the oscillator and the two buffer stages are of the equipotential type 271A. Resistance-capacity coupling is used from the oscillator to the first buffer and a band pass transformer from the first to the second buffer.

The second buffer stage utilizes two 271A Tubes in parallel. This stage is neutralized and is inductively coupled to the grid circuit of the modulating amplifier.

The modulating amplifier employs two 212E Vacuum Tubes in a neutralized push-pull circuit where modulation is accomplished by an improved grid-bias process. This improved method involves the use of stabilized feed-back and provides a modulator

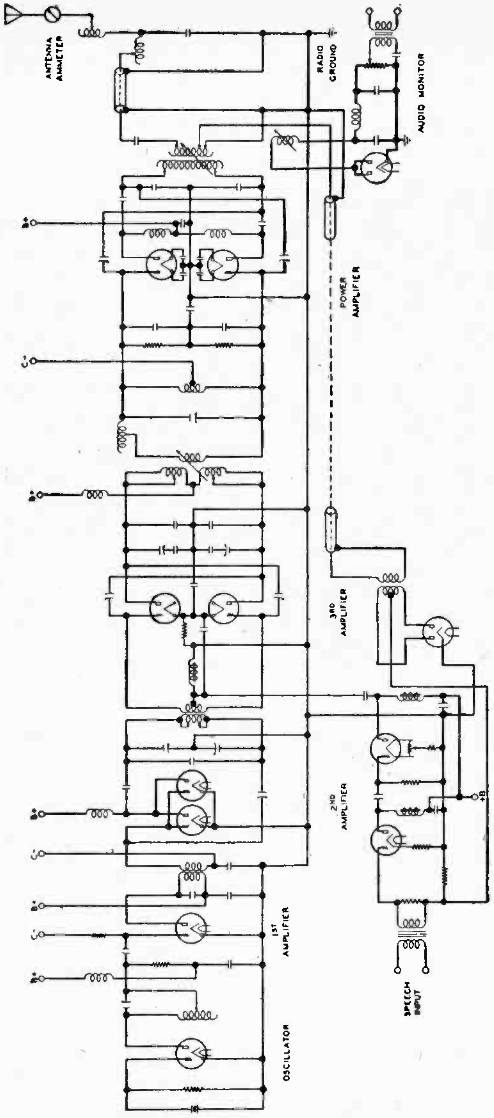


Fig. 331. Simplified Schematic of the 5 KW. Transmitter.

which contributes less than 1 percent in distortion to the transmitted signal at 100 percent modulation.

Control of the radio frequency grid excitation is obtained by potentiometer adjustment of the grid bias on the first buffer amplifier.

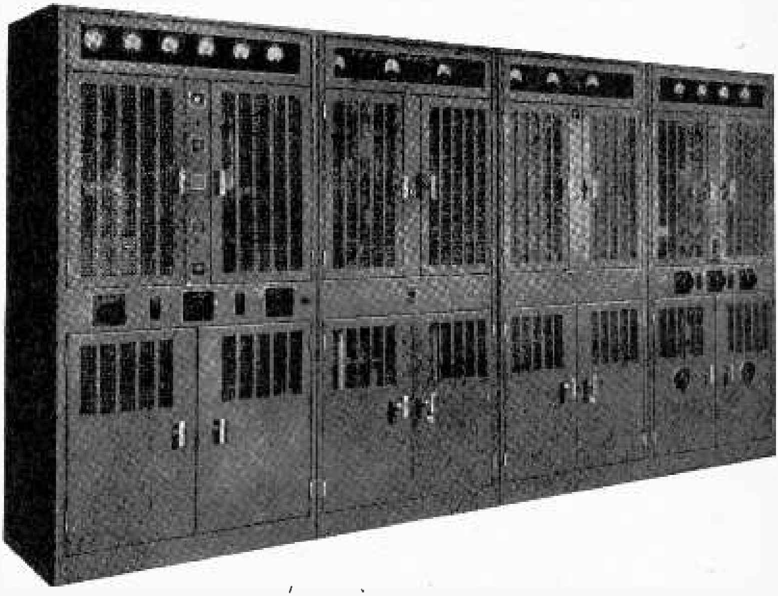


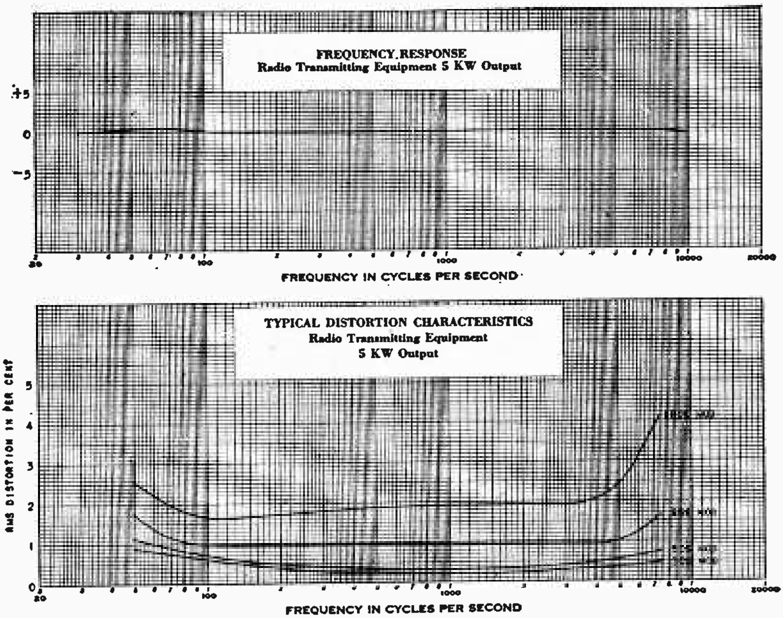
FIG. 331, A. Western Electric 5 kw. Radio Transmitter (355-D-1).

The power supply for this unit consists of two mercury vapor tube rectifiers which provide plate and grid potentials. The first rectifier employs two 258B Tubes in a full wave circuit and uses a voltage divided arrangement to supply potentials for all grid bias requirements as well as plate voltages for the oscillator and the first buffer amplifier. A second rectifier, using four 258B Tubes in a bridge circuit, furnishes plate voltages for the second buffer and modulating amplifiers.

The power circuits are fused and overload circuit breaker relay protection is provided in the modulating amplifier plate circuit. A reset button is located on the front panel for restoring this relay.

The filaments of the rectifier tubes are automatically given the required time to reach operating temperature before plate voltages are applied and the grid bias voltages are applied to the grids of the second buffer amplifier and modulating amplifier before plate voltages are applied.

Power Amplifier Tube Unit—Two 220B Tubes in push-pull are mounted in the power amplifier tube unit together with the filament transformers and apparatus associated with the grid and plate supply circuits. The input tuning circuit for this amplifier is located in the oscillator modulator unit and the output tuning circuits are located in the power amplifier tuning unit.



Figs. 331, B and 331, C.

The amplifier tubes are water cooled and the flow indicator and relays for protection against faults or failure in the water circulating system are mounted in association with the tube sockets. Each tube is equipped with a specially designed overload relay which operates an associated signal lamp on the control unit.

A water-cooled tube may be changed with very little delay by operating a switch to the "tube change" position. This switch stops the water pumps and removes the filament voltage of the amplifier tubes without opening the filament supply to the high voltage rectifier tubes. This arrangement permits the transmitter to go back on the air without the warming-up period which would be required had the rectifier tubes been allowed to grow cold.

The rectifiers which supply plate and grid voltages are located in a separate enclosure. A switch on the front of the unit controls the high voltage rectifier plate supply. The cabinet doors are equipped with locks associated with the rectifier grounding switch, in addition to safety switches. Opening a cabinet door removes all voltages except the amplifier and rectifier filament voltages. This arrangement provides complete protection for the operating personnel.

Individual reverse-current relays are provided for each of the power rectifier tubes and individual overload relays for each of the power amplifier tubes, with lamp indication for each.

Power Amplifier Tuning Unit—The output tuning circuit for the power amplifier is located in this unit and consists of two meshes inductively coupled. The first mesh offers the correct working impedance to the amplifier tubes and the second mesh matches the input impedance of the transmission line to the antenna.

A monitoring rectifier is also provided together with terminals for connection to monitoring facilities in the speech input equipment, to a monitoring loud speaker, and to oscillograph equipment.

Control Unit—This unit may be placed in the main transmitter line-up or located separately. It contains time delay and control relays, rheostats, meters, and the grid bias rectifier, using two 258B Vacuum Tubes for the power amplifier. Pilot lamps show when the important parts of the circuit are functioning properly and immediately indicate the location of any trouble that may arise. This enables tube replacements to be made in a comparatively short time.

A feature of the control circuit is the restoring relay which automatically restores the transmitter to operation in the event of momentary interruptions in the power supply. This feature protects the broadcaster against the loss of program time resulting from such interruptions which are too short to require reheating the rectifier tube filaments before resuming operation. Also, an emergency delay release switch is provided. This switch is a momentary contact push button, the operation of which permits the operator, at his discretion, to cut out the five minute delay normally imposed by the control circuit to allow proper heating of the filaments of the high voltage rectifier tubes. Should a flash-over occur in any of the tubes, the power will be tripped off and an associated pilot will go out, indicating where the trouble occurred.

Water gauges and a dial thermometer are also located in this unit.

Meters for measuring the plate voltage, filament voltage, bias voltage, and the leakage current for the final amplifier are mounted on the front panel together with controls and adjustments. The leakage current is an indication of the conductivity of the cooling water.

An hour counter provides means for checking the time of operation of the transmitter and tubes.

27. Antenna Coupling Unit—The coupling unit to be installed at the base of the antenna is designed for use with a co-axial transmission line of low impedance whose outer sheath is grounded, thus affording greater protection to personnel.

This unit is equipped with switches associated with the main transmitter control circuit for control and protective purposes. Two antenna current meters are provided. One is mounted in this unit and the other is located in the power amplifier tuning unit so that the antenna current may be read at that point. Separate antenna ammeters are provided for full and reduced power operation with full protection against surge current.

28. High Voltage Rectifier Equipment—This equipment contains the transformers, contactors and switches, rectifier tube units and filters. The circuit is of the bridge type employing six 315A Tubes, each with individual relays. A spare tube position permits a heated tube to be ready at all times for replacement of a rectifier tube without the usual initial heating delay. The filter consists of a retardation coil, condensers and a current limiting resistor which is automatically short circuited as soon as the filter condensers have been charged.

Protection is provided by individual tube reverse current relays, a d.c. overload relay, and transformer primary relays. An indicating lamp is associated with each reverse current relay.

A switch connects the primaries of the power transformer in Y or Δ so that the rectifier may be operated at approximately 70 percent of normal voltage during tuning or reduced power operation.

29. Water Cooling System—A complete cooling system is furnished for the water cooled tubes in the final amplifier stage.

This system includes a bronze pump, porcelain insulating coils, a copper storage tank, and an air blast radiator.

An indicating flow meter and relay guard against failure of water flow and an indicating contact-making thermometer protects against excessive temperature of cooling water.

30. **Power Supply**—The power required is approximately 28 kw. for 5 kw. operation and 13 kw. for 1 kw. operation. The power factor is approximately 95 percent. The standard equipment is designed to operate from a three-phase 230-volt ± 10 percent supply.

31. **Installation**—The cabinets may be mounted side by side, as a continuous panel front or may be installed in groups of two units each, not more than 20 to 30 ft. apart. The control unit may be placed in line with the three transmitter cabinets, or it may be installed separately as individual requirements may dictate. The weight of the four-panel assembly is approximately 5400 pounds and the overall dimensions are approximately 12′ 1″ wide, 7′ high and 3′ 2″ deep.

Enclosures for other apparatus should be furnished by the customer in whatever form meets the architectural requirements of the transmitter building. These enclosures may be separate rooms on the same floor with the cabinets, standard office partitions, or wire fencing in the basement. The three transmitter units and the control unit can be employed as part of the enclosure, forming a panel front to a screened-off section.

The high voltage rectifier and power supply equipment should be arranged as best suited to the building in which the transmitter is installed.

The water pump and cooling radiator are usually at a distance from the transmitter and are not necessarily enclosed.

CHAPTER 11

MARINE RADIOTELEGRAPH TRANSMITTERS AND RECEIVERS

Introduction—On May 20, 1937, Congress amended the Communications Act of 1934, by the enactment of a bill, Public 97 for the purpose of promoting safety of life and property at sea and to make more effective the International Convention for Safety of Life at Sea, 1929, ratified by the government of the United States on November 7, 1937.

Section 15 of Public 97 repeals the Ship Act of 1910 as amended so far as it relates to the ocean and steamers navigating thereon but the Ship Act is continued in force with regard to vessels navigating the Great Lakes. Passenger ships subject to Public 97 require two complete transmitters and receivers, a main and emergency, as well as an emergency power supply. In addition to the above requirements passenger ships of 5000 gross tons or over are required to be fitted with a direction finder and certain motor lifeboats are required to have a complete radio transmitter and receiver. Prior to the enactment of Public 97, passenger ships required but one transmitter and receiver and in addition an emergency power supply. Certain rules of interest to operators of ship stations will be found in Chapter 19.

The radiotelegraph transmitters and receivers described in this chapter will be found on ships subject to the Communications Act of 1934, as amended, and students preparing for examination for radiotelegraph operator licenses should study the contents so as to become familiar with the adjustment, operation and maintenance of marine radiotelegraph equipment.

RMCA MODEL ET–8006 RADIO TELEGRAPH TRANSMITTER (300 WATTS)

1. **General**—The ET–8006 radio telegraph transmitter is designed primarily for marine applications where a compact medium power transmitter is required. The design of this equipment embodies several features not heretofore available, such as quick

selection of operating frequencies, plate modulation of the power amplifiers for A–2 emission (modulated telegraphy), and the use of high efficiency Litz inductances throughout.

Rating—The transmitter is designed to deliver approximately 300 watts to the antenna on continuous wave transmission (A–1), and 400 watts for modulated telegraphy (A–2).

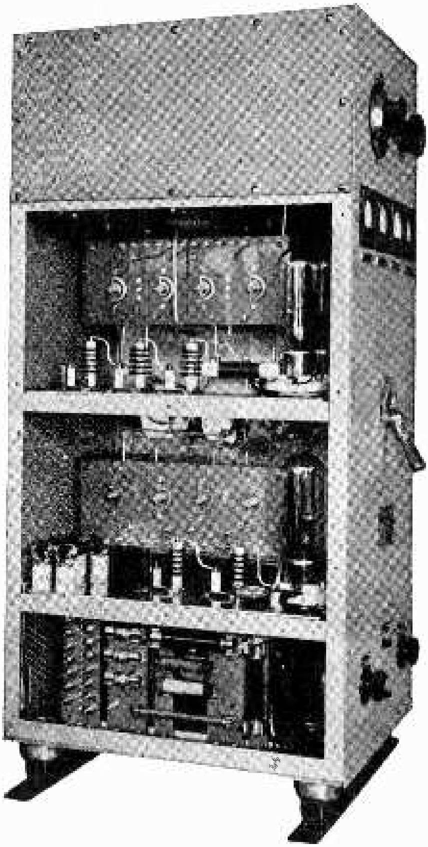


FIG. 332. R.M.C.A. Model ET–8006 Radio Telegraph Transmitter.

2. **Frequency Range**—The design permits the set to be pretuned to any four frequencies in the band 375 to 500 kc. (800 to 600 meters). The actual operating frequencies for which the

transmitter is tuned appear on the frequency switch and in case it is desired to set up the transmitter for different frequencies within the specified range, removable nameplates are provided. Nameplates are available for the following frequencies: 375, 394, 400, 410, 425, 454, 468, 500 kc. For ordinary service the transmitter is usually tuned to 375 and 500 kc. and two additional working frequencies within the band.

3. **Vacuum Tubes**—Four UV-211 tubes are used in the transmitter, one as a master oscillator, and three in parallel as power amplifiers.

4. **Power Supply**—The transmitter is designed for 110 volt d.c. or 240 volt d.c. supply, and the appropriate motor generator set for the line supply voltage is included as part of the equipment. The motor generator set is a three-unit two-bearing machine, consisting of a d.c. motor with slip rings for filament supply, a 1200 volt d.c. generator for plate supply, and a 500 cycle alternator for modulated telegraphy (A-2). For 110 volt d.c. supply the M. G. set is rated as follows. Motor—type F-42, 110 volts, 16 amperes d.c., 1875 r.p.m. with slip rings to deliver 75 volts, 2 amps. at 31 cycles. High voltage generator, 1200 volts .65 amps. d.c. Alternator 110 volts 1.82 amps. at 500 cycles. The 240 volt M. G. set is rated the same as the 110 volt unit, except for the motor, which is rated 240 volts, 8 amperes d.c. with slip rings to deliver 184 volts, .91 amps. at 31 cycles.

5. **Type of Circuit**—The transmitter utilizes a master-oscillator power-amplifier circuit with plate modulation on the power amplifier tubes through a modulation transformer for A-2 or modulated telegraphy. The master-oscillator circuit consists of a tapped coil and four small variometers adjustable inside the set for the four spot frequencies. A similar circuit arrangement is used for the power amplifier. A two pole four position switch is used to select the appropriate circuits in the M. O. and P. A. for the four spot waves. The power amplifier is coupled to the antenna circuit by means of relatively high capacity condensers which are in series with the P. A. tank circuit so that a minimum amount of harmonic power is transferred to the antenna system. The antenna circuit is tuned by means of a variometer and a tapped loading coil, the taps being adjustable by means of a switch from the front panel. Break-in operation is provided by means of a special break-in relay. Complete internal and external connections are shown in figure 333.

6. **Antenna Characteristics**—The transmitter is designed to cover the specified frequency range on any antenna whose char-

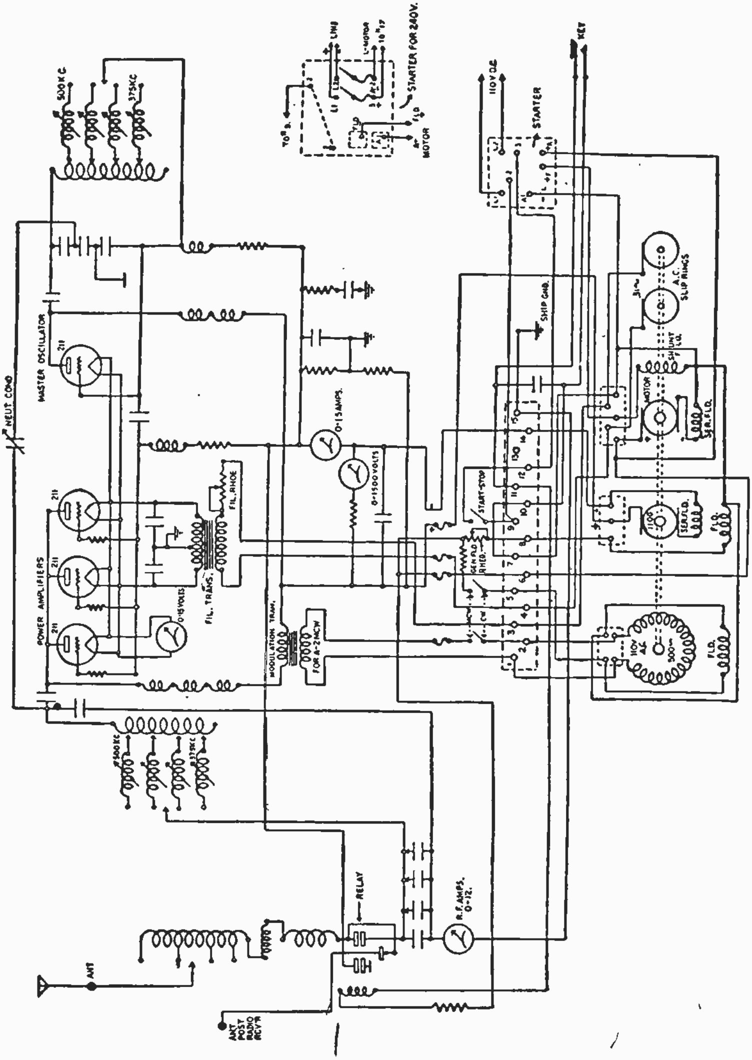


FIG. 333. ET-8006 Radio Transmitter, Radiomarine Corp. of America.

acteristics fall between 500 and 1500 mmfd. with a resistance of 4 to 10 ohms.

7. **Transmitter Adjustments**—When the transmitter is initially tuned, care must be taken to keep the power amplifier tank circuit in resonance with the master-oscillator. Proceed as follows: Set the frequency switch at 500 kc. Turn the plate rheostat to the extreme left for minimum plate voltage. Start up the transmitter and with the key open adjust the filaments to 10 volts. Remove the left shield from the transmitter. The first variometer, that is the one nearest the front panel, in the master-oscillator compartment, should then be adjusted for 500 kc. While this is being done care should be taken to keep the similar variometer in the P. A. compartment also adjusted so that the plate current as read on the plate ammeter is at a *minimum.* These adjustments may be made without any antenna current flowing. After the P. A. has been adjusted to the M. O. the antenna circuit may be brought into resonance. The frequencies should then be checked again and any slight adjustments made to the M. O. and P. A. variometer. In all cases the P. A. variometer should be adjusted for a minimum plate current with the antenna detuned so that no antenna current is flowing.

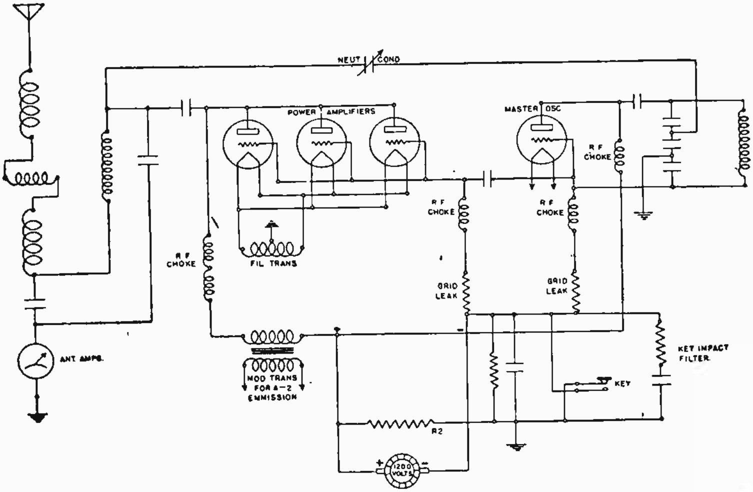


FIG. 334. Schematic Showing Blocked Grid of Keying.

After the set is tuned to 500 kc. resonate the antenna, raise the plate voltage to 1200 volts and observe if the plate current is between .5 and .6 amperes. The total plate power drawn by the set, which should not exceed under any conditions .6 amperes at 1200 volts, is determined by the number of antenna coupling condensers which are in the circuit. These condensers are three units mounted to the left of the break-in relay in the upper section of the transmitter and are rated .001, .002 and .003 mfd. They will be found mounted over a larger .01 mfd. condenser. For a low resistance antenna the three coupling condensers should all be connected in parallel in the circuit. At all times the .01 condenser must be in circuit. For the average four ohm antenna the three additional condensers should be in parallel to the .01 mfd. unit. If the antenna resistance is higher so that the set cannot be loaded up to .6 amperes with 1200 plate volts the .001 coupling condenser may be disconnected. This will increase the coupling to the antenna and cause greater input and output. However, whenever the antenna coupling condensers are changed, care must be taken to re-resonate the power amplifier variometer for minimum plate current, with no antenna current, as previously specified. It will be seen that with the three antenna coupling condensers that may be cut in or out of circuit by means of the connection links, that a wide variation of antenna coupling is possible. For example, considering the three condensers, a total capacity of .006, .005, .004, .003, .002, or .001 mfd. may be used. When adjusting this transmitter keep in mind that the more coupling capacity that is used will decrease antenna coupling. This action is the reverse to that normally encountered with magnetic coupling.

After the set has been adjusted to 500 kc. the same procedure should be followed for the other three frequencies. It will be observed that adjustable links are provided on the M. O. and P. A. tank variometer assemblies so that each variometer may be connected to any one of three taps from the tank circuit inductance proper.

8. General Instructions for Radio Operators—1. Do not exceed 1200 volts or .6 amperes plate input.

2. Always keep the filament voltage adjusted to 10 volts.

3. Keep all shields of transmitter fastened tightly to frame.

4. Keep break-in relay contacts adjusted with minimum clearance for best keying. When this relay is properly adjusted, no sparking should occur on the right pair or antenna contacts and only slight sparking should be observed on the left pair or power contacts. Make sure that the lower contacts, which connect the

antenna circuit to the receiver, always are open when the relay coil is energized.

5. Keep the transmitter and motor generator free from dust and oil. Occasional dusting of the transmitter and all nameplates on the panel will help maintain new appearance. The Isolantite switches in the tank circuits and antenna circuits should be cleaned about every six months from accumulations of dust and dirt which will cause flash-over.

RMCA MODEL ET-8003 RADIO TELEGRAPH TRANSMITTER

9. **General**—This apparatus is designed primarily for marine applications to permit communication in the intermediate frequency band. Particular care has been taken in the construction and design of the apparatus to provide a high degree of reliability, together with simplified operation and minimum drain from the power supply circuits.

10. **Component Units**—The following items comprise the major component units:

Radio transmitter
Battery charging and power control panel
Control unit
Motor generator set
Plate transformer

In addition, for certain types of installations where a 60 volt storage battery is used a battery change-over switch may be supplied. This switch is a 10 pole double throw unit mounted in a metal box and should be connected so that the 60 volt battery is divided into five 12 volt sections. The 10 pole switch in one position then connects the five 12 volt batteries in parallel for emergency power supply to the transmitter. In the other position the five 12 volt batteries are connected in series, delivering 60 volts for the ship's Gyro-compass or other purposes. This switch is not required when the standard 12 volt MVA-17 battery (6 hour rate, 256 ampere hours) is used.

11. **Power Supply**—The radio equipment is designed to operate both from the normal 110 volt d.c. shipboard supply and also a 12 volt storage battery. When connected with a 110 volt d.c. supply a current of approximately 6 amperes is required. When connected to a 12 volt storage battery the current drawn from the battery is approximately 35 amperes. Both of the above

values of current are based on the power drawn when the key is held down.

12. Radio Transmitter—The radio transmitter is housed in a metal cabinet and so arranged that it may be mounted against the bulkhead or on the operator's table. The unit is protected from the effects of vibration by means of 4 special rubber mounts. The overall dimensions of the transmitter are

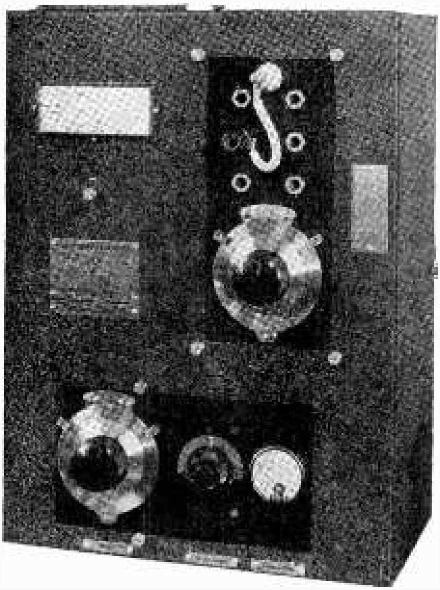


FIG. 335. R.M.C.A. Model ET-8003 Radio Telegraph Transmitter.

Height 20 1/8″
Width 15 1/8″
Depth 7 1/2″

Complete access to the various parts in the transmitter is easily obtained by removing the metal cabinet which fastens to the transmitter panel. Access to the vacuum tubes is obtained through a small door at the top of the unit.

The transmitter covers a frequency range of 375 to 500 kc. (800 to 600 meters). It is designed to operate into an antenna whose capacity falls between 500 and 1500 mmfd. and whose resistance is between 2 and 10 ohms.

Normal output of the transmitter delivered to the antenna system is approximately 50 watts. Four UX–210 radiotron tubes are used in the oscillating circuit.

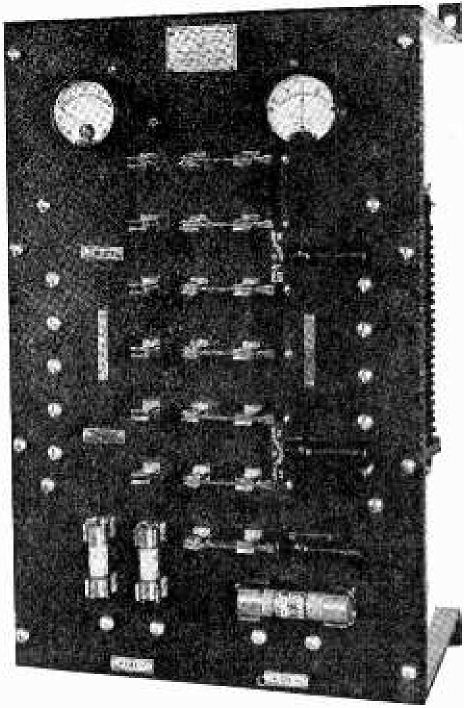


FIG. 336. Model 8003 Battery Charging Panel.

13. **Battery Charging and Power Control Panel**—The battery charging and power control panel performs several functions. It permits the motor generator set to be connected either to the 110 volt d.c. shipboard supply or to the 12 volt storage battery. This panel also mounts the filament resistor and alternator field resistor, both of which are adjustable so that the transmitter will deliver normal output with either power supply. Battery charging resistors are mounted back of the panel and arranged so that the

12 volt battery may be charged either with a 10 ampere rate or trickle charged at a 1/2 ampere rate. The motor starting resistor for the 110 volt motor is also mounted on this panel. Fuses are provided to protect the 110 volt and 12 volt circuits and 2 meters are mounted on the panel, one to indicate battery charging current and the other battery voltage. This panel should be installed so that ample ventilation takes place in order to carry off the heat of the battery charging resistors.

14. **Control Unit**—The control unit is designed for mounting on the operator's table and contains a send-receive switch, a 12 volt motor starting switch and a 110 volt motor starting switch.

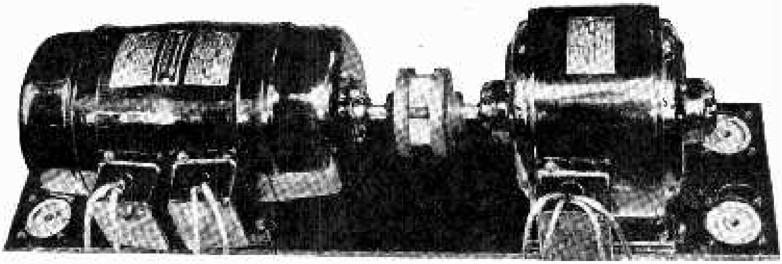


FIG. 337. Motor Generator Set for Model ET–8003 Transmitter.

15. **Motor Generator Set**—The motor generator set (Electric Specialty Company) is a 2 unit 4 bearing machine using ball bearings and provided with 4 rubber mounts to minimize the effects of vibration and noise. One unit of this machine contains both the 12 volt and 110 volt motors while the second unit comprises a 350 cycle alternator. The rating of each unit is as follows:

110 volt motor, type RL–144, h.p. 1/3 compound wound, amps. 5, 1750 r.p.m.
12 volt motor, volts 12–8, amps. 40–10.
Alternator, type BS–2, volts 110, amps. 1.5, 350 cycles, single phase.

16. **Plate Transformer**—The plate transformer is designed for external mounting beneath or near the transmitter and has the following rating. Specification No. 17599, type CB, American Transformer Company, .15 kva., single phase. The primary is rated at 110 volts, 350 cycles. The secondary delivers 1500 volts at 350 cycles and is provided with a mid-tap at 750 volts. Both the primary and secondary leads of the transformer are brought

out through insulated bushings at the top so that the five leads may be connected directly to the respective five terminal studs on the radio transmitter.

The lead from post No. 6 of the radio transmitter to the send-receive switch in the control unit should be run separately and maintained a reasonable distance from grounded surfaces as this lead in the receive position connects to the antenna post of the radio receiver.

The transmitter is designed for normal installation on the bulkhead directly above the operator's table and should be located so that the various controls are within convenient reach of the operator. When bulkhead mounting is not feasible a pair of suitable metal brackets should be used, and the four rubber shock mounts fastened to these brackets.

In mounting the transmitter on the bulkhead, the following procedure is recommended. Support the transmitter temporarily on the bulkhead and spot at least two holes for each of the four shock mounts. After this has been done remove the four nuts which hold the shock mounts to the transmitter and then proceed to secure the mounts on the bulkhead. The transmitter should then be replaced and fastened temporarily to the two upper mounts. This will enable the transmitter to be swung forward from the bottom a short distance, permitting access to the eight terminal studs which are arranged for rear connection. A small amount of slack should be left in the eight leads to avoid undue damping of the rubber mounts. After the connections have been made the lower two nuts may be fastened to the shock mounts.

17. **Important**—Care should be taken that the secondary leads of the plate transformer which are tagged 3, 4, and 5 connect respectively to terminals 3, 4 and 5 on the transmitter. If two of these leads are interchanged it will result in applying excessive voltage to the tubes and causing the transmitter to act as a half wave instead of a full wave oscillator. A simple check on the correctness of these connections may be made by removing first the two tubes at the left of the tube socket and noting the antenna current and then replacing these tubes and removing the other pair. The same value of antenna current should be obtained in either case. A resistance measurement may also be made and with correct connections there should be approximately 180 ohms betweeen terminals 4 and 5 and between terminals 4 and 3. The primary resistance is about 1.4 ohms.

An understanding of the switching functions and controls provided by the charging panel are necessary in order to properly adjust the equipment. The four pole double throw switch on the charging panel functions as follows. The first or upper pole in the 110 volt position connects one side of the line to the three position 110 volt motor starting switch. The second pole in the 110 volt position selects a suitable tap on the variable alternator field resistor. In the 12 volt position the second pole selects a second tap on the alternator field resistor. The third pole in the 12 volt position permits connection to the 12 volt motor starting switch. The fourth pole controls the filament resistor, selecting the proper tap in either the 110 volt or 12 volt position.

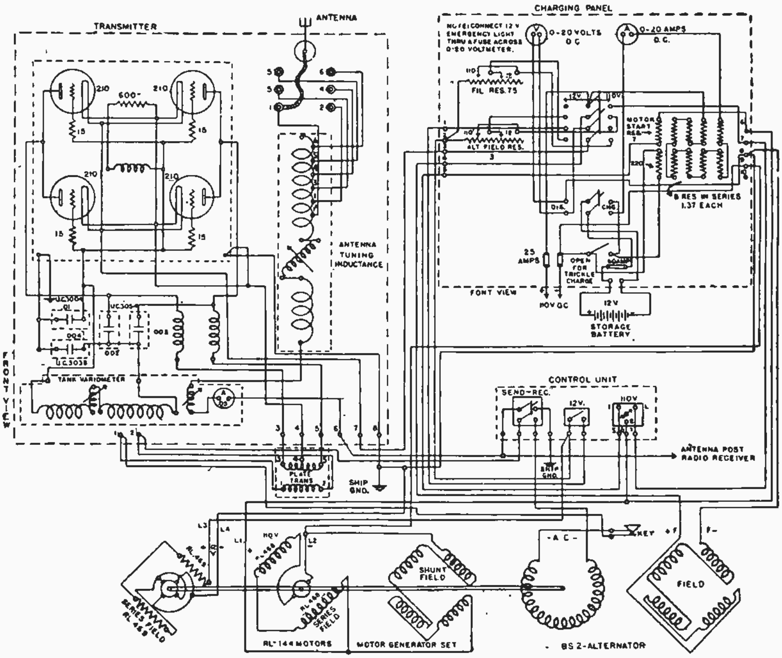


Fig. 338. ET–8003 Transmitter, Radiomarine Corp. of America.

The double pole double throw switch on the charging panel is arranged in the conventional manner to permit charge or discharge of the 12 volt storage battery. The single pole single throw switch connects a 220 ohm resistor in series with the other charging resistors to enable the battery to be trickle charged at a 1/2 ampere rate. When this switch is closed the battery is charged at its normal rate of approximately 10 amperes.

Charging current is read on a zero to 20 ampere d.c. meter and care should be taken to observe that this meter reads in the correct direction. If it indicates discharge this shows that the polarity of the 110 volt supply is reversed. The condition of the 12 volt battery may be observed by means of the zero to 20 volt d.c. voltmeter. This meter should read approximately 12.5 volts when the battery is in good condition and when no load is being drawn. When the 12 volt motor is started there should not be an excessive drop in voltage as indicated by the meter, provided the battery is in good condition and well charged.

Since the apparatus is normally operated from the 110 volt line it is recommended that the 12 volt battery be left on continuous *trickle* charge.

After all units have been connected as shown in the diagram the 12 volt motor should be tested by throwing the switch on the panel to the 12 volt position and the battery in the discharge position. The motor generator should then start when the 12 volt starting switch on the control unit is closed. The four pole switch on the charging panel should then be changed to the 110 volt position and the motor generator started by means of the three position 110 volt motor starting switch. Care should be taken not to operate the set with this switch in the " start " position.

A zero to 15 volt d.c. voltmeter should be connected temporarily across terminals 7 and 8 of the transmitter. The set should now be operated on 12 volts with the key open and the variable tap on the filament resistor on the charging panel changed until the voltmeter at the transmitter reads 7.5 volts. The filament resistor is the unit at the top of the charging panel. The set should then be transferred to 110 volt operation and the second variable tap on the filament resistor adjusted until the filament voltmeter again reads 7.5 volts.

The transmitter should then be tuned to one of its assigned frequencies and the antenna circuit adjusted to resonance until a reasonable value of antenna current is obtained. This will load the motor generator, causing a slight drop in supply voltages. The reading on the filament voltmeter across terminals 7 and 8 should again be noted. It may be necessary to slightly readjust both the taps on the filament resistor so that 7.5 volts are obtained at the filaments when the key is closed.

The alternator field resistor is mounted in the lower section of the charging panel underneath the enameled resistors and is provided with two adjustable taps as already described. These taps are adjusted at the factory and normally need not be changed. However, to check their adjustment it is simply necessary to observe that the same value of antenna current is obtained on both 110 volt and 12 volt operation. If the antenna current is lower on one power supply than on the other, one of the flexible clips on the resistor should be moved until uniform antenna current is obtained. This adjustment permits the motor generator unit to run at different speeds for the two supply voltages, which may occur on account of voltage drop on the wiring, but at the same time the alternator field may be so adjusted that the same 350 cycle voltage is obtained under either condition.

The operation of the motor generator set for both power supply conditions may be explained as follows. When the 12 volt supply is used the storage battery operates the 12 volt motor, supplies the filaments through the filament resistor, and excites the alternator field through the alternator field resistor. The 110 volt motor runs idle under this condition.

When the equipment is switched to 110 volt operation the 110 volt motor drives the motor generator set and the 12 volt unit is then used as a generator to supply the filaments and the alternator field. Under this condition the 12 volt unit delivers 8 to 9 volts and for this reason less resistance is required in the filament and alternator field resistors. As already explained the resistance values are automatically changed by the four pole switch on the charging panel.

18. Adjustment of Transmitter—A small bakelite panel in the lower section of the transmitter contains the frequency control variometer, the antenna coupling control and the antenna ammeter. The frequency control variometer is provided with a Vernier dial and is arranged so that the frequency increases (wavelength decreases) as the dial is turned from zero to 100. A typical calibration of the frequency control is shown on the chart included in this instruction book, which may be used to determine the approximate settings of the dial when the set is calibrated with an accurate wavemeter.

The bakelite panel in the upper right section of the transmitter contains the antenna variometer and a plug and jack combination so that any one of six taps on the antenna loading inductance may be selected. The variometer in this unit has sufficient range so that a single tap may be selected for a given antenna to permit the 500 kc. calling wave and one or two of the adjacent working frequencies to be obtained without changing the antenna plug. This point should be kept in mind when the set is calibrated.

19. Adjustment of Antenna Coupling—The adjustment of the antenna coupling control must be made with care in order to avoid excessive coupling between the antenna and the oscillator circuit. The proper adjustment may be determined easily for any frequency by simply observing that the antenna current rises and falls smoothly when the antenna variometer is rotated through resonance. If the coupling is too tight it will be found that when going through resonance that the antenna current will break sharply on one side of resonance. This is an indication that the coupling is too great.* Zero coupling is obtained when the pointer of the coupling control is approximately vertical or around 25 on the dial. The control may be moved to the right or left to increase the coupling. On the average ship board antenna it will be found that loose coupling can be used at all times and it should not be necessary to adjust the control more than a few degrees either side of 25 on the dial.

20. Important—The operators should observe carefully that zero on the frequency control Vernier dial is *not* at the center of this dial, but is at the right where the heart shaped index is located. In other words the markings " 5 and 10 " on the stationary Vernier dial are to be used only for setting the dial to fractional parts of a scale division. The operators should become familiar with the method of reading this Vernier dial. The following example will make this clear. Suppose a setting of 50.1 is desired. First set the dial so that 50 on the movable scale lines up directly under the zero or heart shaped index mark. Then turn the dial slightly in a clockwise direction until the first Vernier Division to the left of the index mark lines up with the *nearest* dial division underneath it. This is then the correct setting for 50.1. As another example set the dial for say 50.5. It will then be found that the " five " setting on the stationary Vernier scale will line up with a division on the dial and by inspection it will be evident that the index mark will point midway between 50 and 51.

21. Lubrication of Motor Generator—The motor generator is a ball bearing machine and is shipped with the bearings greased to last several months. If service and conditions are severe bear-

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* When the circuits are too closely coupled the circuit has two frequencies at which it is capable of operating. The transmitter may, therefore, oscillate at one frequency for sometime and suddenly when keying start to oscillate at another frequency. As the coupling is loosened by increasing the distance between the tank and antenna circuit the two frequencies at which the transmitter may oscillate approach each other and at a given value of coupling these two frequencies coincide. The value of coupling at which this occurs is called "critical coupling" and the phenomenon is referred to as "split tuning."

ings should be greased every six months, if not, less frequently. To grease the bearings either of two methods may be used. The grease plugs over the bearing caps may be unscrewed and grease forced down into the bearings. To do this on the motor end requires that the motor end covers be removed. The other alternative is to remove the four small screws which hold the bearing end caps, remove the caps and pack the bearing with grease. Do not force in excessive grease since it will get on the commutators or windings. Gulf Refining Company No. 2 cup grease or equivalent should be used except where temperatures run very high, in which case No. 3 cup grease is recommended. *Great care* should be taken to keep the grease and bearings clean. Dirt will destroy bearings quickly. Grease caps should always be removed yearly, bearings cleaned well with benzine and new grease put in.

22. **Brushes**—The motor brushes are of a specially selected type and when replacements are required they should be ordered, giving the type and serial number of the motor generator set.

23. **Access to Parts**—Complete access to the various parts in the transmitter may be obtained by removing the cover. When replacing the cover it should be fastened tightly so that vibration will not cause movement with respect to inductances in the transmitter.

24. **Spare Parts**—Spare parts for the transmitter or other component units should be ordered by first referring to the name and rating of the part where given, as shown on T–189. The model number and serial number of the transmitter also should be specified. If it is necessary to replace a tube socket at any time it is recommended that this be done by removing the entire casting which mounts the four tube sockets. This will permit easy access to any of the sockets and also to the 15 ohm parasitic resistors and the grid leak choke.

MACKAY RADIO TRANSMITTER 142 (FEDERAL TELEGRAPH CO.)

25. **General Description**—Radio Transmitter 142 is a simple oscillator of the tuned plate untuned grid inductive feed-back type, using four Type 10 oscillator tubes, with full-wave self-rectified plate supply. Provision is made for quick change to any one of five frequencies. This transmitter is designed to operate from a 12 volt battery source, using Motor Generator 103. If operation direct from a 120 volt d.c. line is desired, Motor Generator 113 and Power Transfer Unit 102 are required in addition.

Meters are provided to read antenna current, filament voltage and battery charging current. The filament voltmeter has a toggle switch which indicates the filament voltage in the normal position and battery voltage in the other.

The antenna tuning device consists of a loading coil provided with taps for coarse adjustment and a variometer rotor for fine adjustment of the antenna circuit to resonance.

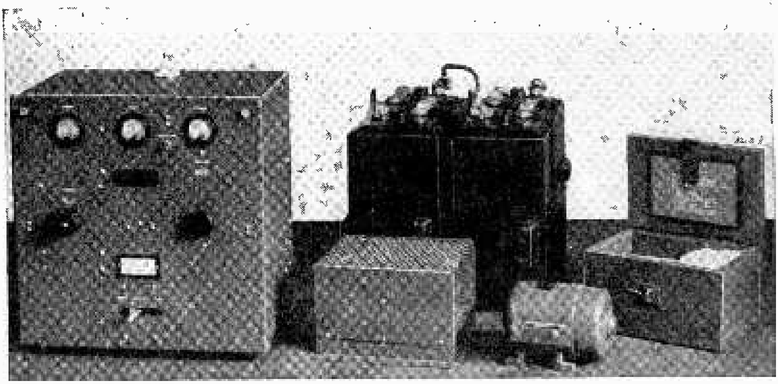

FIG. 339. Mackay Radio Transmitter 142.

The frequency switch is a part of the oscillator tank coil assembly, and consists of three separate single pole 5-point switches. The upper contacts at the back of the tank coil connect to the clips for the tank inductance which set the frequency. The bottom rear set of contacts are connected to the taps on the antenna load coil. The upper front set of contacts are connected to the antenna coupling clips. The tank inductance and the antenna load coil taps are switched by one of the concentric knobs, and the antenna coupling by the other knob. Both knobs are switched together and placed in the same position in every case.

Keying is accomplished by breaking the power supply to the plate transformer with the hand key. A modulated or ACCW signal only is provided by the transmitter (A–2 emission).

A three-position switch on the front panel starts the 12-volt motor generator and connects the antenna to the transmitter in the "Send" position, stops the 12-volt motor generator and connects the antenna to the receiver in the "Receive" position, and charges the storage battery leaving the antenna connected to the receiver in the "Charge" position.

In case it is desired to run the transmitter directly from a 120 volt d.c. line, Power Transfer Unit 102 and Motor Generator 113 are furnished in addition. Motor Generator 113 supplies 360 cycles for operation of the plates and 60 cycles for the filaments. Power Transfer Unit 102 contains a field rheostat for adjusting the 360 cycle voltage from Motor Generator 113, a filament rheostat, filament transformer, 120 volt line fuses, power switch and Emergency-Main switch. This latter switch transfers from 12 volt to 120 volt operation.

26. Installation Instructions—Radio Transmitter 142 is intended for mounting on the wall or bulkhead by means of six bolts through the back of the case. If desired, however, it may be mounted on a table on raised supports. External wiring enters through 3 nipples in the bottom, with the exception of the antenna, which attaches to an insulated terminal at the top.

Motor Generator 103 and the two 6-volt storage batteries should be as near the transmitter as possible since the currents drawn are heavy and the wiring should be short. No. 8 B&S gauge or larger conductor should be used for connections to the battery and motor, from transmitter terminal 1, 2, 20 and 21. All other interconnecting wires should be No. 14 B&S gauge lead covered wire. The transmitter case, generator frame, and all lead sheaths should be substantially grounded.

A ground stud for the transmitter is located in the center of the bottom. Connections may be made to it on the outside, or by running a ground wire through one of the nipples to the inside.

Battery Charger 102–A may be mounted on the wall or bulkhead at any convenient location, bearing in mind that considerable heat is developed and ventilation is important.

In case operation from the ship's 120 volt d.c. line is required, Power Transfer Unit 102 and Motor Generator 113 are furnished. The connections between the transmitter, power transfer unit and Motor Generator 113 should be No. 14 B&S gauge lead covered with grounded sheaths, with the exception of the leads between terminal No. 16 and 17 which should be No. 8 or larger. Motor Generator 113 should be placed as far from the receiver as possible. The generator frame should be grounded. Power Transfer Unit 102 should be near the transmitter. It may be mounted with bolts either to the wall or table. Knockouts are provided on the top, back, and bottom, through which the wiring can be brought to the terminal block in the manner best suited to the particular installation.

The terminal block and line fuses are located behind the front panel of Power Transfer Unit 102, accessible through a cover which is secured by two thumb screws.

27. Tuning Instructions—The front panel of the transmitter is hinged at the bottom for accessibility. Two stops are provided for allowing it to swing outward at about 45 degrees. If desired, these stops may be pressed inward and the panel released to swing completely down. The process of tuning adjustment is facilitated by means of two holes into which a pin may be inserted at the center of the top panel. In order to swing the panel out, the two knurled thumb screws in the upper corners must be removed. After making internal adjustments, the panel is swung back into place, and the pin inserted to keep the panel in place while the adjustment is checked, after which the thumb screws are replaced and the pin removed. The importance of checking adjustments with the panel closed is emphasized, because the case has a marked effect both on frequency and coupling.

Tuning adjustment of the transmitter may be accomplished equally well whether main or emergency operation is used. The tank circuit has been adjusted in the factory to the following five frequencies: 375, 400, 425, 468 and 500 kc. It is possible that slight readjustments of the tank inductance clips may be necessary to make these frequencies exactly as desired. All antenna and antenna loading adjustments depend on the particular antenna available and must be made in the field.

Starting with the 500 kc. antenna coupling clip connected to the upper front contact of the frequency switch, position No. 1, locate this clip on one of the turns between the front panel and the ground clip and select the corresponding antenna coil tap so that the antenna can be resonated to the desired frequency. Then adjust the antenna coupling clip until upon tuning the antenna variometer through resonance, antenna current rises smoothly to a maximum and drops again without breaking or flipping. This condition where " Flipping " just does not occur is the condition of critical coupling and the transmitter will provide maximum output compatible with best frequency stability when so adjusted.

A similar procedure should be followed for each of the five frequencies. It may be necessary to thread the wire connecting to the antenna coupling clips through the end of the coil between the winding and the bakelite panel in order to obtain exactly the critical coupling conditions, since shaping the wire about the outside of the coil may either add to or subtract from the mutual inductances to such an extent that critical coupling cannot be obtained.

While the grid adjustment is quite broad, and the setting used at the factory satisfactory for most cases, three taps are provided for grid adjustment on the bottom of the front bakelite end of the tank coil assembly.

A careful check should be made to see that none of the clip leads are touching each other or the tank coil winding or any other points which might result in a voltage break-down.

A tapped resistor is provided, mounted at the rear on the bottom of the case to adjust the filament voltage to a suitable value and compensate for drop in the wiring when operating from the 12 volt battery. This should be set so as to produce approximately 8.5 volts on the filament voltmeter with a fully charged battery. This provides a suitable range of filament voltage as the battery discharges.

28. Operating Instructions—To place the transmitter in operation, throw the Send-Receive Charge switch to the send position, set the Frequency Switch to the desired frequency, and close the key. Adjust the antenna tuning control for maximum antenna current and proceed with keying. Throwing the Send-Receive Charge switch to the receive position, connects the antenna to the receiver and permits reception. The same switch on the charge position charges the 12-volt battery, the charging rate being read on the ammeter at the center of the transmitter panel. In order to place the switch in the charge position, the metal stop link which normally limits the travel of the switch to the receive position must be swung upward with the finger. The antenna remains connected to the receiver while the 12-volt battery is charging.

If Motor Generator 113 and Power Transfer Unit 102 are provided with the installation, throwing the Main-Emergency switch of Power Transfer Unit 102 to the Emergency position, results in operation exactly as described above. With the switch in the "Main" position, Motor Generator 113 is started by closing the Power switch. The filament voltage is then adjusted by means of the filament rheostat on the control unit to 7.5 volts as indicated on the transmitter filament voltmeter. The plate voltage is adjustable by the Field Rheostat on the control unit. Operation of the transmitter is the same as outlined above for emergency operation, the Send-Receive switch performing the antenna change-over function.

29. Tubes—4 Type '10 Tubes.

MACKAY RADIO TELEGRAPH TRANSMITTER TYPE 131–A (FEDERAL TELEGRAPH COMPANY)

30. Installation Instructions—Radio Transmitter 131–A (not illustrated) is intended to be mounted on the wall or bulkhead over the operating table. The transmitter is secured by bolts at the four corners of the metal base.

Motor generator 103 and its associated battery should be placed as near the transmitter as practical in order to reduce the line drop due to the heavy current drawn by the primary of the motor generator. Primary wiring, that is wiring from the battery to transmitter terminals No. 1 and No. 2 and from transmitter terminals No. 14 and No. 15 to the primary of motor generator 103, should be done with the No. 8 or larger wire in order to minimize this line drop. All other wiring in connection with the transmitter installation may be of No. 14 and preferably lead covered.

31. General Description—Radio Transmitter 131–A provides for operation from a 12 volt storage battery source only. Motor generator 103 delivers 110 volts at 800 cycles a.c. which is used for the transformer. The filaments are lighted directly from the 12 volt battery source. The transmitter employs a simple oscillator circuit of the tuned plate untuned grid inductive feedback type, using full-wave self-rectified plate supply. Four type '10 tubes are required.

The antenna tuning device consists of a long loading coil provided with taps for coarse adjustment and a variometer rotor for fine adjustment of the antenna circuit to resonance. Two antenna connections are provided, one for use on the main antenna and the other for use on the emergency antenna. A movable link makes connection from the antenna to either one of these antenna connections.

The frequency is determined by a closed oscillating circuit in the plate circuit which is adjustable by means of a clip on the inductance and a rotating half turn so that the frequency may be set at any desired degree of precision. The antenna is inductively coupled to this oscillating circuit and two clips are provided for adjusting these couplings, one for use on the main antenna and one for use on the emergency antenna. The movable link makes connection to one or the other of these antenna coupling clips.

Meters are provided to read antenna current and filament voltage. The filament voltmeter has a toggle switch which indicates the battery voltage when up and the filament voltage when down.

Keying is accomplished by breaking the power supply to the plate transformer with the hand key. A modulated or ICW signal only is provided by the transmitter.

A three-position switch on the front panel starts the motor generator and connects the antenna to the transmitter in the "Send" position, stops the motor generator and connects the antenna to the receiver in the "Receive" position, and charges the storage battery leaving the antenna connected to the receiver in the "Charge" position.

32. **Tuning Instructions**—To place the transmitter in operation for the first time after installation, the following routine should be helpful.

Remove the cover and disconnect both antenna coupling clips. These clips are the two clips at the left hand end of the tank coil assembly. This tank coil assembly is the unit wound on the ceramic coil form at the lower center of the transmitter. Place the switch in the "Send" position and close the key. Check the frequency with the wavemeter. The frequency is then adjusted to the desired value by means of the clip on the right hand end of the tank coil assembly and the adjustable half turn at the end of this assembly. A movable link at the top of the transmitter permits connection to either one of two antenna tuning connections and a similar movable link at the left end of the tank coil assembly permits connection to either one of two antenna coupling clips. With both movable links in the position for operation on the main antenna, attach the antenna coupling clip corresponding to the main antenna three or four turns from the left hand end of the tank coil assembly and again close the key. Tune the antenna tuning adjustment throughout its range until maximum antenna current is indicated on the antenna ammeter. If resonance cannot thus be obtained, adjust the antenna tuning tap until it is possible to tune through a maximum of antenna current. Then readjust the antenna coupling tap until the maximum of antenna current is obtained without any sudden breaks or jumps in antenna current as the antenna circuit is tuned through resonance. The two adjustable links should then be shifted to the emergency antenna position, the emergency antenna connected, and the adjustment of the antenna tuning circuit and antenna coupling repeated as outlined above. Some slight change in frequency may be noted when the cover is replaced. In this case the readjustment of the tank tuning clip or of the adjustable half turn will produce the desired frequency.

With a fully charged battery the filament voltage should read 8.5 volts under full load operating conditions. A tapped filament resistor is mounted on the base at the right of the antenna load coil. The tap on this resistor should be selected which gives the nearest to 8.5 volts on the filament voltmeter with a fully charged battery under full load conditions.

33. **Operating Instructions**—To place the transmitter in operation, check that the proper antenna is connected to the transmitter, throw the switch to the " Send " position, and operate the key. Throwing the switch to the " Receive " position stops the motor generator and connects the antenna to the receiver. When the transmitter is not in use the switch should usually be kept in the " Charge " position. This charges the storage battery at a 5 ampere rate, at the same time leaving the antenna connected to the receiver so that reception is possible.

A weekly check should be made of the specific gravity of the storage battery electrolyte which should be kept at a value of 1.275. Distilled water should be added to the battery at least every two weeks so that the level of the electrolyte is kept well above the plates. The operator should ascertain that his battery is fully charged at all times, but should not leave it on " Charge " so much that it gasses continuously as this will shorten the life of the battery.

In the absence of a hydrometer a fairly good check on the battery condition may be obtained by use of the voltmeter switch. Read the battery voltage with the " Send-Receive " switch in the " Receive " position. Then throw the switch to the " Send " position, starting the motor generator and closing the key. Again read the battery voltage under full load conditions. The difference between these two voltmeter readings as compared with similar readings taken when the battery is known to be fully charged will provide some indication of the condition of the battery.

34. **Tubes**—4 Type '10 tubes.

RMCA MODEL ET–8007 LIFEBOAT RADIO TRANSMITTING AND RECEIVING EQUIPMENT

35. **Important**—Keep the ground lead connected to Antenna Post when set is *not* in use.

Never test lifeboat set on deck with actual antenna while main radio room transmitter is in operation or you may burn out lifeboat receiver.

When lifeboat is tested in water and is away from strong field of ship's main antenna this rule does not apply.

When lifeboat transmitter is tuned to 500 kc. by inspectors and when antenna coupling adjustment is made, always make certain ship's main antenna is open. Otherwise main antenna may cause erratic operation by absorbing power from lifeboat antenna.

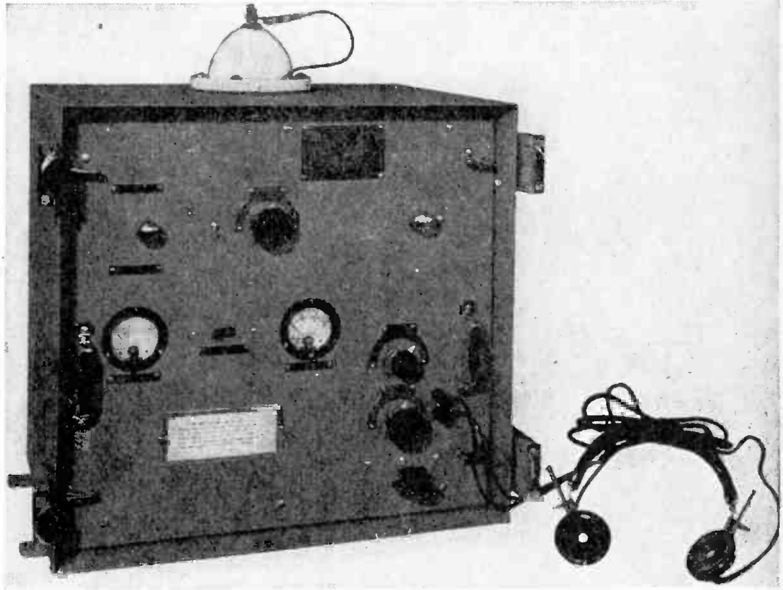

FIG. 340, A. R.M.C.A. Model ET-8007 Lifeboat Radio Transmitter and Receiving Equipment.

36. **General**—The equipment covered by these instructions is designed to meet the requirements of the Federal Communications Commission rules governing Lifeboat sets. Radio operators are particularly urged to familiarize themselves with this equipment in order that proper maintenance may be carried out and to comply with certain special requirements of F. C. C. rules which require periodic inspection by the radio operator.*

37. **Description of Transmitter and Receiver**—The transmitter-receiver unit is housed in a steel cabinet and the cover for the cabinet is designed with a special rubber gasket and cam type latches. When the cover is placed in position and the cam latches tightened, the rubber gasket is drawn up firmly against the front edges of the cabinet, thus providing a weatherproof enclosure.

The radio transmitter uses two type 10 tubes in a full wave

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* See Chapter 19.

self-rectified Colpitts oscillator circuit. It is designed solely for the distress frequency, 500 kc. The input to the plate circuit of the oscillator tubes is approximately 85 watts. Plate supply is obtained through a step-up transformer from a 110 volt 500 cycle output dynamotor. This dynamotor operates from the 12 volt storage battery and is mounted inside the transmitter cabinet. The transmitter is adjusted to 500 kc. by means of a small rotor at one end of the tank inductance. This rotor is adjusted by removing the name plate on the panel marked " Frequency," which exposes the screw. A screwdriver is then used to turn the rotor for the 500 kc. adjustment. A ratchet wheel on the rotor shaft maintains the setting. Antenna coupling is adjusted in a similar manner by removing the " Antenna coupling " name plate. After both of these adjustments have been properly made the name plate is replaced, thereby covering the controls and preventing tampering.

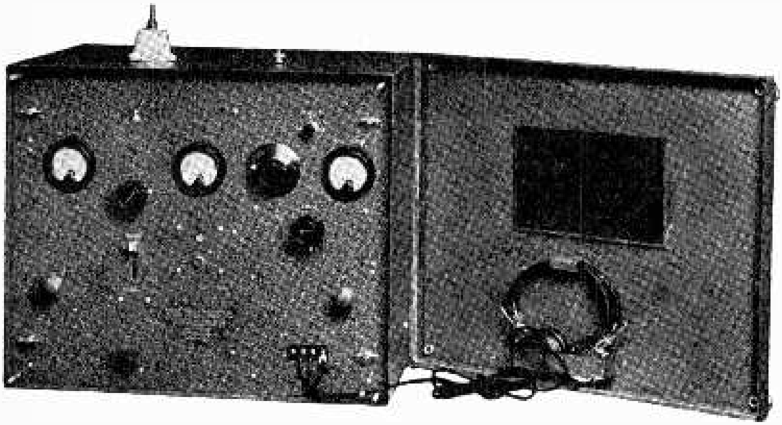

FIG. 340, B. Mackay Radio Lifeboat Radio Equipment 101A. Front View —Cover Removed (Not Described).

The antenna circuit, which requires considerable loading on account of the very small antenna which must be used, is provided with a loading coil containing a variometer and six taps on the stator winding. On initial installation the correct antenna tap must be determined by trial, selecting that tap which resonates 500 kc. with the variometer pointer as near as possible to the middle of its scale.

The radio receiver uses a twin triode type 79 of which one-half

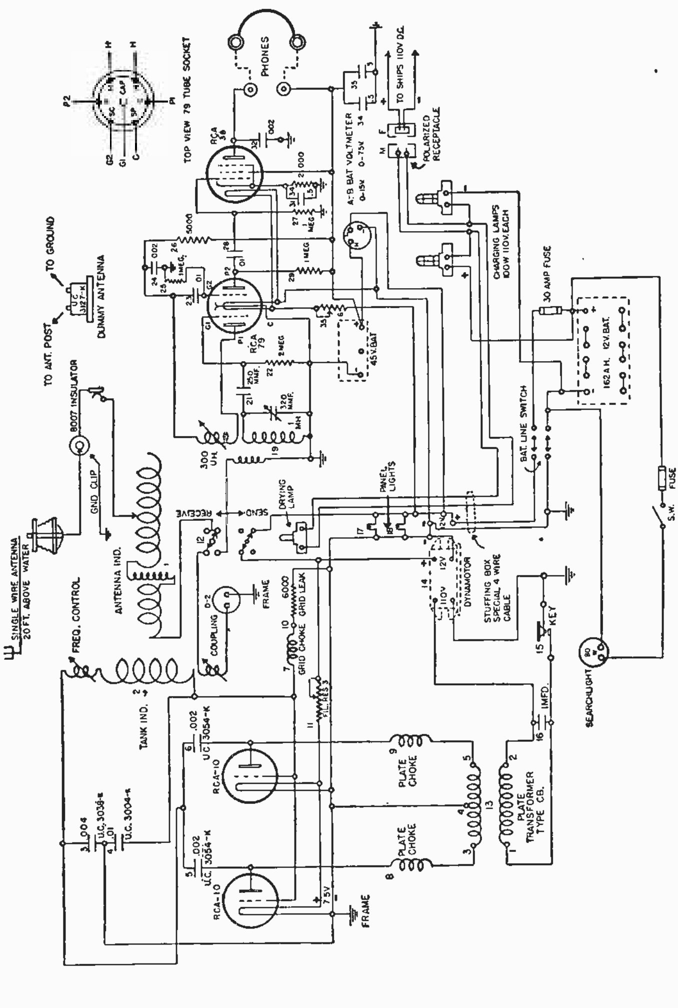

FIG. 341. ET-8007 Radio Transmitter, Radiomarine Corp. of America.

is used as a regenerative detector and the other half as the first stage audio amplifier. The second tube in the receiver is a type 38 pentode and functions as the second stage audio. The receiver covers a range of 350 to 500 kc. The receiver may be used for C.W. signals by increasing the coupling of the tickler coil, which is adjustable with respect to the detector grid coil. Plate supply for the receiver is obtained from a 45 volt Burgess No. 5308 "B" battery, which is clamped inside the cabinet assembly. Filament supply for the receiving tubes is taken from the 12 volt storage battery through a suitable resistance which is adjusted at the factory to apply six volts to the receiver filaments or heaters.

Transmitter filaments are energized from the 12 volt battery through a 3 ohm resistor which is adjusted at the factory to apply 7.5 volts to the type 10 filaments.

A send-receive switch on the panel transfers the antenna circuit either to the coupling coil of the transmitter or the coupling coil of the receiver and also in the transmit position closes the 12 volt circuit to the dynamotor input and to the type 10 transmitter filaments. The receiver filaments, however, are energized as soon as the external battery switch is closed. Also when this switch is closed, 12 volts is applied to the two panel lights on the transmitter-receiver panel.

In order to keep the inside of the equipment free from moisture a 25 watt 110 volt light lamp is mounted inside the assembly and is connected through the outgoing power cable to the 110 volt charging line circuit. This lamp should burn at all times when the lifeboat is on the davits. No lamp larger than 25 watts should be used to avoid excessive temperature rise inside the cabinet.

Antenna current is read by means of a 2 ampere r.f. instrument. Battery voltage from the 12 volt storage battery is read from a small voltmeter mounted on the panel. This is a double range instrument designed so that by pressing the small button on the meter, the "B" battery voltage of the receiver may also be measured. Since F. C. C. ship rules require that the "B" battery be replaced when its voltage has fallen under load by 15 percent, the No. 5308 battery should be replaced when its voltage is less than 38 volts.

In order to permit easy withdrawal of the transmitter receiver assembly, a pair of rollers is fitted in the base of the cabinet. After the main cabinet cover has been removed, turn the four panel latches so that they are in a vertical position. Then by means of the handles on the panel carefully withdraw the assembly. The four conductor cable is made sufficiently long so that the assembly may be pulled out to the edge of the cabinet. For major repairs the cable should be disconnected from the transmitter-receiver unit. However, to replace a " B " battery or tubes it is only necessary to withdraw the assembly about half way. When replacing the unit in the cabinet make sure that the four conductor cable does not get fouled in the rear.

38. General Maintenance and Operation—When the equipment is first installed the masts and antenna should be erected and a temporary ground connection made to the hull of the ship while the lifeboat is resting on the davits. The correct antenna load coil tap may be selected and the coupling and frequency adjustments made. When the lifeboat is in the water it will be found that these adjustments will hold with possibly a slight change in the setting of the antenna variometer.

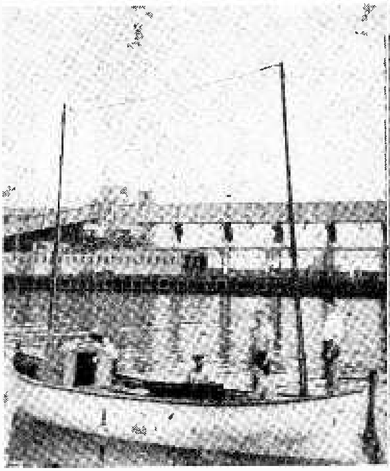

FIG. 341, A. Radio Equipped Lifeboat.

FIG. 341, B. Radio Transmitter Receiver in Protective Housing on Lifeboat.

For routine testing as required by rules a small dummy antenna UC–3127–K is furnished. This unit should be kept in the spare parts box when not in use.

F. C. C. Ship Rules Sec. 8.204 require that the lifeboat equipment be tested *" within 24 hours prior to departure to sea* *from any port and at least once each year with the lifeboat afloat in the water."* For this test and inspection when the lifeboat is not in the water the dummy antenna may be used.

Operators should follow the procedure outlined below:

1. Inspect antenna, antenna insulators and main canopy insulator to see that they are in good condition and available for immediate use.

2. Examine both charging lamps to insure that the battery is being charged.

3. Remove main cover from cabinet.

4. Temporarily disconnect lead from cabinet antenna post to canopy deck insulator and connect dummy antenna between ground and antenna post on transmitter. A wing nut is provided on transmitter antenna post to facilitate this operation.

5. Close battery switch which should cause panel lights to be turned on. The panel send receive switch should be in the receive position. After about 30 seconds required for the receiver tubes to heat up, the receiver may be checked by listening in the phones and by turning the tickler coil to maximum regeneration. The usual tube noise should be observed and possibly strong nearby signals may be picked up by the dummy antenna. After the receiver has been operating a few minutes, press the voltmeter button and determine that the "B" battery is not less than 36 volts. If it is, a new "B" battery is required.

6. The panel send receive switch should now be placed in the send position, which will start the dynamotor and close the transmitter filaments. The key should then be closed and the antenna variometer rotated until maximum antenna current is obtained. Hold the key closed for about five minutes (not in silent period) and observe that the battery voltage does not drop appreciably under load.

7. If these tests indicate that transmitter and receiver operation appear normal, the transmitter switch should be left in the *receive* position and the battery switch turned *off*. The antenna variometer should be retuned to its original position as determined by initial tests on the actual antenna. The dummy anfenna should be disconnected, returned to the spare parts box, and the main antenna lead firmly connected to the transmitter antenna post.

8. The main cabinet cover should then be placed back in position, taking care that the four cover latches are drawn tightly. This is important to insure that dampness will not get inside the set.

9. Once each 60 days the operator should partly withdraw as-

sembly from cabinet and inspect the 25 watt " drying " lamp to see that it is burning. Once each six months the steel rollers at the bottom of the cabinet should be well greased to prevent sticking.

39. Battery Maintenance—F. C. C. Rule 19 requires that once each seven days the operator shall inspect all batteries and in the case of storage batteries log the condition and gravity of the battery. In the case of the dry battery, Burgess No. 5308, this should be replaced when it falls below 36 volts as previously explained.

The MVA–11 12 volt battery with this equipment is arranged for continuous trickle charge. The correct charging rate is determined to a certain extent by the time of year and whether or not a ship is in the tropical latitudes a considerable part of the time. In hot weather or in tropical latitudes a charging current of 500 milliamperes will keep the battery in first class condition. This is obtained when two 100 watt 110 volt tungsten filament lamps are used in the charging lamp receptacles. For ships in more northerly waters and in the winter time a lower charging rate is desirable. This may be obtained by using a charging rate of 400 milliamperes. Once each seven days the operator should measure and log the specific gravity of the battery and determine that it does not fall below approximately 1250. If it is found that the battery requires excessive water, indicating overcharge, then smaller size lamps should be used. If two or more successive battery readings indicate low specific gravity, then larger charging lamps should be used. In general 75 watt lamps will be found satisfactory and will provide sufficient charge to overcome the internal losses of the battery as well as the small proper drawn from the battery when the equipment is being tested. Operators are cautioned to watch the condition of the battery, using approved water to keep the electrolyte level above the plates, and to make sure the charging plugs and receptacles are in circuit at all times and that the polarity of the charging circuit is not accidentally reversed by ship's personnel. In case the ship's power supply fails for short periods of time, the battery will not be adversely affected since the leakage current back through the line is limited to a fraction of an ampere by the charging lamps. Remove charging plug when ship is in drydock.

It will be noted from the diagrams in this instruction book that one charging lamp is used in series with each side of the line. This is to prevent short circuits or damage to the equipment or lines in case one side of the ship's supply should be grounded at the same time that the negative 12 volt battery is grounded through the battery switch. For example, if negative ship's ground on minus 12 volts, the result will be to extinguish one of the charging lamps and cause the other to burn brighter.

40. Test for Battery Rating—When F. C. C. inspectors require a test of the equipment to determine if the battery rating is adequate, the following procedure is used. The maximum current drawn from the battery by the transmitter receiver unit with the key closed is determined. In the case of the ET–8007 equipment this current will be approximately 22 amperes. The searchlight load is then measured and in the case of an 80 watt 12 volt searchlight, will be 6.5 amperes. The battery is then discharged at 70 percent of the transmitter-receiver key locked load, which will be 15.4 amperes. During this discharge the searchlight is turned on for the first 30 minutes of each hour of the six hours. A calculation will then show that the transmitter has required approximately 92.5 ampere hours, and the searchlight about 20 ampere hours, or a total of 112.5 ampere hours. Since the battery is rated as 162 ampere hours, it is evident that considerable additional capacity is available before the voltage per cell at the battery falls below the permissible value of 1.8 volts under load.

Federal Communication Commission Ship Radiotelegraph Requirement for Lifeboat Radio Equipment

41. Lifeboats—The radiotelegraph installation on a motor lifeboat designated by the Bureau of Marine Inspection and Navigation as requiring a radio installation shall consist of an emergency installation in efficient operating condition which shall comply with the following requirements:

(*a*) *Frequency of operation of transmitter:* 500 cycles.
(*b*) *Type of emission of transmitter:* A2.
(*c*) *Frequency tolerance of transmitter;* 0.5 percent.
(*d*) *Power of transmitter:* Not less than 75 watts into the plate circuit of the stage supplying power to the antenna.
(*e*) *Antenna:* A single wire inverted L or T not less than 20 feet above the water line with a horizontal section of the maximum practicable length.
(*f*) *Receiver:* Electron tube type. Frequency range at least 350 to 550 kilocycles and capable of reception on types A1, A2, and B waves.
(*g*) *Power Supply:* For transmitter, storage battery; for receiver, dry battery, storage battery, or dynamotor operated from transmitter power supply. The power supply shall at all

times be capable of operating the entire radio installation for a continuous period of at least six hours. If the power supply is also used to operate electrical equipment other than radio, its capacity must be sufficient so as not to adversely affect its ability to fulfill the foregoing requirement.

(*h*) *Installation:* The component parts and assembly of entire installation shall primarily insure the utmost dependable operation, the design shall be such that heavy vibration and physical shocks to which a lifeboat is subject will cause no damage, and they shall be so housed and treated as to withstand saline dampness for extended periods without damage and to minimize the adverse effect of prolonged exposure to salt water or salt spray. Storage batteries shall be mounted in cabinets which will provide protection from salt water spray and also allow proper ventilation. Provision shall be made to protect the operator from the elements when the lifeboat is afloat. Provision shall also be made for the expeditious erection of the antenna system under adverse weather and sea conditions. The use of metal masts and stays, unless broken by insulators, or of any structure of ground potential at the mastheads is not permitted.

(*i*) *Inspection:* (1) The lifeboat radio installation shall be inspected and tested by a qualified representative of the licensee of the ship radio station within 24 hours prior to departure to sea from any port and at least once each year with the lifeboat afloat in the water. The results of the inspection and tests shall be noted in the ship's radio station log and the master informed. The test shall include an actual test of the transmitter connected to the regular antenna (erected) and receiver to determine that both are in effective operating condition; provided that, when testing with the lifeboat not afloat in the water, the transmitter may be tested on an artificial antenna, in lieu of the regular lifeboat antenna, having electrical characteristics equal to the regular antenna. Transmission tests shall be conducted under the same procedure as prescribed for testing of the ship's radio station transmitters to avoid interference. Transmission tests shall not be made during the silent period.

(2) When the vessel is under way, provision shall be made for the charging of storage batteries and the routine inspection of all batteries, without removing them from

the lifeboat. Examination shall be made at least once every seven days by a licensed operator on the vessel and a statement as to the condition and specific gravity, in the case of a lead-acid battery, or voltage, in the case of dry or Edison batteries, shall be entered in the ship's radio station log. Dry batteries shall be replaced when it is found that the voltage under load has fallen 20 percent below the rated voltage of the battery.

(*j*) *Spare parts and tools:* In addition to spare parts and tools kept elsewhere, there shall be kept in the lifeboat at least one vacuum tube of each type used, a supply of insulated wire of such length and nature as to be suitable as an emergency antenna, and such tools as may be necessary.

(*k*) *Instructions:* Instructions shall be plainly marked on the apparatus in sufficient detail to permit uninstructed personnel to place equipment in operation and to transmit signals which are suitable for use in obtaining direction finder bearings.

Spare parts box containing:

35 Feet of No. 346 Packard cable for emergency antenna
1 RCA type 10 tube
1 RCA type 79 tube
1 RCA type 38 tube
1 Millers Falls No. 7777 3″ screwdriver
1 Pair Utica No. 1050 6″ pliers
2 12 volt 3 candle power panel lights.
6 Catalogue No. 1115 30 amp fuse links
1 UC–3127–K dummy antenna
1 Spec. V–1681 6000 ohm grid leak

The antenna masts, two in number, and hinged for stowage, are supplied by the steamship company.

RMCA Model AR–8504 Radio Receiver (300 to 900 KC.)

The AR–8504 is a compact intermediate frequency receiver designed primarily for shipboard use where an emergency vacuum tube receiver is required for the marine communication band of 375 to 500 kc. The overall frequency range of the receiver is approximately 300 to 900 kc., and the design provides for the reception of types A1, A2 and B signals.

Three metal tubes are used in the receiver as follows:

RCA 6–K–7—Regenerative detector
RCA 6–K–7—First audio amplifier
RCA 6–F–6—Second audio amplifier

Power supply required for the receiver consists of a 6 volt " A " battery and a 90 volt " B " battery. The " A " battery drain at 6 volts is 1.5 amperes. The " B " battery drain at 90 volts is 5 milliamperes.

The receiver is housed in a metal cabinet with rubber shock mounts on the base and the overall dimensions of the unit are:

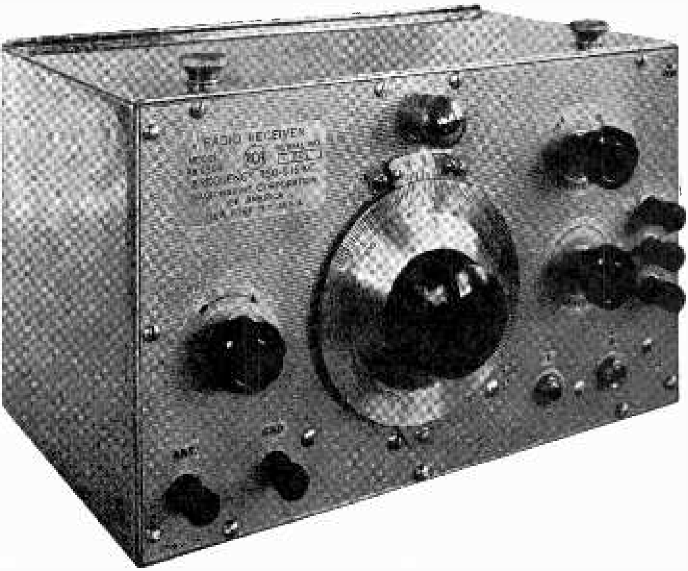

FIG. 342. R.M.C.A. Model AR–8504 Radio Receiver.

Length 11″, height 7 7/8″, and depth 8 5/8″, including knobs. The weight of the complete receiver is 11 pounds. The top of the cabinet is hinged to permit access for tube replacement. The front panel is provided with a satin chromium ripple finish, with all necessary markings etched directly on the panel. Binding posts at the left provide for antenna and ground and at the right for power supply connections. It is not necessary to remove the chassis from the cabinet in order to connect up the receiver or to insert the tubes.

The following controls are provided on the AR-8504: Antenna coupling—Regeneration—Main tuning control—First and second stage phone jacks—On off switch. A 6.3 volt, No. 46 Mazda pilot lamp is provided to illuminate the dial when the receiver is turned on. In case of failure of the regular emergency light in the radio room the small metal cover may be removed from the pilot light to furnish emergency illumination in the radio room.

42. **Circuit**—The circuit used in the receiver and its external connections are shown in figure 343. There are three tuned circuits which are built in the receiver to cover the range specified above. The main tuning condenser is a three gang unit and provides for tuning two pre-selector circuits and the detector grid circuit. The antenna coupling coil provides variable coupling to the first pre-selector circuit, which in turn is inductively coupled, with fixed coupling, to the second pre-selector circuit. The second pre-selector circuit is coupled to the detector grid circuit inductively, using fixed coupling between the coils. Regeneration control is obtained by means of a potentiometer which controls the screen voltage on the regenerative detector. Fixed coupling is used between the detector grid and plate coils.

The regenerative detector is coupled to the first audio stage through a low pass filter, while the first audio stage is resistance coupled to the second stage as shown on T-360. The plate current of the second audio stage is carried through the telephone receivers and for this reason it is important to use the correct polarity on the telephone cords to prevent demagnetization. With Trimm headphones the phone plug *tip* should be connected to the red tracer. With W.E. phones the plug *tip* should be connected to the green tracer.

The " on-off " switch controls the plus 90 and plus 6 volt circuits. Care should be taken not to operate the receiver with the cabinet cover opened as the entire design has been made to provide complete enclosure of the chassis, which is desirable under marine atmospheric conditions.

43. **Tuning**—Correct procedure in tuning and adjusting the receiver should be carefully studied by the operator. The " on-off " switch should be turned to the " on " position, allowing about 15 seconds for the tubes to heat up. The antenna coupling knob should be turned clockwise for maximum volume. Regeneration control should be turned about two-thirds counter clockwise. The main tuning dial should now be rotated for the desired signal. After the signal is heard, adjust antenna coupling for the desired signal intensity. The regeneration control may then be adjusted

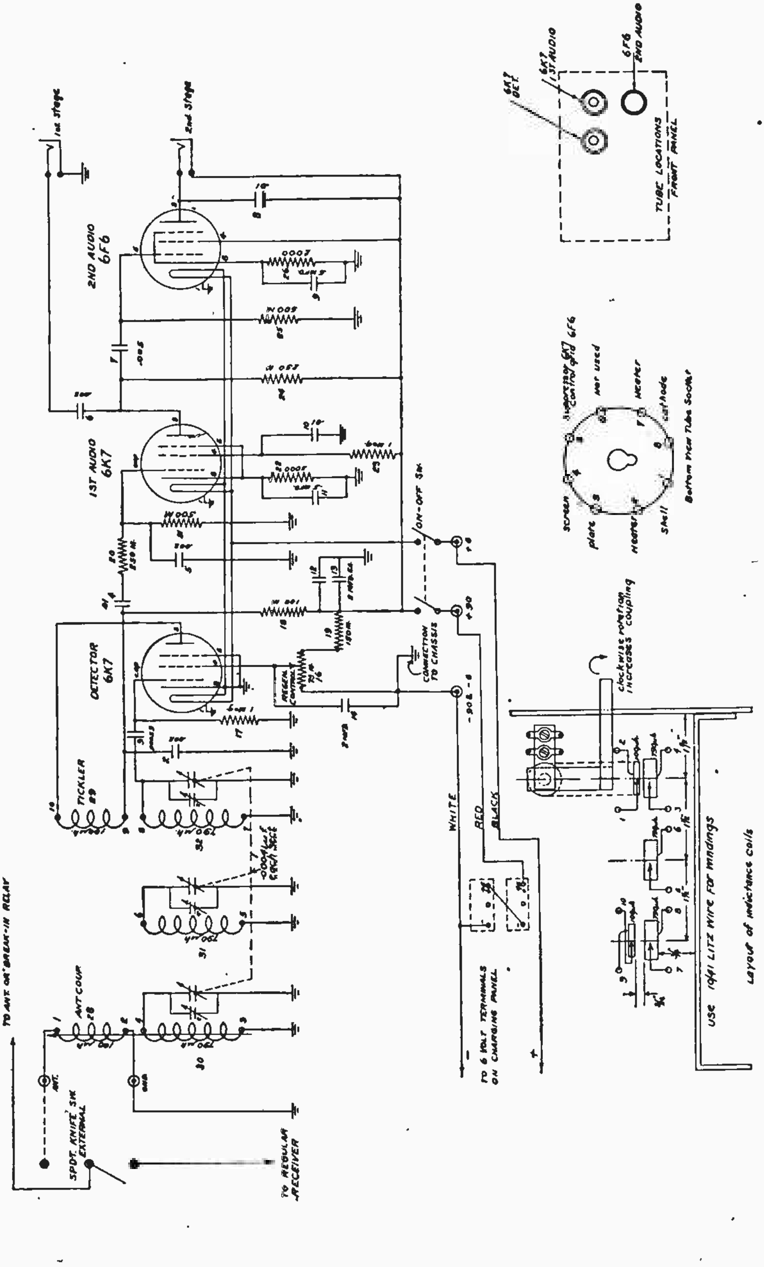

FIG. 343. AR-8504 Receiver Wiring Diagram.

to improve the selectivity or to produce oscillations for C.W. reception. For very strong signals, the antenna coupling control should be used to regulate volume.

44. Approximate Calibration—Approximate dial settings for the AR–8504 are as follows:

Kc.	Tuning Dial
300	11
350	28
375	34
400	40
450	48
500	56
600	69
700	79
800	87
900	94

45. Installation—When the receiver is installed, care should be taken to use suitable wire for the 6 volt circuit to prevent excessive drop. For short runs No. 14 wire should be used while for longer runs No. 12 or larger wire is recommended. The antenna lead to the receiver, which will usually run from the break-in relay in the radio transmitter, should be kept as short as possible and should run not closer than 3″ to the other wiring, steel bulkheads, etc. Care should also be taken not to install the antenna lead to the receiver near high voltage radio frequency circuits, such as the main antenna lead. A S.P.D.T. knife switch should be installed so that the main antenna may be used with either the regular receiver or the AR–8504.

46. Maintenance—The special chromium panel used on the receiver should be kept clean and dry to preserve its original appearance. Under no circumstances should brass polish or other polishes be used on this panel. If the panel becomes soiled it may be wiped carefully with a cloth moistened with carbon tetra chloride (Carbona cleaning fluid). The receiver chassis should not be removed from the cabinet unless repairs or maintenance are required.

When inserting tubes for the first time observe that the two rear sockets with adjacent flexible grid leads are for the 6–K–7 tubes. The front socket is for the 6–F–6 tube.

Tube Characteristics—The 6–K–7 is a triple grid super control amplifier. The heater rating is 6.3 volts and .3 ampere. At 90 volts plate and screen potential the tube has an amplification factor of 400, a plate resistance of .315 megohms and mutual conductance of 1275 (with 3 v grid bias). The 6–F–6 pentode, which is used as the second audio amplifier, has a 6.3 volt .7 ampere heater rating, a plate resistance of 80,000 ohms, an amplification factor of 200 and a mutual conductance of 2,500. All tubes use the same Universal 8 prong socket, with a keyway in the center section, so that it is important to place the correct tubes in their respective sockets.

RMCA AR–8503 Radio Receiver (15 to 600 Kc.)

The AR–8503 is a compact intermediate and low frequency receiver, using metal tubes, and designed primarily for marine applications.

47. Frequency Range—The receiver covers a continuous frequency range of 15 to 600 kc., divided into four bands, with appropriate selector switches so that any frequency within the range may be quickly selected from the front of the panel. The four frequency ranges are as follows:

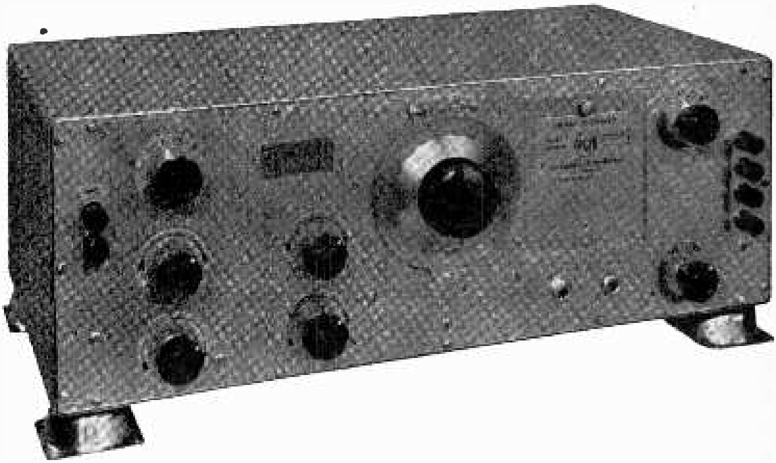

Fig. 344. R.M.C.A. Type AR–8503 Marine Receiver.

Range 1—15 to 40 kc.
Range 2—40 to 100 kc.
Range 3—100 to 250 kc.
Range 4—250 to 600 kc.

Four metal tubes are used in the receiver as follows:

RCA 6–K–7—R. F. amplifier
RCA 6–K–7—Regenerative detector
RCA 6–K–7—First audio amplifier
RCA 6–F–6—Second audio amplifier

Power supply required for the receiver consists of a 6 volt " A " battery and a 90 volt " B " battery, with a tap at 22 volts. The " A " battery drain at 6 volts is 2 amperes. The " B " battery drain at 90 volts is 8.6 milliamperes for maximum volume and 5 milliamperes for minimum volume.

The receiver is housed in a metal cabinet with rubber shock mounts on the base and the overall dimensions of the unit are: Length 20 1/8", height 8", and overall depth 12", including knobs. The weight of the complete receiver is 29 pounds. Access to the four metal tubes is obtained through a removable metal door in the right section of the front panel. The front panel is provided with a satin chromium ripple finish, with all necessary markings etched directly on the panel. Binding posts at the left provide for antenna and ground and crystal connections and at the right for power supply connections. It is not necessary to remove the chassis from the cabinet in order to connect up the receiver or to insert the tubes.

The following controls are provided on the AR–8503: Antenna coupling—Volume—Regeneration—Trimmer—Main tuning control—Range selector switches (2)—First and second stage phone jacks—On off switch.

48. Circuit Arrangement—The circuit used in the receiver is shown in figure 345. There are three tuned circuits and four sets of coils, which are built in the receiver to cover the four ranges specified above. The main tuning condenser is a three gang unit and provides for tuning a pre-selector circuit, which is coupled to the antenna, the r.f. amplifier grid circuit, and the r.f. amplifier plate circuit. A small trimmer condenser adjustable from the front panel is also used in the r.f. amplifier grid circuit. The antenna is coupled to the first or pre-selector tuned circuit through a small variable condenser. The pre-selector circuit is coupled to the r.f. amplifier grid circuit inductively using fixed coupling between the coils. Volume control is obtained by means of a potentiometer, which applies a bias to the cathode of the r.f. tube. Regeneration control is obtained by means of a second potentiometer which controls the screen voltage on the regenerative detector.

Fixed coupling is used between the amplifier plate coils and the detector tickler coils.

Two selector switches are used, one in the upper left section of the panel, which controls the pre-selector and r.f. grid coils, while the second switch in the upper right section of the panel controls the amplifier plate and tickler coils. Separate coils are used throughout for each range so that stable operation is obtained without dead spots or other erratic performance which might result from tapped coils.

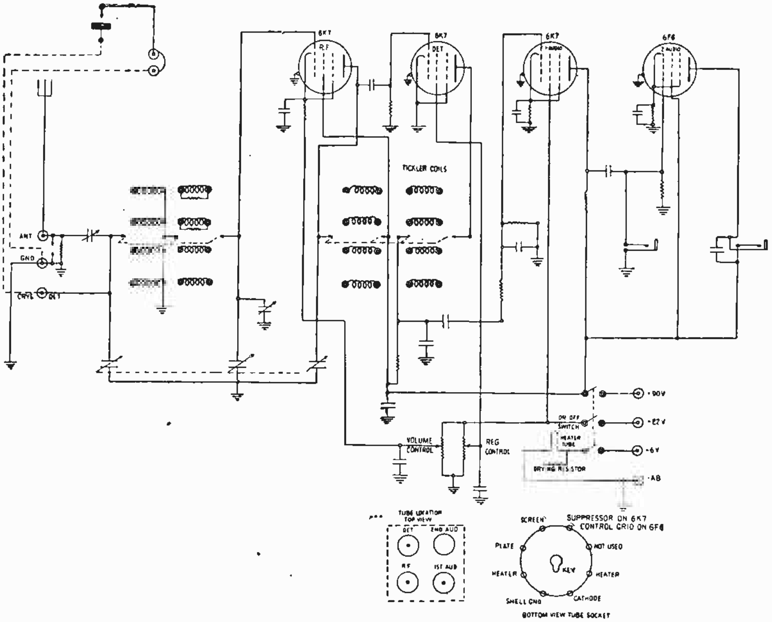

FIG. 345. R.M.C.A. Type AR-8503 Marine Receiver Circuit.

The regenerative detector is coupled to the first audio stage through a low pass filter, while the first audio stage is resistance coupled to the second stage as shown in figure 345. The plate current of the second audio stage is carried through the telephone receivers and for this reason it is important to use the correct polarity on the telephone cords to prevent demagnetization. With Trimm headphones the phone plug *tip* should be connected to the red tracer. With W.E. phones the plug *tip* should be connected to the green tracer.

The on off switch controls the plus 90, plus 22 and plus 6 volt circuits. A special 15 ohm "drying" resistor is mounted on the under side of the chassis to produce a small amount of heat so that the component units are kept dry and free from corrosion. Care should be taken not to operate the receiver with the tube door removed as the entire design has been made to provide complete enclosure of the chassis, which is desirable under marine atmospheric conditions.

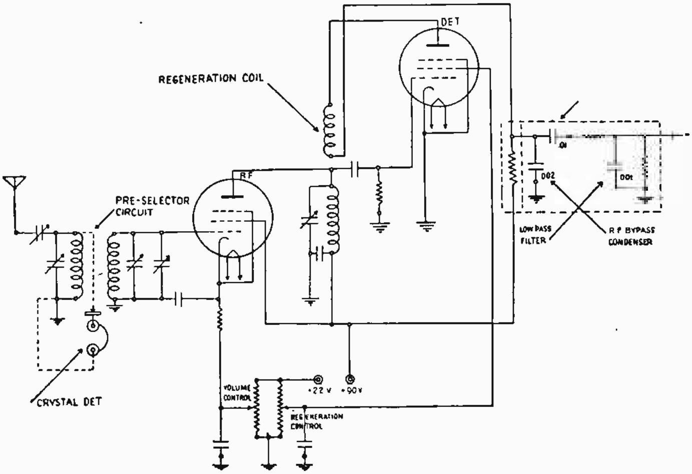

FIG. 345, A. Equivalent Schematic Circuit R.F. Portion of Type AR-8503 Receiver.

49. Tuning Procedure—Correct procedure in tuning and adjusting the receiver should be carefully understood by the operator. Each range selector switch should be placed at the proper point for the range desired. The on off switch should be turned to the on position, allowing about 15 seconds for the tubes to heat up. The antenna coupling should be turned about 90 degrees clockwise and the volume control about three-quarters clockwise. Regeneration control should be turned about one-half counter clockwise. The main tuning dial should now be rotated for the desired signal. After the signal is heard, adjust antenna coupling and trimmer condensers for maximum and adjust the volume control for the desired signal intensity. The regeneration control may then be adjusted to improve the selectivity or to produce oscillations for C.W. reception. It is emphasized that the volume control should never be used at its maximum position unless very weak signals are to be received with low static level. Intelligent use of the volume control will not only result in maximum selectivity and freedom from interference, but will also keep the " B " battery drain to a minimum. For very strong signals, the antenna coupling may also be reduced if desired, although best selectivity is obtained when antenna coupling and trimmer condensers are adjusted to maximum response as this provides accurate lineup of all three tuned circuits. When using ranges one or two for C.W. reception, adjust for a low beat note. This will provide maximum selectivity.

50. **Approximate Calibration**—Approximate dial settings for the various ranges of the AR–8503 are as follows:

Range 1		Range 2		Range 3		Range 4	
Kc.	Tuning	Kc.	Tuning	Kc.	Tuning	Kc.	Tuning
15	5	35	10	100	30	250	27
20	45	40	30	120	50	275	37
25	63	50	55	140	63	300	46
30	73	60	65	160	70	325	53
35	81	70	73	180	77	350	60
40	88	80	80	200	81	375	65
		90	85	220	85	400	69
		100	90	240	89	425	72
				250	91	450	75
						475	77
						500	80
						525	82
						550	84
						575	85
						600	86

51. **Installation**—When the receiver is installed, care should be taken to use suitable wire for the 6 volt circuit to prevent excessive drop. For short runs No. 14 wire should be used, while for longer runs No. 12 or larger wire is recommended. A 4 conductor shielded cable for " A " or " B " circuits is considered the most satisfactory. The antenna lead to the receiver, which will

usually run from the break-in relay in the radio transmitter, should be kept as short as possible and should run not closer than 3" to the other wiring, steel bulkheads, etc. Care should also be taken not to install the antenna lead to the receiver near high voltage radio frequency circuits, such as the main antenna lead.

52. **Maintenance**—The special chromium panel used on the receiver should be kept clean and dry to preserve its original appearance. Under no circumstances should brass polish or other polishes be used on this panel. If the panel becomes soiled it may be wiped carefully with a cloth moistened with carbon tetrachloride (Carbona cleaning fluid). The receiver chassis should not be removed from the cabinet unless repairs or maintenance are required. Once each six months a drop of light oil or vaseline should be placed on the roller stops, which are used on the selector switches. Care should be taken, however, not to get any lubricant on the switch contacts, which are silver plated. The main condenser shaft near the front panel and the shaft extensions for the selector switches near the panel may also be given one drop of oil at each semi annual inspection. When withdrawing the chassis from the cabinet it should be pulled straight out, taking care not to damage the selector switches which clear the cabinet by a small amount.

When inserting tubes for the first time refer to the tube layout on T–319, which shows the relative position of the tubes. The two tubes nearest the tube door in the front row are 6–K–7 and also the tube to the left in the rear row is a 6–K–7. The tube to the right in the rear row is the 6–F–6.

Tube Characteristics—The 6–K–7 is a triple grid super control amplifier. The heater rating is 6.3 volts and .3 ampere. At 90 volts plate and screen potential the tube has an amplification factor of 400, a plate resistance of .315 megohms and mutual conductance of 1275 (with 3 v grid bias). The 6–F–6 pentode, which is used as the second audio amplifier, has a 6.3 volt .7 ampere heater rating, a plate resistance of 80,000 ohms, an amplification factor of 200 and a mutual conductance of 2500. All tubes use the same Universal 8 prong socket, with a keyway in the center section, so that it is important to place the correct tubes in their respective sockets.

53. **Crystal Detector**—The crystal detector is mounted on the rear of the removable tube door. For emergency operation when no spare tubes are available or if receiver power supply is disabled, proceed as follows: Remove tube door with crystal de-

tector and place it near antenna and ground posts of receiver. Remove plug from phone cords. Connect crystal and phones in series. Connect the other side of crystal to the post directly below the ground post. Connect the other side of phones to ground post. These connections for crystal operation are clearly shown in figure 345.

CHAPTER 12

TRANSPORT AIRCRAFT AND GROUND STATION TRANSMITTERS AND RECEIVERS

1. The Commercial Transport Aeronautical Radio Operator—Aviation is one of the most specialized of the services in which a radio operator may expect to be employed. While it is true that in certain terminal offices operators may be employed exclusively for radiotelegraph transmissions, in other stations the operator may make special meteorological observations in addition to acting as operator. This is one service in which the operator is often called upon to exercise initiative and to demonstrate executive ability. In a number of cases operators have been confronted with an emergency which required them to exercise considerable ingenuity in bringing an aircraft lost above the overcast down to a safe landing.

In general there are three classes of stations licensed in the aviation service: Airport, Aeronautical and Aeronautical point-to-point. The professional radio operator usually has little to do with the operation of an airport station other than assisting in equipment maintenance. This class of station is used for the control of aircraft in the vicinity of an airport, and is usually operated by specialized traffic control personnel. From their point of view, the airport station is merely another telephone.

The aeronautical station is used for communication with aircraft enroute between airports. In many cases the operator at the aeronautical station merely supplies the pilot with information given to him by other personnel and relays information and requests received from the pilot to other personnel for appropriate action. However, in other circumstances, the operator must in addition to transmitting the information, be in a position to assemble the information required by the pilot and to answer his questions without the aid of other personnel. Aeronautical point-to-point stations are radiotelegraph stations authorized for the transmission of messages with reference to the aviation needs of the air transport operating companies. This is practically the only operating position in the aviation service which requires very little executive ability on the part of the operator. In general the messages transmitted are prepared by other than the operating personnel and the messages received are acted upon by the various airline departments.

In the domestic service the radiotelephone radio station in the aircraft is operated by the first pilot or second pilot in the same manner as anyone would use a push-to-talk type of telephone. The equipment is so stowed that it is inaccessible and is operated by remote control. Considering the length of flights and the type of terrain over which these aircraft are operated, and the existence of various aids to navigation, the pilot operator has been found to be satisfactory.

In overseas aircraft operation radiotelegraphy is used by aircraft licensed by the Commission. An operator, separate and distinct from the pilot, is carried and he has in addition to his primary duty of maintaining communication, the duty of obtaining bearings from the various classes of stations and assisting the pilot in using radio aids to navigation.

In domestic operation, with few exceptions, the pilot talks only with those aeronautical stations with which he is associated. In overseas operation the operator talks not only to his own aeronautical station, but must also establish communications with ships at sea and stations operated by foreign governments.

An operator desiring to enter the aviation field must not only prepare himself by a thorough grounding in radio practice and theory, but must also have a good background in the field of meteorology and general aviation practice.

2. United Air Lines Aeronautical Radio, Inc., Ground Station—The photograph shown in figure 346 shows the interior of a ground station of the United Air Lines. Of particular interest is the especially designed typewriters and operating tables used. It will be noted that the typewriters are arranged with split platens (rollers) so that two continuous form radiograms can be used. Each radiogram can be advanced individually, which makes it possible for the operator to quickly shift his machine to a new form by simply touching the tabulator key. Such a procedure is required if the operator, while copying a message from another ground station and during the *listening period, which occurs throughout the first ten seconds of every minute,* is required to communicate with a pilot who may call with special information. Since radio telephone is used exclusively by the United Airlines, and other domestic transport lines, the operators must be on the alert at all times in order to obtain a verbatim copy of every conversation.

In the ground station picture there will be noted a group of telephones and a pneumatic tube system in the right foreground. These telephones make it possible for either operator to communicate with the C. A. A.* regarding the operation of Airways radio beacon facilities, and so forth, or to announce the incoming airplanes over the local public address system, or to communicate with the Airways Traffic Control office, or to communicate with his dispatcher or other personnel of his company, through separate telephone systems. The pneumatic tubes make it possible for him to send a copy of each radiogram or plane position report to the Dispatch Office.

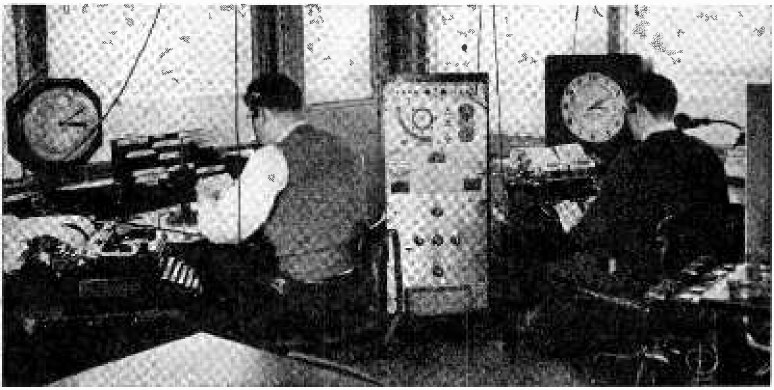

Fig. 346. United Air Lines Ground Station.
(Courtesy of United Air Lines.)

The equipment on the ground station relay rack shown in the center rear is from top to bottom: Systems and Switching Panel, Weather Instrument Panel (showing wind direction and velocity, barometric pressure, and outside air temperature), Local ES–192 Ground Station Receiver, Remote Receiver Telephone Line Amplifier, Speech Input Automatic Volume Limiter and Constant Output Amplifier, 200 volt " B " power supply, and 12 volt Hot Cathode Mercury Vapor Rectifier, 12 volt relay power supply.

Radio rooms are often located on top of hangars at vantage points so that the operators may have a clear view of the airport, which makes it possible for them to assist incoming pilots in determining whether the airport is clear for landing. Although an airport Control Tower normally governs all air traffic on or around

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* Civil Aeronautics Authority.

the airport, this method of duplicate checking promotes safe operation.

The ground station depicted in the attached photograph is operated by two operators with separate transmitters and receivers. This particular picture shows only one transmitter at the right side of the photograph. The other transmitter is remotely controlled by means of the dial shown on the operating desk at the left of the picture. Another relay rack provided with duplicate equipment is not shown in the picture.

A standard ground station, of which United Air Lines have thirty-five, utilizes a 400 watt, 4 frequency, voice transmitter. The receivers are usually located several miles from the airport at a point well isolated from man-made interference, and their outputs are carried to the radio station by means of telephone lines over which their sensitivity and frequency channel selection are dial controlled.

Other transport lines have similar communication facilities and operating procedure. The description of the apparatus that follows will be helpful to those preparing to enter the aeronautical service as a radio operator or co-pilot since the material has been extracted from the instruction books issued by the companies and is used with their permission.

Material on the radio and teletypewriter procedure used by Operators of the Air Navigation Division, C. A. A. as well as a special examination conducted by a transport company for the position of radio operator will be found in Chapter 20 and Appendix I.

3. Proposed A.C. Operated Aircraft Transmitters—In all transport aircraft now in use on the civil airways the primary power source is direct current. High d.c. plate voltage is obtained by the use of a dynamotor operated from a storage battery.

However, it has been realized for some time that an a.c. current supply, not only for the radio apparatus but the entire electric requirements of the ship, offered definite weight savings in wiring which is a considerable item, and also in transformers if a sufficiently high primary frequency was selected.

Experimental work over a long period of time indicates that the optimum primary source should be 110 volts, 800 cycles. A new aircraft of approximately 40 passenger capacity has been tested equipped with two separate gas engine driven generators supplying a total of about 15 kilowatts of 110 volt, 800 cycle power. Switches are provided so that if one of these should fail the other will carry the vital load for radio, landing lights, electric pumps and other equipment. New transmitters and receivers designed for operation at 100 volts, 800 cycles have been completed for this aircraft.

W4A RADIO DOUGLAS INSTALLATION

4. **Description**—For the purpose of familiarizing personnel with the location and functioning of the W4A radio apparatus in the Douglases, the following descriptive matter is prepared. A portion of operations circular 95 is included which gives directions as to operation of equipment.

5. **Control Unit**—In the cockpit there are located two jack boxes, and the control unit. Immediately behind the co-pilot the 17A auxiliary beacon receiver is placed, with its panel through the bulkhead. In the aisleway, near the cabin door, is the front terminal box. A small cover on this box, opened by means of two thumb screws, allows entrance to the main radio fuse. The spares for this use are located on the cover clips. One of the first things to look for in the event of complete radio failure is the condition of this fuse. Immediately below the fuse, and accessible by removing the front terminal box cover, will be seen two relays. The largest relay is the main 12-volt supply to the radio equipment. Its operation is controlled by the "on-off" switch on the control unit. In the event of failure of this control unit switch it is possible to manually operate this relay box. Before operating it, the control unit switch should be placed in the position desired, regardless of whether the relay is the dynamotor relay. By pressing the top of this relay down, the 1000 volt dynamotor will be turned on regardless of whether the microphone button is pushed or not, as the push button on the microphone operates two switches, one closing the voice circuit and the other closing a relay in the transmitter which lights its filaments and also operates this relay.

At the back of the front mail compartment, near the top, will be seen the power unit, with spare fuses mounted on its fuse box outside. A small slip cover, upon being lifted, gives access to two high-voltage fuses. It is very important that while replacing these fuses no one else presses the microphone button, for in this event a dangerous shock might result. One good way of being sure of this is to unplug the microphone and carry it with you while you replace one of these fuses. The 1000 volt dynamotor hum, with which everyone is familiar, should be listened for to make sure this dynamotor is not operating before changing fuses.

The major portion of the radio apparatus is located in the compartment behind the rear baggage compartment, which will be called the tail compartment. A rack located in the tail compartment holds the fuses and terminal strip, transmitter, receiver, and blank receiver panel, in the order named, from top to bottom.

By removing the fuse panel at the top of the rack, three fuses will be seen. These three fuses are properly labeled and need no explanation. Beside the fuses are three jacks, which are properly labeled on the terminal board cover. These can be used for any testing necessary. At the right hand end of the terminal board will be seen a raised binding post. This raised binding post carries 1000 volts, and should be carefully avoided, particularly when transmitting.

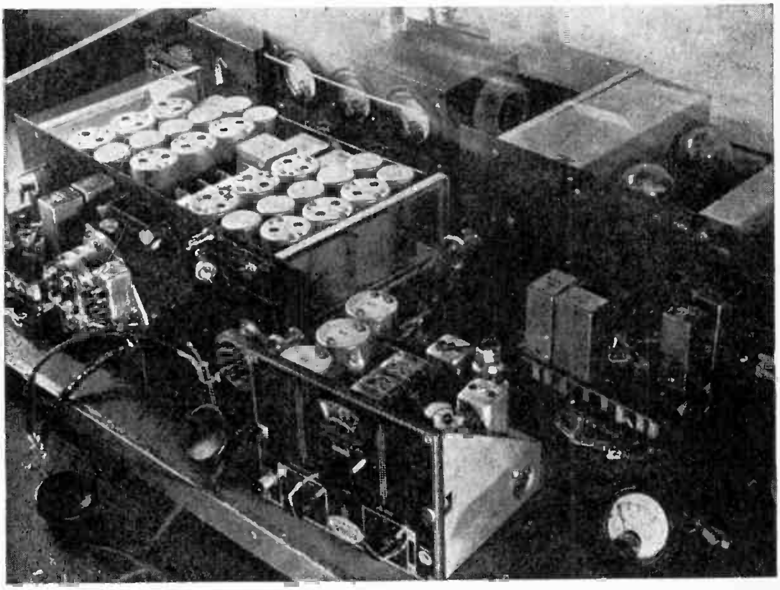

FIG. 347. TWA-W4A Radio Transmitter (right rear) and W4A Dual Receiver (left front), Also 17A Auxiliary Receiver (right front).

6. **Transmitter**—The next unit below this is the transmitter. A cover on the front of the transmitter serves to protect the crystal relay unit, which will be described later. At the left hand lower corner of the transmitter will be seen a detachable plug, which serves to connect the transmitter to the tuning unit in the tail cone and the trailing wire antenna. The antenna is connected

to the receiver from this plug to the lower right hand corner transmitter binding post, which has a small connecting link on it, to the receiver unit below. It is essential that this link be in place, for otherwise the two-way receiver will not operate properly, although side tone may still be heard from the plane's transmitter. The transmitter may be pulled out of the rack a short distance without removing the large power unit plug, but it will be necessary to remove the small connecting link to the receiver. In pulling the transmitter out from the rack the two knurled knobs at the center on the sides must be unscrewed. When these are loose they will not drop out. Pulling the transmitter forward will break the seal between the rack and the transmitter, which should be noted on the form 76. Looking into the transmitter through the crack at the top, five tubes will be seen. The two tubes near the front of the panel are the oscillator (right hand) tube and the doubler tube to the left of it. All tubes should light when the microphone button is pressed. The two large tubes at the left hand center of the transmitter are the power tubes, and if one of these tubes is not operating, transmission is still possible, as they operate in parallel. If one tube did not light, but all other tubes in the transmitter did, it would be possible to remove that tube (as its filament may have fallen over the other elements of the tube). The tube at the rear right center of the transmitter is the modulator tube which serves to supply the voice to the transmitter. With one of these three smaller tubes out, which are interchangeable, the transmitter will still operate as a continuous wave transmitter, provided the oscillator and doubler tubes are arranged to be the good ones. If the modulator, or rear small tube did not light it could be removed with an upward pull. The two large tubes have a twist socket and must be rotated in order to remove them.

7. **Receivers**—The receiver is located immediately below the transmitter and has two antenna connections. The first is from the transmitter-binding post through the link and supplies signals through the transmitter from the trailing wire antenna for two-way operation. The binding post at the lower right of the panel is the beacon antenna.

The cover on the front of the receiver covers the beacon drive unit for electrical tuning and the crystal unit similar to the unit on the transmitter, both of which will be described later. The receiver may be partially pulled out from its rack after detaching the antenna connecting link, as described before, and the operation of the tubes can be seen by removing their small shield covers. The receiver can be pulled all the way out of the rack by loosening the lock-nut on the large lower right hand plug and pulling it forward without rotating it. If a receiver tube fails, actually two tubes will not light, as they are connected in pairs. The tube row at the right is for the beacon receiver, and the tube row at the left is for two-way receiver. Tubes on both sides are interchangeable, as long as they are interchanged from right to left, that is, the tube next to the panel on the right hand side is interchangeable with the tube next to the panel on the left hand side, the tube second from the panel on the right hand side is interchangeable with the same tube on the left hand side (second tube), etc., and thus the tubes from the beacon receiver could be taken and used on the two-way receiver, and vice versa. Two tubes at a time would have to be removed. Tube change is not recommended.

8. **Jack Box**—In addition to the power wires there are three voice leads running to the front of the plane, through the rear junction box and front junction box. These are the microphone, the two-way, and the beacon phone leads. The microphone lead goes to the two jacks in the front jack boxes. If the one jack is faulty, the other jack can be used. If one jack is short-circuited both jacks will be useless. A transfer of the microphone from one to the other will test this condition quickly. The two-way audio lead connects to both jack box switches. The beacon audio lead also connects to another contact on the same two switches. Each switch is connected to the phone jack beside it. It will be seen that the top switch is in control or "both" position, while the lower switch is in "two-way" position. Due to this fact, both leads from the receiver (beacon and two-way) are connected together in the upper jack box. As this is true, the two receiver outputs are tied together and the pilot operating his (lower) jack box cannot select one of the two receivers alone. When the co-pilot's (upper) jack box is thrown to either beacon or two-way, the pilot operating his (lower) jack box may then select either of the receiver outputs at will. If he places his jack box in "both" position, the co-pilot using the upper jack box is then prevented from selecting either individual output. In the front junction box the 17A auxiliary receiver output is permanently connected to the two-way output lead. It is thus impossible to hear the auxiliary beacon receiver on any but the "two-way" or "both" position. There is, however, a jack on the face of the 17A auxiliary receiver which, when a pair of phones is plugged into it, disconnects the auxiliary receiver output from the two-way audio lead. In this manner the head phones which are plugged into the auxiliary receiver will be used only for that receiver and nothing else. (If

the two-way lead is short-circuited this makes it possible to use the auxiliary 17A receiver.)

In the instance of a plane approaching an airport, in bad weather, the co-pilot should place *his* jack box in "two-way" position while the pilot places *his* jack box in "beacon" position. The co-pilot would then hear the airport traffic control station (278 kilocycles or whatever was used) on the auxiliary receiver, as well as the ground station on the two-way receiver. He could then use his microphone to transmit without disturbing the pilot, who in turn would have his jack box in "beacon" position with the main beacon receiver tuned to the government radiorange on the field being approached.

The small output meter on the control unit (upper left hand corner) shows the amount of volume from the beacon receiver lead, but will also show the "two-way" volume if either jack box is in the "both" position.

9. **Volume Controls**—The volume controls are quite conventional, as is the "on-off" switch which serves to turn on the complete radio apparatus. The volume indicator (output meter) at the upper left hand corner of the control unit has been mentioned. The autosyn beacon frequency indicator (upper center) shows the position of the main beacon receiver tuning. The automatic volume control switch which should always be left in "On" position, except in bad static, automatically holds the volume of the two-way receiver constant. It has nothing to do with the beacon receiver nor is there an automatic volume control incorporated in that receiver. Even in automatic volume control position the two-way volume control serves the same purpose as any ordinary volume control. It should be advanced (clockwise) to a position where all stations, in which the plane is interested, can be heard, but need not be advanced any further as atmospheric noises would then become bothersome.

10. **Tuning**—The small knob under the control unit serves to tune the main beacon receiver. In rotating the knob a small contact is closed which either tunes the receiver clockwise (forward) or counter-clockwise (reverse). This switch immediately returns to the central position, by spring action, upon being released. The reason for the tuning procedure in Operating Circular No. 95 can be better interpreted by this sketch. The arm making contact is driven through a slip clutch, so that the knob may be rotated continually in either direction. Rotation accomplishes no purpose after the contact is made, which occurs within a few

degrees, but the clutch serves to protect the switch from being damaged by this rotation.

11. **Frequency Selector Switch**—The frequency selector switch is in the upper right hand corner of the control unit. It operates the crystal selector unit on the transmitter unit and receiver unit simultaneously. An arm, upon rotation, serves to contact these points one by one and energizes the relay in the transmitter and receiver crystal units, so that it falls in step. Upon reaching the number 1 position it releases the arm on the crystal unit allowing it to drop to No. 1 position. The selector knob can only be turned in one direction as indicated, due to the mechanics of the switch.

Operating instructions in Operating Circular No. 95 describes the operation of this receiver. It is wired into the plane's power supply and is turned on by rotating its volume control clockwise from zero position. It may be switched to dry battery operation by breaking the seal of the small switch located in the bulkhead nearby. The high-low switch at the left hand corner of the panel serves to select the night frequency band (high) or the beacon band (low). The scale on the receiver is calibrated in frequency for both bands, the night frequency coming in near 31 on the high scale. If there is any doubt as to which scale is to be used, the dial may be rotated clockwise or counter-clockwise fully to the end of the scale, which has a marking on it showing which scale corresponds to which position. The antenna leads out to the small binding post on the lower left hand corner.

12. **Crystal Units**—The complete revolutions of the control unit selector should be made with trial transmission before inspecting the crystal units. To operate this unit remove the "relay fuse" on the rack terminal strip above the transmitter. The two (transmitter and receiver) crystal dust covers should be removed. A small pin projecting from the front edge near center of the crystal relay units, when pulled out slightly, allows the arm to drop to the No. 1 position. This should not be done unless the arms have both stopped at the same position selected on the control unit. If they have failed to notch equally or to the contact selected (the numbers on the crystal unit contact points and crystal sockets correspond to those on the cockpit control unit selector) the release pin may be pulled to allow the arm to drop to No. 1 position. The arms are then advanced carefully (clockwise) by hand to the frequency position desired, and then the fuses are replaced in their holder. Operation may now be attempted. If the selector arms move after the fuses are placed back in the

holder, the relay fuses should be left out of the circuit, but not unless necessary. Poor or dirty contacts can be cleaned with a handkerchief.

Immediately above and to the left of the crystal unit on the receiver, a small arm will be seen projecting through the panel. After selecting the correct frequency this arm should be pushed or pulled depending upon whether day or night operation is desired on the receiver. The directions for the day or night bands are marked on the dust cover which must necessarily be removed to inspect this unit. This arm is found on the receiver only. The arm does not have any control over the crystal selected and the proper day or night crystal must be arranged for the proper frequency as well.

13. **Beacon Receiver Control**—Beside the crystal unit on the receiver and under the same dust cover will be seen a drive unit that operates the beacon receiver. The lower motor is the one that is made to rotate clockwise or counterclockwise by the control unit tuning knob. If the motor does not rotate when the pilot in the cockpit turns the control unit tuning knob, the little armature may be rotated with a finger to attempt to free any sticking. A dirty commutator may be cleaned with a handkerchief with the motor running. The brushes should make good contact. This motor is geared through two worm gears which finally operate an arm which turns the beacon condenser for normal tuning. The arm on the drive unit engages with an arm on the receiver so that the complete beacon drive unit may be removed by loosening the three thumb screws located at right and left top of the unit and at the center bottom. When the unit is pulled off it will be possible to manually operate the tuning unit by rotating the arm projecting through the panel. An emergency tuning dial supplied on the cover of the rear junction box may be unscrewed from the face of that box and will replace the electric drive unit. Great care should be taken to make sure the two arms engage by rotating with one of them to a proper position. If they do not engage tuning can be accomplished in one direction only and the emergency tuning dial calibration will be badly off.

The other motor, which is completely encased, at the top of the electric drive unit, transmits the position of the arm to the cockpit frequency indicator. This motor has a contact arm on the back center which must make contact for proper indication in the cockpit. This arm sometimes becomes bent or dirty, but has no effect upon the actual tuning of the receiver.

14. **Forced Landing Operation**—The tuning unit in the tail

of the plane serves to couple the transmission line from the transmitter antenna plug to the trailing wire. Little need be said about this operation as it cannot be reached in flight. The trailing wire cannot be reached in flight either, and in the event of its loss a landing must be made for replacement purposes. For operation on the ground after a forced landing the trailing wire will operate very efficiently if about six feet of the wire is doubled back on itself and a person holds the doubled over end of the wire, by means of a handkerchief, above the ground as far as possible. The handkerchief or rag should be tied to the antenna and the person should hold the rag as far as possible from the knot. In case of contact with the wire while transmitting, a burn will result, but the voltage on this antenna is harmless, except for a burn, very much like the burn of a match. There is no high voltage d.c. on this wire.

T.W.A. TYPE W-4-A RADIO TELEPHONE TRANSMITTER & BEACON RECEIVER

15. Functions of Each Part of the Apparatus—1. *Receivers*—The receivers are superheterodynes. The beacon receiver and the two-way receiver are on one panel (figure 347) and are practically identical, but have the following differences:

(*a*) They operate from separate antennas.
(*b*) The radio frequency and oscillator coils of a different size and arrangement in each.
(*c*) The beacon receiver (right) is tuned by a motor-driven 4 gang condenser, while the two-way receiver (left) has fixed tuning with a magnetic day-night switch and an oscillator controlled by one of eight crystals, which are selected by a ratchet relay. (Figure 347 shows these devices on the panel.)
(*d*) The automatic volume control in the beacon receiver is short-circuited and not in use. It does not go to the control unit.
(*e*) R-22 is of a different value from R-222.

Each of the two receivers consists of a radio frequency amplifier, followed by a combined first detector and oscillator. Following this tube there are two stages of intermediate frequency amplification, operating at 515 kilocycles in each case. A diode detector, also used for automatic volume control, follows the intermediate frequency amplifier, and enclosed in the same bulb is a stage of audio frequency. This tube drives the final audio amplifier tube, which is followed by a conventional output transformer.

Part numbers where not marked are shown by the attached print, which gives the proper part number.

The tubes are arranged in both halves of the receiver in the following order: The nearest tube to the front panel is a 6–F–7, which is the oscillator and first detector. Behind this is the first intermediate frequency tube, a 78. Behind this is the radio frequency amplifier, a 78 and next the second i.f. tube, another 78, and at the back of the chassis, in line with these tubes, is the diode detector-audio amplifier, an 85 tube. To the right of this tube is the 38 audio output tube.

2. *Transmitter*—The transmitter consists of a 210 oscillator tube, which is controlled by the crystal. Its plate circuit is tuned and drives the 210 doubler tube. The plate of the doubler is modulated by another 210 tube, which is the audio amplifier tube.

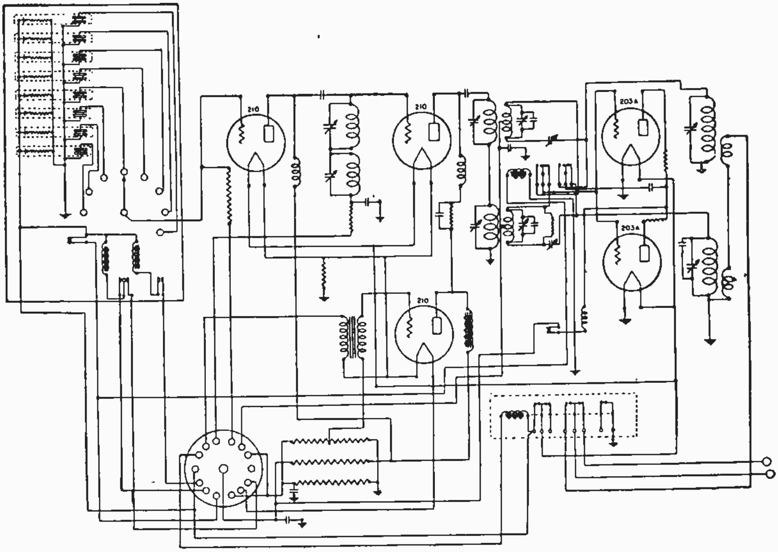

Fig. 348. Transcontinental and Western Air, Inc., W4A Transmitter.

The doubler tube is not neutralized. The doubler drives the two paralleled 203A tubes, which are coupled to the antenna through a tuned circuit. The 203A tubes are neutralized separately on day and night frequency.

The trimmers to the rear of the center line of the chassis are for night frequency. Those forward of the center line are for day frequency. The right hand trimmers, as viewed from the front of the receiver, are for the oscillator plate circuit. The trimmers to the left of these are for the doubler plate circuit. The four trimmers to the left of these are the two neutralizing condensers and the grid circuit trimmers for the 203A tubes. The two trimmers near the center of the chassis are for neutralizing, while the nearest one to the panel, and the furthest one from the panel, are for the grid circuit. A door in the panel gives access to the 203A plate circuit tuning condensers. The upper one is for day frequency and the lower for night frequency.

3. *Crystal Unit*—Both the transmitter and the receiver have a crystal selector mounted on the front panel (figure 347). They are identical, and have two functions. One is to select the proper crystal, and the other is to select the day or night switching. In the receiver the day-night switching is accomplished by means of a magnetically operated fan switch. In the transmitter, the switching is accomplished by a day-night relay under the transmitter chassis, and the tuning unit switching is operated from the same crystal unit contact. The day-night switch is located on the top face of the unit and is automatically operated by a cam fastened to the crystal selector shaft.

The crystal unit operation can be divided into two parts. The first function is to notch up the rotating arm to the desired position (this can be done by hand, but only after the relay fuse on the rack has been removed), and the second is to release the arm after it gets to the No. 8 position and allow it to fall back to the No. 1 position for a repetition of the cycle. (This can be done by hand by pulling on the knurled pin at about the center of the front of the crystal unit.) The notching and releasing is done with two solenoids of the impulse type. (That is, in both cases the solenoid will continue to operate until it has completed its functions, at which time it interrupts its own current.) The contact opening actually occurs just before the solenoid completes its cycle, inertia supplying the power necessary to complete the function. The adjustment of the impulse contacts is important for trouble-free operation. In their open positions the contacts should have about 30 to 40 thousandths clearance, and they should be clean.

4. *Beacon Receiver Drive Unit*—This unit is located on the front of the receiver panel (figure 347), and is attached by three thumb screws. It consists of two separate parts, as to function. The first part is a reversible d.c. motor, operated on 12 volts.

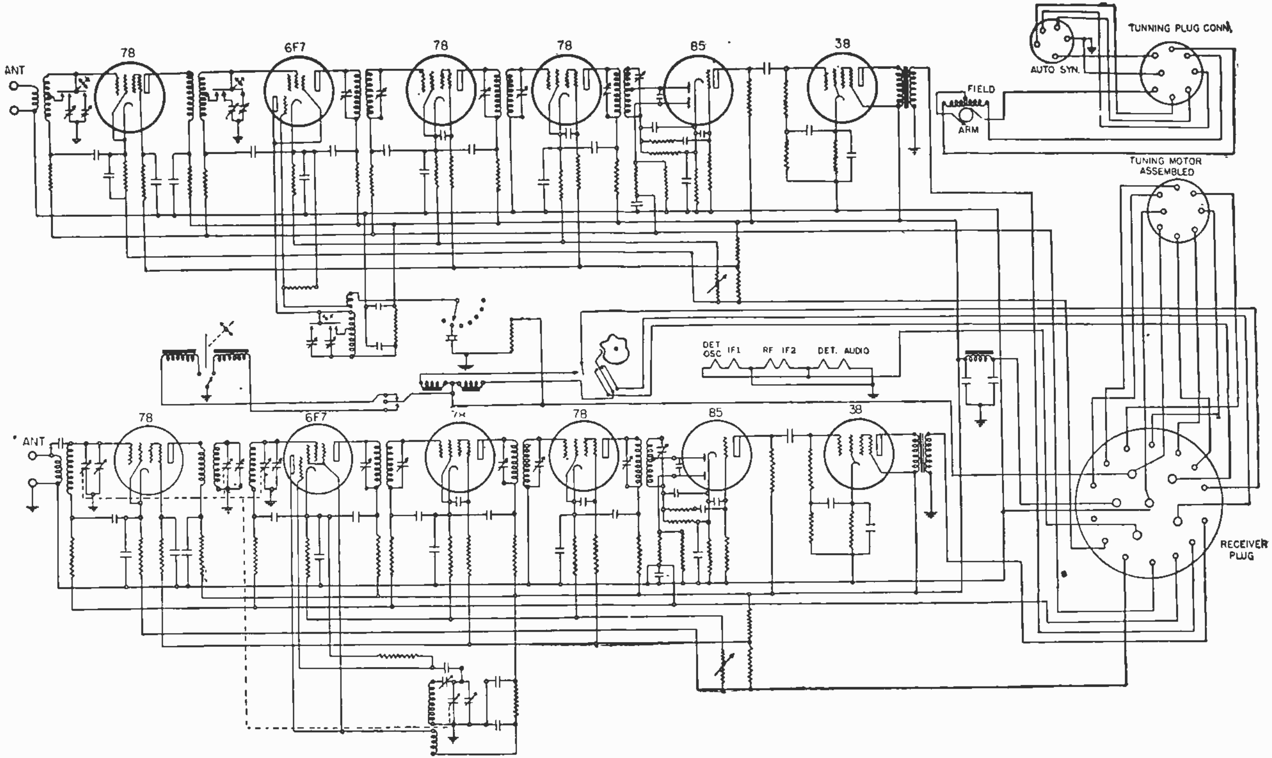

FIG. 349. Transcontinental and Western Air, Inc., Type W4A Receiver, Type W4A Dual Receiver. Top, 2-Way 8-Fixed Frequency Communication Unit. Bottom, Motor Tuned Beacon Receiver.

The field is tapped in the center, and the two ends of the field winding go to the control unit. If either end is grounded the motor will turn in one direction or the other, as voltage is supplied to the center tap through the armature. The motor is geared approximately 2500 to 1 to the beacon condenser tuning shaft, and rotates it slowly one way or the other. The speed of rotation is controlled by a brake on the motor shaft, which can be reached by removing the cover plate from the side of the beacon drive unit after the whole unit has been removed from the panel. This brake should be adjusted so that the condenser moves through 180 degrees in about 15 seconds by actual timing. The brake is important, as it keeps the motor from over-running after voltage has been removed from the motor. The second function of the tuning motor assembly is to transmit the dial reading back to the control unit in the cockpit. This is accomplished by the use of two synchronous non-rotary Autosyn motors. One is on the control unit in the cockpit and the other on the beacon drive unit.

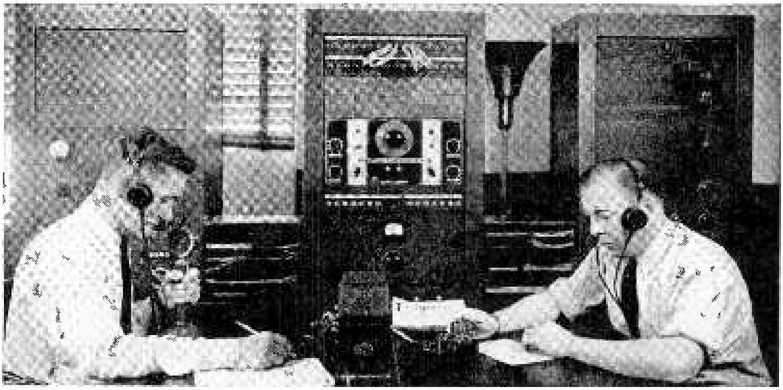

FIG. 350, A. Ground Station Set-up at Kansas City. Two operators are using two remote transmitters for CW and telephone. Four remote receivers come into the patch panel at the top of the center board and are used to transfer the service between operators. (Courtesy Transcontinental and Western Air, Inc.)

As one turns, the other will accurately follow it. The alternating current supply for these motors is obtained from a separate dynamotor in the power unit.

5. *W4A Beacon Receiver Emergency Tuning Dial*—The emergency tuning dial for the W4A beacon receiver is located on the

cover of the rear radio terminal box in the radio compartment, and is to be used in emergency cases, such as a failure of the Autosyn electrical tuning unit.

To install on W4A beacon receiver:

(*a*) Remove crystal shield (box) from front panel of W4A receiver.

(*b*) Remove Autosyn drive, by backing out three (3) knurled thumb screws and pull Autosyn drive straight out to disengage cannon plug.

(*c*) With the condenser plates of the W4A beacon receiver full in, turn the emergency dial to the special mark below 200 kilocycles and engage drives of both the emergency dial and the receiver. Care shall be used so as not to bend or damage the drives otherwise.

(*d*) The emergency dial may now be secured to the beacon receiver by tightening the three (3) knurled thumb screws.

(*e*) The Autosyn electrical drive shall be replaced on the W4A receiver at the next field having a spare receiver. This receiver shall be removed with the defective Autosyn drive unit and returned to Kansas City complete, with detailed information on Form No. 177.

(*f*) It shall be the responsibility of the station removing the receiver to replace the emergency dial to its proper location on the terminal box cover.

6. *Control Unit*—The control unit has several functions. The first is the "On-Off" switch for the complete radio apparatus. This switch closes the circuit through an impulse relay located in the front radio junction box (which can be operated by hand). When the switch is in "On" position the impulse relay supplies 12 volts to the receiver, transmitter and dynamotors. An additional relay in the transmitter prevents any current from flowing to the transmitter, dynamotor or filament circuits until the microphone button is pressed, at which time the filaments and the dynamotor come up together. Due to the fact that the filaments reach full brilliance before the dynamotor supplies much voltage, no damage to the tubes results.

The beacon Autosyn motor has been described before, and indicates the frequency to which the receiver is tuned on its dial. The tuning switch, located beneath the control box, is a single pole double throw switch which grounds either side of the tuning motor field. A spring returns the switch to a central "Off" position as soon as the knob is released.

The two volume controls operate in the conventional manner.

The AVC (automatic volume control) switch on the two-way receiver serves to short-circuit the AVC when in " Off " position. The two-way volume control operates whether the switch is on AVC or not. The volume control should be adjusted so that the weakest stations will be received, but need not be adjusted to a more sensitive point, as noise may be disturbing.

The frequency selector switch supplies energy to the notching solenoid in Positions 2 to 8 inclusive, and in Position 1 it supplies energy to the return solenoid. The switch actually grounds the end of the solenoid as the other ends of the solenoids go to plus 12 volts through the relay fuse. The solenoid impulse switches are in series with the contacts of the selector switch, so that even though the switch is on a contact, no current will flow after the solenoids once operate. The solenoid actually keeps one step ahead of the notch where voltage is supplied by grounding at the frequency selector switch. Contacts 2, 4, 6, and 8 are wired together, as are 3, 5, and 7. When contact 2 is closed the solenoid operates and transfers the voltage to contact 3, and so on. In the No. 1 position, current is supplied to the releasing solenoid which returns the selector arm on the crystal unit to the No. 1 position. Three wires and ground return are necessary for this function.

The output meter is a conventional audio voltmeter, having a protective series resistor and condenser, and reads the beacon receiver output. The meter will also read the output of the two-way receiver if either jack box is in the " Both " position.

The dial light switch and rheostat controls the indirect lighting of the control unit.

7. *Power Supply*—The power supply consists of three dynamotors, one at 100 volts, one at 200 volts, and one at 32 volts a.c. The 200 volt dynamotor supplies a plate voltage for all receivers. The 32 volt a.c. dynamotor supplies energy for the Autosyn motors.

8. *Rack*—The rack has a terminal board located at its top, which contains three fuses. The values and functions of the fuses are marked on the terminal board. When the cover plate is removed, there is danger of high voltage shock, and reasonable precaution should be taken to see that the transmitter is not turned on while the fuses are being removed or replaced. The 1000 volt fuses are located in the power supply. The only other radio fuse is located in the front junction box above the impulse relay.

9. *Tail Cone Tuning Unit*—This unit has a relay operated from the transmitter crystal selector relay. In " Day " position, current is supplied to the solenoid, which has an additional contact to

lessen the current once the solenoid has operated as it adds a series resistor.

10. *Jack Boxes*—The jack boxes in the cockpit have selector switches for selecting the output of the beacon receiver, the two-way receiver, or both. If either jack box is in the "Both" position it is impossible to select an individual receiver on the other jack box. The auxiliary beacon receiver is wired into this box on the two-way audio channel. The jack on the front of the auxiliary beacon receiver, upon plugging in 'phones, removes the output of this receiver from the jack boxes.

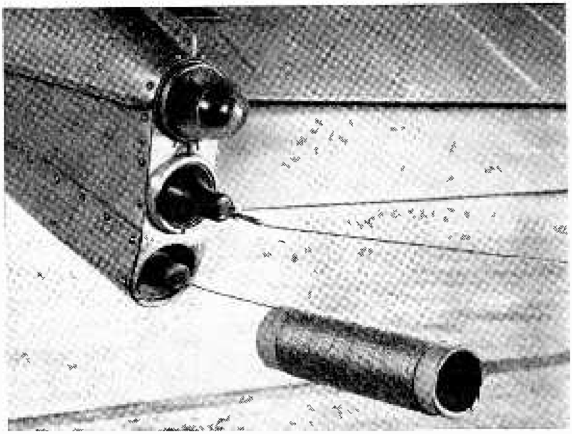

FIG. 351. This Shows the Auxiliary Trailing Wire Mechanism at the Moment of Release, with a Cylinder with a New Antenna About to Unravel. The standard trailing wire is shown attached above this unit. (Courtesy of Transcontinental and Western Air, Inc.)

11. *Antennas*—The trailing wire antenna is automatically loaded for the frequencies used by means of the antenna tuning unit.

12. *Plugs*—Plugs on the various units are removed by first loosening the ring and removing the plug. The plugs cannot be inserted incorrectly.

WESTERN ELECTRIC RADIO TELEPHONE EQUIPMENTS
NOS. 208A AND 208B

16. **Description**—Complete communication systems for airplanes are offered by the Western Electric Company in the No. 208A and No. 208B Radio Telephone Equipments, designed by

Bell Telephone Laboratories. These equipments provide facilities for radio telephone communication with aeronautical ground stations and with other airplanes operating in the frequency band of 2750 to 6500 kilocycles per second; and for the reception of Civil Aeronautics Authority radio range signals and weather reports transmitted by radio telephone in the frequency band of 220 to 445 kilocycles per second. In addition, the equipments permit telephone communication between individuals in the airplane.

The two equipments employ the same radio apparatus units, differing only in the form of the power supply apparatus used. In the case of the No. 208A Radio Telephone Equipment, power is obtained from the airplane 12-volt storage battery and transmitting and receiving dynamotors. The No. 208B Radio Telephone Equipment obtains power from the airplane 12-volt storage battery and a double-voltage engine-driven generator which furnishes power at 1050 volts to the plate circuits of the radio transmitter and at 12 volts to the storage battery. This generator may be operated as a dynamotor, when the engine is not running by using the 12-volt battery as an energy source. (A remotely operated mechanical switch is provided to change the circuits of the generator so that the machine will operate as a dynamotor.) A receiving dynamotor is used as the power supply to the plate circuits of the radio receivers.

The essential units of these equipments are a radio transmitter, two radio receivers, power supply apparatus and control and associated circuit apparatus. The operation controls of the equipments are small, compact units which may be located in the cockpit of the airplane, on the instrument panel or closely adjacent to it. The controls are simple to operate and cause no interference with the piloting of the airplane.

The persons using the radio telephone equipment are supplied with telephone receivers in the form of a headset and with a special type of microphone which tends to exclude from the telephone circuit the engine and propeller noises. In open cockpit airplanes where a helmet is worn by the pilot, a special telephone set consisting of telephone receivers and a microphone which may be attached to his helmet, is available in place of the headset used by the pilot in cabin cockpit airplanes.

The radio equipment used for two-way communication consists of a radio transmitter which may be operated on any one of three preselected frequencies and a radio receiver which may be operated on either of two preselected frequencies. The control used to change frequency in the radio transmitter and radio receiver, which are connected through a common remote mechanical control, enables the pilot to change frequency adjustment when desired.

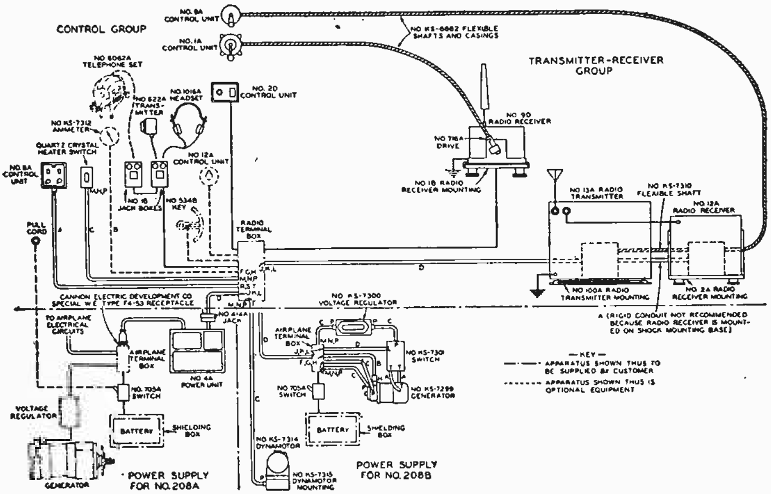

FIG. 352. W.E. 208-A—208-B Radiotelephone Equipment Layout. (Identical except for power equipment.)

Usually the radio transmitter and radio receiver are adjusted to operate on the same carrier frequency.

The radio transmitter is capable of supplying 50 watts of carrier power to a suitably designed antenna. When speech signals of normal value are supplied to the input of the radio transmitter they cause substantially complete modulation of the carrier.

The high frequency radio receiver is of the superheterodyne type and is provided with automatic gain control. Its sensitivity is such that adequate output volume is obtained for operation of two low impedance headsets connected in parallel with an applied radio input signal of one microvolt.

These radio telephone equipments may be operated for short intervals over an appreciable period of time from the 12-volt storage battery alone. The desirability of such an arrangement is obvious when consideration is given to the need for communication in cases of a forced landing or an emergency stop-over at an intermediate field.

Two fixed antennas are employed: one for both transmitting and receiving at high frequencies in two-way communication, and the other, connected to the low frequency radio receiver, for the reception of weather information and range signals transmitted by the Civil Aeronautics Authority Radio Stations.

When used for communication the equipment operates as a push button or " simplex " circuit: i.e., the circuit is one-way; the listener cannot interrupt the speaker. After turning on the power for the equipment, the pilot presses a conveniently located button or key when he wishes to speak. When this key is released, the circuit is returned to a listening or receiving condition. Conversation is accordingly carried on by manipulating this key as required. When in the receiving condition the outputs of the two radio receivers are connected, permitting reception of signals from either one. A manual " Sensitivity " control, associated with the low frequency radio receiver, and a " loudness " control, associated with the high frequency radio receiver, may be varied individually so that the audio output from either radio receiver may be selected in case of interference between signals received simultaneously. The " Sensitivity " control for the low frequency radio receiver, when rotated completely in a counter-clockwise direction, opens the plate power supply circuit to this unit. The position of the " Sensitivity " control for the high frequency radio receiver determines the upper limit of amplification in that unit. A loudness control permits the operator to adjust the signals in the headsets to a comfortable value. This signal level is maintained substantially constant by the automatic gain control for a wide variation in the received radio frequency voltage.

17. **Two-Way Communication**—For two-way communication the No. 13A Radio Transmitter supplies the required high frequency transmitting power and the No. 12A Radio Receiver is employed for the reception of the incoming signals. Circuits are provided in both the radio receiver and radio transmitter for tuning the high frequency antenna. In the radio transmitter a thermocouple is provided which may be used with an external meter when it is desired to have an indication of the antenna current. For this purpose a No. KS–7312 Ammeter may be mounted on the instrument panel so that the pilot will know by the deflection of the meter that the radio transmitter is operating properly.

By means of a relay, the antenna is connected to the radio transmitter during the talking interval, and to the radio receiver during the listening interval. This relay is operated by means of the " Press to Talk " control key in the microphone or by a similar key located on the airplane's control stick or wheel.

The No. 9A Control Unit is used for remote operation of the frequency changing switches in the radio transmitter and in the No. 12A Radio Receiver. A signal light, located in the No. 8A Control Unit is used to warn the pilot when changing from one frequency channel to another if the operation is incomplete. The light is extinguished only when the frequency change switches are centered on one of the operating positions.

Operation of the " Press to Talk " control key connects a branch from the speech input circuit of the radio transmitter to the audio amplifier in the No. 12A Radio Receiver. Through this circuit sidetone is obtained from the output of the Radio receiver.

The master switch, marked " Off-on," located in the control unit, closes the battery circuit to the filaments of the two radio receivers, to the No. KS–7176 dynamotor and to the transmitter switch marked " Rec.-Tran.," " Receive." The radio receiver tubes require approximately one minute to reach operating temperature and the master switch is normally in the " On " position during flight so that the radio receivers will be continuously in operation. The transmitter switch is thrown to the " Rec.-Tran." position only when the pilot desires to communicate with a ground station or some other airplane. This switch closes the circuit from the storage battery to the filaments in the radio transmitter.

In the No. 4A Power Unit, the No. KS–7175 Dynamotor provides 1050 volts for the No. 13A Radio Transmitter, and the No. KS–7176 Dynamotor supplies 200 volts for the No. 9D Radio Receiver and the No. 12A Radio Receiver. The No. KS–7175 Dynamotor operates only during the actual transmitting interval when the microphone key is pressed. The No. KS–7177 Relay, employed to start the radio transmitting dynamotor, and fuses for the 12-volt and 1050-volt circuits are located in the No. 4A Power Unit. Additional fuses are provided in the No. 8A Control Unit to protect the 12-volt circuits which branch from the switches in that unit.

The No. KS–7299 engine-driven Generator and a No. KS–7314 Dynamotor furnish the high voltages required by the radio transmitter and the two radio receivers respectively in the No. 208B Radio Telephone Equipment. This engine-driven generator also serves as a charging generator for the storage battery. A No. KS–7301 Switch is used to transfer the circuits of the generator when it is desired to operate the machine as a battery driven dynamotor. This feature permits intermittent operation of the radio equipment from the battery alone for an appreciable period of time. A No. KS–6993 Relay, controlled by the microphone key, is used to start the No. KS–7299 Generator when that machine is operated as a dynamotor.

The No. 12A Radio Receiver is of the superheterodyne type and uses quartz crystals to control the frequencies of the beating oscillator circuits. Provision has been made so that the radio receiver may be adjusted for reception on either of two frequencies and a remotely operated switch is used to change to either set of tuned circuits. Electric oscillator circuits may be used in this radio receiver provided that the No. 3A Quartz Plates are removed and No. 8 Type Tuning Units substituted. In addition two circuits must be connected as indicated in the instruction bulletin for the radio receiver.[1] When an electric oscillator circuit is used, a No. 12A Control Unit, located in the cockpit, is used to correct for slight variations which may occur in the beating oscillator frequency.

When two-way communication is completed, the pilot will ordinarily wish to operate the equipment for receiving purposes only. This is accomplished by moving the transmitter switch to the " Receive " position, which removes the filament power of the No. 13A Radio Transmitter. The outputs of the two radio receivers are connected at all times to the headset, and when the microphone key is operated for intercommunication, sidetone is provided in the headsets through the audio amplifier in the No. 12A Radio Receiver.

United Air Lines ES–192 Receiver

18. Description—This specification covers a two-frequency superheterodyne receiver for use in aeronautical radio ground stations for the reception of aircraft and ground station modulated radio signals. It is primarily designed to operate in the ranges of 3000 and 6000 kcs., but the receiver could be modified to cover other frequency channels by minor changes in the r.f. transformers and in the crystal frequency.

Crystal control of the beating oscillator frequency is provided to maintain the frequency stability of the receiver. Also, variable air condensers are used throughout the receiver in the r.f. trans-

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[1] When No. 8 Type Tuning Units are used in the No. 12A Radio Receiver, it is desirable to strap Terminal Nos. 1 and 2 in the No. 2 Type Radio Receiver Mountings. The filament circuit conductor to Terminal No. 1 must be removed when this strap is added.

This change allows the radio receiver to reach a normal operating temperature during the warming up period of the quartz plates in the radio transmitter.

formers and i.f. transformers to prevent frequency shift due to aging of dielectrics, etc.

The intermediate frequency of the receiver is 385 kilocycles. Two stages of intermediate frequency amplification are provided.

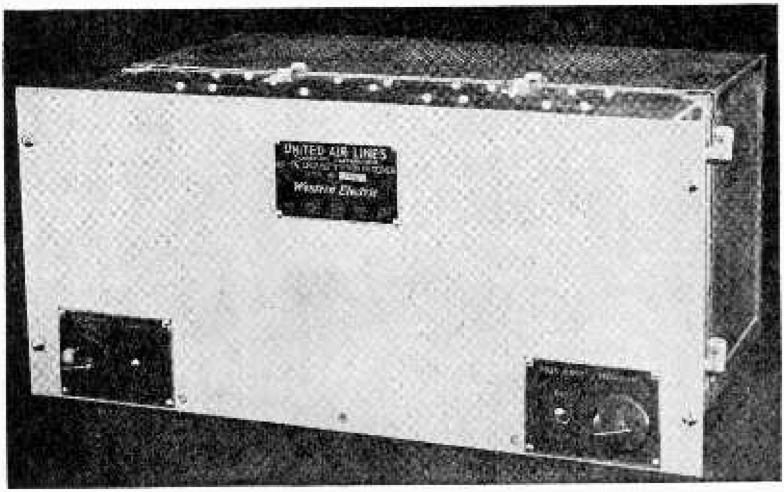

FIG. 353. United Air Lines Western Electric–ES198 Ground Station Superheterodyne Receiver.

Automatic volume control is applied to the grids of the first r.f. tubes and to the i.f. tubes. Audio automatic volume control is provided on very strong audio signals to prevent overloading and blocking of the audio amplifier tubes. A manual sensitivity control is provided to adjust the sensitivity to a value consistent with local static and noise level conditions. When the manual sensitivity control is properly adjusted, the automatic volume control will not begin to reduce the sensitivity of the receiver until full audio output is obtained. This delayed action makes possible optimum sensitivity to any signal above the noise level.

A plate power supply is not provided in this unit, since each ground station is equipped with a standard ES–151 " B " Power Supply. A transformer included in the receiver provides filament power. A filament switch is provided on the front panel.

Frequency shift from day to night and vice versa are accomplished by a relay controlled by a toggle switch on the front panel. A relay is also provided to disconnect the high voltage and to

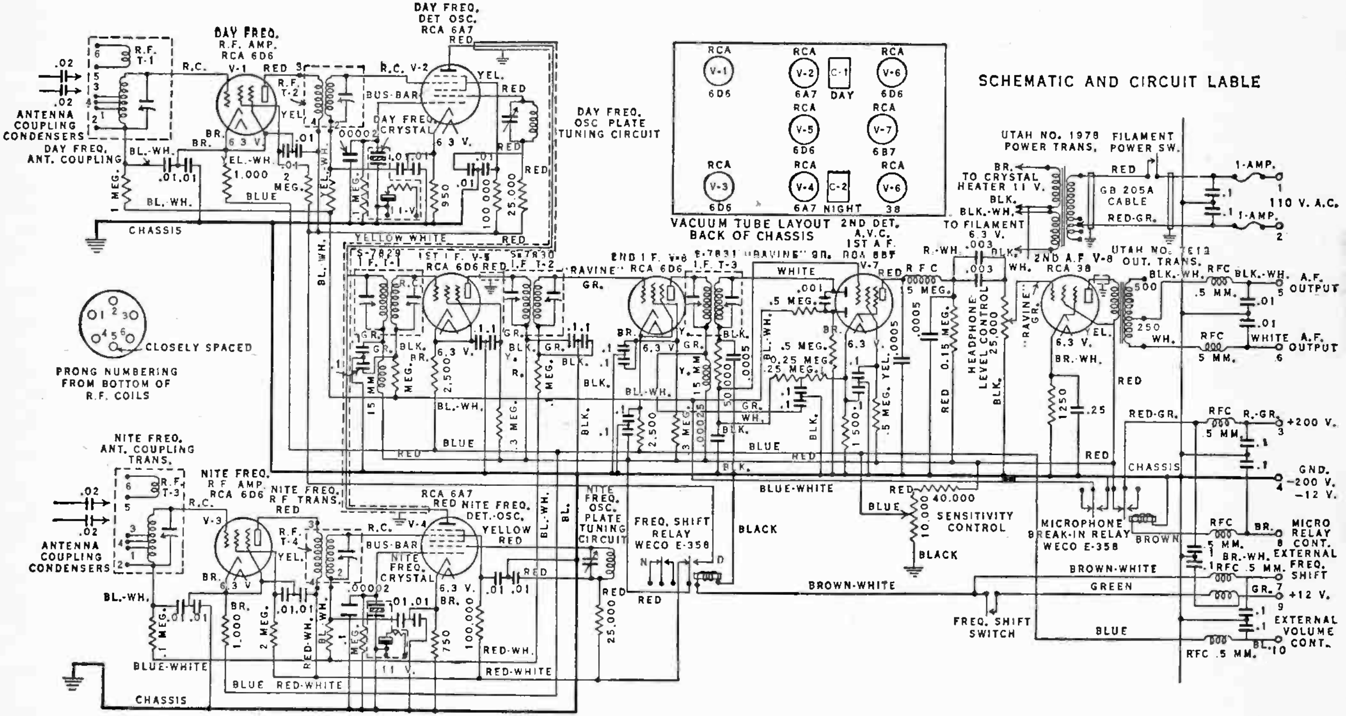

Fig. 354. Wiring Diagram of United Air Lines ES-192 Receiver.

ground the automatic volume control circuit when the ground station transmitter is operated, in order to permit break-in and to prevent the receiver from being "blocked" by the strong signal from the transmitter. This relay operates when the "Press to Talk" button of the transmitter is actuated.

Service Notes on the United Air Line ES–198 Beacon Receiver Description

Type of Circuit	Superheterodyne
Intermediate frequency	175 kilocycles
Frequency range	200–400 kilocycles
Signal frequency stages	One
Intermediate frequency stages	Two
Audio frequency stages	Two
Number of tubes	Six

General Information—The first detector and oscillator are combined in a single "pentagrid converter" tube, in which part of the tube is used as a conventional oscillator, and the remainder as a mixer and rectifier to produce the intermediate frequency.

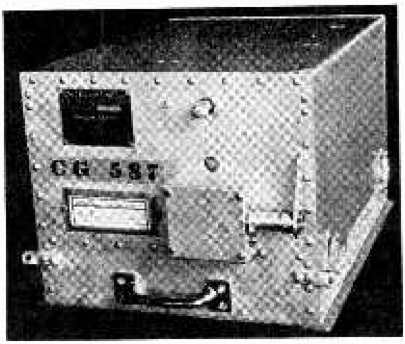

Fig. 355. United Air Lines ES–198 Beacon Receiver.

The second detector and first audio stages are combined in a "double-diode triode" tube. The diode part of the tube is used to rectify the signal from the intermediate frequency amplifier, which produces the audio signal and also the voltage for the automatic volume control. The triode part of the tube is used for the first audio stage.

The first radio frequency and the two intermediate frequency tubes are of the "super-control" r.f. pentode types. The output tube is a pentode.

All tubes are of the heater cathode type, rated at 6.3 volts on the filament. The filaments are connected in series parallel; two tubes in series, three pairs in parallel, so that they may be operated direct from a 12 volt battery.

Plate supply is obtained from the regular dynamotor, the proper voltages for the tubes being obtained by series resistors in the various leads.

A solenoid operated switch is provided which disconnects the main 3-gang tuning condenser and connects in its place 3 adjustable capacities. These adjustable capacities are set so that the receiver tunes to some predetermined frequency when the switch is operated. A cockpit control is provided for operating this switch.

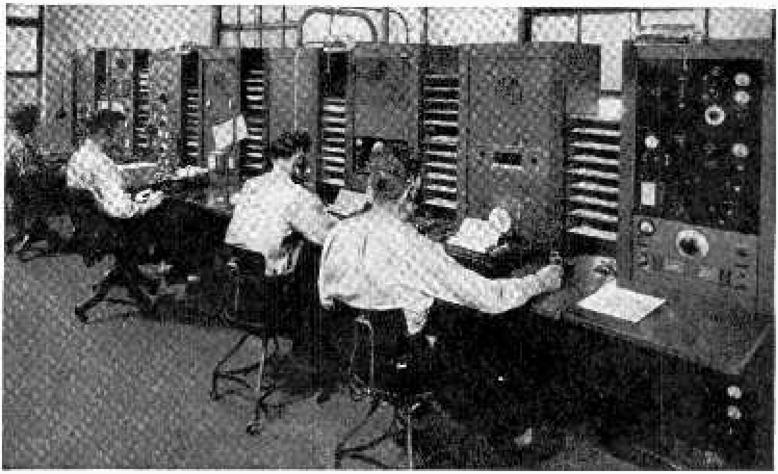

Fig. 356. Receivers and Control Position of Eastern Air Lines' Miami Radio Station. Also Showing Frequency Standard.

Tuning over the 200–400 kilocycle band is accomplished by a three-gang condenser. The oscillator section of this gang has specially cut plates, which, together with a suitable padding circuit, keeps the oscillator frequency 175 kilocycles higher than the signal frequency at all times.

CHAPTER 13

MARINE RADIO DIRECTION FINDERS

1. **Radio Direction Finders**—The coil type radio compass or direction finder was principally developed in this country by the U. S. Navy and successfully introduced as an aid to navigation. Since its introduction and increasing use the United States Coast Guard has established automatic radio beacons on light vessels and at lighthouses in the vicinity of harbor entrances and places dangerous to navigation, the exact locations of which are clearly shown on all sailing charts. These stations sent out characteristic radio signals similar to light flashes, thus enabling the master of a vessel fitted with a radio compass to take bearings as often as desired.

2. **Fundamental Principles**—It has long been known that an antenna consisting of a loop or closed coil has "directional" properties. Consider the coil of wire in figure 357 marked (*a*) as being supported vertically and its edge pointing in the direction of a radio transmitting station. A radio wave from the transmitter will pass through that portion of the loop marked *F* the merest fraction of time before it does that marked *R*. The result of this is that a difference of potential will exist between the two sides of the loop, thus producing a radio frequency current in the coil and condenser circuit. If this circuit is resonant to the frequency of the incoming wave a maximum e.m.f. will exist across the terminals of the condenser.

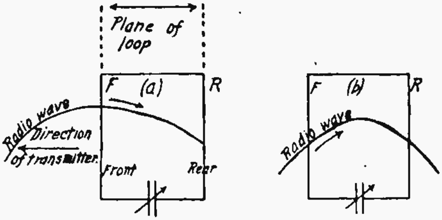

FIG. 357. Radio Wave Striking Loop Antenna.

As the wave advances there will be an instant when both *F* and

R are subject to the same potential as the amplitude of the wave cutting both wires is the same. This is represented by *b* in figure 357.

As the wave continues to advance, the *R* wire will have a greater e.m.f. than that of *F* and again a current will flow in the loop circuit. As the end of the wave passes over the loop the current will fall to zero only to repeat the cycle of events just mentioned upon the arrival of the next wave.

Now consider the loop turned so as to be at right angles to the transmitting station. The wave arriving from the station will strike both the *F* and *R* wires at the same time. This results in e.m.f.s of equal potential but opposite in sign being induced in the loop, the result of which they cancel, and no current will flow.

If the terminals of the loop and condenser were connected to a vacuum tube detector and amplifier the signals from the transmitting station would have been heard the loudest when the loop was pointing in the direction of the station, i.e., when the plane of the loop lay in the direction of the source of transmission. As the loop is turned from this position, through 180 degrees, the signal will gradually disappear, and when the plane of the loop is at right angles to the source of transmission the signal intensity will be zero. If the loop is continued in rotation the signal will gradually reappear, being at a maximum when the plane of the loop again lies in the direction of the source of transmission. Referring to figure 357, the *R* turn has now become *F* and *F* become *R*. The signal intensity thus varies in accordance with the figure-of-eight characteristics as shown in figure 358, the direction *A* or *B* indicating maximum signal intensity.

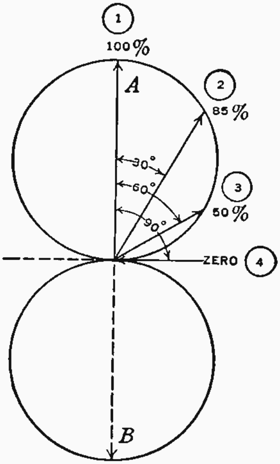

FIG. 358. Figure-of-8 Characteristics of Loop When Balanced to Earth.

3. Capacity of Loop Circuit to Ground—An important factor that has to be considered in the use of the loop antenna in its application as a direction finder is the effect produced in the coil by virtue of the coil structure having an appreciable capacity to earth. Also the detector and amplifier circuits are electrically unsymmetrical with respect to earth. This results in a distortion of the ideal figure-of-eight signal intensity characteristic obtained by rotation of the coil about its vertical axis. The critical position of "no signal" no longer exists and the directive qualities of the loop have been distorted.

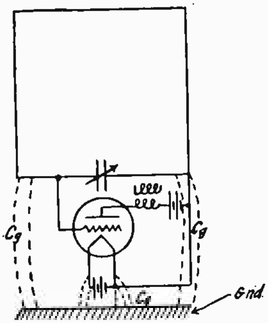

FIG. 359. Loop Circuit Showing Capacity to Ground.

An examination of figure 359 will show how this is brought about. The grid of the vacuum tube is actuated by an e.m.f. directly from the tuned input circuit consisting of the coil L and condenser C. The dotted lines C_g represent the capacity of the coil and apparatus to ground. Because of the electrically unsymmetrical relation of the coil system with respect to earth, an appreciable current will be set up in the loop circuit by the incoming wave acting through the earth capacities C_g. The potential produced by this current across the condenser C will likewise operate on the grid of the vacuum tube.

The ideal figure-of-eight signal intensity characteristic is therefore distorted by these additional effects, the degree of distortion depending upon their relative magnitudes. The signal variation characteristic which results from these effects is shown in figure 360. The position of minimum or zero signal intensity is no longer at right angles to the plane of the loop, nor does it coincide with the axis of the loop as in the ideal case.

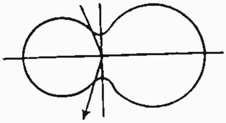

FIG. 360. Loop Characteristic Showing Effect of Current Set Up in Coil by "Antenna Effect."

The complete solution of the problem depends upon obtaining exact electrical symmetry of the loop system, including the vacuum tube apparatus with respect to earth. This is accomplished by balancing out this so-called "antenna effect" with a condenser connected as shown in figure 361. It can also be improved by inductively coupling the loop circuit to the vacuum tube.

4. Determination of Sense—As already explained, the loop system when properly balanced will give a critical zero signal, thus giving the line of direction which is of course at right angles to the point of zero signal. However, the loop is subject to a possible 180 degree error, owing to the fact that there are two points at which the signal disappears, obtained by rotating the loop half a turn. When taking bearings from a coast station the general direction of which is known, the two points of zero signal do not matter, as the correct one is easily recognizable.

The occasion may arise wherein the location of the signalling station is necessary, such as locating and proceeding to the aid of a ship in distress. To obtain the true direction it is necessary to unbalance the loop by exaggerating the antenna effect. This is accomplished by connecting a small antenna to one side of the loop through a disconnecting or uni-directional switch. Normally the uni-directional switch is open when taking a bearing, but when the true direction is desired, the operator closes the switch and turns the loop to the position of maximum signal at which point the plane of the coil lies in the direction of the signalling station and points toward it as indicated by an index pointer provided for that purpose.

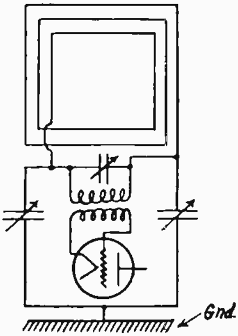

FIG. 361. Method of Balancing Out "Antenna Effect" of Coil and Apparatus to Ground.

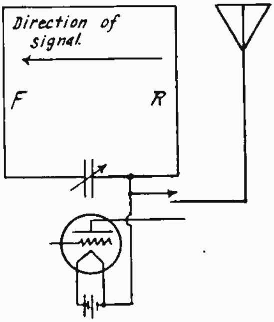

FIG. 362. Loop Unbalanced by "Sense Antenna."

Referring to figure 362, the loop is turned so as to pick up the signal from the advancing wave as indicated by the arrow. Attached to one side of the loop is the small antenna previously mentioned. This antenna is connected to the rear side of the loop and picks up just enough energy to offset that picked by the front of the loop and the result is that no signal is heard.

Now, if the loop, with its small antenna attached, is rotated 180 degrees there will be communicated to the grid of the tube the combined energy of both loop and small antenna. The effect is that the combined e.m.f.s will greatly overbalance the feeble e.m.f. induced by the rear of the loop. Thus when the side of the loop with the antenna attached is turned so that a signal is heard at a maximum it establishes the direction of the transmitter. If the loop is turned in any other direction the signal will be lost or considerably weakened.

5. **Wave Front Distortion**—When a direction finder is installed on shipboard there are certain distributing effects due to the ship's equipment, the most serious of which are due to currents induced in the d.f. by wires, forming closed circuits, stays, whistle cords and the like and which have a natural wavelength considerably less than the working wavelength. These currents are in phase opposition to the currents induced by the signal direct and therefore have the effect of decreasing the apparent sensitivity of the direction finder. Since the masts, stays, etc., are in various directions from the direction finder, they also have the effect of shifting the apparent direction of the arrival of the signal. This latter effect is more prominent when the wave is approaching from approximately 45 degrees from the ship's center line. In the fore-and-aft direction and directly abeam the error is at a minimum.

Currents induced in the direction finder by masts, grounded stays and any metal objects, which can act as a vertical antenna and which have a natural wavelength considerably less than the working wavelength, are 90 degrees out of phase with the current due to the signal. Therefore, no value of signal current can be obtained to cancel these antenna currents as the vectorial addition is always to make the resultant greater than either component. The effect apparent to the observer is the broadening of the minima, in two opposite quadrants, in taking of bearings in which the resultant mass effect causes currents to be induced in the direction finder. Usually these induced currents are not of sufficient magnitude to cause an appreciable shift in the apparent bearing of the signal.

In order to compensate for the apparent shift in direction of signal and adjustment to obtain a sharp minimum signal at all angles it becomes necessary to calibrate the direction finder. Calibration is done by taking simultaneous sight and radio bearings on a radio transmitter as described on pages 742 and 743. After calibration, a deviation or correction curve is plotted and applied to an automatic compensator which makes the instrument direct reading and eliminates the necessity of applying a correction to the bearings.

6. Proceeding with Calibration—Since the received wave is distorted or bent by the metal objects on the vessel it becomes necessary to place such objects in a permanent condition, i.e., either insulated or grounded. The latter method is most practical as it is easiest and cheapest. However, this cannot be done to the whistle cord, fore-and-aft stays or any such stays that form a closed loop around the d.f. loop. Therefore these are always broken up into small lengths by insulators so that each length has a fundamental wavelength lower than that of the range of the direction finder receiver.

Usually a direction finder is equipped with two scale pointers. One is mounted under the compensating cover and is known as the upper scale. This indicates the actual position of the loop. The other is at the bottom end of the extension shaft and indicates the true bearing after compensation is completed. During calibration only the upper scale is used and it is adjusted so that scale reads zero when plane of loop is 90 degrees from the lubber line and the glass indicator reads on the lubber line.

Radio and sight bearings are taken as near to 10 degrees apart as possible and each bearing recorded and numbered as follows:

Bearing Number	Upper Scale	Pelorus (Sight Bearing)	Correction
1	72	76½	+ 4½

where 72 is the position of the d.f. loop, 76 1/2 is the correct bearing as per pelorus, + 4 1/2 is the correction to be added to the d.f. bearing to give the true bearing.

When the d.f. loop is rotated by means of the hand wheel, the characteristic signals from a beacon station will be heard with a gradually varying degree of loudness until the plane of the coil is at right angles to the direction of the incoming waves at which point the signals should die out entirely. This position of silence is critical and sharp and therefore indicates with great accuracy the line of direction of the source.

After the ship has been swung and the required number of bearings taken they are recorded and a curve drawn. In practically all calibration curves there are four angles where no correction is necessary and the form of the curve resembles a sine wave. Theoretically, the curve is a sine wave for practically all cases with a given amplitude and phase angle for each installation. Considerable emphasis should be given this fact in drawing the curve from the data obtained, as it will help in judging what points are in error.

7. Compensation for Error—The compensator as employed with R.C.A. direction finder consists of an arm mounted at the top of the lower scale pointer shaft which has a roller fitted in the end. This roller bears on a circular band that is held semi-rigid by 24 screws spaced 15 degrees apart; by screwing or unscrewing as the occasion necessitates the shape of the cam is changed which causes the roller to move outward or inward at the appropriate points, thereby changing the position of the arm which in turn rotates the lower scale to read the true bearing.

These twenty-four screws are numbered from 1 to 24 inclusive and are mounted directly under the upper scale.

Record should be made of the numbers on the upper scale that are immediately over the screws. Consult the calibration curve at the point indicated by screw number 1 and note the correction.

Screw Number	Upper Scale	Correction	Lower Scale
1	6	+ 2	8
2	21		
3	36		
4	51		

As in the table below, screw number 1 is under 6 on upper scale and 6 degrees shows a 2 degrees plus error, $6 + 2 = 8$, so that when the loop is at an angle of 6 degrees the pelorus indicates a plus two degrees error. It then becomes necessary to set the upper scale pointer on 6 and adjust screw number 1 until the lower pointer reads 8 which is the pelorus or true bearing at this particular angle. After this one is completed move upper scale to figures over screw 2 and adjust screw 2 until the lower scale pointer reads plus the error indicated by the chart and so on until the 24 screws have been adjusted. It should be noted that a minus as well as a plus error has to be compensated for, depending upon the angle of the loop for a particular reading.

While the d.f. is being operated the antenna employed for transmission and reception is placed in a neutral position, i.e., ungrounded.

8. Bellini-Tosi Direction Finder—This type of direction finder, named after the inventor, is used extensively in European countries both on vessels and aircraft. It is rarely used in this country except on aircraft. In view of this last statement it has been thought best to omit an elaborate technical description of operation and simply give the reader a synopsis of the system.

A distinctive feature is the use of two fixed loops arranged to bisect each other at right angles and to make a 45-degree angle with the bow and stern of a vessel or aircraft. Each loop is tuned by a variable condenser and there is a coil in series with each loop arranged so as to be in an inductive relation to a rotating coil termed the exploring coil. This coil is fitted with a pointer and arranged to turn over a scale of 360 degrees and its energy fed into a vacuum tube detector and amplifier. In operation the effect produced in the exploring coil is such that its pointer will lie in the plane of the advancing wave. Bearings can then be taken in the same manner prescribed for a rotating loop direction finder, that is, by fading the signal out on each side of maximum audibility and taking the mean value in degrees from these readings as indication of the plane of transmission. To obtain the true direction it is necessary to unbalance one loop by coupling energy to it from a small antenna similar to that used with the rotating loop method which has already been described in the early part of the chapter.

U. S. Coast Guard

LIGHTHOUSE SERVICE

Notes for Masters of Vessels Using Radiobeacons of the United States

9. **Radiobeacon Charts**—In order to facilitate the use of the system of radiobeacons established along the coasts of the United States, radiobeacon charts are issued upon which these stations are shown, with their characteristics and operating schedules, including some Canadian stations. These charts are designed for mounting in the ship's chart room or pilot house; they are reprinted when there are important changes, and may be obtained, free, from the Superintendent of Lighthouses in the principal ports of the United States

10. **The Use of Radiobeacons in Navigation**—The general problems and practice of navigation are the same using bearings on radiobeacons as they are with visual bearings on lighthouses or other known objects, excepting for the much greater distances at which bearings may be utilized. The radio bearings may be combined with the results from any other source of information. The Radiobeacons are now operated so as to facilitate frequent checks, both in clear weather and in low visibility. Subject to proper allowance for the effect of current and wind, if successive radio bearings do not change, it is shown that the vessel is proceeding

directly from the radiobeacon station. In setting courses, the possibility of some error in direction finder bearings should not be overlooked. Especial care should be used when conditions for taking radio bearings appear to be unfavorable, as for example, when the bearings may be affected by unusual static, or by night effect, and at such times they should be repeated, and checked by any means available. Bearings passing over the land or parallel to the shore line, taken from a ship near the land, may have appreciable errors. Possible error due to reciprocal bearings must be guarded against. For bearings taken at a distance of over fifty (50) miles, a correction must be applied when plotting on a Mercator chart.

Radio bearings are useful in clear weather navigation as well as in fog. For a vessel approaching the coast or a harbor entrance radio bearings provide a valuable check on position from other sources and from dead reckoning.

Many navigators are using the direction finder as a help in avoiding collision in fog, detecting with it the presence and observing the direction of approaching vessels.

11. **The Shipboard Radio Direction Finder** on the ship should be located conveniently to the navigator, so as to enable him to take radio bearings, and plot them on the charts; all deck officers should be practiced in observing radio bearings. It is important that this be an efficient instrument of good selectivity and modern design, and that it is maintained in an effective and reliable state. It should be carefully calibrated and checked, as opportunity offers, by visual bearings, and frequent use should be made of it in clear weather as well as in fog, in order that its capabilities and possible errors may be well known, and practice had in its use. Careful re-checking and re-calibration, if necessary, should always be made following any structural changes, or alterations in the disposition of other radio equipment on the vessel, which might affect the original calibration. Such continued practice in the use of the radio direction finder on board ship will give the navigator first hand information as to the reliability of the bearings he observes, and the value of the positions he obtains by this means.

12. **Caution in Approaching Lightships**—The attention of mariners is directed to the serious danger which may arise from the misuse of radio signals, and particularly to the danger of collision with lightships operating such signals. The mariner who in thick weather approaches a radiobeacon directly ahead on a radio bearing and relies on hearing the fog signal in sufficient time to alter course to avoid danger, is taking an unjustifiable risk. The

vagaries of sound fog signals are well known, and warnings regarding them are widely printed; such signals may not be heard with certainty in time to avoid collision. Safety demands that all precautions be taken in approaching lightships. The risk of collision can be avoided by getting the radiobeacon on the bow, taking successive bearings, and ensuring that the radio bearing does not remain constant; the angle between the course and the radiobeacon should increase for a vessel passing clear.

Nearly half of the radiobeacons on the coasts of the United States are placed on lightships, and these radio signals provide valuable marks for approaching the coasts and ports. In using radio bearings for approach, it is important that the courses at all times be set to pass safely clear. Radiobeacons offer to navigators a convenient means of checking this by methods well known in ordinary navigation, but sometimes overlooked in navigation by radio bearings. The navigator may check his position with respect to the lightship radiobeacon when steering to pass to one side, by taking successive radio bearings and using these with the intervening distance run, to ascertain the distance off from time to time. Radio cross bearings should also be taken; also soundings should be taken, and the effect of currents should not be overlooked. Where warning radiobeacons and direct distance finding facilities are provided, they should be utilized.

The caution as to passing lightships at a safe distance, and approaching them using all care, of course applies to all lightships, whether or not they are provided with radio beacons, and it applies also to radiobeacons at lighthouses which may be approached close to.

In preparing these notes, advantage has been taken of many reports from practical mariners, who systematically make use of radio direction finders or radio-compasses in navigation, and it is appreciated that great interest is already taken in the problems of radiobeacon navigation. Further suggestions and reports on these subjects are invited, and may be sent to the Commandant, U. S. Coast Guard, Washington, D. C.

RCA Radio Direction Finder

Radiomarine Corporation of America

Foreword

Before the radio direction finder can be used for taking bearings, it must be calibrated and adjusted to compensate for errors caused by metal objects aboard ship. The error will always be the same for any given position of the loop.

The instrument is so designed that when once calibrated the necessary corrections may be read directly from a correction scale located above the main compass scale.

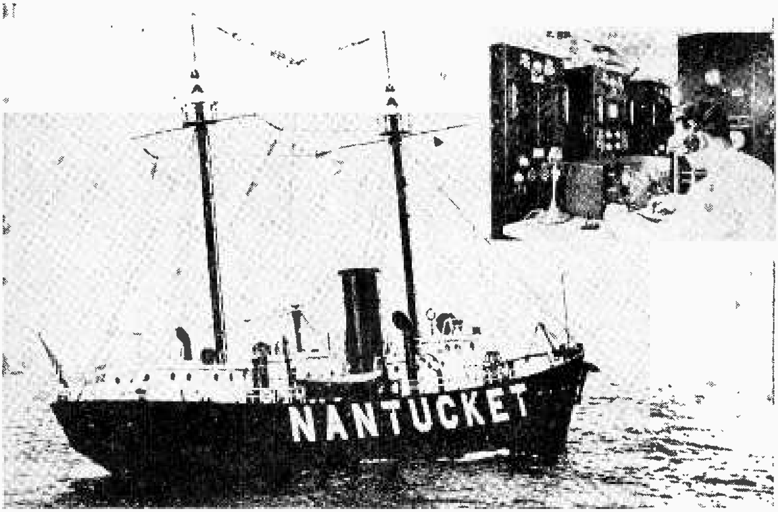

FIG. 363. Nantucket Lightship Showing Radio Antenna and Radio Equipment in the Insert.

This calibration and adjustment is usually carried out on the first voyage after the instrument is installed. It must be done by someone familiar with such work and requires the close co-operation of the Master of the ship. The procedure is to take simultaneous sight bearings with a pelorus and radio bearings with the direction finder on some station while swinging the ship. The difference between the sight bearings and the radio bearings will be the error of the direction finder. The sight bearings must be taken with great care as the accuracy of the instrument after calibration will depend upon the accuracy of the sight bearings taken during calibration. Usually, the maximum error will exist on bearings taken on stations off the bows and quarters. The error on bearings right ahead, or astern, or on the beam, is usually negligible.

At the time the direction finder is calibrated, the ship should be in condition for sea, with booms stowed. Bearings should be taken with the ship in the same condition, as it must be borne in mind that changes in the position of large metal objects, particularly if close to the loop, may cause a change in the calibration.

To prevent the wind from turning the loop, a lock has been provided on the shaft of the handwheel. It is recommended that this lock be set whenever the instrument is not in use.

The calibration should be checked from time to time by taking simultaneous sight and radio bearings when approaching and passing Lightships equipped with radio fog signals, or by asking any passing vessel to transmit signals. Stations used for calibrating the direction finder must be within range of visibility, but should not be less than one mile distant.

To avoid confusion, it might be well to point out that the terms "radio direction finder" and "Radio compass" are synonymous. (TWA usage otherwise however. See latter part of chapter on aircraft beacons.) Either term might be applied to the instrument described in this book. "Radio direction finder" has been used in the belief that it more truly defines the function of the instrument. The terms "Radio position finder" and "radio pelorus" might also be used to describe this instrument. In fact, it should be regarded as a pelorus with which bearings may be taken at distances greatly beyond the range of visibility.

Instructions for Operating Radiomarine Direction Finder

13. Determination of Ship's Position by Radio Bearings—The most general use of the radio direction finder is to ascertain the true bearing, or line of direction of a radio beacon or radio station of known latitude and longitude. At the time the bearing is taken the ship will be somewhere on the line of direction, and if the position of the vessel as determined by dead reckoning or observations is correct, or nearly so, it should fall on, or close to the line.

The single bearing, or line of direction, can be utilized as a danger bearing, or more properly, a safety bearing; for example, if two ships are approaching each other during thick weather, or if one ship is overtaking another, a radio bearing can be taken and the angle from the ship's head noted carefully. If then other bearings are taken at intervals of ten or fifteen minutes (depending on speed and estimated distance) the angle from the ship's head will either be increasing or decreasing. If the angle is found to be decreasing it should be taken as a danger signal and the ship's course altered one or two degrees, or until the angle is found to be increasing, and the ships will pass with safety. The distance between the vessels can be roughly estimated with experience in noting how quickly the angle between the vessels changes. If the distance is, say, fifty miles or more, the angle will not show much change for some time, whereas if it changes quickly it can be assumed that the other vessel is quite close.

The Radio Operator can be of much assistance to the Master in cases of this nature, as he can advise of any ships in the vicinity, and by listening in on the telephones of the direction finder can identify the ships on which bearings are desired. He can also judge approximately by the strength of the signals whether or not the other ship is within a short distance.

The line of direction can be used to good advantage when running for a lightship equipped with a radio beacon, provided the precautions outlined previously are observed, namely the angle between the course and the radio beacon should increase for a vessel passing clear.

14. **Cross Bearings**—If a single bearing taken to check the ship's position does not give satisfactory results, due to the angle of bearing, or possible error in noting reading of the direction finder, or figuring dead reckoning or observations, a good reliable fix can be obtained by taking bearings on two or three radio beacons. If unable to pick up more than one radiobeacon, a radio telegraph station can be used, provided such station is on or close to the shore; is not obstructed by intervening land; and its position accurately known. The ship's Radio Operator will again be of assistance in such instances to identify the station being used.

When the morning time sight is taken and a single line of position laid down, another line to cross it can be obtained by taking a radio bearing. The radio bearing should be taken simultaneously with the time sight. If there is any appreciable difference of time between them, due allowance should be made for the speed and course of the vessel, and the distance run. This will obviate the necessity of waiting until the sun changes its bearing sufficiently to obtain another position line which will cross the first at a good angle. This method can, of course, be used at any time of day or night when it is possible to obtain the altitude of a celestial body. Other similar uses of the Radio Direction Finder can be devised by the Master, for instance, in approaching a harbor where it is possible to obtain a bearing of a distant mountain peak, or Lighthouse, another bearing to cross the first can be obtained by radio.

15. **Precautions to be Observed**—Whenever a radio bearing is about to be taken, the wheelsman should be told to stand-by and

call out when the ship is right on the course, for if the ship has yawed off two or three degrees the bearing will be in error by a similar amount. On ships equipped with Direction Finders having a live Gyro repeater, the observer can himself determine when the ship is on the course.

If any doubt exists in the mind of the observer as to the accuracy of the observed bearing, or if the ship is yawing badly due to heavy weather, several readings should be taken and the mean reading used as the correct one.

16. **True and Relative Bearings**—On vessels fitted with Radio Direction Finders equipped with a movable dumb compass card, bearings can be taken either from the meridian or relative to the ship's head. On bearings taken to determine the ship's position, it is suggested that they be taken from the meridian, and if the dumb compass is adjusted to the true course (NOT magnetic) of the vessel, the observed radio bearing is the true bearing. On bearings taken on Lightships or other vessels to determine their position relative to the ship's head, the Direction Finder dumb compass should have its 0–360 mark set on the lubber line. Bearings taken in this manner will give the bearing or angle in degrees from the ship's head. If the angle from the ship's head on the port side of the vessel is desired, the observed reading is subtracted from 360 to give the desired result.

It is again suggested that occasional check bearings be taken when passing radio beacons under conditions of good visibility. Radio bearings should check with pelorus or azimuth compass bearings. Distance from the beacon should be at least two miles. Visual bearings in doubt due to rolling of vessel should be rejected. Such check bearings will serve to assure the Master of the accuracy of the instrument. Whenever any large metal objects are added to or removed from the ship's deck structure the direction finder calibration should be checked, particularly through the arc in which the object is located, and if any unreasonable errors are detected steps can be taken to have same corrected.

17. **Convergency Correction Table for Radio Bearings Laid Down in Mercator Chart**—As radio bearings are true great circle bearings, it is necessary that due allowance be made for chart distortion before they can be plotted by the Navigator from the regular compass rose of a Mercator Chart. A table furnished with each installation will give the required corrections for each degree of latitude from 2 to 70 degrees, and for each one half degree of longitude from 1/2 to 16 degrees. For radio bearings taken at distances under fifty miles these corrections can be neg-

lected, but should be used on all bearings taken at greater distances.

The arguments used in the table to find the correction are the Middle Latitude and Difference of Longitude between the vessel's dead reckoning position and the position of the radio beacon station used. Should the position by dead reckoning differ much from the true position as determined by a first plot, then the retrial, using the new position, is necessary to get the proper correction. The sign of the correction is as follows:

In NORTH latitude when the vessel is $\frac{\text{Eastward}}{\text{Westward}}$ of the radio beacon the correction is $\frac{\text{Subtractive.}}{\text{Additive}}$

In SOUTH latitude when the vessel is $\frac{\text{Eastward}}{\text{Westward}}$ of the radio beacon the correction is $\frac{\text{Additive.}}{\text{Subtractive}}$

Example—A vessel in Lat. 38° 45′ N., Long. 63° 45′ W., by dead reckoning, observes that Nantucket Lightship bears 282 degrees true.

To find the Mercator bearing:

Nantucket Lightship	Lat. 40° 37′ N.,	Long. 69° 37′ W.
D.R. Position	Lat. 38° 45′ N.,	Long. 63° 45′ W.
Middle	Lat. 39° 41′ N.	Diff. Long. 5° 52′ W.

Enter table with Mid. Lat. 40° and Diff. Long. 6°. The correction is found to be 1° 56′ minus (since vessel is in NORTH Latitude and eastward of the station).

Mercator bearing is then radio bearing minus correction, or 282° — 1° 56′ = 280° 04′.

The table is computed from the formula:

$$\text{Tan. correction} = \frac{\text{Tan. Diff. Long. Sine Mid. Lat.}}{2}$$

It may be noted again, as a measure of precaution, that the corrections given in the following table correct only for chart distortion, due to angular error in construction of charts on Mercator projection, and has no relation to error of calibration of the Direction Finder.

18. Elements of Apparatus—*Loop*—The signal from the radio station on which a bearing is to be taken is picked up on the loop above deck. When the plane of the loop is in the direction from which the signal is coming, the signal is maximum. Conversely, the signal received is zero when the plane of the loop is at right angles to the direction of the signal, and the balance properly adjusted. As the loop is turned through 180 degrees, the manner in which the signal changes intensity is shown in figure 358. Thus it is seen that a change of 30 degrees from position 1 to position 2 only changes the signal intensity from 100 percent to 85 percent, whereas the same movement of 30 degrees from position 3 to position 4 changes the signal intensity from 50 percent to zero. Consequently, to obtain accurate bearings, the indicator is set to take readings on the minimum signal.

Indicator: Bearings are read by means of a 7 in. (diameter) movable compass scale, which rotates whenever the handwheel is turned. Further, this compass scale may be moved by hand with the loop in a fixed position so that bearings may be taken from the Meridian so that when the scale is adjusted to the true course (not magnetic) of the vessel, the observed radio bearing is the true bearing. A second scale, permanently locked to the loop drive shaft, is provided as a correction scale and this upper scale is used to apply corrections to the bearing due to errors caused by the ship's hull, rigging, etc. When the d.f. is calibrated this correction scale has marked on it plus or minus figures, which represent the number of degrees to be added or subtracted from the observed bearing.

FIG. 364. RCA Type AR8703 Direction Finder.

Receiver-Amplifier—The receiver-amplifier must function to give a relatively loud signal in order that the minimum may be well defined, and to eliminate other signals or disturbances of whatever sort which otherwise would seriously interfere with obtaining an accurate reading. The superheterodyne receiver ranks highest in accomplishing this, and at the same time with a simplicity of controls. The selection of stations requires the operation of only one tuning control.

19. Stations Available for Taking Bearings—In choosing a station on which to take a bearing, the following limitations should always be considered:

(*a*) A bearing should be avoided which involves a signal that has travelled any appreciable distance along the shore line. In such cases, the line of separation between the water and land acts as a partial reflection, bending the waves and possibly resulting in an erroneous bearing.

(*b*) A bearing taken on a station separated from the ship by intervening land should be considered approximate.

(*c*) A bearing taken on a station more than 150 miles distant should be considered as approximate.

(*d*) On bearings taken shortly before sunrise or after sunset errors due to so-called "night effect" may be observed. These errors are manifested by rapid swinging of the minimum so that the signal stations seem to be changing their positions while bearings are being taken. Bearings observed under such conditions cannot be relied upon. Errors due to "night effect" are usually negligible at distances of less than 100 miles.

There are four classes of stations which are available for taking bearings:

1. Special Radio Fog Signal Stations. A list of these stations, giving locations, characteristic signal, and other data is contained in a chart published by the Department of Commerce, Lighthouse Service, a copy of which is supplied with each new installation. These special Radio Fog Signals should be used wherever available in preference to any other station, for the following reasons:

They have been erected by the U. S. Government and various other governments specifically for navigational aids in connection with radio direction finders.

They emit a characteristic signal which may be readily distinguished by any one without knowledge of the telegraph code.

They are so located on Lightships and Lighthouses that bearings taken will in most cases be entirely over water.

The published positions of these special radio fog signal stations may be depended upon as accurate.

They are operated continuously, by groups, during thick or foggy weather.

2. Radio transmitters associated with the U. S. Naval Radio Compass Stations. A list of these transmitters with their geographical locations is given in the publication "Radio Aids to Navigation."

3. Other commercial and Government radio shore stations.

4. Ships (under way).

To obtain bearings on stations in classes 2, 3 and 4, it will be necessary to call on the Radio Operator to identify the desired station by its radio call letters. When taking bearings on shore stations in class 3, it should be borne in mind that the published locations of such stations are, in many cases, only approximate. Also such stations are likely to be separated from the ship by intervening land, which may cause swinging of the apparent direction of the stations from the true reading. In general, bearings should not be taken on stations in class 3 unless the station used is known to be located directly on the shore.

Airway radiobeacons or broadcasting stations should never be used for bearings.

20. **Operation of Apparatus**—1. Plug telephones in phone jack. Loosen loop lock so that the loop may be turned freely.

2. Turn control switch to the "on" position. If there is a radio room signal and interlock circuit used with the installation, turning the control switch on will close a light circuit in the radio room, which is a signal for the radio operator to close his d.f. switch and at the same time open the main antenna. The relay in the battery box will then close, connecting the "A" battery to the filaments of the tubes. After about 15 seconds which are required for the tubes to heat up, the receiver is ready for use. The small red indicator lamp on the receiver panel will light up when the radio operator has closed his switch. On ships where no radio room control circuits are used the red light should be light as soon as the panel switch is turned on and after 15 seconds the receiver should be "alive."

3. Turn the volume control approximately three-quarters way around toward the right.

4. A beacon signal may now be tuned by rotating the large metal dial in the upper right section of the panel. Carefully tune this control, moving it back and forth over the position for maximum signal to secure the best adjustment. In doing this turn the loop or adjust the volume control so that the signal is not disagreeably loud.

5. Set balance pointer at zero or to that position which is found by practice to be the best point for zero balance.

6. Swing the loop to the arc of minimum signal and back, gradually decreasing the arc of swing until the compass scale marks the weakest signal. Also adjust the balance control back and forth slightly until a still better null or minimum signal is heard. When the correct adjustment is secured, moving either the loop or the balancer slightly in either direction should result in a perceptible increase in signal. If static and other noises are not too loud, keep

the volume control well to the right as the louder the signal the more definite will be the bearing.

7. If the "sense" or general direction of the beacon signal is not known, proceed as follows:

(*a*) Adjust loop and balance in accordance with paragraph 6 above.

(*b*) Then turn the balance control to the extreme left, against the spring which is in the mechanism until the pointer is on the sense position and hold it there. Then turn the loop a few degrees to *lower* readings and then a few degrees toward higher readings. If the signal increase is more when turning toward lower scale readings, the observed bearing is correct. However, if the signal increase is more when the loop is turned toward higher readings, the bearing is 180 degrees in error and the loop should be turned around by this amount and a new bearing taken.

8. To receive continuous wave signals, throw the small toggle switch on the panel marked C.W. This will give a beat note to incoming signals and may be found of value in taking bearings under conditions of noise and interference.

21. Maintenance—The following elements should be inspected at least once each week.

1. Turn on direction finder and determine if operation appears normal.

2. Measure voltage of "B" batteries which should total not less than 70 volts. If voltage drops below this figure the batteries should be renewed. New "B" batteries measure 45 volts each or a total of 90 volts.

3. The storage battery used for the tube filaments is so arranged that when the panel switch is in the off position this battery is on trickle charge. The rate of charge is normally adjusted to provide for average use one hour per 24 hour day. This charging is accomplished by means of a 25 watt lamp in the battery box. If this charging rate is not sufficient to cover more frequent use of the direction finder, a 40 or 50 watt lamp may be substituted for the 25 watt lamp.

Sufficient distilled or (approved) water should be added to the "A" battery once each month to bring the level of solution to 1" of the top of the container. This battery is a special low gravity type of about 1.220 specific gravity when fully charged. This battery is an Exide 3-cell six volt type KZH–7 with 18" leads.

4. A polarized plug and receptacle is provided for the battery box to carry the 110 volt d.c. charging circuit into the box. This plug should always be removed when the vessel goes into dry dock

or layup, as sometimes short lines carrying a.c. or reversed polarity d.c. are connected to the ship's lighting circuits. When the vessel goes in service the polarity of this circuit should be checked to make sure that it is correct. The top or nickel-plated terminal of the receptacle should be positive while the lower or brass terminal is negative.

22. **Spares**—The following spares are supplied with each equipment on installation, and Masters should see that the complement is kept complete aboard.

3 Spare tubes (RCA–76, 77 and 78)
1 Spare pilot light, 6 volt Mazda T–6
6 Spare 3 amp. fuse renewals (for 110 volt circuit)
2 Spare 1 amp. glass fuses (for B battery circuit)
1 Calibration record (sheet 1 of these instructions)

23. **Troubles and Remedies**—1. If the direction finder does not operate see that the relay in the battery box opens and closes when the on-off switch on the panel is actuated. Relay contacts should be clean.

2. See that filament battery reads 6 volts and " B " battery reads not less than 70 volts.

3. Check that all tubes are in their sockets tightly, that the grid clips at the top of the tubes make good connection and are not touching the tube shields, and also check that all tube shields are tight as loose shields will cause noise. Make certain that the 77 and 78 tubes are in their correct sockets (see T–264 top view of chassis).

4. See that brushes and collector rings located in the drive mechanism housing are clean and making good contact. These rings and brushes are silver plated and must not be cleaned with sandpaper or crocus cloth. Use a piece of canvas, or a cloth soaked in alcohol.

5. The " B " battery fuse will blow if troubles occur in the tubes or receiver wiring. If the fuse continues to blow with all tubes removed, it indicates shorts in the wiring.

6. A wiring diagram of the instrument is included in these instructions for which it is possible to check for broken down units, but service at sea is not recommended except in emergencies unless a competent radio operator is available to do the work. Radiomarine service stations with experienced service men are maintained in the principal ports of the United States and may be called for service at any time. The radio operator has the ad-

dresses of the various offices and is authorized to radio in for service where needed.

7. Attention is called to the fact that keeping the equipment clean and dry will prolong its life and usefulness. The loop and other exposed metal parts above deck should be protected by painting at frequent intervals. Care should be taken to keep paint *off* the insulating joint at the top of the loop casing.

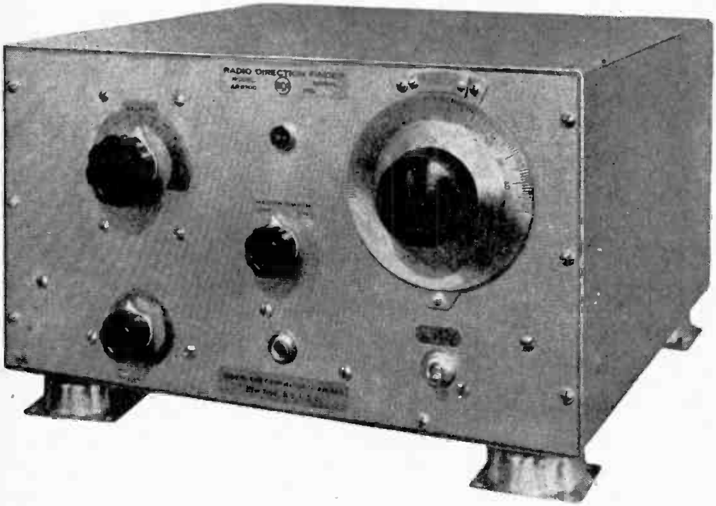

FIG. 365. RCA Model AR8700 Direction Finder.

24. Technical Information on AR–8700 Direction Finder—Refer to diagram T–264 included in these instructions. The receiver covers a range of 270 to 520 kc. Seven tubes are used in the receiver as follows:

RCA–78	R.F. amplifier
RCA–77	First detector
RCA–78	I.F. amplifier
RCA–77	Second detector
RCA–76	Audio amplifier
RCA–77	High frequency oscillator
RCA–76	C.W. oscillator.

It is important to have the tubes placed in their correct sockets to secure proper operation. Refer to T–264 (top view chassis) which shows the relative position of the various tubes and also the i.f. transformers and the i.f. oscillator transformer.

The diameter of the loop is 23 1/4″ and is intended for mounting directly on the deck. A special pedestal can, however, be furnished when it is necessary to elevate the loop to clear railing or other metallic objects near the loop. When mounted directly on the deck the height of the loop above deck is 28″. The deck flange is 7″ in diameter and should be used with a 9″ diameter wood crib about 1″ thick. Maximum permissible deck thickness is 3 5/8″. The handwheel diameter is 9″ and the weight of the complete loop assembly is 35 pounds. Correction for quadrantal error due to the ship's hull, stays, etc., is accomplished by means of a correction scale, which is directly over the compass scale. After the d.f. has been calibrated and the usual calibration curve drawn, corrections may be marked in pencil or ink, preferably the latter, every five degrees on the removable paper scale which is provided. This paper scale is then replaced on the upper drum, taking care to locate it accurately with respect to the lubber line. In all cases the loop should be rotated when calibrating so that no correction is required for a true dead ahead bearing.

The loop proper consists of an aluminum casting with an insulated joint at the top and a removable cover plate around the circumference, which is held against the main assembly by means of flat head screws with rubber gaskets underneath to exclude moisture. This cover plate should never be removed during installation unless it is necessary to replace the loop winding or to connect new leads from the loop to the collector rings. The midtap of the loop is grounded through a separate collector ring and no midtap condenser is used.

The radio receiver is in a cabinet 14″ wide, 14 1/2″ deep and 9″ high and may be mounted underneath the drive wheel or slightly to one side provided the connections between the loop and the receiver are not too long. The loop leads to the receiver should be run inside flexible brass tubing with the two leads spaced every few inches by means of suitable insulating spacers. The ground connection may be carried through the brass tubing. The weight of the receiver is 30 pounds.

A six volt compass scale light is provided in the loop housing and one lead is brought out above the split lock bushing on drive assembly and connects to terminal 7 on receiver. The other side of this compass light circuit is carried through ground.

The total 90 volt "B" battery drain with full volume is approximately 10 milliamperes and with half volume about 7 milliamperes. The seven tubes in the receiver require a heater current at six volts of 2.1 amperes, while the additional load due to the compass light and the panel lead brings the total "A" battery drain to approximately 3 amperes.

Tuning of the receiver is accomplished by means of a four section condenser ganged on a common shaft. The first section nearest the panel (400 mmfd.) tunes the sense antenna circuit. The next section (400 mmfd.) tunes the high frequency oscillator. The third section (400 mmfd.) tunes the r.f. amplifier plate. The fourth section is connected to the three section unit through a flexible coupling, has a capacity of (800 mmfd.) and has both rotor and stator insulated from ground. This fourth section tunes the loop.

Airdielectric trimmers are used throughout the receiver so that they will hold their adjustment under conditions of changing temperature and humidity. Two 100 mmfd. units connected in parallel are used to adjust the sense antenna. Two similar units also in parallel are used to trim the high frequency oscillator circuit. Another 100 mmfd. unit is connected in parallel to the main loop condenser and is used to trim the loop circuit. There are two intermediate frequency transformer units also with airdielectric condensers and these are carefully tuned at the factory to the intermediate frequency of 175 kc. The i.f. transformer unit used for C.W. is provided with a knob at the top so that the pitch of the beat note may be adjusted if desired. Service men and operators are warned not to change the adjustments of the high frequency oscillator trimmers or the intermediate frequency transformers unless an accurate oscillator is available for line-up.

The adjustment of the sense antenna trimmer condensers is not very critical and is made as follows. Tune in a signal in the beacon band. Rotate the loop for minimum signal and leave it in that position. Short circuit the 500 ohm sense resistor, then, holding the balancer knob to the sense position, adjust either or both of the sense trimmer condensers for maximum signal. Remove the short from the 500 ohm resistor which completes the adjustment. The sense trimmers and the sense antenna post are located in the extreme left rear of the chassis.

The receiver circuits are designed for normal line-up on a 300 kc. signal with the main tuning dial set at 35. Under these conditions the loop trimmer condenser and the r.f. oscillator trimmer condensers are adjusted for maximum signal. When these adjustments are being made the volume control should be turned so that the incoming signal is not too loud. Usually it will not be

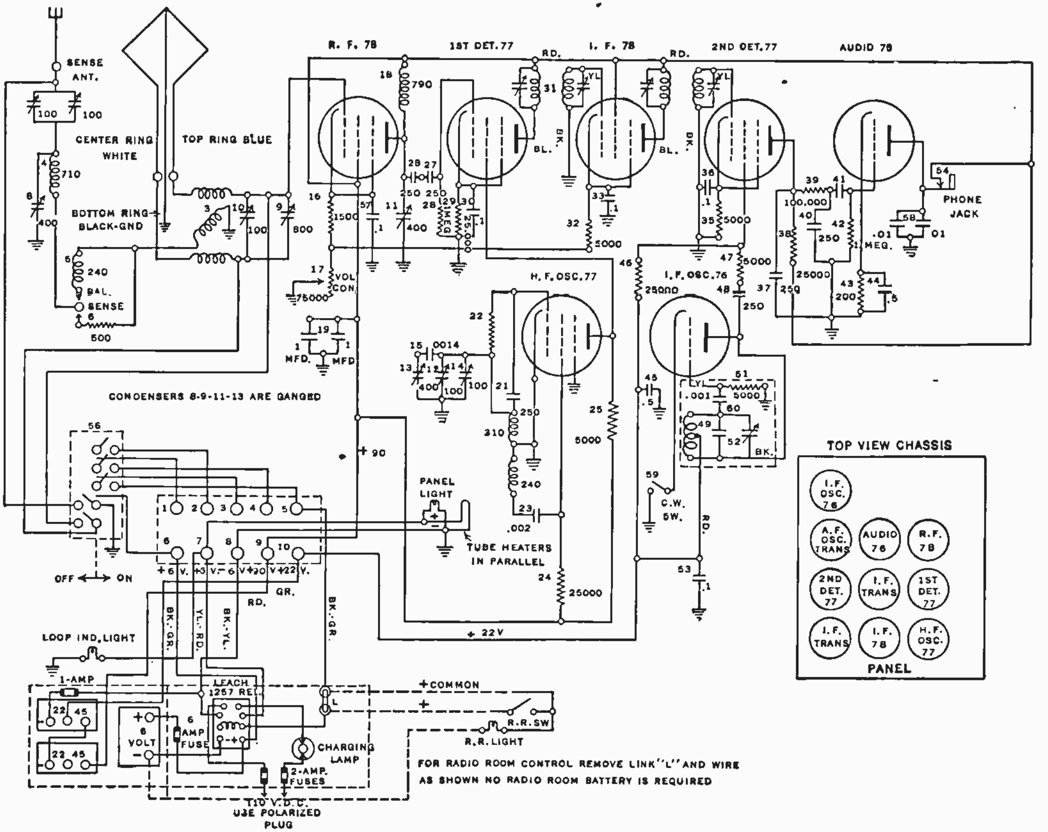

FIG. 366. AR8700 Direction Finder, Radiomarine Corp. of America.

necessary to adjust the oscillator trimmers unless these have been disturbed. If it is desired to line up the loop and oscillator circuits on beacon signals of other frequencies, then the main tuning dial should be set to the scale reading shown on the following tabulation. For example if the d.f. is being lined up on Ambrose Lightship or 286 kc., the main tuning dial should be set at 27.5. *Line up points using marine beacons:*

Frequency	Set Tuning Dial at:
284	26
286	27.5
288	28.5
290	29.5
292	30.5
294	31.5
296	32.5
298	34
300	35
302	36
304	37
306	38
308	39
310	40
312	41
314	42
316	43

Other calibrations (not for line up purposes)

270 kc.	17
330	49
350	56
400	70
450	80
500	88

25. **General**—It is not recommended that airway beacons be used for line up unless no other signals are available since better performance is obtained if the line up is made in the marine beacon band of 285 to 315 kc.

If it is found that the loop trimmer condenser does not go through a well defined maximum, it is permissible to displace the main loop condenser on the drive shaft provided the following instructions are carefully followed. Set the main tuning dial at a line up point as explained above and adjust the two high frequency oscillator trimmers for maximum. Leave the tuning dial fixed. Turn the loop trimmer condenser so that it is about half way in. Then loosen the screw on the flexible coupling which is *nearest* the three section condenser. Then taking care not to touch the loop condenser with the hand, it may be rotated slightly by turning the Isolantite coupling for maximum signal. The lock screw on the coupling should then be carefully tightened.

When adjusting the various air trimmers, care should be taken not to turn them too hard, which may cause the hot terminal coming out of the top of each trimmer to ground against the aluminum case. The clearance here is small and may sometimes cause the receiver to go dead if these small terminals become bent and touch the casing.

A special insulated socket wrench should be used in making all trimmer adjustments on the AR–8700.

As outlined previously the i.f. transformer adjustments must not be disturbed. If one transformer becomes defective and needs to be replaced, it may be lined up on an incoming signal so long as the other transformer adjustments have not been disturbed. However, it is best to use an accurate 175 kc. modulated oscillator. Line up for i.f. is done as follows. Remove the grid clip from the high frequency oscillator tube, RCA–77. Connect the output of the 175 kc. test oscillator between ground and the grid terminal of the first detector. The two trimmer condensers on each i.f. transformer are then adjusted for maximum output, taking care to use low volume so that a maximum may be easily observed in the head phones. One trimmer condenser in each i.f. transformer has plus 90 volts on its adjusting screw and only the insulated socket wrench should be used in making these adjustments. No d.c. voltages, however, are present on the sense, loop or high frequency oscillator condensers.

The battery box supplied with the equipment is 10″ wide, 20″ deep and 10 1/4″ high. The weight complete with batteries is 68 pounds. A Leach double pole double throw relay, type 1257, with a six volt d.c. coil is mounted in the battery box to transfer the six volt "A" battery from charge to discharge. The battery is trickle charged through a 25 watt lamp when the relay coil is not energized. When the panel switch on the D.T. is thrown to the "on" position, the relay is energized, which connects the six volt "A" battery to the receiver filaments.

The capacity, resistance and inductance values of all component units in the receiver are shown on T–264. This information is of value when running down trouble in the receiver. In order to test for open inductances in the receiver the following resistance values of the various coils are given.

26. D.C. Resistance Values—

Item 3. Balance rotator 1.35 ohms.
Item 3. Balancer stator (each) 1.6 ohms.
Item 4. 710 Microhenry balance load coil 5.2 ohms.
Item 5. 250 Microhenry sense load coil 2.7 ohms.
Item 18. 790 Microhenry r.f. amp plate coil 5.5 ohms.
Item 20. 310 Microhenry oscillator grid coil 3.3 ohms.
Item 20. 240 Microhenry oscillator plate coil 2.7 ohms.
Item 31. 9 Millihenry i.f. transformer coil (each) 37 ohms.
Item 34. Same as item 31.

Note—When checking sense and loop circuits, bear in mind that " on-off " switch, in the " off " position, grounds sense antenna and short circuits the loop tuning circuits.

Telephone receivers used with this direction finder carry the d.c. plate current of the 76 audio amplifier stage. The tip of the phone jack is connected to plus 90 volts so that the sleeve which projects through the panel is dead when the phones are not plugged in. Correct polarity should be used on the phone cords to prevent the magnets from becoming demagnetized. When Western Electric 2000 ohm phones are used, the lead with the green tracer should be connected to the tip of the phone plug. If Trimm head phones are used the phone plug tip should be connected to the red tracer.

Kolster Radio Direction Finder (Radio Compass) Type 105

Federal Telegraph Company

Introduction—The Kolster Radio Direction Finder described herein is the culmination of many years of scientific development by its inventor, Frederick A. Kolster. Throughout it represents a major improvement over direction finders heretofore available.

It is suitable for use both on land and on ships at sea. It is designed for accuracy, sensitivity and selectivity along with simplicity of operation. Constructed in a rugged and substantial manner with the use of non-magnetic materials wherever possible, it provides the utmost in reliability and convenience.

27. **Description**—The Kolster Radio Direction Finder Type 105 embraces many refinements and features not found in earlier types. It is a binnacle type unit designed for installation in the chart room or pilot house. The rotatable loop enclosed in a water-

tight housing is mounted on the upper deck. Radio signals picked up by the loop are transmitted to the receiver mounted in the binnacle located in the pilot house or chart room. The handwheel for rotating the loop is mounted on the 45° sloping top of the binnacle. The Kolster Full-Vision Dial Indicator on which the ship's bearing is shown is located inside the rim of the handwheel. In the lower portion of the binnacle is located a neat and compact compartment containing batteries and charging switch.

28. **Loop**—Practical experience and tests under actual marine conditions have contributed many noteworthy improvements found in Kolster design. The loop is streamlined and is readily controlled in heavy weather and high winds. It rotates on ball bearings with a lower sleeve bearing to eliminate side play. An adjustable brake mounted at the top of the binnacle allows complete control under adverse weather conditions. Mounted on the upper deck, the base of the loop projects normally about six inches above the conventional hand rail. The entire loop assembly consisting of the loop and mounting stem is self-supporting and the center of gravity has been placed at a low point so that in case of excessive vibration of the vessel the assembly will not tend to oscillate like a pendulum.

The loop housing and bearings are carefully weather-proofed to prevent entrance of moisture into the direction finder structure.

29. **Compensator**—The compensator is an ingenious mechanical device which automatically corrects the natural errors in radio bearings caused by the influence of the ship's hull and rigging. It is the most rugged and simple of any yet constructed. Absolutely no correction by the navigator for radio deviations is required. The pointer showing the loop bearing leads or lags behind the actual loop position to compensate for radio errors noted when calibrated at time of installation. No change in compensation, therefore, is made once installed, and unless a change is made in structure or stay arrangements on the vessel, re-calibration to eliminate error is never required.

30. **Full-vision Indicator Dial**—Bearings are taken with simplicity, speed and above all with remarkable accuracy. As shown in the illustration the Kolster Full-Vision Indicator Dial faces the operator at a convenient angle of 45 degrees below eye level. It shows the figure of a ship at its center thereby enabling the navigator to visualize the bearings obtained at a glance.

Bearings are read in degrees. A movable outer scale or Ritchie Ring divided into 360° is provided for obtaining true bearings. This movable scale is designed for operation by a Sperry Repeater motor and thus maintains the true course reading at all times. "Off bow" bearings may be taken from the inner stationary scale. The long pointer indicates the bearings on the scale while the short pointer is used in conjunction with the sense button on the receiver to remove the 180° ambiguity from the pointer readings.

The entire mechanism is heavily and ruggedly constructed to avoid possible damage. The dial and pointer are protected by a glass cover.

31. **Receiver**—Accurate bearings may be taken at greater distances than heretofore possible. The circuit is designed to provide maximum selectivity and extreme sensitivity. It covers a tuning range of 540 to 250 kilocycles (550–1200 meters) and will receive both CW (continuous waves) or ICW (interrupted continuous waves).

Stations are tuned in with a single control or "Station Selector." The tuning scale conveniently indicates the allocation of radio beacons, navy compass stations and ship stations. The "Intensity Control" and "Balancing Control" regulate incoming signal strength. The "Sense (Uni-directional) Button" for locating unknown stations and the "CW–ICW" switch are the only additional controls and serve to combine ease of operation with maximum efficiency.

A panel lamp is provided for illuminating the receiver panel.

Careful shielding of individual units in the receiver in addition to complete shielding of the receiver cabinet frees the installation from stray signal pick-up and removes couplings which may affect the accuracy of the bearings.

The receiver employs eight heater type tubes.

32. **Loud Speaker**—A loud speaker is mounted inside the top of the binnacle and is provided with a hinged cover which serves as a reflector to direct the sound toward the operator. A compartment with hinged cover is also provided at the top of the binnacle to house the headphones when not in use.

33. **Batteries**—These consist of a standard six volt storage battery and two 45 volt dry batteries which are hidden in the compartment previously mentioned. By means of a switch accessible from the outside of the compartment, the battery is connected either to the receiver or to the ship's mains for charging. The amount of current is regulated by the external charger which is also part of the equipment.

34. **Installation**—The antenna switch located in the radio room insures that the ship's main antenna is "open" when bearings are taken. Signal lights on the base of this switch and on the

receiver panel indicate when the antenna switch is "open." A relay installed in the receiver grounds it when not in use to prevent damage to the instrument from the ship transmitter. This relay is controlled by the antenna switch in the radio room and prevents bearings being taken while the ship's antenna is connected to the radio transmitter or receiver.

The Kolster Radio Direction Finder is installed in either the pilot house or chart house depending upon the arrangement desired and the space available.

CHAPTER 14

APPLICATION AND USE OF RADIO AIDS TO AIR NAVIGATION

Part 1. General Principles

Marked progress has been made in the last few years in the application of radio as an aid to air navigation. A radio beacon system of today includes (*a*) the main beam, (*b*) sending a beam along the course to be flown, airway radio obstruction marker and (*c*) airport marker. In addition, progress has been made in the application of (*d*) radio landing systems developed to assist airplanes in making safe landings under conditions of zero visibility. Such a ("blind landing") system requires three elements, a runway beacon, marker beacons and a landing beam, thereby providing the pilot with continuous and accurate information on the position of his ship (in three dimensions) as it approaches and reaches the instant of landing. The development of apparatus and tubes capable of efficient operation in the ultra-high frequency bands has greatly accelerated experiments with blind landing systems. The " main beam or radio range (*a*) is intended for use by aircraft with non-directional receivers. Instead it is possible to use (*e*) directional receivers in aircraft somewhat as loops or "radio compasses" are sometimes carried aboard ship, as was discussed in Chapter 13. The aircraft may then triangulate on several radio stations for position or may "home" toward one station. The station need not have a directional transmitter. For example a broadcast station might be useful.

1. **Directive Radio Range Beacon**—The directive radio beacon transmitter is a special kind of radio station, usually located at an airport, just off the landing field. Instead of having a single antenna, it has two directional antenna structures. The course indication is secured (Fig. 367–A) by the intersection of two space patterns produced by these antennas properly excited. In order that this pattern remain fixed in space, the relations between the currents in the various structures must be maintained constant, both as to phase and magnitude, to a high degree of accuracy. This action is secured in one of two ways, first by the use of transmission lines 90 electrical degrees in length connected in parallel

to the power amplifiers, and second by lines 180 degrees long connected in series. Tests of the system show it to perform very satisfactorily and it has been adopted as the standard method of installation on the government airways (figure 367–B).

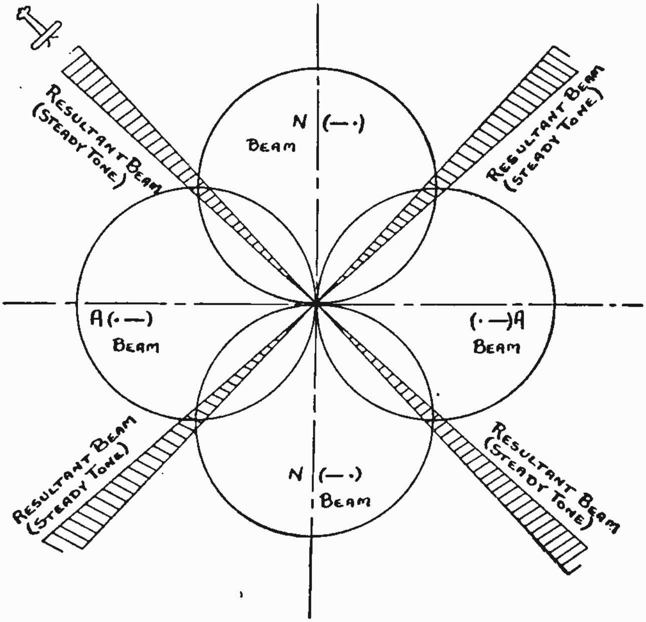

FIG. 367, A. Field Intensity Diagram Radio Range Beacon. Planes flying along any of the four paths receive continuous signal except when NA signal is interrupted to permit station to sign its call.

Referring to the field intensity diagram of figure 367–A if one antenna is energized by the modulated International Code signal A (.—) and the other by N (—.) a pilot flying any one of the four courses indicated by the hatched lines, will receive (*with an ordinary receiver*) equal signal from the antennas transmitting A and N and the two signals will blend into a continuous dash. If however, the ship deviates from the course a stronger A or N signal will be received, the strongest signal indicating to which side of the course the ship has drifted.

Recent developments permit of simultaneous transmission of weather reports from the same antennas.

2. **Squeezed and Bent Courses**—It is often desirable to have the courses arranged so that they pass over airways which are not located at 90° or 180° to one another. This is accomplished by antenna and tuning arrangements at the beacon transmitter. Figure 379 shows a radio range in which a bend has been made, the northerly course having been bent to the northwest. Figure 380 shows the characteristics of a radio range in which the courses have been squeezed but not bent. In both cases the symmetrical figure-of-eight pattern has been altered by the antenna and tuning arrangements so as to produce the course required.

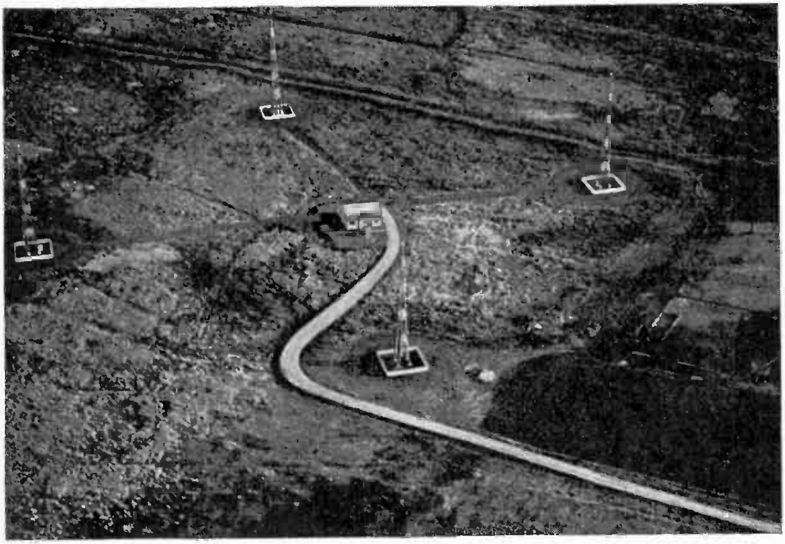

Fig. 367, B. Radio Range Antenna Arrangement.

Figure 381 shows the field pattern of a radio range which has been squeezed and a problem of orientation when flying such a course is described subsequently. It will be noted that the power in the antenna of the "A" towers has been reduced to approximately one-half of its previous amplitude, which means that the radial distance at which the radio range can be successfully received in the "A" quadrants will be less than that in the "N" quadrants.

3. **Multiple Courses**—Multiple courses are known to exist

on radio ranges. They may be due to several causes which are explained in detail later in the text.

4. **Cone of Silence**—Directly above the radio range beacons there is a space during which no signal is heard from the station. This zone of no signal is referred to as the cone of silence. Approaching the cone of silence the signal builds up with marked intensity and suddenly disappears and as the outer boundary of the cone is reached the signal appears again with marked intensity.

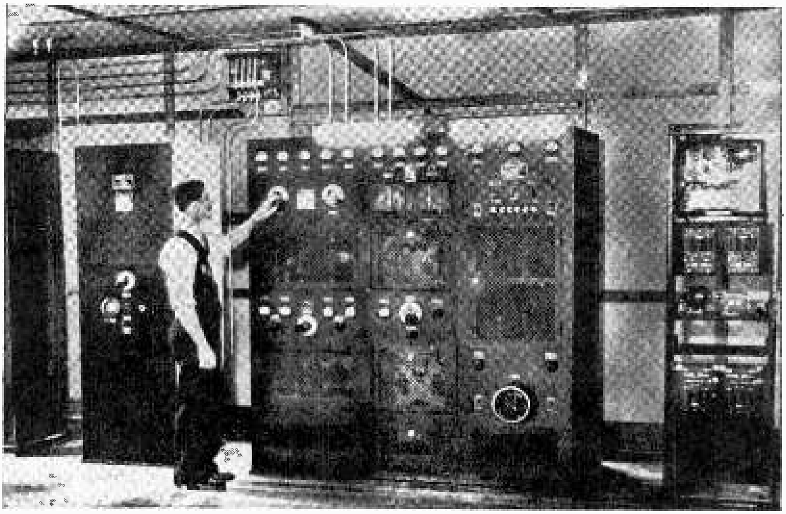

FIG. 367, C. Broadcast and Range Transmitter.

5. **Cone of Silence Marker**—A cone of silence marker operates similar to a beacon marker by providing radiation in a vertical direction of the radio range beacon and thereby serves to locate the station by a positive check of maximum signal which builds up very rapidly just over the top of the station and fades out immediately after leaving the station. It is superior to the cone of silence method which is a negative rather than a positive check on the location of the station. A separate receiver is required for the marker and it may be equipped to give a visual indication.

6. **False Cones of Silence**—The terrain over which an aircraft flies influences the signal of a radio range beacon to the extent that a small fade or build-up will give the impression of

a cone of silence. As for instance, when passing over the far rim of a canyon the signal may drop below inaudibility for a short period. This is known as a false cone of silence. Usually the signal surges before and after these false cones are not pronounced and do not require readjustments of the volume control of the receiver as required when the abrupt build-up occurs when near the real cone of silence.

When thé normal receiving antenna is employed the false cone of silence will usually be more pronounced in passing over a canyon in a direction heading way from the station and at right angles to the direction of the canyon, that is, when crossing it. At night when passing the position of the false cone of silence observed during daylight, it will be fairly well filled by sky wave so that it is far less pronounced.

True cones of silence above a radio range station will exhibit decreasing surges with increase of altitude and the cone of silence itself will last for a longer period.

Usually, when "homing" (see section 10) with the loop's plane at right angles the station's position will be indicated by the fact that when the plane is about a quarter of a mile from the station, a definite surge and impossibility of maintaining a null will indicate the approach. This applies generally to approaches at altitudes from 200 to 3000 feet above the station. After passing over the cone of silence and at about a quarter of a mile beyond the station the null may be again obtained. As a positive check on the cone, another receiver may be used. On this other receiver, the cone of silence will sound just like any other normal cone regardless of the direction of crossing the station.

7. Maneuvering for a Landing—The procedure followed by a pilot after flying over a cone of silence of the airport range beacon at which he is to land differs between airports and each airport has an approved approach method. Generally the procedure consists of turning the airplane for an approach to the airport or in going in on another leg of the beacon and returning again over the cone of silence for an approach.

8. Visual Indicators—The Bureau of Standards has experimented with a number of visual indicator systems. Such a system involves the use of two steady tone modulation frequencies (instead of the A and N keying) at the radio beacon transmitter and thereby permits the use of continuously indicating instruments on the airplane. If the airplane gets off to one side of the course, the intensity of one of the modulated waves will increase and the other decrease, owing to the directive nature of the beacon.

It is required that a device be used in connection with *one* receiving set on the airplane which will give a visual indication of the relative amounts of the two modulated waves. This requires some form of tuning to these two modulation frequencies. In several devices tried, the tuning was secured by means of tuned circuits attached to the output of the receiving set. Modulation frequencies of 500 and 1000 cycles were used.

9. Types of Visual Indicators—One form of indicator consisted of a pair of neon glow lamps. One of these was in each tuned circuit. They were so adjusted as to just light up when the airplane was on the course and they received equal voltage. Because of their critical response voltage, they gave a rather sharp indication when the voltage of either tuned circuit dropped. In another form of indicator the two tuned circuits were connected differentially to a rectifier and direct current galvanometer. When the airplane was on the course and currents are the same in the two tuned circuits, the d.c. outputs balanced and the galvanometer needle remained in the center of the scale. For deviation to either side the galvanometer needle moved correspondingly. These forms of indicator were found too critical and too complicated for practical use. A third form consists of two steel reeds, tuned to 65 cycles and 85 cycles which are the modulating frequencies in this system. The vibration of the reeds gives the visual indication and they themselves provide the necessary tuning to the two modulation frequencies. The indicator is very simple and practical, merely being connected to the receiving set in place of telephone receivers. When the beacon signal is received the two reeds vibrate. The tips of the reeds are white, with a dark background behind them, so that when vibrating they appear as a vertical white line. The reed on the pilot's left is tuned to a frequency of 85 cycles and the one on the right to 65 cycles. It is only necessary for the pilot to watch the two white lines produced by the vibrating reeds. If they are equal in length, he is on his correct course. If the one on his right becomes longer than the other, the airplane has drifted off the course to the right (into the region where there is more of the 65 cycles). If he drifts off the course to the left, the white line on the left becomes longer.

10. Directional Aircraft Receivers—When not flying a course marked by radio "range" beams such as just described, or as an auxiliary to such a range system it is useful to equip the plane as suggested under (*e*) in the first paragraph of this chapter, that is with a directional receiver. It is then not necessary that the transmitter on the ground be directional. Early forms of this idea employed large loop antennas wound on the wings and vertical struts of biplanes, the intention being to fly directly toward the radio station (" homing ") by keeping the plane turned so as to receive the strongest signal (if the loop was fore and aft) or by working for the weakest signal (if the loop was thwartship). The first scheme gives strong signals but the direction is indefinite, the second is sharper but may encounter signal deficiency. Consequently some systems avoid both of these loop positions. In the Simon Radioguide two loops are used, one turned somewhat to the right, the other somewhat to the left. Both then receive adequate signals while " homing "; also it becomes possible by means of a double receiver to apply the output of the tube coils to a balanced indicating meter whose pointer stays at center scale if on course but deflects if the ship is turned so that one loop receives more signal.

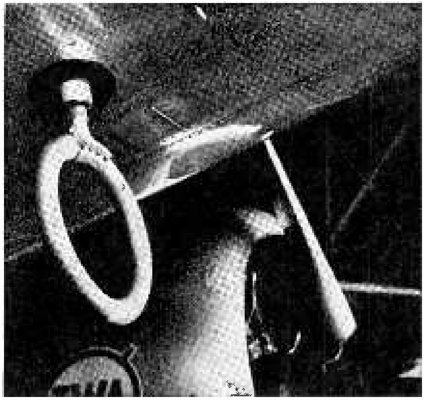

FIG. 368. TWA Rotatable Loop Antenna on Aircraft (See Section 10).

As in marine practice the loop may be a single one capable of rotation but the construction of the loop is more difficult because of the small size permissible at high speeds and the immediate proximity to a large mass of metal, tending to produce serious errors of indicated direction. Figure 368 shows a practical rotatable loop as used on transports of Transcontinental and Western Air Incorporated while figure 369 shows the associated indicator whose non-uniform scale is a method of correcting the directional error and making possible useful bearings on radio stations whose frequency is such that they can be tuned in. By taking bearings on several stations a position "fix" is obtained as in marine practice or the equipment may simply be used for "homing." This is discussed in detail in the latter part of this chapter.

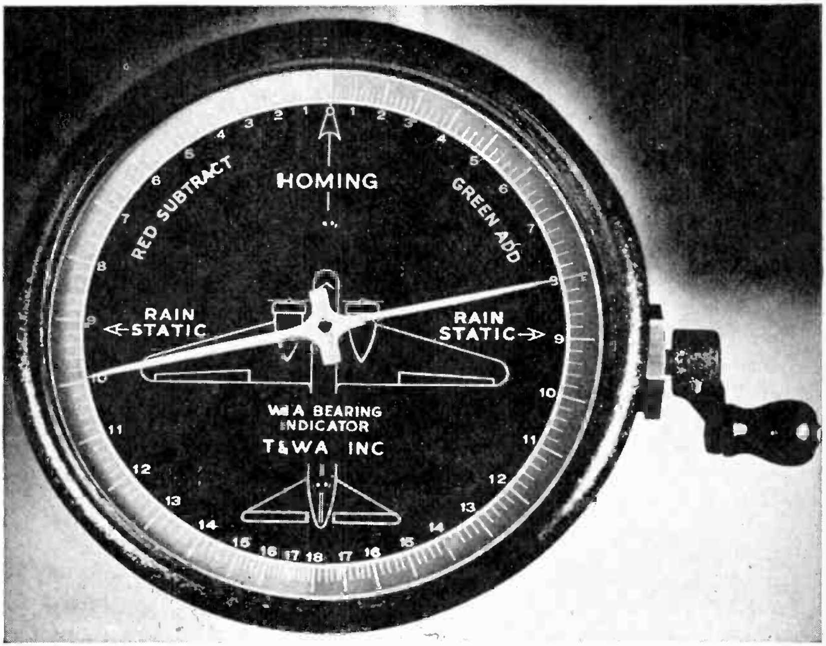

Fig. 369. TWA Radio Bearing Indicator (See Section 10).

11. **Radio Direction Finders on Aircraft**—Radio Direction finders are used on aircraft to determine accurately the position of the plane at any time whether on or off an established airway. Like on the ship the device consists of a rotating loop and a radio receiver. The loop is mounted pivotally on the outside of the fuselage with provisions to rotate it manually from the cockpit either directly or by remote control. On the rotating mechanism a pointer is provided to swing over a stationary dial graduated in degrees from 0° to 360°. This pointer and dial show the angular difference between the airplane's heading and the plane of the loop. When the pointer is at 0° or 180° the plane of the loop is at right angles to the line of flight. The loop exhibits the usual figure-of-eight characteristics, and when in this position no signal

is heard (a null) from a station directly over the nose or tail of the plane. With the loop in this position and the pointer at 0°, the front of the loop is toward the nose and the back of the loop is toward the tail.

12. **Reciprocal Bearings**—Since the loop will produce two nulls with either the front or back of the loop a bearing will always have a reciprocal of the true bearing. In other words, the two nulls should be 180 degrees apart (see chapter 13). As in the marine direction finder this 180 degree ambiguity is removed by connecting a vertical antenna by a switch to the loop antenna. When this switch is thrown to the "sense" position after first obtaining a null, the signal will immediately gain in strength. The plane (or loop) is rotated clockwise, for example, if the signal further increases, the front of the loop is being used. Direction finders have a notation on them such as "On sense position clockwise loop rotation gives signal increase when loop front is being used."

Practical Use of Radio Aids to Air Navigation—The preceding text in this Chapter has described the equipment and the principles and characteristics of operation of radio beacons and aircraft beacon receivers rather than its use. To assist the student pilot and radio operator in the practical use of radio aids to air navigation the following material is taken by permission from the navigation courses of Transcontinental and Western Air, Inc., operators of a major air transport corporation. At the conclusion of the Chapter there will be found a series of questions typical of an examination given pilots at the termination of their study of the navigation courses. The answers to the questions can be found in the text of this Chapter.

Part II. Radio Navigational Devices

13. **Fixed Loop Mounted on a Plane**—Assume that a loop is mounted on an airplane so that its plane is *coincident to the line of flight*. From the above discussion it will be seen that stations directly in the line of flight, either ahead or astern, will be heard best. Stations to the right and left will be heard weakly, and stations exactly at right angles to the line of flight will be barely audible at full volume control position.

Suppose that it is desired to find the position of an airplane by use of this loop. The plane is enroute from Kansas City to Chicago (figure 370). First Kansas City is tuned in and the plane is then at right angles to the plane's heading at that moment (*A* in figure 370).

Next Columbia is tuned in and the plane turned slowly to the left so that the minimum signal is heard from that station (*B* in figure 370).

At position *A* the bearing of Kansas City is at right angles to the plane's heading at that moment. At position *B* the station at Columbia is at right angles to the plane's heading and its bearing can be easily determined. Knowing these two bearings, it is only necessary to set off the reciprocal for Kansas City and Columbia and the position of the plane can then be closely determined. It might be said at this point, that with almost no practice it is possible to determine minimum signal strength by ear with an accuracy of about 3 degrees or better when using a good loop.

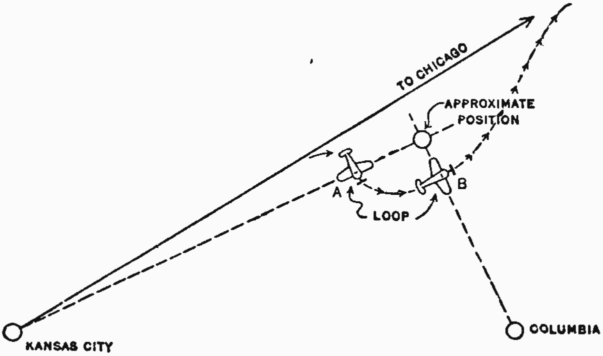

FIG. 370. Finding Position by Use of Radio Loop.

It should also be noted that two bearings may be taken, one minimum bearing off the left wing and the other off the right wing, resulting in a 180° ambiguity; however with a magnetic compass in the plane and the approximate position known, this should cause little confusion. If three stations are used there is almost no possibility of ambiguity since the pattern of the bearings when plotted on a map will show any mistake. For operation of a fixed loop mounted so that its plane is at right angles to the longitudinal axis of the airplane bearings are taken in the same way but over the *nose or tail,* instead of on the plane's beam. This *must* be borne in mind. Although a loop mounted in this way for aural direction finding is rare, nevertheless this is a possible arrangement.

14. Operation of a Rotatable Loop—(Marine use of such loops is discussed in Chapter 13.) The application and operation of a single fixed loop to obtain a position has been explained. However, instead of turning the airplane to the right or left to take a bearing on an off-course station, it can be seen that if the loop were rotatable and there were a pointer and a suitable dial, marked in degrees, it would be possible to hold the ship on its course and, by rotating the loop, secure a bearing on any station or the angular direction of the station from the plane's head. This bearing may be applied to the true heading of the plane to get a true bearing of the station from the plane. The reciprocal may then be taken, thus securing the bearing of the plane from the station. A line drawn on a map from the station will give a line of position somewhere along which the plane *was located* at the time the bearing was taken.

Similarly, as visual bearings, if a bearing is taken on a second station and another line of position plotted, a definite 'fix' would have been obtained.

In order to obtain this desirable feature it is necessary to mount the loop pivotally on the outside of the fuselage with provisions to rotate it manually from the cockpit either directly or by remote control (see figures 368 and 369). On the rotating mechanism there must be a pointer swinging over a stationary dial graduated in degrees from 0° to 360°. This pointer and dial show the angular difference between the airplane's heading and the plane of the loop.

With the pointer at 0° or 180° the plane of the loop is at right angles to the line of flight. In this position there would be no signal in the headphones (a null) when tuned to a station directly over the nose or tail. With the loop in this position and the pointer at 0°, the front of the loop is toward the nose and the back of the loop is toward the tail.

It will be remembered that a null can be found on any station with either the front or back of the loop. These bearings will, of course, be reciprocals. It will thus be seen that there is always the possibility of 180° ambiguity in bearings taken with a rotatable loop, just as there was with the fixed loop previously discussed.

With a plane equipped as above it is possible to determine the direction of a radio range station whether the plane is in an 'A' quadrant an 'N' quadrant, on an on-course signal or during a weather broadcast, but always with the possibility of 180° ambiguity.

With a plane equipped as above, if it is desired to fly a radio range course in the normal manner it is only necessary to turn the loop until the pointer is at 90° left, 90° right, or where graduated from 0° to 360°, at 270°. This places the plane of the loop in the line of flight, in which position it will produce maximum signal strength from stations *ahead* or *astern.*

15. **Homing and Orientation**—The term "homing" is known as flying with a direction finder or radio compass from any point to a transmitting station in as direct a line as possible.

The plane is flown to keep its heading toward the home station without rotating the loop.

To home with a loop, it is so placed that its plane is at right angles to the longitudinal axis of the airplane. The plane is then turned to secure a null and is now heading directly toward—or directly away from—the station. The course is set on the gyro, and maintained for a short period. The signal may be received on the straight antenna during this period to determine whether the signal is building up or decreasing. If building up, the plane is being headed *for* the station and a null in the headphones is maintained using the loop.

With a loop, the cone of silence of a radio range station may not be heard, so that this should be listened for on another receiver employing a straight antenna or by means of a positive cone of silence marker.

Orientation from any point in the vicinity of a range station may be accomplished in this manner much more rapidly than working the conventional orientation problem.

The effect of wind upon homing is a self-evident fact. A plane being homed on a station to the east of its position will, with a north cross wind, follow a course not directly to the station on the great circle course but a course curving southward. In this condition the plane will always be headed for the station but will finally arrive there on a northeasterly bearing.

It should be evident that care must be taken in homing on a radio range leg because the plane, being subject to the effect of wind, could easily be blown over to the wrong side of the airway. The direction finder does not lay out a highway which is fixed, so that keeping to the right is an impossibility.

If an attempt were made to take a bearing with the loop in the position of maximum signal strength rather than a null it would be found that the bluntness of the figure-of-eight pattern would make it almost impossible to find a point where the signals were at a maximum.

If a loop is properly shielded it will cause no error in the reception of radio beacon signals or in the taking of bearings, and will reduce rain, snow and sand static, allowing the use of the receiver when impossible with the ordinary antenna.

16. Use of the Rotatable Loop as a Navigation Aid—With the general principles of rotatable loops or direction finders in mind, the methods to be used in practice will now be taken up.

First it might be well to examine features such as dial graduations and deviation errors. The latter will be explained more fully in a general discussion of errors. It is sufficient here to state that the direction finding loop is subject to deviation errors but that in the following discussion, for simplicity, it will be assumed that this error is non-existent.

As previously suggested, dials for showing the position of the front of the loop with respect to the plane's longitudinal axis may be graduated and arranged in a number of ways. These may be 0° to 360°—0° to 180° on either side of the center line—or a combination of the two. In the case where the graduations are 0° to 180° the right hand semicircle sometimes has a green background and the left, red.

There has been no standardization as yet, so for the example herein the arrangement of 0° to 180° on either side of the center line with the right semicircle green, the left red, has been adopted since this system of arc graduation and coloring is very practicable. Bearings to the starboard (right) are green, those to the port (left) are red.

17. Relative Bearings—The NACA definition is as follows: "*Relative Bearing* is the direction of an object expressed as an angle with relation to the heading of an aircraft. It may be measured either clockwise, in degrees, from the aircraft's heading, or from 0° to 180° left or right from the aircraft's heading."

To obtain a bearing of an object from an aircraft with relation to true North, from a relative bearing, it is necessary to *add a right relative* (*green*) and *subtract a left relative* (*red*) from the aircraft's true heading. Figure 371 further illustrates this explanation of relative bearings.

A bearing is taken aurally with a direction finding rotatable loop by rotating the front side of the loop toward the station until the signal emanating from that station fades to a minimum. This minimum signal is then called a null. Depending upon the type of loop used, and the distance away from the station, the accuracy of detection of the null may vary from 2° to 30° in width. In every case, the relative bearing is the mean of this width, regardless of the width of the null. In other words, suppose that in taking a relative bearing, the signal fades out at 30° and is picked up again at 40°; the null is then 10° wide and the relative bearing (not a true bearing) would be the mean of the two readings which is 35°.

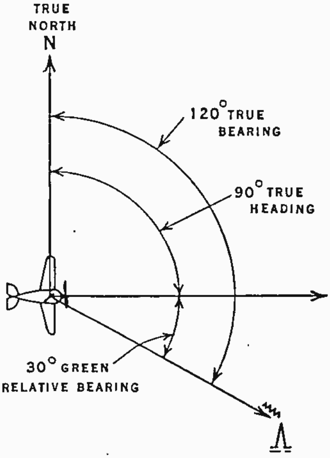

Fig. 371. Relative Bearing.

For the purpose of illustration of the method employed in navigating with a direction finding rotatable loop, let it be assumed that a plane equipped with this apparatus and also a positive cone of silence indication light, is to be flown from Chicago to Pittsburgh by way of Lansing and Goshen. Let it be further assumed for simplicity of explanation that the plane is equipped with a compass indicating true direction.

The pilot takes off from Chicago at 8:15 A.M.C. and flies a true course of 150°, parallel to the S.E. leg of the Chicago beam.

Before taking off, he sets the loop, tuned to Goshen radio range frequency, to the relative bearing between the plane's heading (152° T) and the approximate bearing of the point at which the south twilight zone of the west leg of the Goshen beam (88° T) would cross the 152° course. This relative bearing (wheel bearing) is equal to 64° Red (left), i.e. the difference, 64° in angle between the plane's true heading (152°) and the desired bearing of Goshen (88° True).

After proceeding on this course of 152° for 10 minutes, a null is heard in the pilot's phones and he immediately alters course to 88°, at the same time centering the loop (zero indication).

He finds after completing a long slow left turn that in order to obtain a null after changing his course to 88° true, he must rotate the wheel to 3° Red (minus) which means that he is south of his course due to the slow turn and possible drift (figure 372).

To carefully maintain his prearranged course the pilot, wishing to counteract for this southerly position, deducts 3° from his course to offset the difference in angle between the originally desired 88° course and present line of bearing (85°). Having presupposed a minus 2° drift from a northerly wind on this course, he therefore subtracts two more degrees. Thus the heading becomes 85° — 2° = 83° to fly. This operation should now bring the null to 2° green (plus). As long as the null remains on 2° green the plane must therefore be flying along the desired line of bearing on a constant course. If the plane drifts off to the right, this will be shown up by a decrease in green which may eventually reach zero and become a red wheel reading which will increase if not corrected. If he drifts to the left, the green readings will increase.

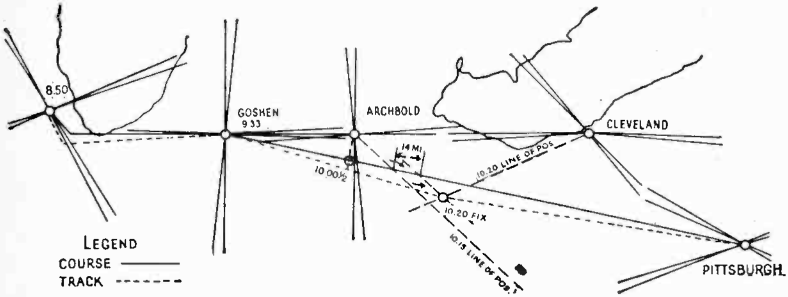

FIG. 372. Illustrating Method Employed in Navigating with a Direction Finding Rotatable Loop.

When the cone indication light comes on at 9:33, indicating that the plane is over Goshen (90 miles in 33 minutes or 163.5 m.p.h.); the pilot alters course to 105° true, the course to Pittsburgh. Allowing minus 1° for drift correction, the heading becomes 104° true.

According to the former groundspeed of 163.5 m.p.h. the plane should be abeam of Archbold at 10:00 1/2 (i.e. Archbold bearing on a perpendicular to the course), consequently at approximately 9:55 the pilot sets the loop, tuned to the frequency of the Archbold range station, for a 90° off the beam (left side) reading on Archbold. If no drift were allowed for, the wheel would be turned to read 90° red, thus setting the front of the loop so that it faces 90° *left* from the desired *course* rather than the plane's heading which is of a more variable value. Thus checks along the desired course maintain the same relation to one another. In this case the wheel instead of reading 90° should read 89° red, which in reality is 90° to the desired course, due to the minus 1° angle of drift being allowed.

The null in the pilot's earphones occurs at 10:00, or one-half minute earlier than estimated, thus indicating a groundspeed of

167 m.p.h. (75 miles in 27 minutes). This is an increase of 3 1/2 m.p.h. in speed which is quite feasible with the northerly wind and increased southerly course.

Approximately 15 minutes later, the pilot decides to take cross bearings on Archbold and Cleveland in order to establish a 'fix.'

At 10:15 a null is observed on Archbold with a wheel reading of 148° red, plane's heading 103° (note small irregularity in steering course); thus an actual bearing of direction with respect to North is obtained of 360° plus 103° — 148° = 315° true bearing on Archbold.

At 10:20, tuning to Cleveland, a null is observed on Cleveland with a wheel reading of 36° red, plane's heading 106° (small irregularity in heading again); and thus a true bearing is obtained of 106° — 36° = 70° on Cleveland.

When plotting cross-bearings it becomes necessary to lay off the reciprocal bearings from the known points on which bearings were observed.

The reciprocal bearing on Archbold becomes 135° true and the reciprocal bearing on Cleveland becomes 250° true.

Now if these lines were plotted on a map it will be seen that they intersect at a point 11 miles off-course in Lat. 40° 57′ 30″ N. and Long. 83° 32′ 00″ W.

However, this is *not* the position of the plane since a 5 minute interval elapsed between the first and second bearings. Therefore it is necessary to move the first bearing parallel to itself a distance of (5 minutes at 167 m.p.h.) or 14 miles along the course line. This new intersection of the moved-up Archbold bearing and the Cleveland bearing is the position of the plane at 10:20. This point is 9 miles off course in Lat. 41° 00′ N. and Long. 83° 23′ 30″ W.

Now by referring to the calculator and working an off-course correction problem, it is found that it takes a minus 4° correction to parallel and a minus 7° correction (4° plus 3°) to intercept the original course at destination, making a necessary true heading of 104° — 7° = 97°.

Since the desired true course was 105° and an estimated drift of 1° was allowed for in the original heading and since it requires an additional 4° to parallel the original course, the drift has been 5°.

In changing to the new heading of 97° it may be assumed that the drift will closely approximate the same amount. Consequently the loop will be set at 5° green, and tuned to Pittsburgh.

After ten minutes on the new heading the loop should be rotated in both directions until a signal is heard and the readings noted. If the mean of the readings is 5° green, the drift is that previously estimated. If, however, the mean should be 7° green the drift correction should be changed to this amount, i.e. steer 95°.

18. Removal of 180° Ambiguity—It is relatively easy to take bearings in the red or green sector up to 90° from the plane's heading with little likelihood of error. Referring to the previous discussion on loops, it will be remembered that the loop has two nulls, one off the front face and the other off the back face. It would be quite easy if a plane were in an absolutely unknown position, to take the readings off the back of the loop without knowing it. To illustrate, a plane is flying a true course of 0°. It is believed that a radio station exists ahead and to the left of the plane. The loop is swung to 30° red and a null found. Actually, due to drift, the plane had passed the station and the station was actually behind the plane and to the right. The direction of the station is actually 150° green (and a null exists there too). This problem will not usually arise, as stations should be selected at a great enough distance so that this error will not occur.

Suppose that a plane were lost and that only two or three rather nearby stations could be heard. The method of locating the plane would be to take bearings on two or three stations using the first null that is found for each. Incidentally, these bearings should be taken in rapid succession so that the plane's position will not have moved appreciably during the process. With the true bearings (after conversion) the pilot sets off the reciprocal bearing from each station and plots them in the usual manner. If they do not intersect, experience will dictate which of the three is probably in error. The bearing in error is then plotted 180° from its previous position and this process is continued until the bearings cross at a point, or form a small triangle (cocked-hat) which is more usually the case.

There is an arrangement for removing the 180° ambiguity from the direction finder loop. The method employed is to use the loop and the vertical antenna on a plane with a special switch which allows the use of both together. When this switch is thrown to the "sense" position, after first obtaining a null, the signal will immediately gain in strength. Then the plane (or loop) is rotated clockwise; for example, if the signal further increases, the front of the loop is being used. All direction finders have a notation on them such as "On sense position clockwise loop rotation gives signal increase when loop front is being used."

The radio compass is arranged (as explained elsewhere) so that sense is automatically determined by a slight movement of the plane or loop (if rotatable). Thus with either a radio compass or a direction finding loop with a sense attachment, it is possible to determine the direction of a station with respect to the course being flown, which may in turn be converted to a true bearing.

19. Plotting Reciprocal Bearings on Sectional Aeronautical Charts—Since a radio bearing follows the arc of a great circle, which means that it cuts each meridian at a different angle, it follows that the reciprocal of the bearing of a station from a plane will not be the bearing of the plane from the station, unless the distance between them is small or the station bears north or south from the plane.

This may very easily be proven by drawing a line from the westernmost meridian at 90° from west to east across a sectional chart and from the point where it intersects the easternmost meridian draw a line back from east to west at 270°. It will be found that the point where this line intersects the westernmost meridian is approximately 20 miles south of the point of origin.

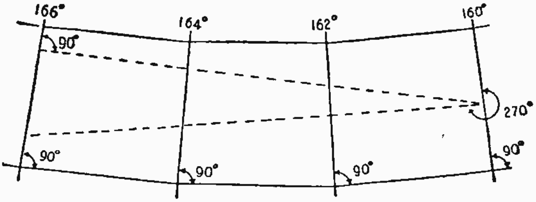

FIG. 373. Plotting Reciprocal Beamings on Chart.

Figure 373, or a distorted scale will graphically explain this feature.

The most accurate method of plotting a line of position on a Lambert Conformal Chart is as follows:

First: Assume a position on a meridian closest to the dead reckoning position of the plane.

Second: At this point lay off the true bearing of the station from the plane and draw a line of indefinite length.

Third: Draw a line, parallel to the above line, that passes through the station upon which the bearing was taken and crosses the longitude of the assumed position.

The plane then is somewhere on this line of position. Figure 374 shows this method graphically.

Another method is to take the reciprocal of the bearing of the station from the plane and to this carefully apply a correction of 0.6° for each degree of longitude between the station and the assumed position of the plane. If the assumed position is west of

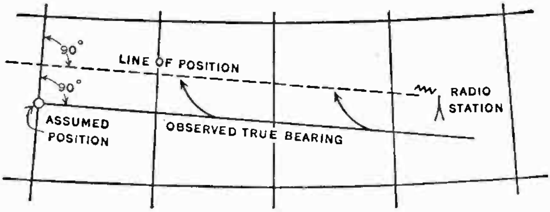

Fig. 374. Plotting a Line of Position on a Lambert Conformal Chart.

the station this correction must be added, if east, subtracted. Figure 375 shows application of this method.

20. Radio Compass (Single Fixed Thwart Loop—Visual Indication)—In conjunction with a loop antenna it is possible to attach a meter to the receiver which will indicate visually whether the plane is headed directly towards the station upon which the receiver is tuned or is headed to the right or left of the station. *This is the so-called Radio Compass.*

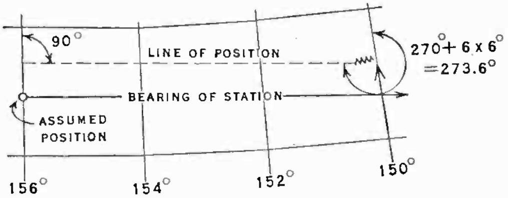

Fig. 375. Alternate Method of Plotting a Line of Position.

In this combination the loop is mounted with its plane *at right angles* to the line of flight. The loop, however, must have a second antenna used in conjunction with it in order to supply a signal to the receiver. The exact purpose of this antenna is somewhat involved, but it will suffice to say that it aids the characteristics of the loop.

In its simplest form the loop is fixed at right angles to the line of flight and in this form is used primarily as a homing device since, as with the fixed audible loop installation previously discussed, to take bearings on off course stations it is necessary to change the heading of the plane. In this case, however, the bearing will be taken over the plane's nose rather than off the beam.

Consider now the operation of the Radio Compass. As in figure 376, a plane is flying toward the station and therefore the loop can pick up no signal. The meter, as shown in figure 376 is so arranged that with no signal its pointer rests at the center and therefore indicates that the plane is headed toward the station.

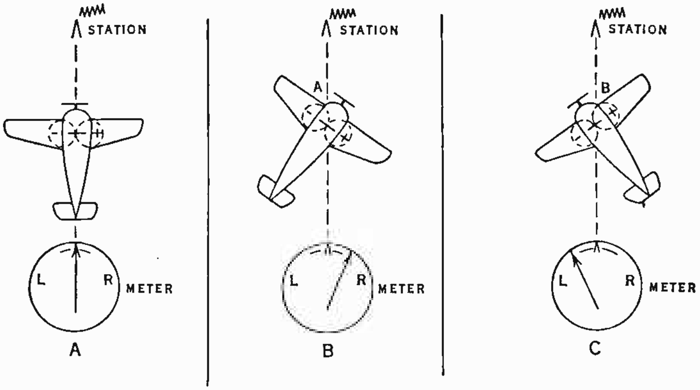

Fig. 376. Illustrating Visual Indicator (Radio Compass) Operation on Aircraft.

The plane is now headed to the right of the station and the loop picks up a signal represented by the deflection of the meter in figure 367–*B*. The compass is electrically arranged so that in the left half of the figure-of-eight loop the meter will be supplied a negative voltage; thus in this case it will indicate negatively, or to the right. (Some radio compasses are arranged with opposite deflection of the needle.) Figure 376–*B* shows that the station is to the left of the plane's heading and the more the plane turns to the right the more to the right the needle will move.

In exactly the same manner, if the plane is turned to the left, the needle will receive a supply of positive voltage, thus deflecting the needle to the left as in figure 376–*C*.

The foregoing explanation briefly describes the principle of the radio compass with the use of a loop. As a fin or mast antenna is used, the plane will be affected by additional drag, especially with a rotatable loop, and with ice formation etc. It is therefore advantageous that the loop be encased in a streamlined bomb, or at some place inside the fuselage where it will not be affected by large deviation errors.

One important advantage of the radio compass is that there is no 180° ambiguity in course and bearing. Right rudder normally produces right needle deflection. When headed away from a station, right rudder, even though the needle may be near center (as it is when either headed directly toward or away from a station) will produce left needle deflection and will immediately show that the plane is headed away from the station.

By testing in the above manner it can be readily seen that the radio compass will indicate whether the direction of the radio station is over the nose or tail. The magnetic compass must be used to tell the *heading* as the radio compass does not give this information.

If the loop or loops are on the ground, as with the radio range stations, the tracks are fixed. When fixed tracks are desired the radio range beacon fills the need. When only the direction of the station is desired, as in orientation, and it becomes necessary to fly to the station from any angle, the radio compass is useful.

21. **Radio Compass (Rotatable Loop)**—In the same manner as has previously been seen in the case of the direction finding loop, so may the radio compass be provided with a rotatable loop. This arrangement has many advantages.

Probably the most important of these from a navigational standpoint is the ability to take bearings on off course stations without changing the heading of the plane. The procedure is the same as with the direction finding loop with the exception that the loop is rotated until a zero reading is obtained on the dial and there is no chance of 180° ambiguity.

Another important advantage over the fixed loop is that allowance for drift may be made. Figure 377 shows the track of a plane with a fixed loop flying towards a station, homing in a cross wind. Obviously if the loop were turned to compensate for drift it will permit a straight track to be made good.

22. **Radio Compass or Direction Finder Deviation Curve**—Except in unusual circumstances the radio compass or direction finder apparatus will have a deviation curve. Usually the fore and aft and the two beam (right and left) bearings will have but a small correction curve reaching a maximum at the inter-cardinal bearings. The error in the usual plane installation is about 10° maximum at these positions. Usually the corrections will be sym-

metrical in plane installations having diametrically opposed quadrants. One diagonally opposite pair of quadrants will have plus corrections and the other minus. A deviation curve is supplied with most installations. Some have the correction curve worked into the loop rotating mechanism or into the dial scale by distortion from the linear scale with uniform angular rotation. This practice makes use of a deviation curve unnecessary and is a great aid in taking bearings. On ship board the radio compass or direction finder scale is often attached to the gyro compass so that true bearings may be instantly found with no resort to any correction except in laying off reciprocal bearings as explained previously.

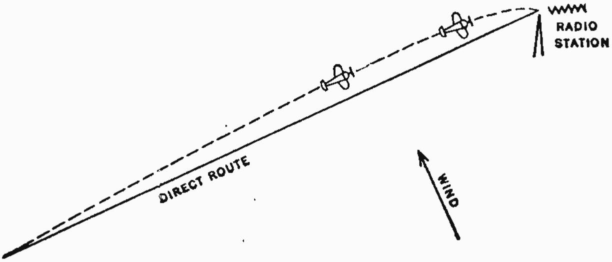

FIG. 377. Showing Track of Plane with Fixed Loop Flying Towards a Station Homing in a Cross Wind.

23. Direction Finding Ground Stations—In European countries there are direction finding ground stations which maintain a watch and, at the pilot's request, take bearings on the plane to determine its position. The general procedure is for the pilot to call the station in charge of the position finding and request a bearing. The station then arranges to take bearings on the plane and informs one or other stations to do likewise. The pilot is requested to transmit for a short period while each ground station swings its loop to determine the bearing of the plane from the station. The ground station having received the bearings noted at the other ground stations, plots them on a map and transmits this information to the pilot.

This same procedure is common at sea where the shore stations take bearings on the ship but in this case the individual bearings are transmitted to the ship and the position is plotted by an officer on the ship. This is not as easy for the pilot and so the position is usually plotted for him on the ground and his position over or near some known location is given by the key ground station. About three minutes or more is required for the latter process.

It should be noted that the ground station bearings need not be corrected for differences in longitude between it and the plane as the bearing was taken at the point from which it is to be plotted. No reciprocals are involved in this plotting.

24. Special Coastal and Great Lakes Non-directional Radio Beacons (see Chapter 13)—The U. S. Government maintains a series of non-directional radio beacons along the coasts and the Great Lakes. These stations are similar to broadcasting stations in that they transmit a non-directional signal. They operate on frequencies in the range from 284 to 314 kilocycles which is the middle of the radio range frequency spectrum.

The operation of these stations follow:

A group of three stations, as a rule, in the same general locality, transmit signals in rotation. For example there are three stations near Chicago; Milwaukee, Chicago and Calumet. All broadcast on 286 kilocycles. Each is silent for two minutes and "on" one full minute, properly synchronized so as not to interfere with either of the other two. These stations are identified with signals as follows:

Calumet —·—
Chicago ·—·—
Milwaukee ——

A plane is flying in the vicinity of the southern tip of Lake Michigan and desires to obtain a position fix. Heading toward Chicago, the pilot tunes his receiver to 286 kc. Hearing the Calumet station transmitting its identification (—·—) he immediately swings his loop for a relative bearing, repeating the process for the other two stations when they transmit in their turn. With these three relative bearings the position is then easily determined.

25. Radio Errors—(*a*) *Mountain Effect*—Mountain effect is a rather simple phenomenon but its cure is far from simple, if not impossible. (See figure 378.) A radio range is operated near a mountain *W*, signals of which hit the side of the mountain and are reflected as light on a mirror face. On the supposed course at *X* the signals from the radio range, if there were no mountain in the vicinity, would show "on course" that is the *A* and *N* vectors are equal. Now suppose that a plane were at *X* and the direct signals from the station were somehow removed for the moment. The reflected signals would indicate to that plane that it was on a course *Z–Z* (*N* zone) as the signals are reflected from the side of the mountain in true proportion. The pilot, to correct himself would fly to the left to get out of the *N* zone which was indicated to him.

Now consider that the direct signals are getting to the plane as well as the reflected ones. As the direct signals are equal and the reflected ones add to them, the combination of the two vectors will give an increase of the *N* signal vector which is the sum of *O–T* and *O–B* and the *A* signal will be the sum of *O–T* and *O–C*. The new *N* signal will be greater than the *A* signal and the pilot will fly to the left to get on course. At position *Y* he will be "on-course" as far as he knows and fly from there on the dotted course to the station. The course flown will be irregular due to variations in the signal reflected from the mountain.

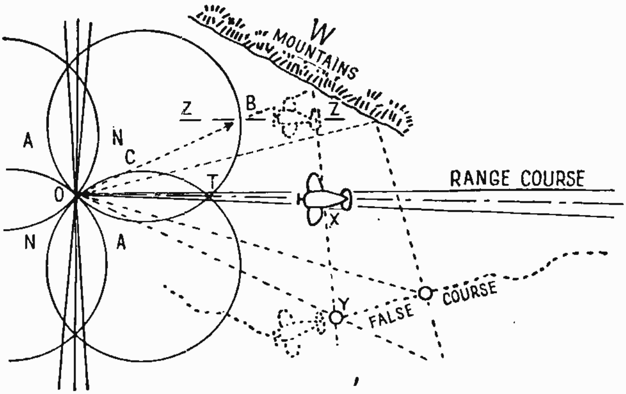

FIG. 378. Showing Mountain Effect.

Imagine the effect of several irregular high mountains on both sides of the course and you have the reasons for multiple courses so common in mountainous regions. The radio compass "homing" on a station is about as bad since it tends to point to both the station and to the direction from which strong reflections come. It will average some course between them but not the true track to the station.

(*b*) *Night Effect*—Above the earth there is a cloud of ions (the Heaviside layer) and due to the sun's effect at night this layer is higher than in the daytime when the sun better ionizes the upper stratosphere. This layer reflects signals downward, so that the ground-hugging waves direct from the beacon mingles with those that have gone up to this layer and back. The effect is quite the same as that of a mountain although the mechanics of the changing of the indicated from the true course is slightly different. It usually causes the course to swing to one side or the other but it is not generally responsible for multiple courses as there is but one layer, while in the case of mountains there may be several with very irregular contours.

This layer is far from smooth and is more like a rolling sea. It will swing the course back and forth even though the plane is moving slowly or standing practically still. Both the plane's motion and the rolling of the layer help to aggregate this swinging. In the older type of beacon station loops which had horizontal and vertical wires, the horizontal portion would radiate energy skyward. (Wires radiate energy at right angles to their axis.) As the horizontal portion played no real part in the beacon operation the horizontal wire was eliminated and the present TL system devised, using only pairs of vertical towers. This reduced night effect but had little bearing on mountain effect as the vertical masts radiate well toward the mountains, but not toward the sky.

26. Radio Errors Classified—In using directional radio equipment there are several types of errors which may be encountered.

1. Error due to night effect. (Radio Compass, Direction Finder and Radio Range.) These errors are due to the reflected wave from the heaviside layer not arriving from the correct direction.
2. Errors due to mountains. (Radio Compass, Direction Finder and Radio Range.) Mountain effect has the same general effect as night effect but the waves are reflected from the surrounding terrain.
3. Errors due to station interference. (Radio Compass.) It may be sometimes found that stations cannot be sufficiently separated by the radio compass due to lack of receiver selectivity. Further, this may not be obvious to the user as the interference need not be necessarily audible.
4. Errors due to failure of part of the antenna system or due to the receiver becoming misadjusted or misaligned. (Radio Compass and sometimes Direction Finder.)
5. Errors due to heavy static. (Radio Compass.) A radio compass will deflect on ordinary heavy static and the static course laid out will be toward the center of the electrical disturbance.

6. Miscellaneous errors such as those due to heavy rain static where the compass ceases to indicate, but these are obvious as a change in heading produces no visual change in indication. Also errors due to the voice transmissions from various beacon stations being made on a nearby antenna and not on the towers.
7. Pulsing of the indicator needle on keyed signals such as *A* or *N* which can be corrected by averaging the readings.

27. **Miscellaneous Radio Range Information**—Radio ranges, the legs of which are arranged at 90° to one another, give symmetrical patterns of field strength. It is often desirable to have the courses arranged so that they pass over airways which are not located at 90° or 180° to one another. Figure 379 shows a radio range in which a *bend* has been made, the northerly course having been bent to the northwest. Figure 380 shows a radio range in which the courses have been *squeezed* but not bent. In both of these examples the symmetrical figures of eight pattern normally resulting from the pairs of towers has been altered for the results shown.

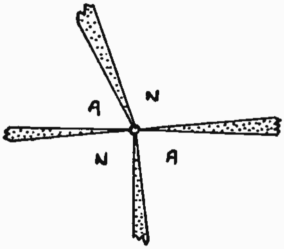

FIG. 379. Course Bending.

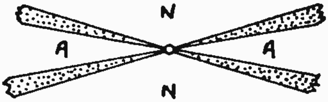

FIG. 380. Course Squeezing.

28. **Squeezed Course**—Figure 381 shows the field pattern of a radio range which has been squeezed. In the example, the power of the " A " towers has been reduced to approximately one-half of its previous amplitude, which means that the radial distance at which the radio range can be successfully received in the A quadrants will be less than that in the N quadrants.

29. **Orientation with Squeezed Courses**—While this range will behave very much like any normal range in which there is no squeeze, there is one important difference to be noted in solving orientation problems on the range shown in figure 381. If a plane is flown parallel to the *N* bisector on the course *WZ*, it will be noted that the signal at point *W* and the signal at point *Y* will be

equal in strength. The signal at point *W* would be an on-course signal, while that at point *Y* would be an *N* signal. From the previous discussion of field patterns, it has been shown that a plane being flown around the circumference of the circles will be receiving a signal of constant strength. It follows that at any point inside of the *N* pattern, the signal will be stronger than at any point outside of this circular field pattern. Therefore, in the flight from *W* to *Z* (parallel to the bisector of the *N* quadrant) the signal strength on flying south away from the station will actually increase from point *W* to a point *X* and will then decrease from the maximum value at *X* till at point *Y* the signal has dropped to the same intensity as at point *W*. In continuing the flight beyond point *Y*, the signal will further decrease in strength.

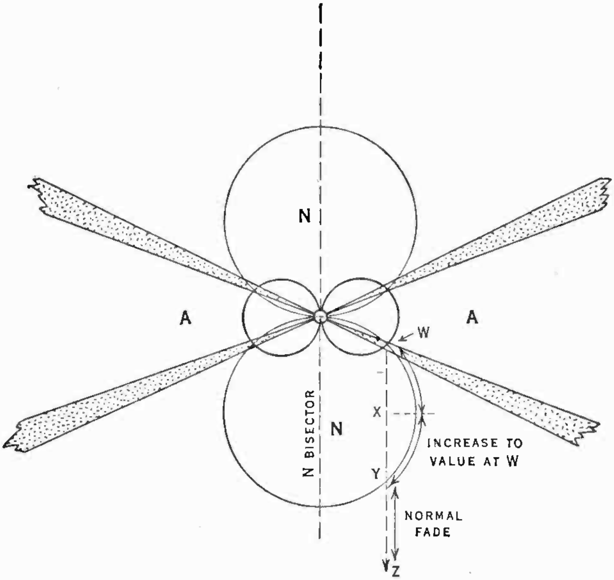

FIG. 381. Orientation with Squeezed Course.

Figure 382 shows a slightly different presentation of this same phenomenon. The cross hatched area in the *N* zones denotes regions in which a plane being flown parallel to the *N* bisector and *away* from the station will actually encounter a build-up in signal.

In solving an orientation problem, it is very important that this be recognized.

A pilot desires to work an orientation problem when he is in one of the *N* quadrants. He decides to fly south to determine whether the signal fades or increases in strength. Suppose that the plane were in the northerly *N* quadrant and headed south.

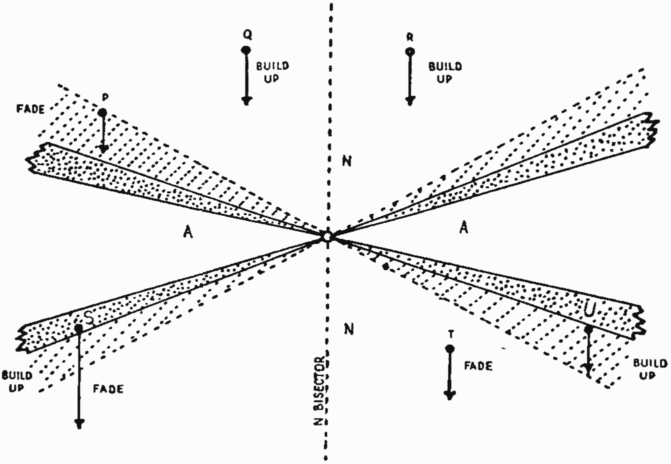

FIG. 382.

If the plane were at point *Q* or *R* a *build-up* of signal would show that the plane was in the northerly quadrant. However, if the plane were at point *P*, a decrease of signal might be misinterpreted by the pilot. In any event, the flight should be continued and, if the plane were actually at point *P*, a beam leg would be crossed in a reasonable time.

In this same example, the plane might easily have been at point *T* and the *decrease of signal* would have indicated that he was in the southerly *N* quadrant. If the plane had been at *S* or *U*, an *increase of signal* might falsely indicate that the plane was in the northernly *N* quadrant. To be sure of this, the plane should continue on the southerly heading. If at point *T*, the decrease would continue normally. If at points *S* or *U*, eventually the signal would start to decrease and *no beam leg would be crossed.*

A safe rule to follow in the case of a radio range which is known to have squeezes follows: *If an increase in signal is heard when flying parallel to the bisector of the wide quadrant, the head-*

ing should be maintained until either a beam leg is crossed or the signal very definitely starts to fade and no beam leg is crossed.

This applies particularly to the wide quadrants and does not apply, as in the example shown, to the narrow *A* quadrants. A fade will result when flying parallel to the *A* bisector when flying away from the station in all cases, and a build-up will be experienced in flying toward the station in the normal manner.

When bends and squeezes, together, are present, orientation problems in the wide sectors should be worked out with the rule set forth in mind. If, by chance, signals of the same letter exist, one in a narrow quadrant and the other in a wide quadrant, there is no way of telling in which quadrant the plane is situated; so the above rule applies.

30. Multiple Courses—Multiple courses are known to exist on radio ranges. They may be due to several causes:

1. Mountainous terrain, hills, etc.
2. Presence of rivers in flat country.
3. Transmission lines or other man-made structures in the vicinity of the radio range station, or particularly when existing near the range legs at any point near the true on-course.

Figure 383 shows a radio range in which multiple courses are experienced. On each leg a different type or multiple has been shown, although all types of multiple may exist on any leg and might even be absent on as many as three of the other legs.

Almost all types of multiples exist only for short distances or generally are very irregularly spaced. Their position varies with altitude, distance from the station and time of day. They may not occur on a leg until a point has been reached many miles from the station. Generally speaking, the angular arc in which multiples occur will extend as much as 10° to 15° either side of the true course. This means that at great distances from the station the multiples may be many miles in separation from the true course.

(*a*) *Multiples Bounded by the Same Letter*—On leg 1 several multiples have been shown which, in each case, are bounded by the same letter on each side of the multiple on-course signals. Multiple on-course signals exist on the lines B, C, D and E. These multiples are fairly easy to recognize by the fact that they are bounded by the same letter of each side.

(*b*) *Multiples Not Bounded by the Same Letter*—On leg 2 in figure 383, the two other types of multiple are shown. As the multiple on-course at H is bounded by an *A* and an *N*, this multiple might be easily confused with the true on-course. The multiple will generally be extremely narrow, in comparison with the true on-course signal. Further, this multiple cannot usually be flown for any great distance before it disappears.

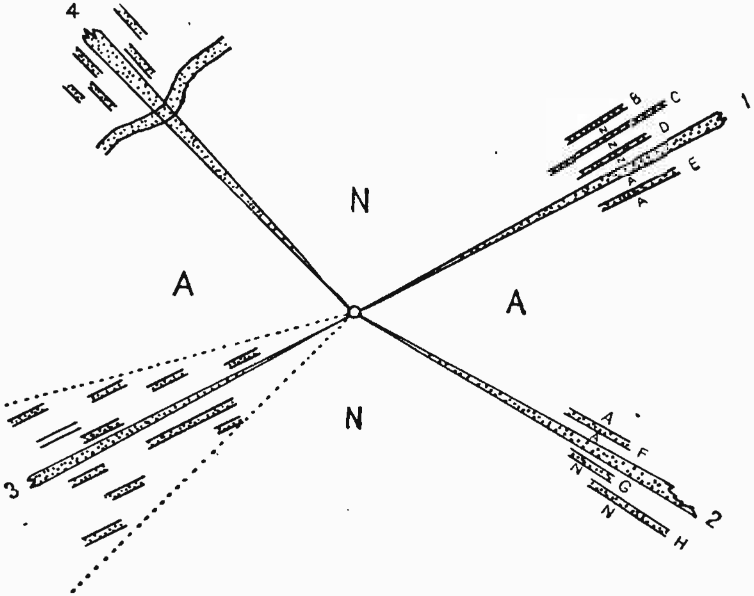

Fig. 383. Multiple Courses.

The multiple on-course signal at G indicates the reversed type of multiple, in which the *A* and *N* appear in the wrong order for that course leg. These two types of multiple may be more easily confused with a true on-course than any other type.

Leg 3 in figure 383 shows the general arrangement of multiples in uniformly mountainous country.

Leg 4 shows the appearance of multiples at some point out on the course and may occur beyond a point where a serious discontinuity in terrain or a river or both exists.

(*c*) *Irregular Course Bending and Swinging*—Figure 384 shows courses which have several bends in them, due to passing over an irregular terrain. Irregular bends on such courses may require a change of heading for short periods of as much as 40° to 50°, although usually they will be much less severe. These are due to the same causes which produce multiples.

Very often these irregular bends in the course will change with time of day, usually being most pronounced in twilight hours and during the night. Frequently these irregular bends are confused with *course swinging.* It is impossible to say whether the course bends or whether the course is swinging in flying a radio range, because the position of the airplane is changing.

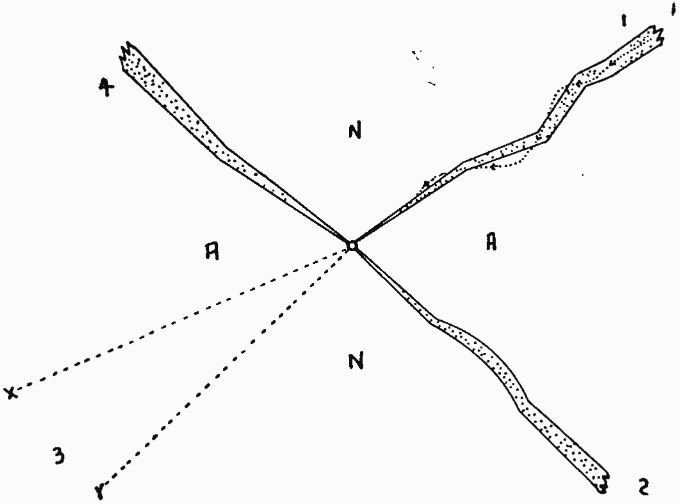

FIG. 384. Irregular Courses.

A dotted line on figure 384 shows a possible course of an airplane attempting to fly a course with irregular bends. As it is impossible to predict the point at which the bend occurs, the plane may be flown from one signal to another in attempting to fly the course exactly.

A receiver on the ground on one of the legs would show whether the course was bending or swinging. In case swinging was present, the signal would change from *A* to *N* and *N* to *A* signals during the time of observation. Leg 3 of figure 384 shows the effect of swinging where the true course might swing between courses *O–X* and *O–Y*. Swinging is more pronounced from dusk to daybreak than at other times, as a rule.

(*d*) *Effects of Multiples on Orientation*—In applying the 90° system of orientation to a radio range where multiples and the other effects produced by the same phenomenon are present, such as swinging and irregular bending, precaution must be observed when intersecting a leg that it is the true on-course; however, a multiple need not necessarily be heard in approaching the true on-course. After the 90° turn is made, which, for example, might bring the plane back into the same letter quadrants as previously, a multiple might be heard which would indicate that the plane was being flown actually across the leg. This can be checked by being sure that a true course has been intercepted and flying long enough after the 90° turn to make sure of the quadrant signal into which the plane is being flown.

A multiple could also be confused with a turn made very close to the station and interpreted as passing over two beam legs; usually if this close to the station, the signal would be very strong.

31. False Cones of Silence—In passing over irregular terrain, the signal level from the beacon station may vary considerably. Figure 385 shows a profile of a mountainous terrain, and below it is shown the relative loudness of the beacon signal in passing over this region.

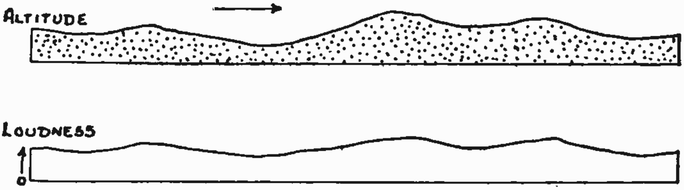

FIG. 385. Variation in Signal When Flying Over Irregular Terrain.

If the first small fade or build-up heard is used as an indication, an error might be made, for this might be a local fade or build-up. In solving orientation problems over such terrain, fades should be obtained which are more pronounced than those required in flat country before being sure that the plane is headed away from the radio range station, when flying a course parallel to the bisector on any range. As can be seen from the figure, there is no definite correlation between the signal and the exact topography. Generally, on flying away from the station and toward an increase in ground elevation, the signal will tend to be raised somewhat by the terrain. As the distance from the station is increasing, the effect will be to keep a somewhat constant level.

Figure 386 shows another profile of a region in which a serious irregularity such as a canyon exists with the signal level has been plotted below. At point *X*, it will be noted that the signal drops to inaudibility for a short period when passing over the far rim of the canyon. This is known as a false cone of silence. It will be noted that surges before and after this false cone are usually not very pronounced, and usually these surges will not require any readjustment of the beacon receiver volume control.

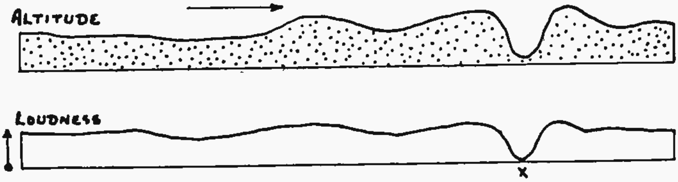

FIG. 386. Showing Variation in Signal When Flying over a Canyon.

Figure 387 shows the signal level above the true cone of silence of a radio range station and heard at altitudes of from 500 to 3000 ft. above the range. As no radio receiver nor the ear is capable of adjusting itself to this wide range of signal, it is necessary to reduce the volume control at least twice in approaching the cone.

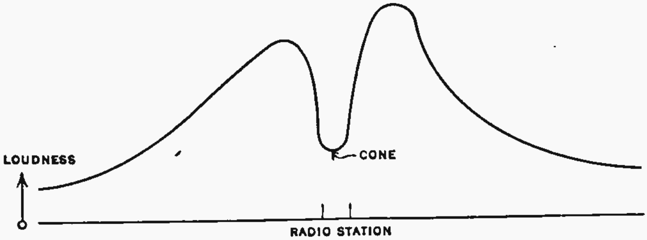

FIG. 387. Showing Signal Level above the True Cone of Silence when Flying at an Altitude of from 500 to 3000 Feet over the Range.

This effect is shown in figure 388 and, where marked *VC*, the volume control has been adjusted to compensate for the rapid change in signal. The surges are just as important as the cone of silence in determining the position above the beacon station.

False cones of silence, with the normal receiving antenna employed on aircraft, will usually be more pronounced in passing over a canyon in a direction heading away from the station and at right angles to the direction of the canyon, i.e., crossing it. The severity of the false cone of silence will vary with the distance above the canyon and generally will be more pronounced at lower altitudes.

These false cones of silence may, in some cases, almost disappear in the late afternoon, due to the fact that a certain amount of the energy from the transmitter is more efficiently reflected from the heaviside layer existing many miles above the earth during the evening hours. When the position where the false cone in daylight is reached during the night, the false cone will be fairly well filled in with this sky wave or reflected signal, so that it will be far less pronounced.

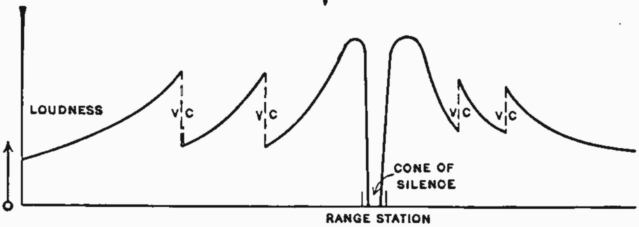

FIG. 388. Adjustments of v.c. to Compensate for Rapid Change in Signal.

True cones of silence above a radio range station will exhibit decreasing surges with increase of altitude, and the cone of silence itself will last for a longer period. The reason that the surges are not so pronounced at higher altitudes is due to the fact that the plane never gets closer to the range station than the difference in altitude between it and the station. In other words, a plane flying 1000 ft. over a beacon station reaches a position 1000 ft. from the station at the closest, whereas in flying at an altitude of 10,000 ft. above the station, the plane never gets closer than about 2 miles (10,000 ft.) from the station.

32. Loop Orientation—There are several methods in using a rotatable loop by which orientation problems can be solved rather easily.

(*a*) *The Fade and Homing Method*—With the loop's plane set at right angles to the line of flight, regardless of the quadrant in which the plane is situated, the airplane is turned until a null is secured. In flying a course on which this null is maintained, the plane will be *heading either toward or away from the station on a radius emanating from the station.* By using another radio receiver to determine whether the signal is fading or building up, it may soon be determined in which direction the station lies. The plane may then be flown directly to the station, by turning the plane toward the station on a heading on which the null is maintained. This method saves a great deal of the time ordinarily required in an orientation problem and furthermore, *regardless of bends or squeezes, a build-up definitely indicates that the station is being approached.* This is shown in figure 389.

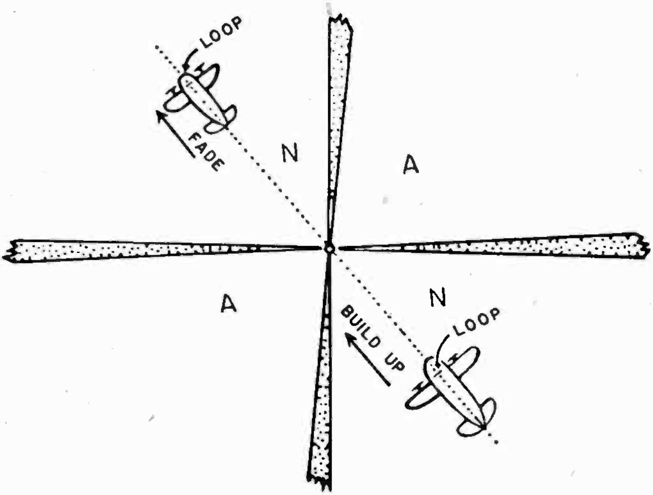

FIG. 389. Loop Set at Right Angles to Line of Flight and Airplane Head to Obtain a Null.

Usually on homing with this method, the station's position will be shown by the fact that when the plane is within about a quarter mile from the station, a definite surge and impossibility of maintaining the null will indicate the approach. This applies generally to approaches at altitudes from 200 to 3000 ft. above the station. About a quarter mile beyond the station, the null may again be obtained. As a positive check of the cone another receiver should be used. On this other receiver, the cone of silence will sound just like any normal cone, regardless of the direction of crossing the station.

33. **The Directional Gyro Progression Method**—The problem of orientation in the vicinity of a station may be solved in another manner. The loop in this case is turned so that its plane lies in the line of flight and the airplane is swung to obtain a null. As in figure 390, the plane must either be at point X or at point Y, which are points 180° apart *anywhere* on a circumference. The gyro reading is then noted and the plane flown so that the null is

maintained. This will result in the plane's making a circle around the radio range station. If the plane were at point *X*, a right turn would be noted. If the plane were at point *Y*, a left turn would be noted. This is indicated by the direction in which the directional gyro progresses during the flight.

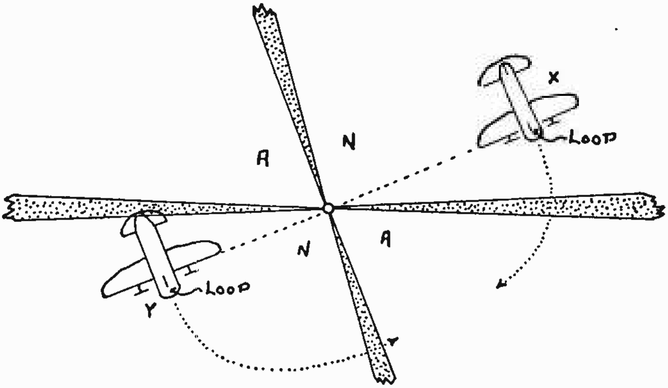

FIG. 390. Looping Plane of Flight and Airplane Headed to Obtain a Null.

A simple rule may be followed. If the plane is turning left during this maneuver, the radio range station is directly off the left wing. If a right turn is noted, the radio range station is directly off the right wing.

By noting the compass heading or listening to the range identification signal in the quadrant in which the plane is flying, its position may be fairly accurately determined.

Further, the distance from the station may be computed fairly easily by timing the rate of progression of the gyro. For example, if the plane were 10 miles from the station, the circumference of the circle being flown would be approximately 60 miles, and 60° of the circumference would require 10 miles of flying. Therefore, at a speed of about 180 miles an hour, the gyro would progress 60° in 3 minutes, roughly. At 20 miles from the station, it would take approximately 6 minutes for the gyro to progress 60°, etc. After determining the position of the station, the plane may be homed with the loop, or a leg intercepted.

34. The Loop Progression Method—Figure 391 shows an alternate method of solving the orientation problem, with the plane flown on a straight course rather than on a circular one.

As is shown, the plane is flown on a straight course, preferably parallel to a bisector. The null is maintained on the loop by means of its rotating mechanism. As the plane passes the station, the loop will be in the line of flight. As the flight is continued, rotation of the loop will be required to maintain this null. The plane will then have passed either to the right or to the left of the radio range station. If the station has been passed on the plane's left side, the loop progression in maintaining the null will be counterclockwise. If, on the other hand, the station was to the right of the plane, the loop progression will be clockwise.

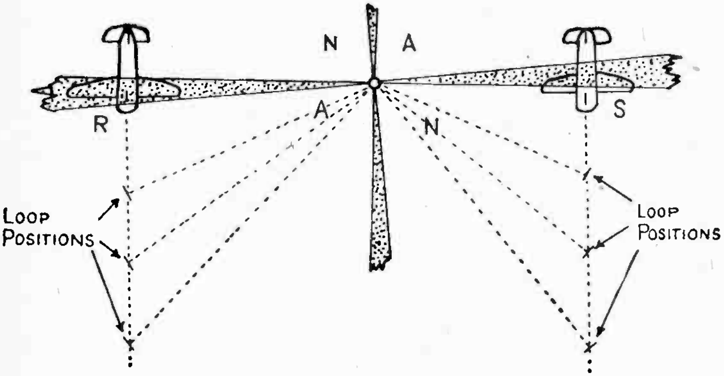

Fig. 391. The Loop Progression Method.

While this method is not as simple as the one explained immediately above, it is applicable to checking a normal orientation problem. For example, while the pilot is solving a normal orientation problem, the co-pilot might check the procedure with another receiver and the loop. After determining the position of the station, the plane may be homed in the usual way, or a leg intercepted.

35. Signal Reversal—All radio receivers have an overload point which is found upon increasing the volume control to a point where increase of audible signal no longer occurs. If the volume control is advanced beyond this point, the audible signal will actually get weaker, due to the fact that the radio tubes have been blocked out of their normal operation.

In flying a radio range in an *A* quadrant, for example, the volume control might be increased to a point where the *A* signal just overloaded the receiver. No ill effect would be noticed up to this point. Upon increasing the volume still further, the background *N* signal could be raised to the overload point. As the *A* signal itself would then be extending far into the overload region, it would, as stated before, not be as loud as a signal at the overload point. Therefore, the *A* would actually be weaker than the *N* and apparent course reversal would be noted, i.e., an *N* would be heard.

It is important, particularly after flying in a region of heavy static, to reduce the volume control until the signal becomes almost inaudible and then raise it to a point for comfortable volume, so that the receiver will not be overloaded with the possibility of signal reversal.

DIRECTION FINDING ROTATABLE LOOPS

(Important points in connection with the use of the rotatable loop and a new method of orientation follow.)

36. **The TWA–W1A Bearing Indicator Dial** (see figure 369). All electrical errors have been taken care of in the calibration of the W1A bearing indicator dial.

Bearings to the **Right** of the plane's heading appear in the *green semicircle.*

Bearings to the **Left** of the plane's heading appear in the *red semicircle.*

All Green bearings are *added* to the plane's heading.

All Red bearings are *subtracted* from the plane's heading.

The **Black** needle is used for bearings *ahead.*

The **White** needle is used for bearings to the *rear.*

STOPS prevent the black needle from being rotated over about 100 degrees, either side of zero.

37. **The Nulls**—When using the loop, if the plane is turned through a complete circle, at some position distant from a range station, the signal will decrease to a minimum or fade out in two headings of the plane. These points are the nulls. These **TWO NULLS** are 180 degrees from one another.

With the **BLACK** needle set at **ZERO** and when flying the null, the plane is either flying **DIRECTLY TOWARD** or **DIRECTLY AWAY FROM** the station. Methods follow for determination of the true condition. The black forward needle should be read until it has been established that a bearing is to the rear, in which case, the white needle should be used.

If the volume control is **ADVANCED** the **NULL** will be **SHARPER.**

If the volume control is **RETARDED** the **NULL** will be **BROADER.**

INCREASED DISTANCE from a station results in a **WIDER** null.

INACCURATE TUNING BROADENS THE NULL.

For **BEST TUNING** rotate the loop for near maximum signal before tuning.

BEST VOLUME CONTROL setting results in a null narrow enough to be definite (5 degrees or less) and yet not so narrow as to be "unflyable."

The **BLACK** needle is always placed on **ZERO** for flying a null.

38. **Flying the Null**—When flying a null, care must be exercised to see that the needle on the dial is exactly on **ZERO.** Due to parallax error, pilots should sight directly over the dial when centering the needle or when obtaining bearings.

When a null is being flown properly, either a slight right or left turn will produce an *INCREASE* in the signal. If a right turn increases the signal and a left turn decreases it, the null is somewhat to the left of the heading being used.

The null may be flown by either of two methods.

1. The directional gyro may be used to determine the proper direction of turn for a return to the null. The plane is set on a null at zero gyro heading. Soon the signal increases and the gyro will have moved a few degrees. Naturally the direction of turn to reobtain the null is the direction which brings the gyro back toward zero. This only holds true under comparatively still air conditions or when heading directly toward or way from the station.

2. An easier method of flying the null is to set the gyro on zero when a null is obtained. Continue flying on this gyro heading and periodically investigate the null with the bearing indicator. If the null is moving slowly to the left (**RED** sector, black needle) a leisurely correction may be made in heading so that the null again falls at zero.

Drift will result in a progression of the gyro reading in one direction as a null is maintained, and will manifest itself quite obviously to the pilot.

39. **Position Finding**—The following rough methods may be used in obtaining approximate fixes. Accurate plotting methods are shown in section 19.

To plot a bearing from an unknown position.

1. Take bearings on two stations in *rapid* succession.

2. Read the black needle and the plot bearing lines at each station so that they extend through the station. Their intersection

is known as a "fix" and must be the approximate position of the plane.

Example: Plane's **TRUE** heading 25 degrees. Station No. 1 80 **RED.** Station No. 2 50 degrees **GREEN.** Set off a bearing through Station No. 1 305 degrees True, through Station No. 2 at 75 degrees true. For a more accurate reading, use the bearing indicated by the **WHITE** needle on Station No. 1 as it may be seen from figure 392 that this station is *actually* to the rear.

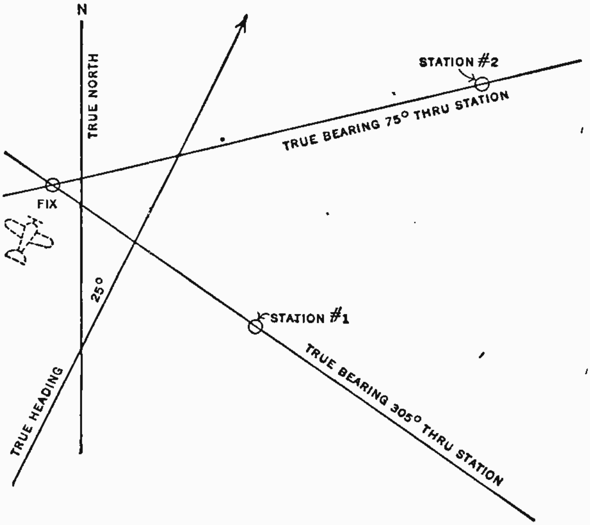

FIG. 392. Position Finding.

40. Maps for Use with Direction Finding Loop—Maps are available on a scale of 1 : 1,500,000 (approximately 25 miles to 1 inch) which greatly facilitate position finding in connection with the rotatable loop.

These maps show prominent rivers, towns, landmarks, lighted fields, etc. Courses are laid down and marked in 10 mile intervals.

A compass rose is placed on each radio station for the magnetic variation of the particular station. The roses are rotated 180 degrees, thus enabling back bearings to be plotted directly.

The maps are issued in strips eleven inches wide.

41. Precautions in Obtaining Positions—Figure 393 shows the effect of inaccuracies in bearings which intersect at small angles.

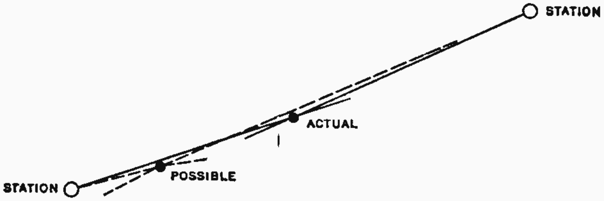

FIG. 393. Showing the Effect of Inaccuracies in Bearings Which Intersect at Small Angles.

The solid lines show exact bearings and the dotted lines show bearings which are less accurate due to slight errors. The fix, shown at the intersections, illustrates the reason for not using bearings which intersect at small angles.

Therefore:

CROSS BEARINGS SHOULD NOT BE USED where the angle of intersection is **LESS THAN 30 DEGREES.**

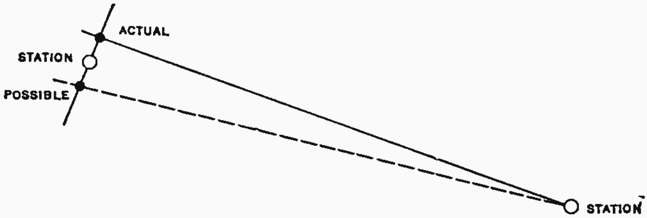

FIG. 394. Showing the Result When Using Bearings from a Close and Distant Station.

Where the distance from the station is suitable a running fix may be obtained by taking two bearings on the same station plotting their reciprocals, then finding a line between the two which is parallel to the track of the airplane and of a length equal to the distance traveled during the interval between the bearings.

For the same reasons stated previously small differences in bearings and bearings not near the beam should be avoided.

Obviously all other forms of bearing plotting heretofore used in ocean navigation by pilotage methods are applicable to radio compass use under the proper conditions.

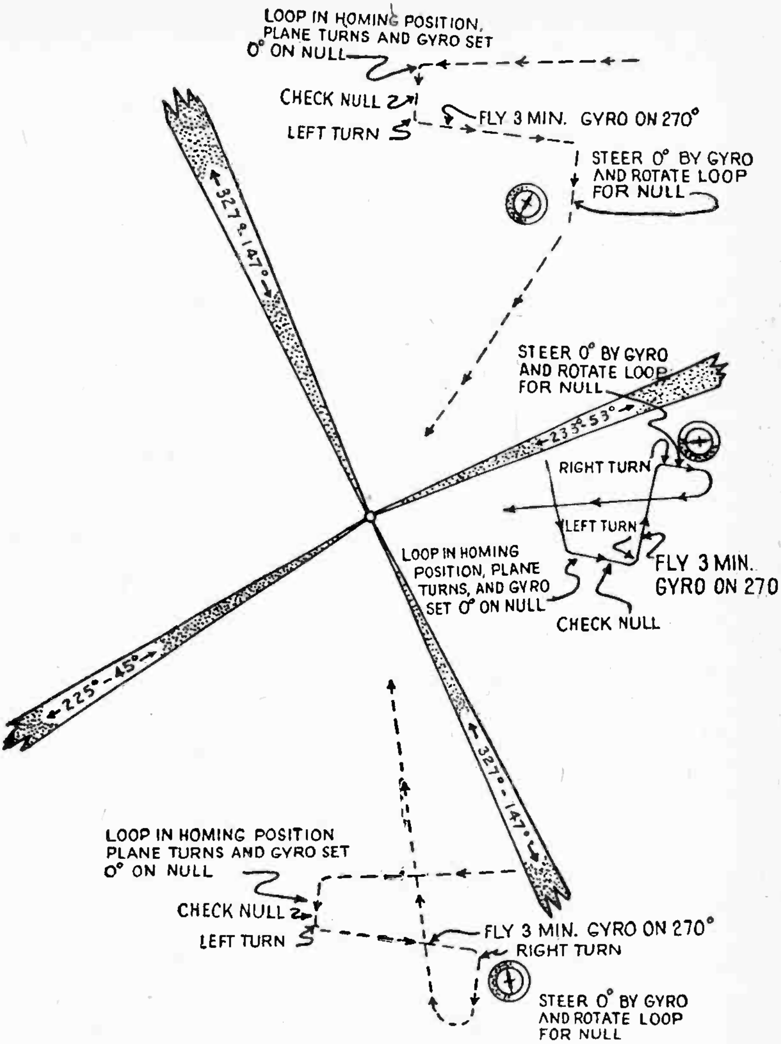

FIG. 395. Orientation with a Loop Antenna.

Figure 394 shows the result of trying to obtain the exact relation for orientation on a nearby station to the plane by bearings on some distant station. Bearing fixes are usually accurate to within about five miles.

42. Precaution Due to Night and Mountain Effect—Night effect or interference from other beacon stations on the same frequency will tend to materially widen nulls. Bearings or loop orientation, with such wide nulls (say over 30 degrees) should be practiced with caution, keeping in mind the fact that a substantial angular error in averaging for the null point may result.

43. Loop Orientation—The following system has been developed for orientation with the use of a loop antenna (see figure 395).

1. Obtain a null, after tuning in a station, by turning the plane with the bearing indicator set at the "homing" or zero position.
2. Set the **GYRO** to **ZERO** and **TEST** the null with the Bearing Indicator. If the null is not exactly at zero, change heading and readjust the gyro. Both **ZERO NULL** and **ZERO GYRO** heading should check to within a degree.
3. Make a 90 degree **LEFT** turn (*ALWAYS LEFT*) and fly this heading (270 on the gyro) for **THREE MINUTES.*** (See reason below.)
4. After three minutes turn right to **ZERO GYRO HEADING** again.
5. While carefully holding the *zero gyro course* take a BEARING on the station by rotating the loop.
6. **READ THE** *BLACK* HAND on the bearing indicator for the null.

   A *GREEN* sector reading shows the station to be *AHEAD* (and slightly to the right). A *RED* sector readings shows the station to be to the **REAR** (and slightly to the right). The amount of right or left reading should be sufficient so that a positive orientation is assured. Readings of over six degrees are usually reliable. Using this orientation system an *eight* degree bearing will result at *75 miles* from the station with a ground speed of 170 **MPH.** (i.e. after the 3 minute leg).

   If the bearing is less than six degrees it would be well to

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* The reason that a left turn was specified in paragraph 3 is for standardization and uniformity.

take bearings on two stations to obtain a position fix, or if desired, the problem could be continued by another 3 minute 270 degree gyro flight with no readjustment of the gyro.

A brief summary of the orientation system follows:

1. Set the **GYRO** to **ZERO** at an exact **NULL** heading.
2. Make a 90 degree left turn and fly 3 minutes. (270 gyro.)
3. Turn back to **ZERO** gyro heading.
4. Rotate loop for a null. If **GREEN** the station is **AHEAD.** If **RED** the station is **BEHIND.**
5. Whether the station be ahead or astern, **ALWAYS TURN** *RIGHT* in order to head into the station.

The following are some advantages of this simple system.

1. Broadcasts will not interrupt the problem. The null is just as good, or better, on the broadcast.
2. Volume control setting is not critical.
3. The plane may be " homed " without flying to a course leg after the orientation (see below).
4. Orientation at any distance up to 75 miles from the station takes about 4 minutes.

44. **Homing**—Fly the null into the station. *Do not reduce the volume control radically as the station is approached.* When within about a quarter mile of the station the **NULL WILL DISAPPEAR** giving way to a **LOUD BUILD UP OF SIGNAL.** After passing the station it is best to switch to the W4A receiver or the belly antenna for the 17AX and turn to a leg of the range, allowing sufficient distance for a gradual turn. Then fly down the leg over the cone in the normal manner. Figure 396 shows the flight.

Volume control setting is very important when homing on a station. The normal reaction upon approaching the station is to keep the volume low and the null too wide. This is incorrect and the null should be kept about 5 degrees wide **PROVIDING** that the volume control adjustments are *very infrequently* made. If the null suddenly becomes very sharp the plane is about to pass over the station. A severe reduction in volume at this time may result in flying past the station without any indication. If any error in volume setting is to be made, allow the volume to be too high. If the signal becomes uncomfortably loud on approaching the station, move the earphones forward on your head. Under no condition cut the volume control so that signals are weak off the null. On the contrary, the volume control should *never be radically readjusted while homing,* and should be kept definitely on the loud side.

An alternative method of approaching an airport where regulations require coming in on a certain beam leg is to fly the airplane to a leg directly after orientation.

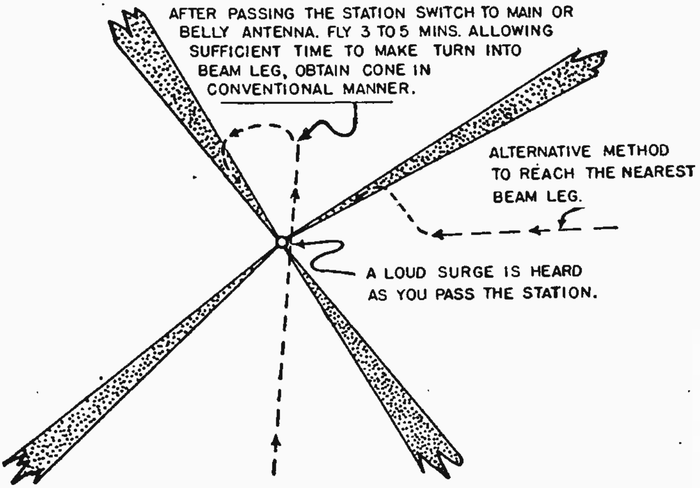


FIG. 396. Alternate Method of Approaching Airport.

45. A–N Problems Using the Loop—When not using the loop leave it in the "rain static" position, never at intermediate angles, for less drag and icing result.

With the *Black Needle* **ON ZERO, RECEPTION IS AT A MINIMUM FORE AND AFT.** No cone of silence will be heard but a **LOUD SURGE** will be heard upon passing over the beacon station, *providing* the volume control *has not been rapidly decreased* because of the disappearance of the null.

With the *Black Needle* in either "**RAIN STATIC**" (90 degree) position, **RECEPTION IS AT A MAXIMUM FORE AND AFT.** Stations off to either side will be received weakly unless the loop is turned. **A FAIR CONE OF SILENCE IS HEARD WHEN PASSING OVER THE RANGE AND "ON-COURSE."** This cone alone should not be relied upon.

Listening for a fade (with the parallel system of orientation) is **NOT RELIABLE WHEN USING THE LOOP** as a slight angular change of heading may produce false fading or building up.

The 90 degree system will be confused when using the loop, as nulls will blot out the signal during turns. Also, a small amount of course leg shifting may result with the loop in certain positions so that great care to determine the quadrant signal must be observed when making the 90 degree "orientation" turns in particular.

The loop orientation method explained is the proper way to solve orientation problems using a loop antenna.

46. The Instrument Approach Systems—The two instrument approach systems which are in use today combine all of the radio navigation aids. These systems will be classified as the Army System and the Department of Commerce System.

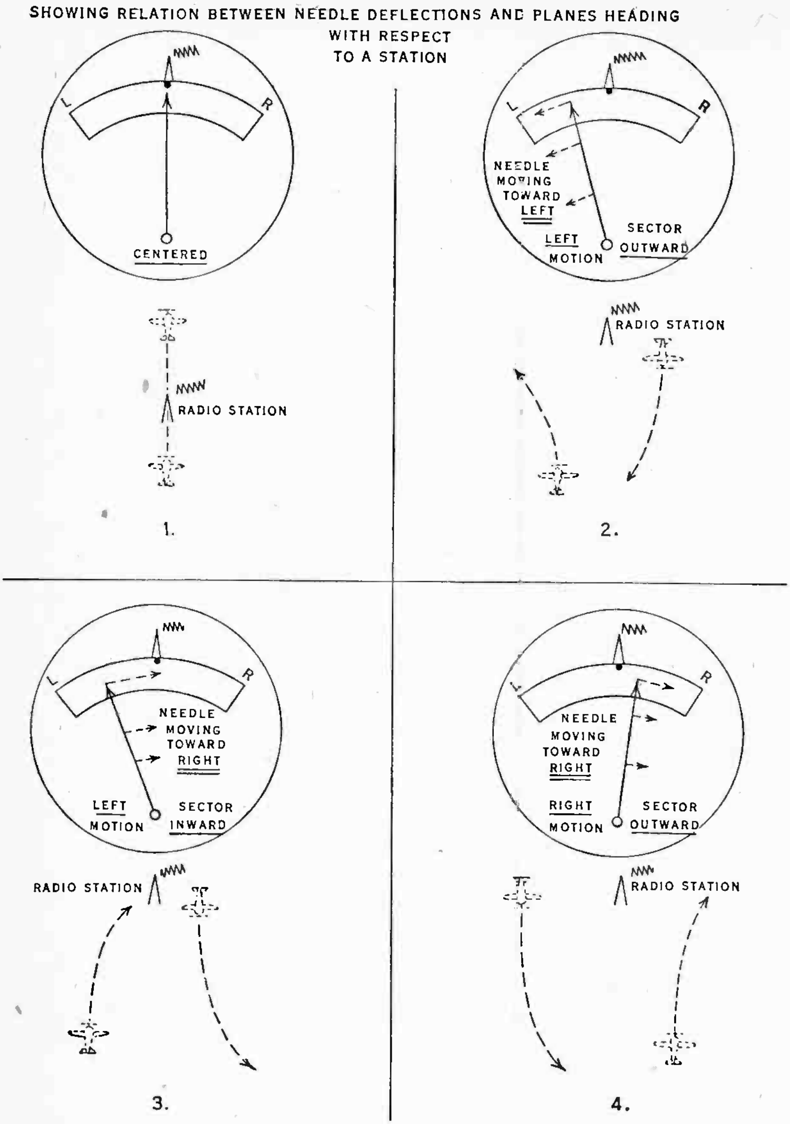
Army System—The Army System utilizes two marker stations which are aligned with the runway on the airport. These stations are approximately two miles apart. The outer station being about two miles from the edge of the airport, the inner is generally about 1/4 mile from the end of the runway.

At each station there is an ultra-high frequency marker transmitter at the same frequency. These marker transmitters send out a signal in the shape of a fan which will actuate a receiver in the plane for about 150 feet before and after passing over either station when on the runway course. The marker signal extends upward to about 10,000 feet above the station and extends to the right and left of the station for approximately 3000 feet on each side, i.e. at right angles to the runway course. The exact shape of the marker area is not important and will vary with the particular system of arrangement.

At each of these marker stations there is also a non-directional low frequency transmitter, each of which has a *different* frequency.

The airplane is equipped with a radio compass which can be tuned to either non-directional low frequency transmitter. In addition to the radio compass in the plane there must necessarily be a high frequency marker receiver. This receiver may indicate aurally, or visually by means of a light, and for the purpose of illustration in this text the visual indication will be used. This marker receiver is permanently tuned to the marker frequency so that on passing over either of the two stations a light flashes, giving a positive cone of silence indication.

47. Analysis of Needle Movement—To study radio compass needle movement under various turning conditions, let it be assumed that the meter of the radio compass is one in which the needle *moves*


SHOWING RELATION BETWEEN NEEDLE DEFLECTIONS AND PLANES HEADING
WITH RESPECT
TO A STATION
L
R
CENTERED
RADIO STATION
1.
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NEEDLE
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TOWARD
LEFT
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RADIO STATION
2.
L
R
NEEDLE
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TOWARD
RIGHT
LEFT
MOTION
SECTOR
INWARD
RADIO STATION
3.
L
R
NEEDLE
MOVING
TOWARD
RIGHT
RIGHT
MOTION
SECTOR
OUTWARD
RADIO STATION
4.

Fig. 397.

to the right when applying *right rudder* and flying toward a station. This means that any station which is forward of the plane's beam will cause a needle movement to the *right with right rudder* and to the *left with left rudder.* A station to the rear of the plane's bearing will cause opposite needle movement, i.e. right rudder will give left movement.

A careful study of figure 397 (page 808) will aid in understanding the following explanation of radio compass needle movement.

Assume that a plane is approximately 25 miles from a station and headed toward it on a northerly course. The needle movement will be analyzed as the plane makes a 360° left turn.

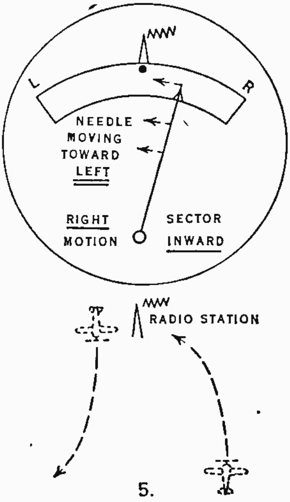

FIG. 397—5.

First of all, as the plane is headed directly toward the station, the needle will be centered. As the plane turns toward the left through the N.W. quadrant (figure 397–2) the needle will show gradual left deflection, reaching a maximum on the plane's westerly heading (i.e. when the station is to the right and at right angles to the fore and aft lines of the plane). As the plane continues its turn through the S.W. quadrant, the station becomes farther and farther astern. Therefore the needle movement must necessarily be opposite to what it was in the N.W. quadrant (figure 397–4). From a maximum left deflection (on westerly heading) at right angles to the station, movement of the needle will decrease gradually until it centers and the plane will then be on an approximate southerly heading (station directly astern). As the plane continues through the S.E. quadrant (figure 397–4), the needle will continue its right movement until, when on an approximate easterly heading, the needle will have reached its maximum right deflection (i.e. station to the left and at right angles to the plane's heading). As the plane completes the circle through the N.E. quadrant (figure 397–5 the station once more is brought forward of the beam and consequently the needle will move toward the left thus bringing the needle from its maximum right deflection on an easterly heading toward the center as the plane's head is turned back to the original northerly heading.

It will be noted that with the station *forward* of the beam *any left turn will produce left movement of the needle regardless of whether the position of the needle lies in the left or right sector of the dial.* A right-hand turn with the station *forward* of the beam gives right movement of the needle.

With the station to the *rear* of the beam it will be noted that *any left turn will produce right movement of the needle* regardless of its position whether in the right or left sector of the dial. With a right turn and station to the *rear* of the beam, *left* needle movement takes place.

48. Operation of Army System—In utilizing the Army System for an instrument approach, various plans and arrangements have been devised and all of them accomplish the desired result in the end. However some are faster than others. A procedure suggested and tried with success by Transcontinental & Western Air, Inc.,. is probably the easiest and quickest method of instrument approach. This method will be briefly explained.

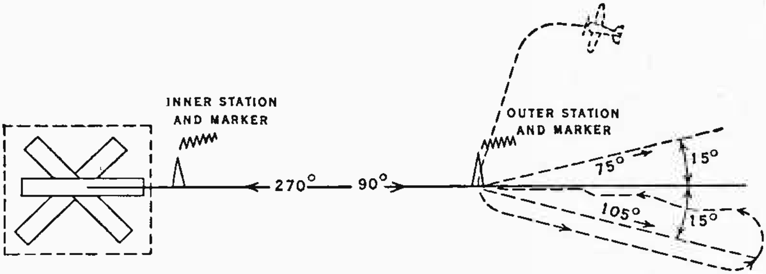

FIG. 398. Arrangement of the Army System.

Figure 398 shows the arrangement of the Army System. The pilot's first step is to head for the outer marker. When any doubt exists as to the plane's position with respect to the station, the plane should always be put into a left turn (purely for standardization) as it may be immediately ascertained whether the station is forward of the plane's beam or not, by observing the motion of the needle. The needle will eventually move *left* and *inward* toward center, which is the combination that the pilot desires, indicating that the station is in the left forward quadrant and that therefore the needle will soon center, at which time he will be headed directly toward the station. The course in this example will then be south. The gyro must now be set to agree with the magnetic compass.

The pilot now refers to an approach diagram of this particular field. (See figure 398.) He finds that on passing over the outer marker he has a choice of flying either 105° or 75°. Either of these two courses being 15° to the right or the left, respectively, of the reciprocal course of approach to the runway, which is 270°. Since the original position of the plane was north of the outer marker, the pilot would rather naturally choose the 105° course which he follows for a prescribed period of, say, three minutes. This period of time should bring him far enough south of the "runway course" of 270° to enable him to make a gradual left turn through an arc of 195° to the plane's correct approach of 270°. When on this heading the radio compass needle should be centered at zero if the plane is in correct alignment with the runway (and markers). If, however, the radio compass needle points to the left, with the gyro reading 270°, the plane must be south of the runway course. If the needle registers right indication the plane must be north of the required course. In all probability, only a slight correction will be necessary.

On passing over the outer marker on the 270° heading (marker indicates passing) the radio compass is tuned to the inner station and the needle should still be centered. Should there be signs of left deflection, a slight change to the right in heading is necessary. After these necessary corrections, *the plane's head must always come back to 270° with a center reading of the needle in order for the plane to be correctly on the runway course.* Shortly after passing the second marker the ground lights or field should be visually picked up and the landing made in the normal manner. Throughout this discussion it has been assumed that rates of descent and airspeed have been properly handled.

The essential steps of the Army Approach System described above are summarized as follows:

1. Set the directional gyro in accordance with the magnetic compass. (Whenever the plane is steadied on a heading for any length of time the directional gyro should be checked and made to agree with the magnetic compass.)
2. Tune the radio compass to the frequency of the outer station.
3. Turn *left* as far as it is necessary until the radio compass needle moves to the *left* and *inward.*
4. Fly to the outer station.
5. When the marker light appears, put the plane on a course away

from the station and at an angle of 15° to the runway bearing *from* the station.

6. Fly three minutes and then turn left 195°, until heading 270° by gyro. Should the radio compass needle be to the right or left of center, alter course to right or left accordingly so that when again headed 270° the needle is properly centered (270° value refers to this example only).
7. Upon passing over the outer station as indicated by the positive cone indication light, immediately tune the compass to the frequency of the inner station.
8. Fly toward the inner station, noting any tendency of left or right movement in the radio compass needle, with the plane headed 270° by gyro.

Other methods of making this approach rely upon the plane being aligned on the runway course by alternately tuning in one station and then the other.

49. **Automatic Radio Compass**—The Automatic Radio Compass as developed by Les Laboratories, Le Materiel Telephonique, an associate company of the International Telephone and Telegraph Corporation, differs from the radio compass described in paragraph 47 in that the latter merely indicates the deviation of the airplane from its proper direction in terms of "left" and "right" deviation and, therefore, is strictly a homing device; while the automatic radio compass, a description of which follows, permits of the determination of the location of an airplane from bearings taken on radio range, broadcast and other radio stations whose exact location is known.

The type R.C. 5 E. Automatic Radio Compass developed by Les Laboratories, Le Materiel Telephonique has been subject to exhaustive tests by both civil and military aviation authorities in France and other European countries and approved as an advanced radio navigation instrument in the field of aeronautics. It is now being demonstrated in the United States by the International Telephone and Telegraph Company. The author is indebted to H. Busignies of the Les Laboratories L.M.T. and the International Telephone and Telegraph Corporation for the following description of the principle of operation and application to air navigation of this instrument and its associated apparatus.

50. **Principles of Operation (R.C. 5 E. Automatic Compass**—A receiving loop aerial turning regularly around a vertical axis permits maximum reception every time that the plane of the loop

passes in the direction of the transmitter. If the loop turns regularly at a certain speed, a certain number of maxima and minima of receptions per second can therefore be observed in a receiver tuned on a transmitter.

A rotating speed of five revolutions per second has been chosen. Maxima and minima of receptions, therefore, take place at the rate of ten a second.

The phase of these maxima and minima, i.e., the moment at which they occur in connection with a given origin, depends on the direction of the transmitter in relation to the axis taken as origin. If the loop turns regularly, these maxima always appear when the plane of the loop points in the direction of the transmitter. If the location of the transmitter changes in relation to the radio-compass, the minima and maxima phases also change. This changing of phases is utilized in the apparatus to obtain the automatic indication.

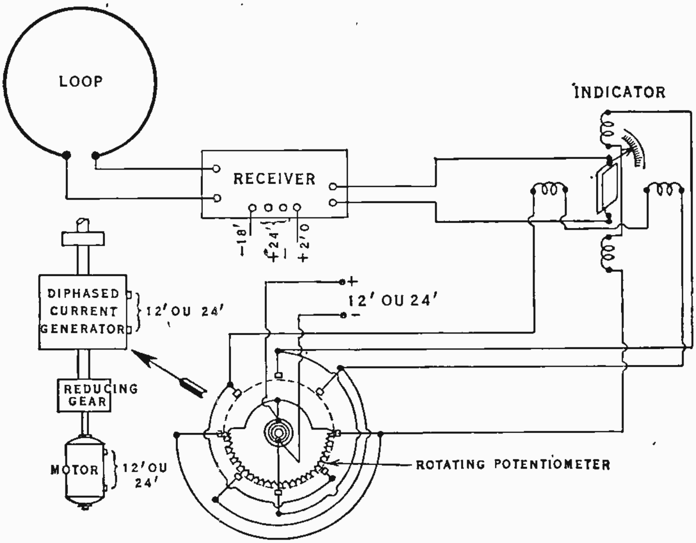

Fig. 399. Schematic Layout of Equipment.

The high frequency waves received in the loop pass through amplifier, detector, and low frequency amplifier stages in the receiver. In the output stage a variable current, representing the maxima and minima of reception, with phases identical to the phases of the wave received, is thus obtained. To obtain the measurement of phase in the indicating instrument, it is necessary to adopt a known origin as point of reference. This origin is obtained by placing on the rotating axis of the loop a 2-phase alternating current generator, the phase of which is therefore constant in relation to the revolutions of the rotating loop.

The variable current obtained at the output stage of the receiver, representing the maxima and minima of reception caused by the rotation of the loop, and the two phase currents from the generator are fed into a special, improved phasemeter. The two phase current creates a rotating field in a magnetic stator, comparable to the stator of a synchronous motor. This field rotates

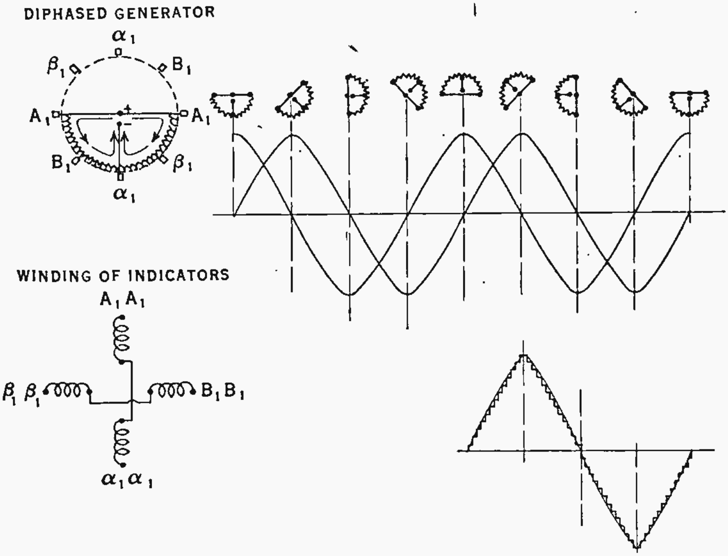

Fig. 400. Showing Output Waveform of Two Phase Current Generator.

at a speed double the speed of the loop. The variable current from the receiver actuates an armature carrying a pointer associated with a dial. In this armature, therefore, an alternating current is produced by the rotation of the receiving loop and, in the stator, a fixed phase rotating field exists due to the two phase current generator. Thus the magnetic reactions of one flux on the other give a definite position to the armature, which sets itself perpendicular to the flux when the current going through it is maximum, thereby indicating the desired phase relationship and, as will be evident later, the direction of the transmitter.

51. General Layout—The 2-phase current generator consists of a revolving potentiometer, fed by d.c. current, rotating between fixed brushes. The result is the production on these brushes of an angular potential waveform but this is rendered sinusoidal by the inductance of the stator of the indicating apparatus. The final result is an ordinary 2-phase alternating current. Accordingly, an indication can be obtained at any distance, as only one simple electric link between the indicator and the other parts of the equipment is employed.

The potentiometer consists only of half a circumference since there are two maxima and two minima for each revolution of the receiving aerial, i.e., two periods of the variable current at the output-stage of the receiver for each one revolution of the loop. In order to synchronize the two phase currents with the variable current at the output-stage of the receiver, it is necessary that they should have the same frequency as the variable current. It is, therefore, necessary to double the rotation speed of the rotating magnetic field by doubling the frequency of the two phase currents relative to the rotating frequency of the loop. This is done by a 2 to 1 gear.

The indicators not only utilize the current maxima to show the direction, but they also entirely integrate the variable current due to the signal. Therefore, the sensitivity is very high and the stabilizing of the indicators is proportional to sin α (α being the angle through which the armature might be artificially pulled out of position).

52. Description—Figure 401 shows the equipment. "*A*" represents the receiving loop. Beneath it, the high frequency collector, which gathers the currents generated in the loop and, also, the high frequency transmission line leading to the receiver are mounted. "*B*" is the 2-phase small generator, the reducing gear, and the motor operating the receiving loop.

The receiver *D* and the rotating loop *A* are remote-controlled by a small control unit, comprising simply the mechanical remote tuning of the receiver, a volume control to adjust the signal intensity, and a main "on" and "off" switch which, in a third position, starts the rotation of the loop.

Two indicators are utilized. One is called "navigator's indicator" and the other, "pilot's indicator." In the first, the indication is read on a movable dial graduated in 360° and moving in connection with a fixed pointer. In the second, the indication is limited to plus or minus 15°. The first is called "navigator's indicator" because it allows any of the crew of the airplane taking bearings to determine the position of the plane in relation to any given transmitter located around the plane. The second is specially limited and designed for flying toward any given transmitter, and especially concerns the pilot. It represents an important advantage over the so-called "homing" systems, and permits correction for drift.

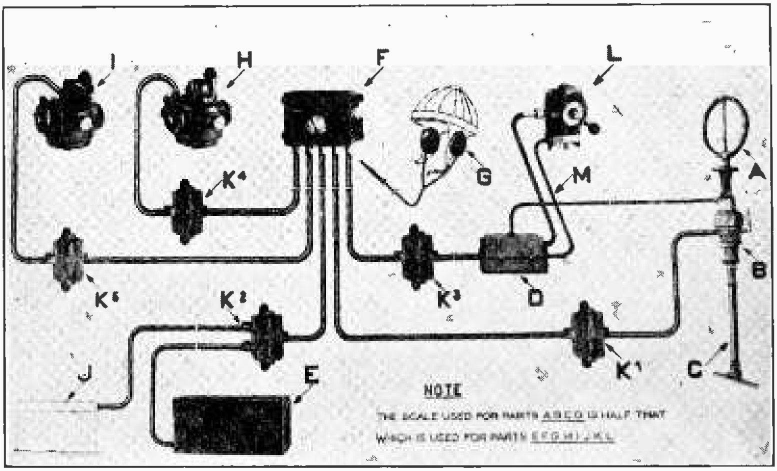

FIG. 401. General View of Equipment.

By means of this indicator the pilot can modify the reference axis by ± 15° in such a way that by altering his pointer the same number of degrees as the angle of drift he can steer with his indicator on zero and thus fly a great circle course directly to the transmitting station. This would not be possible with a so-called "homing" device. In fact, for this facility, it is necessary that the indicating apparatus itself indicate angles and that it be not limited to indicating a movement to the left or to the right. *E* is the converter for the plate voltage; this converter is fed by the storage battery *J*.

The junction boxes K_1, K_2, etc., allow replacement of any part of the apparatus.

The receiver is shock-proof mounted; the wave-length range (covered in two steps) is 200–2000 meters (1500–150 kcs.). The radio compass is entirely supplied by the airplane's battery, 24 or 12 volts, and will operate correctly with a current variation of ± 15 percent.

When piloting, it is difficult to maintain an indicating graduated dial on a predetermined value and pilots prefer to keep a needle in one position without figures, even if they have to do the setting by other means. It is this principle which is used here.

The radio compass does not itself indicate the "sense" of direction. It will be shown later that there are several ways of eliminating this 180° ambiguity.

A relative distance-meter has been incorporated in the equipment. This is a milliammeter in the automatic volume control circuit which indicates the relative strength of the signal. With this distance-meter, the approach of the station can be seen continuously and the attention of the pilot called when he is near the station.

The total weight of the apparatus without the wiring is 48 pounds. Depending on the size and type of the airplane, a few pounds must be added for wiring.

53. Installation on Planes and Quadrantal Deviation—Installation on board airplanes gives rise to a certain number of problems.

The first is the deviation of the waves due to the metal parts of the airplane or to the closed circuits formed by them. These deviations are constant and cause errors in bearings which may be as much as ± 10° or 15°. Nevertheless, by choosing the proper location for the loop it is possible to reduce these deviations to a small figure, sometimes even to zero.

Another problem is to satisfy, at the same time: the condition of location of the loop and other parts, and the condition of the possibility of mounting the parts inside the plane.

From this last point of view the reliability of the equipment is very important and it is pointed out, that all the parts of the equipment are independent and can be installed in any location on board; the transmission line between the loop and the receiver can be any length up to a maximum of 10 meters.

Extensive study has been made of the deviations called "quadrantal deviations" and there has been found, for the usual "shapes" of planes, the best loop location to minimize the deviation.

However, due to the fact that it is sometimes difficult to put the loop in the best position from the radio point of view, there has developed two useful processes to avoid the necessity of consulting a correcting table after checking bearings.

The drag due to the small loop stopped in any position is about 7 pounds at 110 miles per hour and increases only 15 percent when rotating.

This increase is constant for any greater or smaller speed. The effect of rotation is very small because the speed of the sides of the loop is small in relation to the speed of the air stream.

However, to reduce the drag in very high speed planes, loops have been partially recessed in the fuselage and covered with a stream-lined housing. When the loop is half recessed, the attenuation is of 4.5 decibels, which is an acceptable figure. The circuits located on each side of the loop are adjusted to compensate the quadrantal deviation due to the fuselage and reduces this deviation from ± 12° to ± 2°.

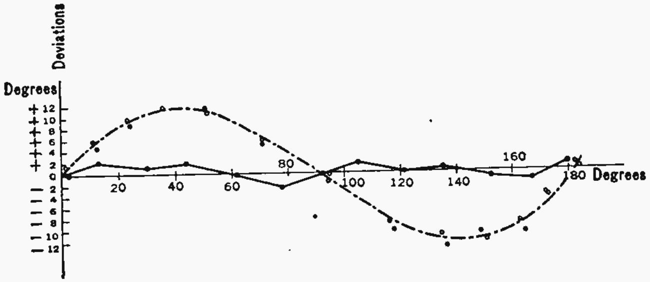

Fig. 402. Reduction of the Quadrantal Deviation by Compensating Circuits.

When this process of compensation is not utilized, it is possible to avoid the use of correcting curve by means of a small instrument called the "Radio-navimeter" which, by adding the true geographic course of the plane with the angle of bearing of the radio station relative to the plane, directly gives the true bearing of the station in relation to the north.

It is only required to put two pointers on the angular values found, and a cam, adjusted according to the deviation curve, automatically operates these corrections, and then assumes true readings.

It should be noted that in "homing," this instrument is not required, the reference to the North not being used and the deviations for angles near zero degree being negligible. Figures 403A and B show two views of the "Radio-navimeter," front and rear, and between them the cam before adjustment.

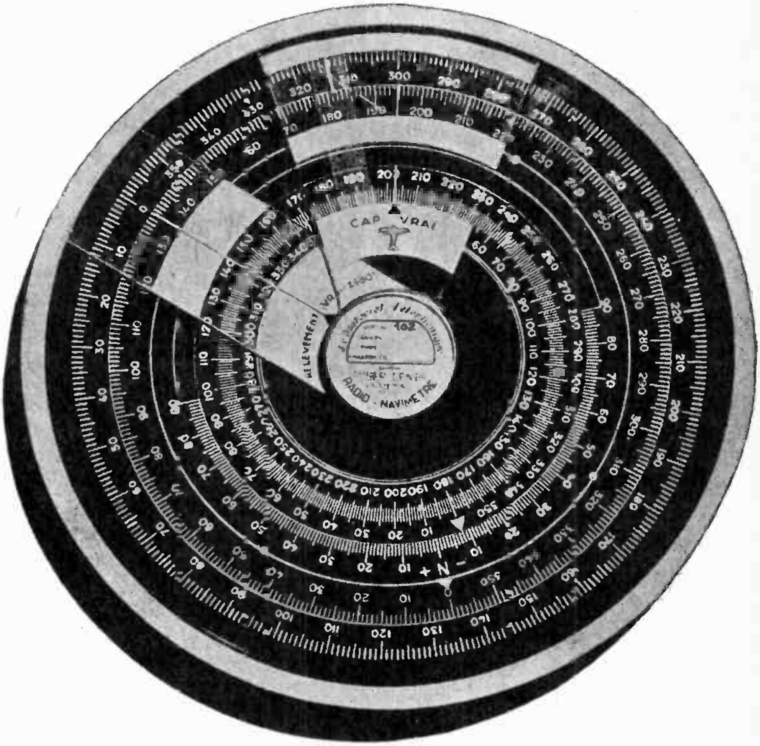

FIG. 403, A. Front View of Radio Navimeter.

54. **Accuracy**—The guaranteed accuracy of the apparatus is ± 2° for a distance of about 500 km. from a 300 watt transmitter. Figure 404 shows how, by the adjustment of polar pieces in the indicators during the development, the error curve of the indicators has passed from curve 1 to curve 4 by curve 2 and 3; the tolerance in manufacture is ± 1°. This error is the only one in the radio compass. The receiver is very sensitive and, in most cases, this sensitivity is not fully employed.

55. Interference—As indications are given automatically, an important point is the question of interfering transmitters. When using the equipment on broadcast transmitters and radiobeacons, interference is not to be feared, due to allocation of wavelengths. However, the use of broadcasting stations operating on common wavelength is recommended only when near the station used (50 miles).

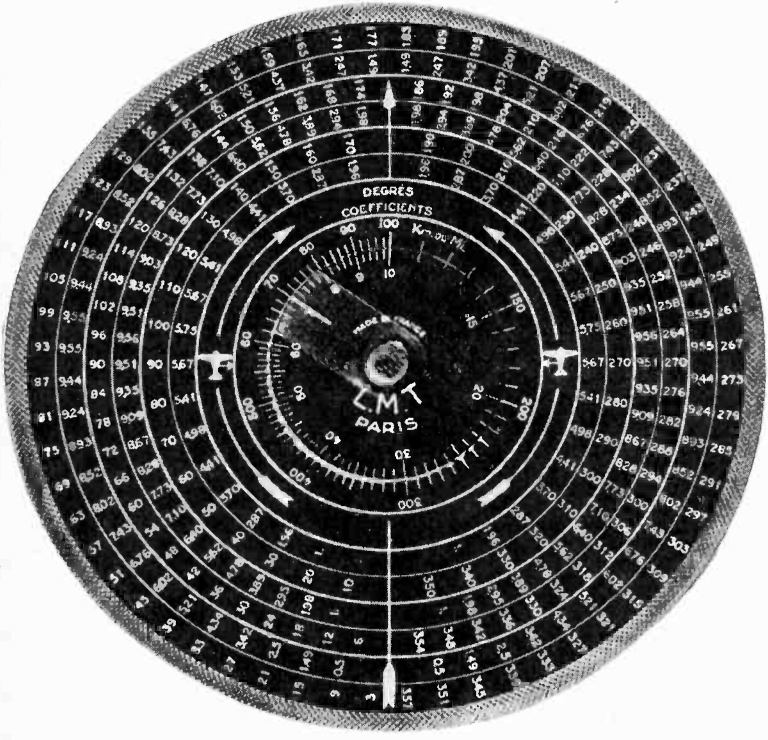

FIG. 403, B. Rear View of Radio Navimeter.

Very exhaustive experiments have been made on the question of interference. Two stations of the same power, at the same distance, were used, situated 90° one from the other, which is the worst case as regards interference: the frequency of one station was varied in order to note when it would start and when it would stop interfering with reception of the station having a fixed frequency.

A difference of 1 kc. between the frequencies of the transmitters is sufficient to give a correct indication on the fixed frequency transmitter. However, interference, if any, can both be seen and heard, and thus the operator is warned against the use of such indications.

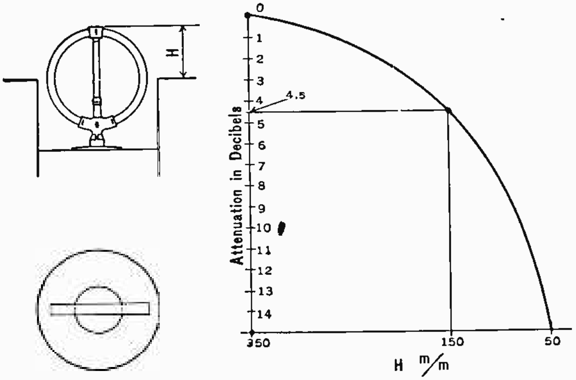

FIG. 404. Recessed Loop; Attenuation of the Signal.

56. Night Effect—Like all radio direction finders, the apparatus can be affected by the "night effect" produced by the fact that at night the radio direction finder receives two or more waves; the direct wave following the curvature of the earth, and the indirect waves being reflected by the ionosphere. On land this error starts at about 70 to 100 km. from transmitters employing ordinary antennae; at sea, the error starts at greater distances: 200 or 300 km.

In order to reduce this error on land, numerous means of transmission can be employed. Transmitters utilizing an aerial strictly vertical or an "anti-fading" antenna, considerably reduce these errors and the operating range increases by 200 km., which is sufficient in most cases where the radio compass is utilized. It is possible to navigate by utilizing stations situated one after the other without having to take, when starting, the most distant station. The vertical antenna-type radio-beacons used extensively in the U. S. A. give a good range without night effect.

57. Navigation with the Radio-Compass—The easiest method of navigating with the radio-compass consists in tuning the radio compass on a given station situated at the aerodrome of destination, and then to operate in such a way that the indicators show the angle as zero degree. In this way, the airplane always flies in the direction of the station and, if the wind is nil, it flies in this direction along a great circle. In most cases when drifting by wind, a curve is traced that pilots and navigators call the "drift-curve."

Figure 405 illustrates such a curve. An airplane equipped with a radio compass always has its axis directed toward station *B*, but the wind causes deviations from the course and should be allowed for. On such a curve, it is easily seen that the angle indicated by the magnetic compass, i.e., the magnetic course followed by the airplane, constantly changes; and, therefore, the true course of the plane also constantly varies. It should be noted that this curve is exaggerated for illustration purposes. The true course varies from 90° to 54° and in the end the airplane reaches the station in the wind's direction on a 37° true course. If it reaches the transmitter's aerial, it passes exactly over this antenna facing into the wind. Indication is given to the pilot by the rise of the volume of reception; and, after having passed by a 180° change in indication, the pilot is enabled to read the wind direction from his magnetic compass.

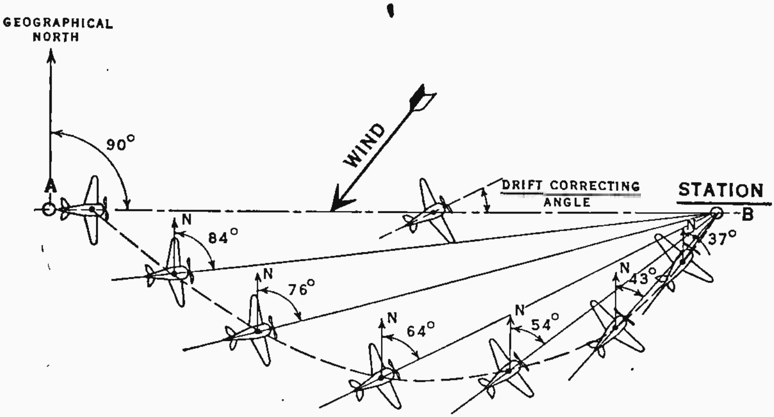

Fig. 405. Exaggerated Curve Illustrating Drift Due to Wind.

But it is possible to fly along a straight course between two points by allowing for the drift. If, after flying for a few minutes towards the station, the pilot finds that the magnetic compass angle is getting smaller, it means that the plane is drifting towards the right and that the wind is blowing from the left. Then the pilot must adjust his course with the aid of the R.C. 5 radio compass. By a method of trial and error, the correct drift angle can be found and thus the airplane can be maintained on a great circle course towards the station. It is the course which gives a constant reading of the magnetic compass with a constant indication of the R.C. 5 radio compass. Thus, when the correct drift angle has been determined, the pilot flies with the magnetic compass and radio compass readings corrected for drift.

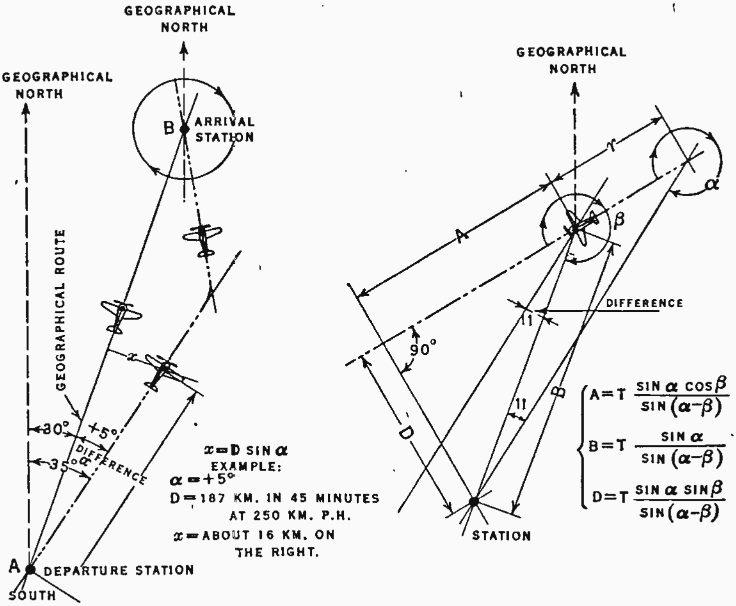

FIG. 406. Illustrating Methods of Correcting for Drift.

Referring to the left portion of figure 406 assume that, from the point *A*, the pilot wishes to maintain a course 30° from the geographic north. He notes after a certain time that, with a 0° bearing of his radio compass on transmitter *A*, his magnetic compass indicates a difference of 5°. This difference enables him to determine the approximate distance he is off his course. If the angular difference had been negative, the pilot would have known that he was on the left of his course. The same process can be utilized with station *B*, but in this cause a positive difference indicates a deviation to the left, and vice versa. The sign and the value of the difference after a determined time of flight give to the pilot the sign and the value of the drift due to the wind permitting the pilot to correct the major part of the drift.

The right portion of figure 406 represents a general case where there are no stations either at the point of departure or destination, but where there is a suitable station situated on the side. Formulae for determining the distance of the plane from this station are indicated in the illustration.

Obviously, neither the pilot nor the navigator would have the time for applying these formulae on board an airplane. Simple course and distance calculators which can be read very quickly have been made and are a part of the " Radio-Navimeter." Given, on the one hand, the distance traveled from T_1 (the product of speed by time in a direction known) to T_2; and, on the other hand, the angles of two bearings taken on the station, the pilot can determine his distance from the station. Information of this character is, of course, highly useful and is readily obtainable by reference to a regular broadcasting station in cases where a transmitter is not available at the points of departure or arrival.

Suppose that the plane is going in a certain direction and that it keeps a steady course. The pilot looks at the radio compass indications and, for example, reads 30°, at the same time noting the exact time. After an interval of 5 minutes at an air-speed of 300 km. per hour, i.e., after flying 25 km., he reads 36°. On his Radio-Navimeter (rear part) he finds the coefficient 4.78 for 36°, and a simple multiplication of this coefficient by the distance he has just flown will give him the distance at which he is from the station, i.e., about 120 km.

When flying a fair distance away from the transmitter the possibility of not knowing the location of the transmitter is small. However, near the transmitter, it might be difficult to locate the exact position (180° fault).

There are two main methods of coping with this situation: (1) there is the intensity variation of the received wave given by the distance indicator, which naturally increases or decreases according to the direction of flight to or from the transmitter very quickly near this transmitter; (2) a 90° deviation to the right of the true course and maintaining this course on the magnetic-compass. A decrease of the radio compass reading indicates that he is flying towards the station, whereas an increase points to the fact that he is flying away.

The larger the difference in these readings the nearer the airplane is to the transmitter.

In general as the radio compass gives the possibility of taking bearings all around the plane, on a great number of stations, it is always possible to determine the position of the plane by a number of bearings, thus eliminating the 180° ambiguity.

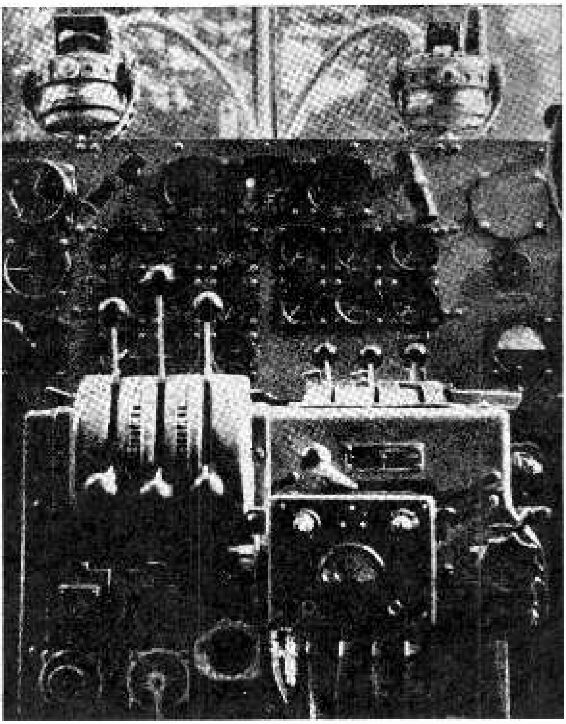

FIG. 407. Pilot's Cockpit Showing Indicator and Control Unit of the Type RCS Radio Compass.

58. Applications to Landing—The fact that, with a radio compass, the airplane passes just over the station towards which it has been flying, leads to the possibility of using the R.C. 5 for landing under conditions of bad visibility.

With the radio compass the exact location of a transmitter can be found; thus this transmitter becomes a marker beacon. From this very accurate position, the pilot can take the true direction of the landing field with the directional gyro, since he knows the position of the transmitter acting as a marker.

First, it should be noted that the airplane is fitted with a sensitive altimeter which, before the landing, must be adjusted to the actual atmospheric pressure of the aerodrome.

Second, a directional gyro is of great assistance to the pilot during the last stages of the approach.

The passing above the radio station is accurately noted. The attention of the pilot is called by the variation of the distance indicator and when he passes just over the antenna the radio-compass indication turns to the left during a few seconds, comes back to zero, turns to the right a few seconds and again comes back to zero.

Part III. Blind Landing Systems

59. Blind Landing of Aircraft—In both the Bureau of Standards system and the Lorenz (German) blind landing systems a landing direction and a gliding path are marked out by low power short-wave radio beams of special type having no immediate connection with the radio range beam used to guide the aircraft to the vicinity of the field. The indications received in the aircraft may be either audible (headset) or visible (indicating devices on instrument board). The Lorenz system has been used extensively in Europe and somewhat in this country. The American (Bureau of Standards) system has a long history in which the present form first became visible during the 1928–30 experiments of the Research Division of the Aeronautics Branch of the Department of Commerce at the National Bureau of Standards.[1] The following account is abstracted from a paper by Mr. Harry Diamond in the Proceedings of the Institute of Radio Engineers, January 1934.

60. Bureau of Standards System of Blind Landing—The system employs three elements, a runway beacon, marker beacons, and a landing beam, to provide continuous and accurate information on the position of the airplane in three dimensions as it approaches and reaches the instant of landing. The first stage of development of the system has been previously described. The present paper gives details of the final stage of the development

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[1] Harry Diamond and Francis Dunmore, A Radio Beacon and Receiving System for Blind Landing of Aircraft. Proceedings I. R. E., April 1931. Bureau of Standards Journal of Research, Paper No. 602, October 1933.

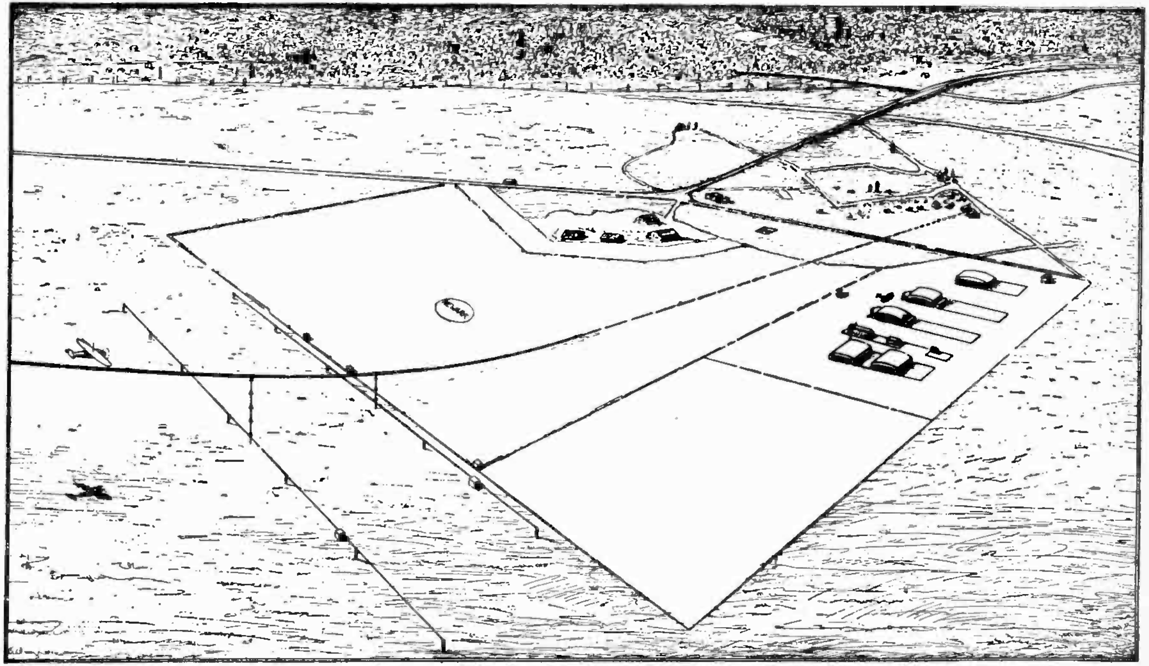

Fig. 408. Three-dimensional View Illustrating Bureau of Standards Radio Landing End at the Newark, N. J., Municipal Airport.

work which comprised the engineering redesign of the system to meet the requirements of practical use.

The runway beacon gives indications of the directional position of the aircraft with respect to the airport and permits keeping the aircraft directed to and over the desired landing runway. A 200-watt transmitting set of the visual beacon type, operating on 278 kilocycles, and feeding small, multiturn loop transmitting antennas, is employed. At the Newark airport the wind, under conditions of low visibility, is usually from the northeasterly quadrant. The runway beacon accordingly is located at the northeast end of the field. With the aid of a goniometer to swing the course anywhere between the two hangar lines, it is possible to accommodate practically all wind conditions during low visibility. On the aircraft, the same receiving set used by air transport operators for the reception of radio range beacon signals and airways weather broadcasts is employed for receiving the runway beacon signals. This set is augmented by an automatic volume-control unit and by a reed converter to convert the beacon signals to pointer type course indications, given by the vertical pointer of a combined instrument. A vertical index line across the face of the combined instrument represents the desired landing runway while the position of the pointer corresponds to the relative position of the aircraft with respect to the runway.

Longitudinal position of the aircraft as it approaches the airport is given by the combination of a distance indicator on the aircraft with the aural signals received from two marker beacons. The distance indicator, operating from the beacon receiver, reads field intensity of the runway beacon and may be calibrated approximately in miles from the beacon (say, 0 to 5 miles). Absolute indication of the longitudinal position of the aircraft when near the airport is given by aural signals from two 5-watt, marker beacon transmitters. One signal, a high pitched note, is heard, when within 2000 feet of the southwest end of the airport. The second signal, a low pitched note, is received when over the field boundary. The marker beacon transmitting antennas, two to six feet high, are stretched transversely across the line of flight of the aircraft, to provide signals for all orientations of the runway beacon course.

Vertical guidance is given by a horizontally polarized ultra-high-quency landing beam (90,800 kilocycles). The landing beam transmitter feeds a directive transmitting antenna array which gives the necessary directivity of beam in the vertical plane while spreading the beam out in the horizontal plane to afford service in the 40-degree sector. On the aircraft, a simple ultra-high-frequency receiver is used, fed by a transmission line from a horizontal half-wave receiving antenna which is located in the wing slightly ahead of the leading edge. The rectified output from this set operates the horizontal pointer of the combined instrument. The receiver sensitivity is so adjusted that the line of constant received signal below the inclined axis of the beam, corresponding to half-scale deflection of the horizontal pointer, marks out a landing path which is suitable for the aircraft and airport considered. The horizontal index line across the face of the combined instrument represents the half-scale deflection and

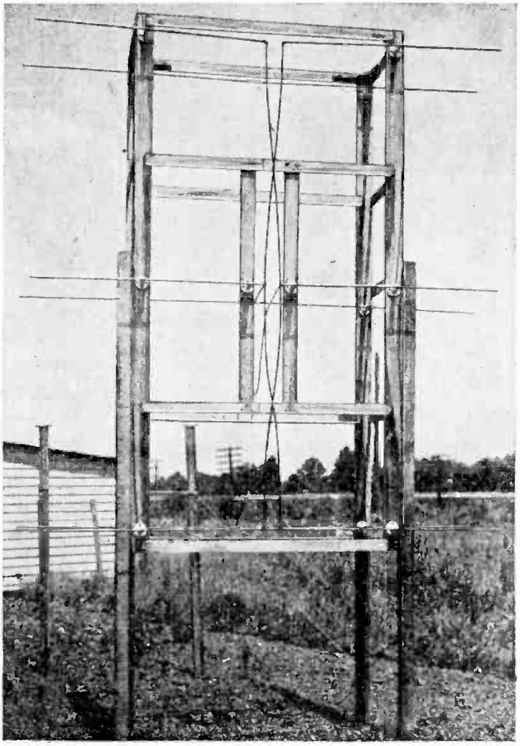

FIG. 409. Ultra High Frequency Transmitting Antenna Used for Setting Up Radio Landing Beam. (Courtesy of U. S. Bureau of Standards.)

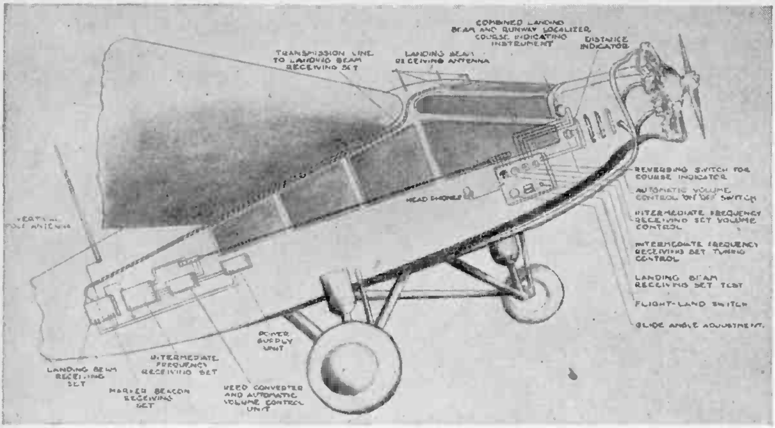

FIG. 410. Skeleton View Showing Disposition of Airplane Receiving System for Use of Experimental Radio Landing System.

corresponds to the proper landing path. The horizontal pointer represents the position of the aircraft relative to this path. The experimental arrangement of the equipment in the plane is shown by figure 410 and the apparatus in the plane in figure 411.

The vertical and horizontal index lines of the combined instrument intersect in the center of the instrument dial. The point of intersection, indicated by a small circle, represents the proper

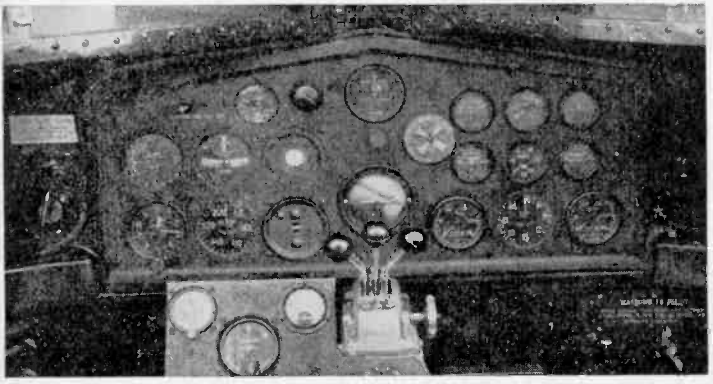

FIG. 411. Instrument Board on Plane Used in Bureau of Standards Test.

spatial landing path. The point of intersection of the horizontal and vertical pointers of the combined instrument represents the position of the aircraft relative to the desired landing runway and the proper landing path. The course indications are therefore instinctive and deviations from both courses may be corrected simultaneously. By keeping the pointers crossed over the small circle on the instrument face, a suitable spatial landing path is followed down to the point of landing. The system requires a minimum of manipulation on the part of the pilot. Once the beacon receiver is tuned to the frequency of the runway beacon, no further adjustments of tuning or sensitivity of any of the receiving equipment is required.

61. Landing Beam—The theory of operation of the landing beam is of particular interest and the following explanation is offered by Messrs. Diamond and Dunmore in their paper, Blind Landing of Aircraft previously referred to.

Consider the vertical directive characteristics of the landing beam shown in figure 412. An airplane flying in a straight line from *B* to *A* directly into the region of maximum field intensity of the beam receives a signal which increases inversely as the distance from the beam transmitter. Such a rate of increase in received signal is of little help in landing. Suppose, however, that the airplane is directed into the beam along the line *OC*, until position *G* is reached, at which point the indicating instrument on the airplane reaches half-scale deflection. At a point directly above *G*, this deflection increases, since the airplane is nearer the line of maximum intensity of radiation of the beam. At a point directly below *G*, the deflection decreases, the airplane now being farther from the line of maximum intensity of radiation. The instrument deflection thus increases or decreases with any increase or decrease in the altitude of the airplane about the point *G*. If, now a straight line were followed from *G* to *A*, the indicating instrument pointer would soon go off-scale due to the approach of

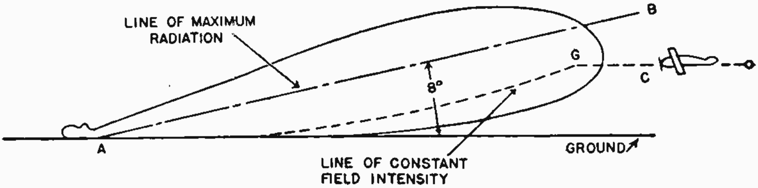

FIG. 412. Directive Characteristic of Glide Landing Beam.

the receiving system to the transmitting source. However (and this is the basis of operation of the system), by dropping away from the line of maximum intensity of radiation as *A* is approached, the instrument pointer may be held at the half-scale deflection position at all times, since the increase in signal due to the fact that the airplane is nearing the source *A* is continuously compensated for by a corresponding decrease in signal due to the angular departure of the airplane from the line of maximum intensity of the beam. The path followed by holding the instrument pointer constantly at half-scale deflection is indicated by the dotted line *GA*. Obviously this is a line of constant field intensity of definite magnitude. By properly orienting the beam vertically and giving it the proper degree of directivity, this line of constant field intensity may be made to coincide with the landing path normally followed by a pilot in clear weather.

Mr. Diamond reported experiments with an ultra-high frequency transmitting antenna in a pit below the ground surface. Service tests of the landing beam in this country and abroad have brought out the desirability of securing a steeper approach path for a given point of contact of the landing airplane with the airport surface. A practicable solution of the problem has been found by placing the landing beam transmitting antenna at the center of the landing field in a pit below the ground surface without any obstruction to the movement of aircraft. A further advantage of this location is that landing-beam service may be provided for all directions of approach to the airport the meet varying with wind conditions.

A theoretical explanation of the phenomena involved in the radiation of an electric field from the transmitting antenna shows a wave front emerging from the pit operates as a larger number of new sources which produce direct radiation to the receiving point (in the aircraft) and also indirect radiation by way of reflection from the ground surface. The two sets of radiation produce an interference pattern exactly similar to that produced by a transmitting antenna a short distance above ground. Other interesting phenomena on the effects of the ground proximity of the emitted wave were observed.

62. Lorenz Instrument Landing System—The following account of the Lorenz Landing System is reproduced by courtesy of Communication and Broadcast Engineering.[2]

Preliminary to a description of the essential advantages of the

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[2] R. Ebsner and E. Kramer, Ultra-Short-Wave Radio Landing Beam, Communication and Broadcast Engineering, March 1937.

C. Lorenz- A. G. ultra-short-wave system, it may be stated that basically it provides radio-telegraph reception, indicating the approach path to the airport, and, similarly, two distance markers governing the landing process. When developing the system, the guiding principle was to employ radio only for such purposes as could not be accomplished by other means, and at the same time provide a receiver which would be electrically independent of that used for communication purposes, thus reducing the manipulation on board the plane to a minimum. In view of these considerations and with due regard to such factors as interference from landing beacons of neighboring airports, the operating frequency had to be chosen. Because of their definitely determined operating ranges, only frequencies above 30 megacycles could be considered, both for the radio beacon and for the marker beacons.

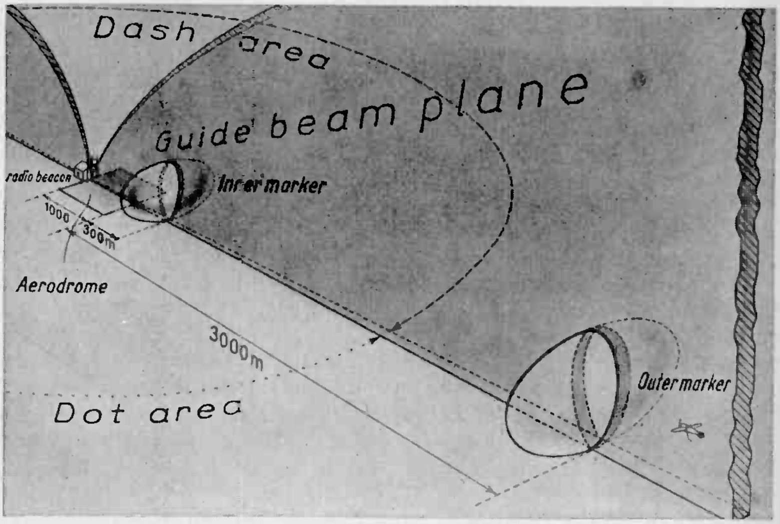


FIG. 413. Illustrating the Lorenz System.

The direction of approach in the C. Lorenz-A. G. system is based on the beacon principle, giving side or boundary indication of the landing path; and, also, at two points along this path, signals serving as distance markers, and indicating to the pilot the distance of the machine from the landing field (figure 413).

Ultra-short-waves, with their lines of constant field strength, may be utilized under specific circumstances in vertical navigation as electrical landing curves. Difficulties in their application lie mainly in the fact that the course of their curve does not correspond to the natural glide path. These difficulties have been overcome with the help of clockwork regulating instruments which reshape the normal indication obtained by means of the beam into a straight glide path. The equipment of the ground station is the same, irrespective of whether the method of electrical vertical navigation is employed or that at present utilized in Germany, viz., of landing at a constant rate of descent (figure 414).

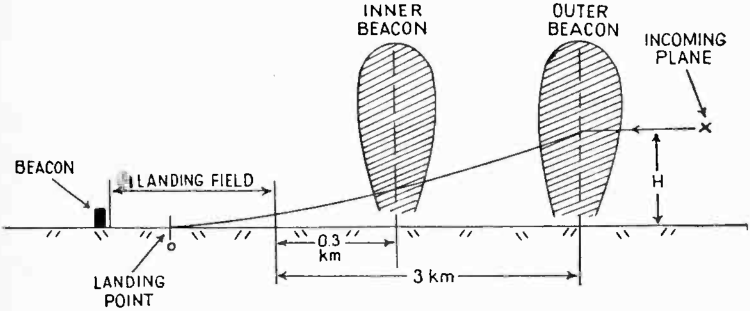


FIG. 414. Schematic Arrangement of Landing Beam.

63. Approach and Landing Process—(A portion of text is omitted here as it relates only to the process of following the long distance beam as previously described. The plane has done this and now seeks the Lorenz local "approach path" of figure 413.) The approach path sector is defined by the intersection of two radiation diagrams produced by the alternate operation of two reflector dipoles (figure 415). Should the airplane be outside of this approach path, short dots are heard on the port side or dashes on the starboard side. Divergencies off the course are again indicated both aurally and visually. By intermittent deflections to left or right of the received signal, the indicating instrument shows the direction in which the pilot should steer his machine in order to reach the approach path in which the (complementary) signals, by merging into one another, becomes a continuous note. (Exactly like blending of *A* and *N* in figure 367–*A*.) At the moment when the continuous note is reached, the direction indicator comes to rest and indicates to the pilot that he should maintain his course for a safe landing at his destination.

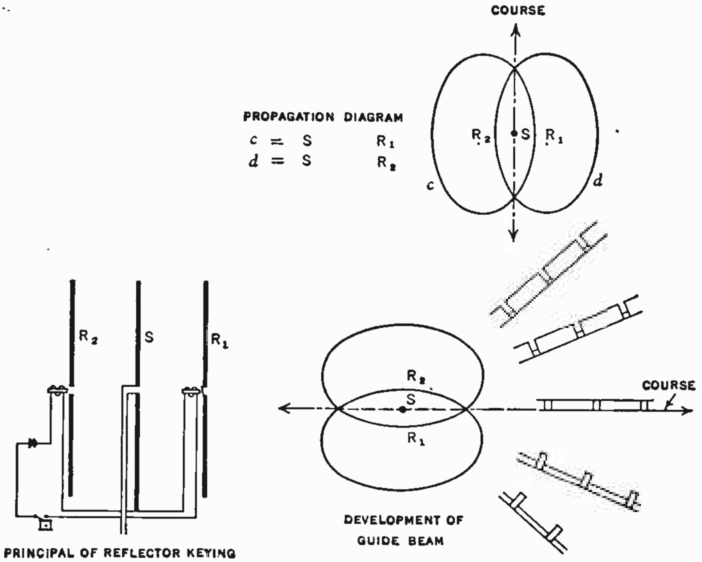


Fig. 415. Illustration of Guide Beam Zone.

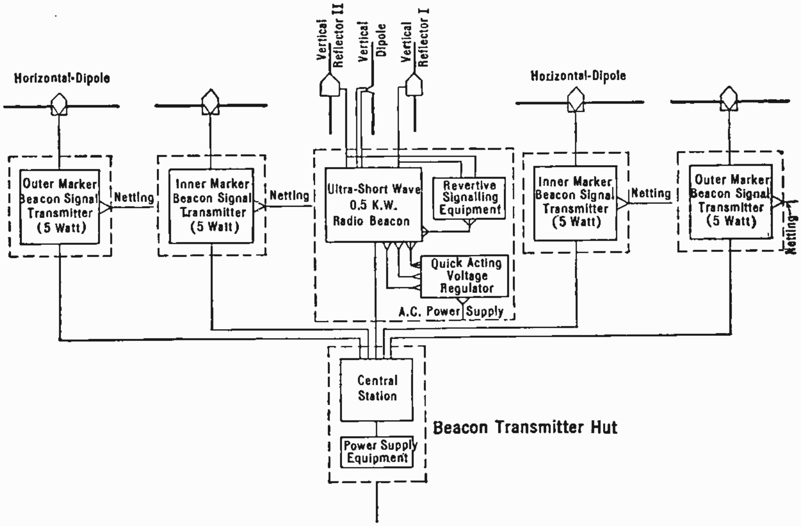


Fig. 416. Plan of a Complete Landing System.

During the approach, the pilot gradually decreases the height to about 200 meters. At about 1.9 miles from the boundary of the landing field when reaching the outer marker beacon signal,

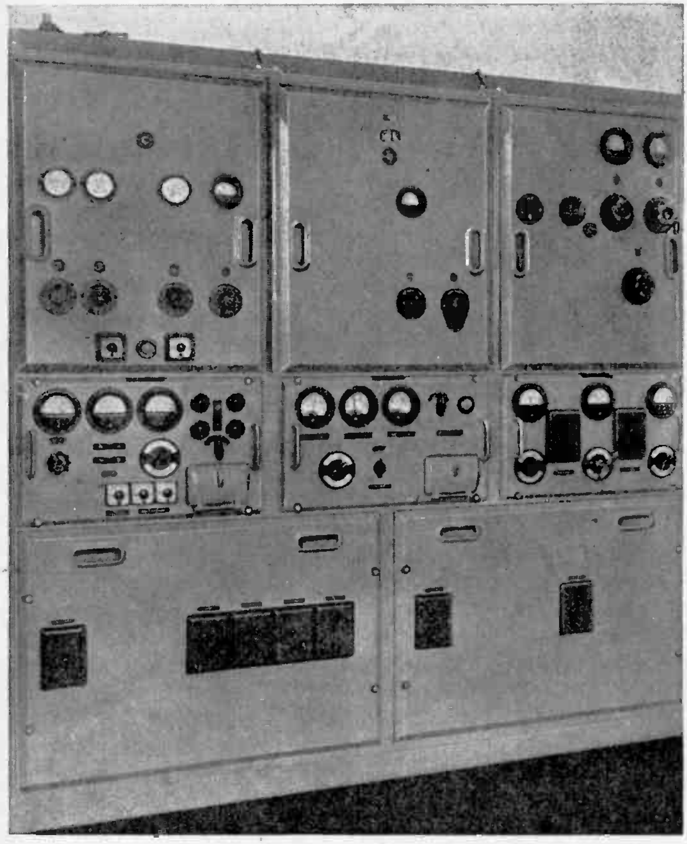


FIG. 417. The Radio Beacon Guide Beam Transmitter.

lamp ("*V*") on the left-hand side of the visual indicator apparatus lights up and, at the same time, a deep note (700 cycles) is heard in the headphones. The pilot then throttles back and gliding down at an approximately constant rate of descent reaches the admissible minimum height at the inner marker beacon. The inner marker beacon signal is given at a distance of approximately .19

miles from the boundary of the landing field—a few seconds before the machine reaches this boundary—and is conveyed to the pilot by a rhythmic short-keyed high note (1700 cycles) as well as by the lighting of the right-hand lamp *H* in the visual indicator equipment. The pilot now knows that there are no obstacles to his flight in the final section of the landing path and can, consequently, further reduce the height of flight in order that he may bring his machine down safely even when ground visibility is at its worst.

64. Design of the System—The ground equipment comprises a 500-watt guide-beam beacon transmitter together with two or four small (5-watt) transmitters for the transmission of the "signals," according to whether provision is made for one or two directions of approach flight (figure 416).

(It is here necessary to abstract the original text.) In figure 416 the two units at the left would not be necessary if all approaches were to be made from the right. The 500 watt guide beam transmitter is shown in figure 417. It employs a 33.3 megacycle crystal controlled oscillator followed by 4 amplifier stages, the last of which is grid modulated by a steady tone of 1150 cycles per second. It is this 1150 cycles steady tone which the pilot hears (or his dashboard instrument observes) when the plane is in the approach beam and on course. If the ship is *in* the beam but *off* course this tone is broken up into dots or dashes as the ship is to left or right of the course. This is shown in various ways in figures 413 and 415, also by the lower part of figure 418. This is accomplished by the antenna system of figure 419 in which the continuous radiation from the central antenna is deflected

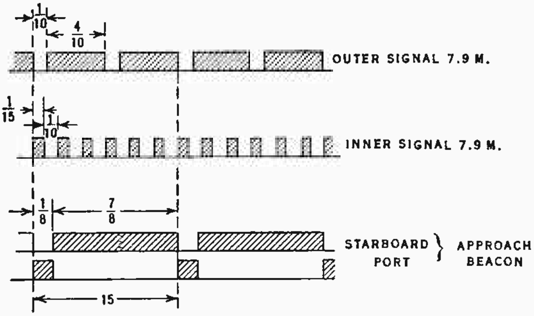


FIG. 418. Illustrating the Keying Sequence.

alternately to right or left (see figure 415) by the dot and dash keying of the reflectors at either side. Continuing along the beam the plane presently encounters another signal, which is the first "marker" 3000 meters from the edge of the field as shown in figure 414. This signal is reflected upward in the manner of figure 420 and consists of dots only (center line of figure 418) which carry a deep tone and may thus be recognized by ear or selectively received and caused to operate an indicator lamp. Near the edge of the field a similar marker sending dashes with a higher tone (top line of figure 418) is encountered. Figure 421 shows a marker transmitter. (The original text is now resumed.)

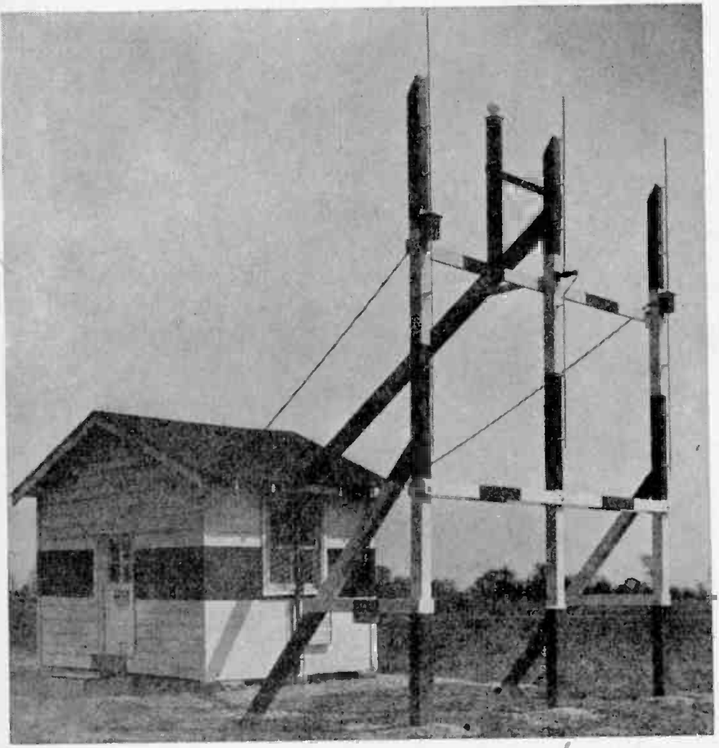
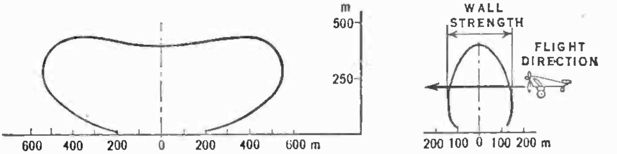


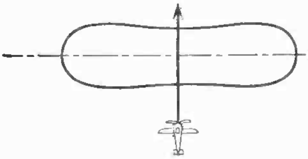
FIG. 419. Lorenz Approach Beam Transmitting Antenna (center) with Keyed Reflector at Either Side.

The operating control of all transmitters is based on the revertive signal process; the mains voltage and demodulated antenna currents from all transmitters are carried back to, and suitably indicated at, the control station.

In practice all transmitters are put in operation by means of one main switch on the remote-control panel.



(a) VERTICAL FIELD PERPENDICULAR TO LINE OF FLIGHT. (b) VERTICAL RADIATION IN LINE OF FLIGHT (WALL STRENGTH)



(c) HORIZONTAL CROSS SECTION

FIG. 420. Radiation Characteristic Curve of the Signal Transmitter.

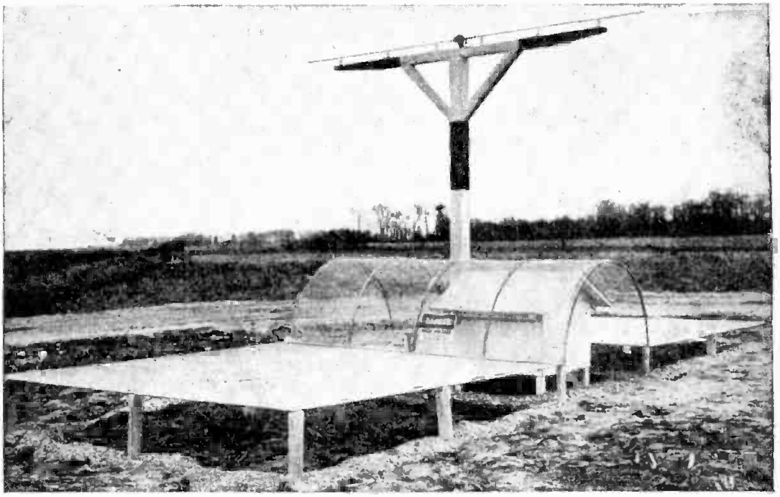


FIG. 421. Lorenz Marker Transmitter with Horizontal Dipole Antenna and Wire Netting Reflector Giving Pattern of Fig. 414.

FIG. 422. The Control Station Operated by the "Revertive" Signal Process.

When planning the ground station the direction of approach to the airport for (perfect) landing is determined with due regard to the wind direction.

The main switch on the remote-control panel with its corresponding control contacts indicated in color on the panel is so arranged that by switching either to one or the other side the appropriate marker beacons for that particular direction of approach are brought into operation. Simultaneously, by the same means, the keying of the beacon transmitter is adjusted in a manner such that dots are always transmitted to the port side of the course. These measures obviously add to the degree of safety in the carrying out of this navigation process.

On the front panel of the "control station" (figure 422) colored signal lamps show the presence of power line voltages and meters show that the transmitters are actually working the needles of these meters, swinging in the keying rhythm of each particular transmitter. Along with these purely visual signals, arrangements may be made for listening to the different keying signals and modulation frequencies. Furthermore, any trouble is indicated acoustically by the operation of an alarm whistle and visually by the warning signal of a drop indicator. In addition, simple means are provided for the quick testing of all control and revertive signal lines to all transmitters.

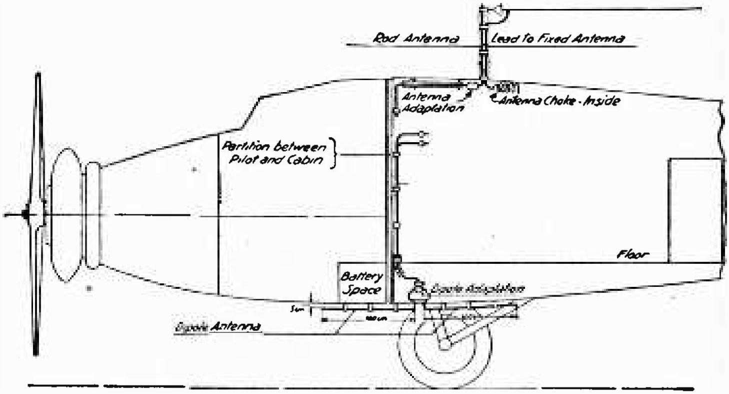


FIG. 423. The Antenna Arrangements of the Airplane Set.

Revertive signal or monitoring equipment which, in particular, is intended for checking the dipole relays and which is mounted near the transmission line, is an additional means of supervising locally the beacon transmitter.

The Airplane Receiving System consists of the receiver and two associated receiving antenna (figures 423 and 424). The apparatus for the pickup of the beacon frequency is a simple amplifier which has a high-frequency amplifier stage, a detector, and a low-frequency amplifier.

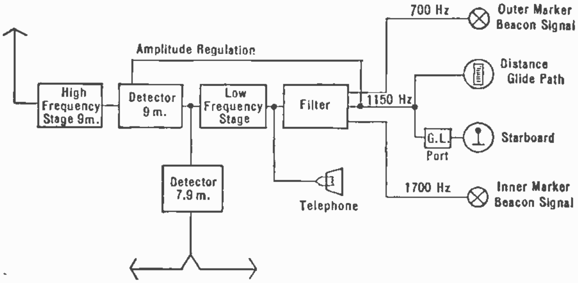


FIG. 424. Fundamental Block Diagram of the Airplane Set.

A vertical dipole about 90 cm. in length, connected through a suitable transformer to the receiver input, serves as an antenna for the 9-meter wave of the beacon transmitter (figure 424). A horizontal dipole consisting of two copper tubes about 1 meter in length is used for the reception of the marker signals. These copper tubes are fastened at an interval of about 5 cm. along the airplane and under the fuselage by means of streamlined supports, and are

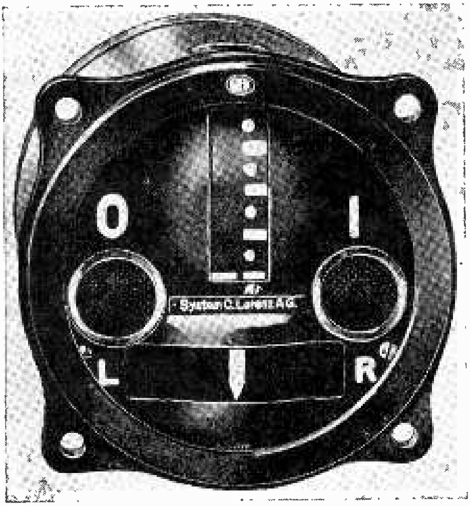


FIG. 425. Visual Indicator Equipment for the Airplane Instrument Bound.

connected through a transformer to the detector. The complete airplane receiving equipment, accordingly, consists of the beacon receiver, which contains the common low-frequency amplifier, the detector, and the frequency filter, as well as the battery box or a rotary converter. On the dashboard of the airplane is mounted the visual indicator (figure 425) which includes the two instruments indicating the distance and the deviation from the course as well as the two signal lamps.

During the approach to the radio beacon, an approximate idea of its distance is obtained by means of a vertical indicator instrument which is in the visual indicator set and which is connected through a rectifier to the low-frequency amplifier. The modulation frequency of the main beacon (1,150 cycles) governs the amplifier regulation as well as the indication of distance and divergence to the side. Special equipment which is connected to the low-frequency amplifier through a rectifying arrangement, and which is mounted horizontally in the instrument container of the visual indicator set, indicates divergences to the side and serves to clearly determine the course of the airplane. During flight, a switch mounted in the operating set on the dashboard of the airplane is placed in the "approach" position, and amplifier regulation is effected. (For the purpose of glide path landing—vertical navigation—this switch is thrown to "glide path" at the outer marker beacon signal, whereupon automatic amplitude regulation is disconnected). The airplane battery provides the power supply for the receiving set and operates the converter; the latter supplies power for the filament lamps as well as the necessary voltage for the anode circuit of the amplifier.

65. Fundamental Elements Necessary for a Uniform Instrument Landing System—Based on knowledge accumulated as a result of experience the airlines, the Bureau of Air Commerce,* the Federal Communications Commission and the Sub-Committee on Instrument Landing Devices of the Radio Technical Committee for Aeronautics have agreed on the fundamental elements which are necessary for a uniform instrument landing system. These elements are as follows:

1. *Runway Localizer*
   (*a*) The runway localizer should operate on an ultra high frequency, preferably in the band 92–96 Mc or, if the localizer transmitter is operated as a separate unit, in the band 108–112 Mc.

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* The functions of the Bureau of Air Commerce are now carried out by the Civil Aeronautics Authority.

  - (*b*) Straight course, i.e., one which has no bends or multiple courses perceptible to a pilot flying in still air.
  - (*c*) The difference in the magnitude of the two patterns of the localized should be .5 db at 1.5° either side of the center line as measured with a linear detector.
  - (*d*) The vertical needle of the cross pointer indicator should give a 10° deflection indication for a 1.9° angular deviation from the center line of the runway.
  - (*e*) The range of use as a runway localizer should be twenty miles at 3000 feet.
  - (*f*) Freedom from interference pattern effects perceptible to the pilot both in elevation and azimuth.

2. *Glide Path*
   - (*a*) The glide path should operate on an ultra high frequency, preferably in the band 92–96 Mc.
   - (*b*) A smooth glide path should be provided, i.e., one which is free from interference pattern effects perceptible to the pilot when on the localizer course.
   - (*c*) The system should be capable of adjustment to provide a suitable glide path.
3. *Markers*
   - (*a*) The markers should operate on 75 Mc.
   - (*b*) It should be possibly to positively identify each marker both aurally and visually by modulation and keying. Modulation frequency of the inner marker should be 1300 cycles and that of the outer marker should be 400 cycles.
   - (*c*) A normal arrangement of markers would be:
     - (1) At the normal intersection with the glide path.
     - (2) Near the boundary of the airport, the exact location to be determined by local conditions.
   - (*d*) The marker beacons should have an array adjustable so that when installed in the boundary position the beam will cause useful indications of a visual device within 700 feet either side of the on-course path and for 300 feet along the glide path trajectory. Indications from this marker should be receivable to an altitude of 2000 feet.
   - (*e*) The outer markers should have sufficient power to accomplish a similar visual indication with the same beam pattern at 2000 feet.
4. *Monitor System*
   - (*a*) Satisfactory means for indicating visually the operation of all equipment should be provided at a central point.
   - (*b*) Whatever form of visual indication may be employed should

be smooth in performance and have no irregular characteristics.

5. *General Characteristics*
   - (*a*) Frequency of emission of all of the elements of the system should be equivalent to that obtained with a low temperature coefficient quartz crystal.
   - (*b*) The number of fixed or portable equipments required will depend on conditions prevailing at individual airports.
   - (*c*) The installation of the foregoing equipment should not constitute an obstruction to a normal approach to a runway.
6. *Approach Lights*
   - (*a*) The installation of the best known type of approach and runway lights appears to be a most desirable measure in combination with instrument landing facilities.
7. *Projected Development*

Additionally, certain desirable features should be provided depending upon the state of the art and experience obtained. These represent improvements over and above the performance to be obtained from the fundamental equipment and are in no sense a substitute for such equipment nor do they require the redesign or replacement of such equipment. These are:

- (*a*) The inclusion of suitable emission for the operation of a radio compass either by
  - (1) The utilization of the U. H. F. runway localizer if practicable,
  - (2) Or the installation of a low-powered low frequency transmitter adjacent to the runway localizer.
- (*b*) The equipment provided should be so designed as to facilitate possible ultimate utilization (with accessories) in a fully automatic landing system in conjunction with a gyro-pilot.
- (*c*) Consideration should be given to possible separation of localizer and glide path transmitter functions in order to
  - (1) Permit alteration of glide path.
  - (2) Accomplish independence of horizontal and vertical indication.
- (*d*) Study should be made of the possibility for obtaining a straight line constant rate of descent glide path.

AIRCRAFT RADIO PROCEDURE

66. Radio Routine Approaching an Airport—The routine followed when a plane approaches an airport is as follows: Reports are given at certain check points as it flies the airway. An example of these follows:

Captain Jones, flight four—" JONES—FLIGHT FOUR TO PITTSBURGH "

Pittsburgh —" PITTSBURGH TO JONES—FLIGHT FOUR—GO AHEAD "

Captain Jones, flight four—" NORTH LEG BUCKSTOWN AT FIFTY TWO AT EIGHT THOUSAND — CLIMBING — ON INSTRUMENTS—ESTIMATED HARRISBURG AT TWENTY FIVE—GO AHEAD "

Pittsburgh —" PITTSBURGH TO FLIGHT FOUR—NORTH LEG BUCKSTOWN AT FIFTY TWO—ESTIMATED HARRISBURG AT TWENTY FIVE—PITTSBURGH "

This gives not only the time that the pilot passed over Buckstown but it gives his estimate at Harrisburg. It will be noted that the hours are never given, only the number of minutes after the hour. At the last reporting point, before arriving at the station, the arrival at the station is given to the ground station and the following procedure takes place:

Plane —" JONES—FLIGHT FOUR TO KANSAS CITY—GO AHEAD "

Kansas City —" KANSAS CITY TO JONES—FLIGHT FOUR—TIME TWENTY EIGHT KOLLSMAN —TWO NINE NINE EIGHT TWO NINE NINE EIGHT—SE5 "

Plane —" OKAY "

67. Aircraft Traffic Control—The arrival, departure and movement of aircraft flying civil airways designated by the C. A. A. is controlled by two independently operated radio communication stations, namely the airport control and the airway traffic control. The airport control station associated with major airports, is usually owned and operated by the municipality owning the airport. The airport zone of control is considered to be approximately within a 30 mile radius of the airport. Outside of this zone, the movement of aircraft flying on designated civil airways is controlled through stations operated by the C. A. Authority. As an analogy, the airways traffic control of the C. A. Authority corresponds to a railroad dispatcher, while the airport traffic control dispatcher is comparable to the railroad station or yard master, the former regulating the movement of trains on their right of way and the latter issuing orders on which track the train shall arrive or depart and providing a clear track upon its arrival and departure within the yard limits.

The airways traffic control station controls the movement of planes in flight to ensure an orderly sequence of arrival up to the zone wherein the ships pass within the jurisdiction of the airport traffic control station dispatcher.

The airport traffic control dispatcher may order the pilot to delay his landing, giving specific instructions as to how it shall be accomplished, or he may order him to come in to land. If ordered in, he is told which runway to use, the direction and velocity of the ground wind, the altimeter correction and such other information as is necessary to effect a safe landing. The transport aircraft calls the airport station on the opposite frequency from that being used for communication with their own ground station, as for example, if the day frequency is being used for service communications, the night frequency is employed to work the airport station. Itinerant ships call on 3105 kilocycles. The airport traffic control operates on 278 kilocycles. Eventually operation will be carried on ultra-high frequencies.

68. Departure from a Controlled Airport—Before the departure of any aircraft making an intentional instrument flight on a civil airway, the person in command is required to furnish the airway traffic control station or the airport control tower with a flight plan giving information relative to the proposed time of departure, proposed cruising altitude, type of equipment and estimated flying time between stops and destination. This plan must be approved before the aircraft is permitted to depart.

When ready to start and while on the airport apron, the pilot calls the airport control station by radio to secure permission to use the runway for the purpose of a take off. The airport control dispatcher will answer and specify which runway to use, the direction and velocity of the ground wind, the altimeter correction and other necessary information such as the proximity of other ships in flight and any hazards which may be encountered in the take off.

After taxiing to the end of the runway, the pilot again calls the airport control and announces this fact and upon being given permission, he takes off. The aircraft remains in control of the airport control station while in the zone of operation of the airport station, after which airway traffic control directs his movement. The pilot also carries on communication with the transport company's ground station employing the procedure explained in paragraph 49. Figure 426 shows the airport control tower at the municipal airport at Newark, New Jersey.

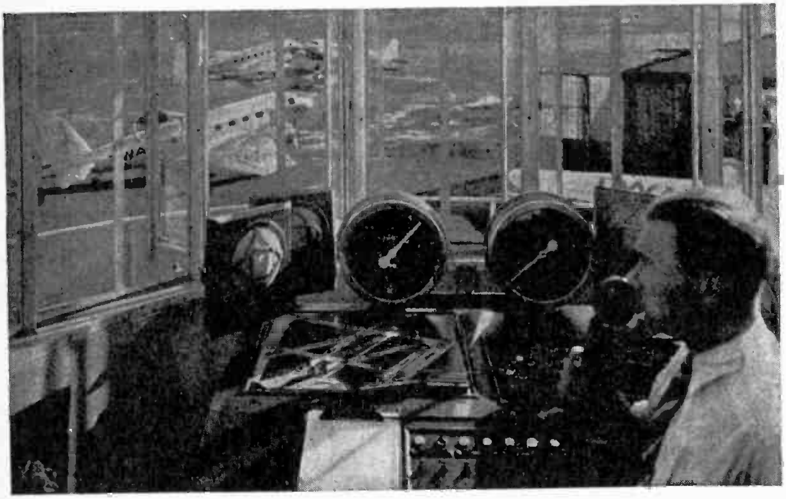

FIG. 426. Traffic Control Tower at Newark Airport, Newark, New Jersey.

On the desk may be seen controls for lighting the fields, two wind indicators and loudspeakers associated with various receivers.

AIR NAVIGATION EXAMINATION

The following questions are typical of an examination conducted by TWA after the completion of a navigation course for pilots.

1. (*a*) Around a standard radio range station, at how many points are the "*A*" and "*N*" vectors equal when in co-incidence?
   (*b*) What are these points called?
2. How would you determine whether you were flying toward or away from a station with a loop mounted on

an airplane so that its plane is co-incident to the line of flight?

3. A radio compass, the loop of which is set up for a zero relative bearing, is tuned upon a station and the heading of the plane is changed until a meter reading of zero is obtained, whereupon the gyro is checked and set. After ten minutes on a constant gyro course, the radio compass needle has moved slightly to the left. What steps should be taken to insure flying a direct course to the station?

4. In "homing" down an airway with a fixed loop radio compass, how would you check to find out whether you were being drifted to the wrong side of the airway—without recourse to the use of the "*A*" and "*N*" signals?

5. With a rotable direction finding loop, how would you orient yourself when lost in the vicinity of a station?

6. With a fixed loop radio compass the needle is well to the left of center, right rudder makes the needle move to the right. What is the plane's approximate relative heading with respect to the direction of the station?

7. (*a*) Explain briefly why bearings with the loop are taken with the plane of the loop at right angles to the station, i.e., the hole in the loop facing the station.

(*b*) At what angular position and in which semi-circle on the bearing indicator dial would the forward black needle be for:

1. Homing?
2. Rain Static?
3. Conventional Beam Flying?

8. (*a*) Assume that a plane is flying a magnetic heading of 75 degrees (variation·7 degrees West) and a relative bearing of 42 degrees Green was observed on the bearing indicator dial. What would be the true bearing from the plane to the station?

8. (*b*) Assume a plane to be flying a magnetic heading of 43 degrees (variation 12 degrees East) and a relative bearing of 167 degrees Red was observed on the dial. What would be the reciprocal true bearing of the plane from the station?

9. Assume that a check pilot has you thoroughly "lost" within a 125 mile radius of St. Louis, Mo. You then take over the controls steadying on the magnetic heading of 25 degrees (variation 5 degrees East). Obtain a fix by bearings on Spring Bluff and St. Louis.

The two bearings are taken within a negligible time interval—Spring Bluff 65 degrees Green—St. Louis 9 degrees Green (black needle used in each case).

What is the position of the plane at the moment of observation?

Answer by latitude and longitude or by distance and direction from a known point on the map.

10. (*a*) What are the reasons for keeping the nulls fairly narrow with ample volume control setting when homing into a station?

(*b*) If, in homing on the station, a signal becomes audible and you find that by testing for the null (with the bearing indicator) it is Zero degrees on one side and 12 degrees Green on the other.

In which direction would you alter your heading and how many degrees?

11. Describe in detail, the recommended system of orientation using the loop, assuming that you are "lost" in the vicinity of a station. Draw a diagram to illustrate.

12. After working a "loop" orientation problem and when rotating the loop to determine the bearing of the station, the bearing indicator shows the black needle to be on 30 degrees Red.

What is the approximate angular amount of turn necessary to home on the station?

After working a "loop" orientation problem and when rotating the loop to determine the bearing of a station the bearing indicator shows the black needle to be on 90 degrees Red.

13. (*a*) Where is the station with respect to the plane?

13. (*b*) Suppose the black needle pointed to 90 degrees Green. Where is the station with respect to the plane?

14. On performing a loop orientation problem and when rotating the loop to determine the bearing of the station, the bearing indicator shows the black needle reading 3 degrees Red with a fairly wide null.

Give two procedures that you could follow to complete the orientation problem, without recourse to *A* and *N* signals.

15. (*a*) Upon homing and when over a station as indicated by the inability to find the null and with the build-up in signal strength:

Outline the procedure of determining the cone of silence (on the second approach into the station) with the *A–N* signals.

15. (*b*) What receivers could be used and with what antennas?

16. Two orientation problems were performed and data secured. In Case (*a*) a reading of 30 degrees Green was obtained on the black needle.
In Case (*b*) a reading of 15 degrees Green was obtained on the black needle. There was no wind and the airspeeds were the same. In which case was the plane farther from the station and what was the comparative difference in distance?

17. The following two problems are not practical due to the time involved in obtaining data, but are included in this list of questions, as their solution shows a thorough knowledge of the orientation problems using the loop.
Immediately following the "right turn to zero gyro heading" at the end of the three minute leg, the pilot has the following information on which to base the necessary deductions to solve the required problem.

Wind—Calm
True Air Speed—170 MPH.
Relative Bearing of Station—Red 20 degrees
Magnetic Heading—Zero degrees
Variation—Zero degrees

What is the bearing from the plane to the station and the approximate distance? (In this particular case allow no time for turns.)
Immediately following the "right turn to zero gyro heading" at the end of the three minute leg, the pilot has the following information on which to base the necessary deductions to solve the required problem.

Wind—North 40
True Air Speed—200 MPH.
Relative Bearing of Station—30 degrees Green
Magnetic Heading—264 degrees
Variation—6 degrees East

What is the True Bearing of the plane from the station and what is the approximate distance of the plane from the station (allow half a minute for turns immediately prior to and following the three minute leg).
Draw a diagram to illustrate the answer.

Part IV. Civil Air Regulations*

The following are pertinent extracts of the Civil Air Regulations of the Civil A. A. pertaining to radio apparatus and its use on aircraft operating on civil airways.

60.112. *Radio Fix:* A radio fix is a geographical location on a civil airway, above which the position of an aircraft in flight can be accurately determined by means of radio only. (Such as a cone of silence marker, Z type marker, fan type marker, or intersection of radio range "on course" signals.) For a list of designated radio fixes, see CAR 60.23.)

60.114. *Radio Range Station:* A radio range station is that point in a radio station from which radio signals are emitted for the purpose of assisting an aircraft to maintain a course.

60.133. *Flight Plan:* A flight plan means a plan of flight which shall contain the following information:

(*a*) The aircraft identification mark, or the name of the governmental service in which the aircraft is employed, if so employed, or the name of the airline operator and the trip number, if engaged in scheduled airline service.

(*b*) The type of aircraft involved and the number of aircraft making the flight, if the aircraft are in formation.

(*c*) The name of the pilot, or of the flight commander if the aircraft are in formation.

(*d*) The point of departure of the particular flight for which such plan is being filed.

(*e*) The proposed cruising altitude or altitudes.

(*f*) The point of first intended landing.

(*g*) The proposed cruising airspeed.

(*h*) The radio equipment carried in the aircraft. (If no radio —NORDO; if radio receiver only—RONLY; if two-way radio, statement of transmitter frequency to be used.)

(*i*) The proposed time of departure. (The time of departure shall be considered as the time when the aircraft leaves the ground.)

(*j*) The estimated elapsed time until arrival on the ground at the point of first intended landing. (For scheduled operation, the first stop to be made, together with additional stops if requested by an airway traffic control station.)

(*k*) The alternate airport, if the flight is to involve instrument flight.

(*l*) The route, if other than a direct course, and any other pertinent information which the pilot deems useful for control purposes or which may be requested by an airway traffic control station.

60.134. *Approved Flight Plan:* An approved flight plan is a plan of flight, containing the information required by CAR 60.133, which has been approved solely with respect to known air traffic conditions by

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* The Civil Aeronautics Authority has assumed the jurisdiction of the authority formerly vested in the Bureau of Air Commerce.

the Bureau airway traffic control station into the control area of which the flight will first enter. (For a list of airway traffic control areas, see CAR 60.24.)

NOTE.—Approval of a flight plan is an authorization for an aircraft to proceed in accordance with the provisions of such flight plan only insofar as known air traffic conditions are concerned and does *not* constitute authority to violate any provision or provisions of the Civil Air Regulations.

60.1340. Traffic control instructions issued to the pilot before departure or enroute shall be considered to be a part of the approved flight plan..

60.53. *Flight Plan:* Prior to take-off from any point within an airway traffic control area, and prior to entering such an area, an approved flight plan as prescribed in CAR 60.134 is required. No flight plan shall be submitted until after the pilot has made a careful study of available current weather reports and forecasts and believes the flight can be made with safety. (For a list of airway traffic control areas, see CAR 60.24.)

60.530. *Traffic Control Instructions:* Traffic control instructions from a Bureau airway traffic control station issued to the pilot before departure or enroute are a part of the approved flight plan, and the pilot shall comply with the same in all respects.

60.531. *Control Zone of Intersection:* No control zone of intersection served by a Bureau radio voice communication station shall be entered without first establishing communication with such station, directly or through other communication channels, and forwarding the expected time of arrival over the center of such zone, the altitude to be flown through such zone, and thereafter observing such traffic instructions as may be issued by such station: Provided, That such procedure shall not be required within an airway traffic control area if the flight plan has been approved by a Bureau airway traffic control station prior to entering such zone.

NOTE.—For a list of control zones of intersection, see CAR 60.22. For further information concerning aids to air navigation, see "Tabulation of Air Navigation Radio Aids" published periodically by the Bureau of Air Commerce.

60.532. *Notification of Arrival:* The pilot of an aircraft shall immediately upon landing or upon completion of the flight, file an arrival message for transmittal to the point of departure.

60.571. *Communications Contacts:* The pilot shall maintain a continuous listening watch on the appropriate radio frequency and shall, by radio, contact and report as soon as possible to the appropriate communication station the time and altitude of passing each radio fix or other check point designated by the Secretary or specified in the flight plan together with unanticipated weather conditions being encountered and any other information pertinent to the aircraft movement and, further, if not within an airway traffic control area, shall prior to entering a control zone of intersection, served by a Bureau radio voice communication station, establish communication with such station, directly or through other communication channels, forwarding the expected time of arrival over the center of such zone, the altitude to be flown through such zone, and the course or courses proposed to be followed while within such zone.

60.5710. Aircraft utilizing airline communication facilities shall transmit information as required in this paragraph through such facilities, or such information may be transmitted directly by radio, to the appropriate agency of the Bureau.

NOTE.—For further information concerning aids to air navigation, see "Tabulation of Air Navigation Radio Aids" published periodically by the Bureau of Air Commerce.

60.572. *Communication Failure:* In the event of mechanical failure of aircraft two-way communication equipment or in the event that the pilot does not receive radio signals sufficient to permit his maintaining an instrument flight on coarse (see CAR 60.342), one of the following procedures shall be observed.

60.5720. (*a*) *Continue Flight in Accordance with Contact Fight Rules:* The pilot may proceed provided that the flight may be made in accordance with contact flight rules as provided for in CAR 60.4.

60.5721. (*b*) *Effect a Landing:* The pilot may effect a landing at the nearest suitable airport at which favorable weather conditions exist and where no airway traffic control station is located.

60.5722. (*c*) *Continue Fight in Accordance with Flight Plan:* In the event weather conditions do not permit the procedures provided for in CAR 60.5720 or 60.5721, the pilot shall proceed according to his flight plan, including any amending instructions issued and acknowledged enroute, with particular attention to maintaining his last acknowledged assigned altitude until the approach time last authorized for, and acknowledged by, the pilot of such aircraft, after which landing may be made.

NOTE.—Normal traffic will resume as soon as the aircraft has landed or been accounted for, but, in any event in not more than 30 minutes after the approach time last authorized for the aircraft and acknowledged by the pilot of such aircraft.

60.573. Flight Plan Changes—No change shall be made enroute in any approved flight plan until approval has first been obtained from the Bureau airway traffic control station for the area in which the flight is progressing, unless an emergency situation arises which requires immediate decision and action, in which case as soon as possible after such emergency authority is exercised the pilot shall inform the proper control station of the new flight plan and obtain approval therefore.

60.66. *Distress Signals:* The following signals, separately or together shall, where practicable, be used in case of distress:

60.66 (*a*) *The International Signal, S O S by Radio:* In radiotelephony, the spoken expression MAYDAY (corresponding to the French pronunciation of the expression "m'aider"). When, owing to the rapidity of the maneuvers to be accomplished, an aircraft is unable to transmit the intended message, the signal P A N not followed by a message retains such meaning.

60.661 (*b*) The international code flag signal of Distress, NC.

60.662 (*c*) A square flag having either above or below it a ball, or anything resembling a ball.

(On the following rules only the radio equipment required is described.)

04.51. *Non-Airline Carrier (NAC) Airplanes:* Airplanes which are certificated as non-airline carriers, shall have at least the following equipment:

04.512. NAC LANDPLANES—VISUAL-CONTACT NIGHT FLYING.

(*a*) Radio equipment, if the aircraft is operated for hire, as follows: A radio beacon and weather broadcast receiver operating within the frequency range of 200 to 400 kilocycles. Under normal atmospheric conditions this receiver must be capable of receiving with a range of 100 miles intelligence emanated from a radio range or weather broadcast station the equivalent of an SBRA installation.

(*b*) A set of spare fuses. (See CAR 04.5822 for installation requirements.)

04.513. NAC LANDPLANES—INSTRUMENT DAY FLYING:

(*a*) Radio Equipment: Same as CAR 04.512 (*a*), whether the aircraft is operated for hire or not, and, in addition, a radio transmitter operated on 3105 kilocycles with a power output sufficient to establish communication at a distance of at least 100 miles under normal atmospheric conditions. Additional frequencies may be employed subject to approval of the Federal Communications Commission.

(*b*) A storage battery suitable as a source of energy supply for the radio equipment installed. (See CAR 04.5821 for installation requirements.)

(*c*) A generator.

(*d*) A set of spare fuses. (See CAR 04.5822 for installation requirements.)

04.514. NAC LANDPLANES—INSTRUMENT NIGHT FLYING: Airplanes of this category shall have the equipment specified in CAR 04.512 and CAR 04.513 combined. The storage battery shall be suitable as a source of energy supply for both the radio equipment and the lights.

04.515. NAC SEAPLANES AND AMPHIBIANS: The equipment requirements for seaplanes and amphibians shall be the same as specified for landplanes (CAR 04.510 through 04.514) except that seaplanes and amphibians shall not be certified for operation over water out of sight of land unless they have at least the equipment specified in CAR 04.511, and except that all certified seaplanes and amphibians shall also have an approved life preserver or flotation device for each person for which there is a seat, and except that all seaplanes and amphibians certificated for night operation shall also have a white anchor light. (See CAR 04.5824 for installation requirements.)

04.53. *Airline Carriers—Passengers (ACP):* Airplanes certified for use as airline passenger carriers shall have installed at least the following equipment:

04.530. ACP LANDPLANES—VISUAL-CONTACT DAY FLYING: Radio equipment as follows: An *approved* two-way radio system consisting of a transmitter and receiver capable of operating on the frequency or frequencies specified by the Federal Communications Commission and independent of any facility provided by the Federal Government. In addition an *approved* beacon and weather broadcast receiver is required. The question of power and/or range of this equipment will be determined by the Secretary upon application for a Letter of Authority to operate a scheduled service.

04.531. ACP LANDPLANES—VISUAL-CONTACT NIGHT FLYING: Radio equipment same as CAR 04.530.

04.532. ACP LANDPLANES—INSTRUMENT DAY FLYING: Radio equipment as follows: Same as CAR 04.530 and, in addition, an *approved* auxiliary beacon and weather broadcast receiver capable of receiving radio range signals and emergency broadcast. Such receiver system is normally operated from the main source of electrical supply of the aircraft but in the event of failure of the normal power source may be switched to operate from an independent power supply. This system shall include an independent power supply capable of operating such auxiliary receiver continuously for a period of at least four hours. It is also required that this emergency receiver operate from an independent antenna. Two sets of head-phones shall be required in the aircraft at all times. Effective January 1, 1938, there shall also be installed in such aircraft an *approved radio direction finder,* covering at least the frequency range of 200 to 400 kilocycles. The design of the radio direction finder shall be such as to permit its regular operation in the taking of line bearings on any station to which the direction finder may be tuned without altering the course of the aircraft. The radio direction finder shall also be provided with means to eliminate, insofar as possible, consistent with the advancement of the art, that type of interference commonly known as rain, snow, sleet or dust static. The radio direction finder shall provide means for audible reception of radio range and weather broadcast messages. This radio direction finder may be installed in lieu of the emergency receiver described herein provided that an independent power source equal to that described for the emergency receiver is employed on either the beacon receiver required under CAR 40.235 or on this radio direction finder. Effective November 1, 1937, there shall be installed on such aircraft an *approved radio antenna system,* which has for its purpose the collection of radio range signals, weather broadcast and emergency messages transmitted within the frequency range of 200 to 400 kcs. The design of this antenna system shall be such as to eliminate insofar as possible, consistent with the advancement of the art, that type of interference commonly known as rain, snow, sleet or dust static. This antenna system shall be so designed that it will operate efficiently when used in conjunction with a receiver installed aboard such aircraft which has for its primary purpose the reception of radio range signals, weather broadcast and emergency messages.

(*b*) A deicing signal to indicate icing conditions in the carburetor if the deicing device specified in CAR 04.6291 requires the manipulation of controls.

(*c*) A storage battery suitable as a source of energy supply for the radio equipment installed. (See CAR 04.5821 for installation requirements.

04.533. ACP LANPLANES—INSTRUMENT NIGHT FLYING: The same as specified in CAR 04.531 and CAR 04.532 combined. The storage battery, in this case, shall be of sufficient capacity for all radio equipment and all lights installed.

04.534. ACP SEAPLANES AND AMPHIBIANS: The same as specified for landplanes (CAR 04.530 through CAR 04.533) and including the life preservers specified in CAR 04.515, except that when certified for night operation, they shall also have installed the anchor light specified in CAR 04.515.

04.54. (*Unassigned*).

04.55. (*Unassigned*).

04.56. (*Unassigned*).

04.57. (*Unassigned.*)

04.58. *Installation Requirements:* The following regulations apply to the installation of specific items of equipment and are additional to the regulations of CAR 04.50.

04.580—INSTRUMENTS: The following regulations shall apply to the installation of instruments when such instruments are required by these regulations.

04.5800. *Air Speed Indicator:* This instrument shall be so installed as to indicate true air speed at sea level with the maximum practicable accuracy but in no event shall the instrument error be more than plus or minus 5 miles per hour at approximately 0.9 V_L. (See CAR 04.111.)

04.5801. *Powerplant Instruments and Controls:* (See CAR 04.650 and 04.651.)

04.5802. *Fuel Quantity Gauge:* (See CAR 04.624.)

04.5803. *Magnetic Compass:* This instrument shall be properly damped and compensated and shall be located where it is least affected by electrical disturbances and magnetic influences.

04.5804. *Navigation Instruments:* Navigation instruments for use by the pilot shall be so installed as to be easily visible to him with the minimum practicable deviation from his normal position and line of vision when he is looking out and forward along the flight path and they shall also be visible to the second pilot.

04.5805. *Gyroscopic Instruments:* All gyroscopic instruments shall derive their energy from engine-driven pumps or from auxiliary power units. Each source of energy supply and its attendant complete installation shall comply with the instrument manufacturer's recommendations for satisfactory instrument operation. On multi-engine aircraft each instrument shall have two separate sources of energy, either one of which shall be capable of carrying the required load. Engine-driven pumps, when used, shall be on separate engines. The installation shall be such that failure of one source of energy or breakage of one line will not interfere with proper functioning of the instruments by means of the other source.

04.581. SAFETY EQUIPMENT INSTALLATION.

04.5810. *Safety Belts:* Safety belts shall be so attached that no part of the attachment will fail at a load lower than that specified in CAR 04.2640.

04.5811. *Fire Extinguishers:* The portable fire extinguisher specified in CAR 04.510 shall be so installed as to be accessible to the passengers. The two portable fire extinguishers specified in CAR 04.530 shall be so installed that one is readily available to the crew and the other is near the main external cabin door where it shall be readily available to passengers and ground personnel.

04.5812. *Safety Belt Signal:* The signal or sign specified in CAR 04.530 shall be suitable for indicating to the passengers, at appropriate times, that the seat belts should be fastened. It shall be located in a conspicuous place and so arranged that it can be conveniently operated from the seat of either pilot.

04.5813. *Landing Flares:* Landing flares shall be releasable from the pilot's compartment. Structural provision shall be made for the recoil loads.

04.5814. *Deicers:* Positive means shall be provided for the deflation of all wing boots.

04.582. ELECTRICAL EQUIPMENT INSTALLATION.

04.5820. *General:* Electrical equipment shall be installed in accordance with accepted practice and suitably protected from fuel, oil, water and other detrimental substances. Adequate clearance shall be provided between wiring carrying appreciable current and fuel and oil tanks, fuel and oil lines, carburetors, exhaust piping and moving parts.

04.5821. *Battery:* Batteries shall be easily accessible and adequately isolated from fuel, oil and ignition systems. Adjacent parts of the aircraft structure shall be protected with a suitable acid-proof paint if the battery contains acid or other corrosive substance and is not completely enclosed. If the battery is completely enclosed, suitable ventilation shall be provided. All batteries shall be so installed that spilled liquid will be suitably drained or absorbed without coming in contact with the airplane structure.

04.5822. *Fuses:* Fuses shall be so located that they can readily be replaced in flight. They shall break the current in a generating system at a sufficiently small current flow to adequately protect the lights, radio equipment and other parts of the circuit.

CHAPTER 15

UNITED STATES AUTO-ALARMS

Introduction—On November 9, 1936, the government of the United States became a party to the International Convention for Safety of Life at Sea. This Convention, held in London in 1929, recognized the need of providing on vessels carrying one radio operator, a method whereby they might be called upon by radio for assistance during the time when the operator was off watch. It was the consensus of opinion of radio experts of the principal maritime nations in attendance at the Convention that such a method could be developed by providing an instrument which, when actuated by the proper radio signal, would actuate an alarm bell in the radio operator's quarters, in the radio room and on the bridge. To accomplish this purpose the automatic alarm receiver and associated apparatus was developed and an International Auto Alarm Signal was adopted consisting of twelve dashes of four seconds each with one-second intervals (figure 427). International Radio law requires that this auto-alarm signal shall be transmitted *prior* to distress signal, S O S and thereby summons the operator of a ship within communication range to the radio room in time to intercept the details of the distress message.

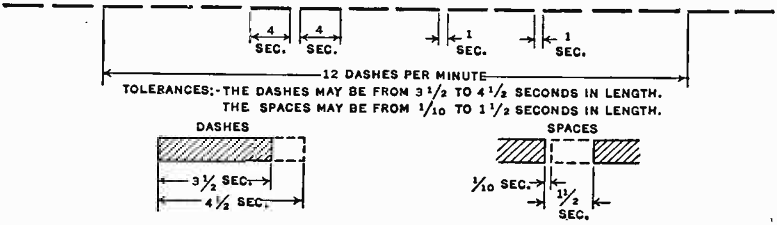


FIG. 427. International Auto Alarm Signal. The auto alarm signal consists of a series of 12 or more dashes sent at the rate of 12 per minute, each dash having a duration of 4 seconds with spaces between the dashes of 1 second duration. Auto alarms for vessels of U. S. Registry must require 4 consecutive dashes to actuate the alarms.

The Telecommunication Convention of Madrid provides that: "Before an automatic alarm receiver may be approved for use on ships, the administration having jurisdiction must be satisfied by practical tests made under suitable conditions of interference, that the apparatus complies with the provisions of these regulations."

The Telegraph Division of the Federal Communication Commission on March 10, 1937, entered its Order No. 28 conditionally approving certain automatic alarm devices for use on cargo vessels subject to certain restrictions and this order was effective on July 10, 1937. The Radiomarine Corporation of America, Model AR-8600 auto-alarm and Mackay Radio and Telegraph Company auto-alarm type 101-A manufactured by Federal Telegraph Company, the descriptions of which are to follow, are the only two automatic alarm devices given conditional approval by the Commission.

It will be noted that the Mackay device depends upon a modulated signal for operation whereas the Radiomarine instrument operates on an unmodulated carrier signal.

Mackay Radio and Telegraph Co. Auto Alarm 101-A

1. INTRODUCTION

To Masters, Radio Operators and Ship's Officers:

The auto alarm is a device authorized by the International Convention for the Safety of Life at Sea and by other laws, which are intended to increase safety of life and property at sea. Intelligent maintenance of this equipment and careful observation of its operation will assist in furthering the purpose for which it is designed and installed.

The Mackay Radio Auto Alarm, 101-A, is a receiving device which will respond to the International Alarm Signal sent by a ship in distress and will call the radio operators on ships receiving the signal to their respective radio rooms as well as notify the deck officers on duty at the time. The International Alarm Signal consists of twelve four-second dashes spaced one second between dashes and is sent on the international distress frequency of 500 kilocycles (600 meters). The auto alarm is chiefly intended for operation on ships carrying only one radio operator but it may be installed on any vessel to guard the distress frequency during such times as the operator on watch may not be listening on that frequency.

The auto alarm system consists of receiving and selecting apparatus located in the radio room, alarm bells and warning lights located on the bridge and in the radio room, and a third alarm bell located in the radio operator's cabin. The auto alarm is placed in service by the radio operator during such times as he is not on watch and the vessel is under way. The alarm bells are intended to call the operator to the radio room when an alarm signal is received or when the auto alarm apparatus refuses to function properly.

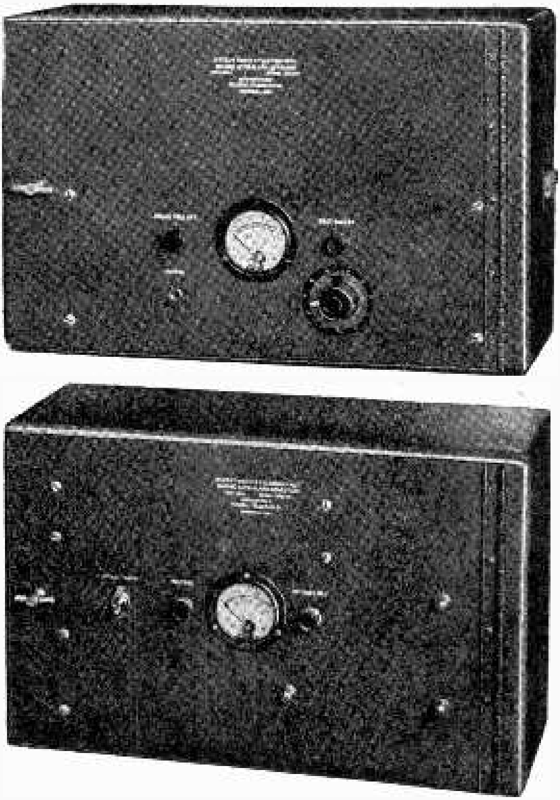


FIG. 428. Mackay Radio Auto Alarm Type 101A Receiver and Selector Units.

Upon receipt of an alarm signal, the auto alarm will cause the bells to ring. On the sounding of such an alarm, steps should be taken to inform the operator immediately so as to guard against the possibility that he may not have heard the alarm. The ringing of the bells also serves to indicate when the auto alarm receiving equipment becomes inoperative due to a failure of power or to the burning out of a tube. Regardless of the reason for sounding the alarm it can only be stopped from the radio room.

The warning lights located on the bridge and in the radio room, when lighted continuously, with the alarm bells not ringing, will indicate that the auto alarm device is inoperative for reasons outside the instrument itself, such as during heavy electrical storms when static has the characteristics of continuous signals, and during periods when other types of uninterrupted electrical noises may be prevalent. These lights also indicate when the ship's power to the radio room fails during the periods that the auto alarm equipment is in operation. At other times during normal operation of the equipment, these lights may flash at intervals. These intermittent flashes will not indicate that the equipment is inoperative and should be disregarded. When the warning lights remain lighted continuously for a period of five minutes, the radio operator should be informed.

Detailed instructions for the operation and maintenance of the apparatus are given on the pages following. Strict adherence to them will assist in creating the highest degree of safety possible with such an instrument and under circumstances most satisfactory to all concerned. It should be realized that the auto alarm is an electrical and mechanical device and as such, it must be given intelligent supervision and careful maintenance to insure satisfatory operation.

These instructions are not intended to supplant those instructions issued by the Federal Communications Commission or other governmental agencies having jurisdiction over the auto alarm equipment and the details covering its operation. It is recommended that all applicable regulations be carefuly studied.

2. TECHNICAL DESCRIPTION AND PRINCIPLES OF OPFRATION

The Mackay Radio and Telegraph Company's Auto Alarm 101–A consists of the following units:

A. Auto Alarm Receiver 101–A
B. Auto Alarm Selector 101–A
C. Antenna Switch
D. Alarm Bells (3)
E. Warning Lights (2)
F. Auxiliary Equipment, consisting of—
  a. 24-volt Storge Batteries (2 Sets)

b. Charging Equipment for above
c. Receiver Power Supply Unit
d. Auxiliary 90-volt B Battery

G. Instruction Books (2)
H. Set of Spare Parts

The relation of the various components to each other and the interconnections between them is shown on the Interconnection Diagram, figure 429 and on the Schematic Circuit Diagram, figure 430.

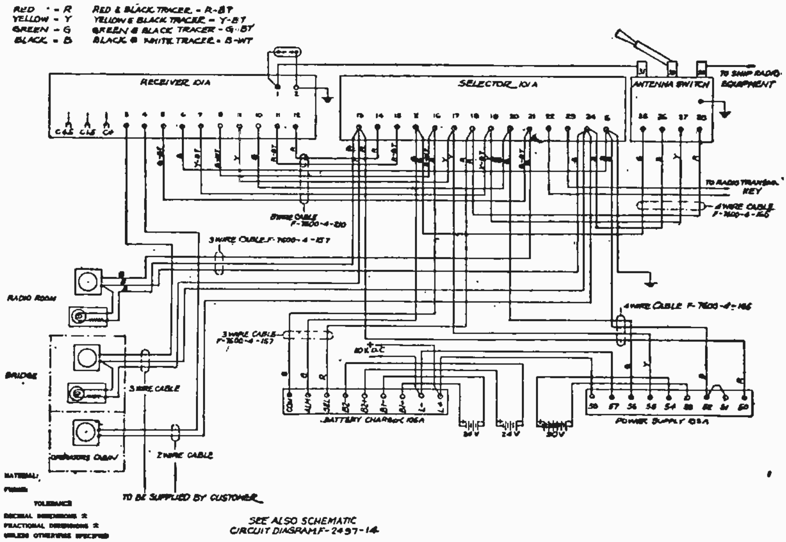


FIG. 429. Interconnection Diagram Type 101A Mackay Auto Alarm.

The power requirements for the equipment are:

1.4 amperes from the 24-volt batteries

12 to 25 milliamperes from the power supply unit or from the 90-volt B battery

1.7 amperes from the ship's 115 volt d.c. line for the charging of the batteries and for operation of the power supply unit.

1. (2–A) **Receiver**—It is the function of the receiver to accept all signals within the prescribed frequency band of 487.5 to 512.5 kc., modulated at least 30 percent at frequencies between

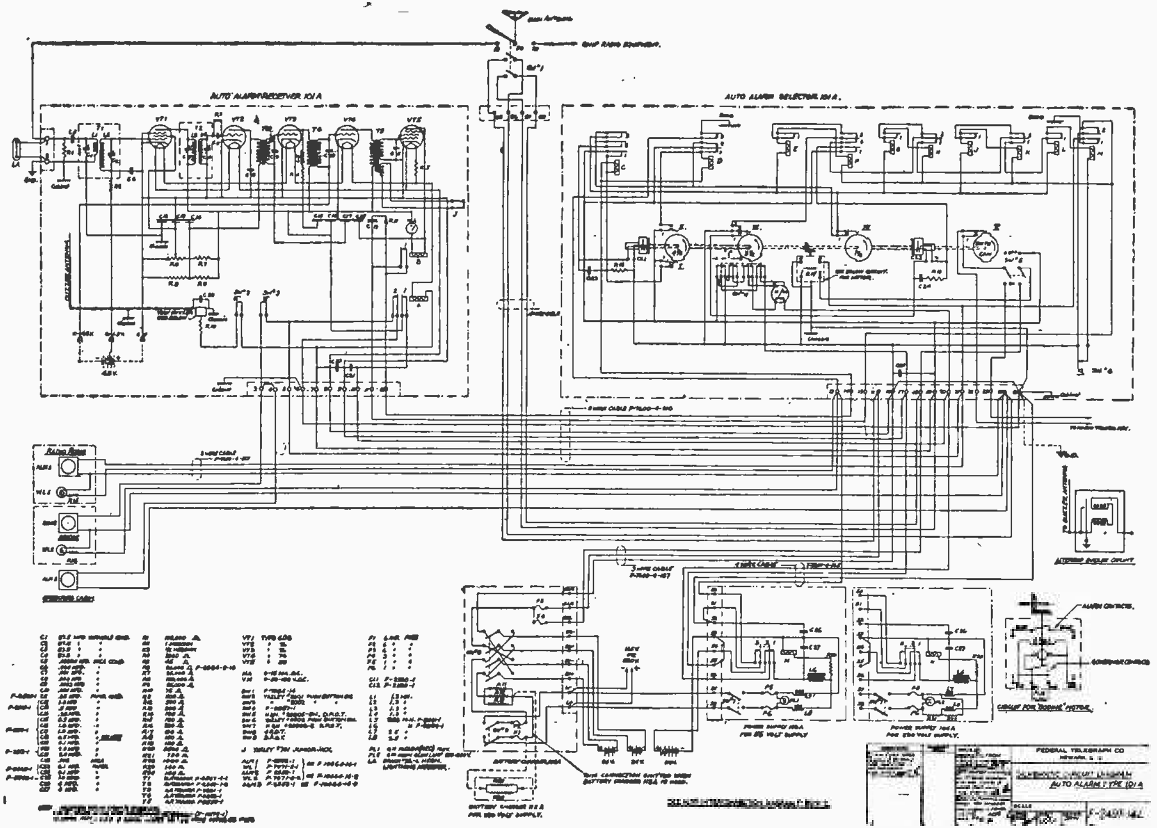


FIG. 430. Type 101A Mackay Auto Alarm.

100 and 2500 cycles, and transform those signals into such a form that they will operate the signal relay whenever those signals produce at the receiver input terminals an r.f. voltage of 500 microvolts or more.

Other requirements placed upon the receiver are that it must function equally well with very strong signals as with weak ones and that it must accept a weak alarm signal in the presence of strong interference. These requirements have been met in the design of the various circuits and components entering into the make-up of the receiver. Although the circuits of the receiver are not very different from those of any other one-stage t.r.f. receiver, they are, however, in many respects different from the usual receiver, in that the parts have been designed for this specific service, that of operating a relay as nearly as possible in conformance to the signals applied to the receiver. Steps have been taken therefore to provide as great an overload capacity as possible, to minimize the tendency toward "blocking," and to make its operations as "fast" as possible in order to utilize any breaks in the signals. In this manner then, the relay "*B*" will act as a "key" and deliver to the selector impulses which are a faithful reproduction of the signal combinations applied to the input of the receiver.

The receiver of the Mackay Radio Auto Alarm is of the tuned radio frequency type employing a single stage of radio frequency amplification in which the tuning is fixed, followed by a detector, two stages of audio frequency amplification and a rectifier.

The receiver uses five tubes of the 6-volt heater type: one 6D6 as the r.f. amplifier, one 76 as a detector, two 76's as a.f. amplifiers and an 89 as a rectifier.

Referring to the Schematic Circuit Diagram, figure 430, the heaters of tubes VT_1 to VT_4 are in series and are then connected in parallel with the heater of tube VT_5 and its series resistor. The total heater current passes through the winding of the low resistance relay *A* which operates and opens the alarm bell circuit through its back contacts 2, at the same time closing its front contacts 1, thereby completing the plate supply circuit to the receiver. This relay is adjusted to operate when full heater current passes through its winding. The burning out of any heater will reduce the current to a value which will release the relay, closing the contacts which complete the alarm bell circuit thus indicating that the equipment is out of order.

The antenna feeds the first of two resonant circuits through the small coupling condenser C_5, a resistor R_1 being connected between the antenna and ground to drain off static charges accumulated by the antenna. The two resonant circuits L_1C_1 and L_2C_2 are each tuned to 500 kc. and are overcoupled with each other sufficiently to produce two small humps, one on either side of 500 kc. The second circuit feeds the grid of the r.f. amplifier tube VT_1. This tube is in turn coupled to the detector tube by two similar circuits L_3C_3 and L_4C_4. In this manner the receiver is made to respond efficiently to signals within the frequency band of 487.5 kc. to 512.5 kc. and to exclude signals outside this band in the manner specified by the regulations. The resonant circuits are adjusted to proper resonance before leaving the factory, except for the first, or antenna circuit, which is adjusted at installation. The r.f. transformers use air core coils which are tuned by air dielectric condensers in order to maintain proper resonance under various conditions of temperature and humidity.

The detector VT_2 employs grid rectification and feeds the audio frequency signals to the rectifier tube VT_5 through two audio frequency amplifier tubes VT_3 and VT_4 which are transformer coupled by T_3, T_4 and T_5. The condensers C_8, C_9, C_{10} and C_{11}, together with the broadly resonant circuit $L_5R_4C_{15}$ are for the purpose of providing a flat frequency characteristic to the audio amplifier over the frequency range of 100 to 2500 cycles per second.

The rectifier tube VT_5 operates upon the principle of plate rectification. When a signal voltage is applied to its grid, its plate current increases from its low no-signal value to a higher average value sufficient to operate the signal relay *B*, which is included in its plate circuit. The value of this plate current is indicated by the milliammeter *MA* which is mounted on the panel of the receiver unit. The condenser C_{18} connected between the plate and cathode of the rectifier tube serves to smooth out the current and prevent relay chatter. The contacts 1, of this relay, control the operation of the selector, or timing unit. The condense C_{19} and the Resistor R_{11} are connected across the relay contacts to reduce sparking and radio frequency interference in the receiver.

The sensitivity Control R_6 is a potentiometer for controlling the screen grid potential of the r.f. amplifier tube so that the sensitivity of the receiver may be adjusted between the limits of approximately 250 and 50,000 microvolts. This is made use of in adjusting the sensitivity of the receiver to the "optimum" value for the prevailing conditions of noise or static. This optimum value is the highest sensitivity which can be used without causing the signal relay to be energized except momentarily by the noise or static during periods of no-signal. A higher sensitivity would cause the signal relay to be energized by the noise or static for extended periods during which time it would be incapable of further operation by signals.

A buzzer with its controlling push-button SW_2 of the non-locking type is provided for the production of r.f. test signals. The output of the buzzer is coupled into the antenna circuit by means of the buzzer antenna which is a short piece of wire from the buzzer to a point near the antenna lead. This antenna is adjusted to produce an r.f. input into the receiver of about 2000 microvolts.

The switch SW_3, also of the non-locking type, opens the circuit to the bridge and cabin bells when depressed so that those bells may be cut out of circuit when desired during routine tests.

The phone jack, *J*, connects a pair of headphones to the low impedance winding of transformer T_5, feeding the rectifier, so that the operation of the receiver may be monitored by ear.

All component parts of the receiver are mounted upon a formed metal chassis which is attached to the hinged door of the metal cabinet. The milliammeter, sensitivity control knob and scale, buzzer push-button knob, the bridge and operator's cabin bell disconnect switch knob and the monitoring phone jack are located on the front of the cabinet door. All parts are protected against the effects of temperature and humidity.

The grid, plate and cathode circuits of the receiver are isolated from the grounded chassis and cabinet except through by-pass or grounding condensers so that the receiver may be operated from power supplies which may or may not themselves be grounded.

2. **(2–B) Selector**—It is the function of the selector to accept and register the correct auto alarm signal and sound the alarm and to reject all other signals and atmospherics. It does so by measuring the length or duration of the signals as well as the spaces between the signals.

The selector of the Mackay Radio Auto Alarm consists of three motor-driven timing elements and a bank of counting relays. The timing elements are cams which operate contacts after a certain angular rotation. The motor, which rotates the cams, operates during all the time the equipment is "watching." It is shunt wound and is equipped with a governor in which centrifugal force opens contacts and places a resistance in series with the armature circuit, thereby maintaining the speed of the motor constant at 1800 r.p.m. The motor, through a reduction gear, drives a slow motion shaft at 6 r.p.m. On this shaft are two electro magnetic clutches which, when energized, engage and rotate the cams. Two of these cams are integral with each other and are operated by one of the clutches. This clutch measures the length of the dashes. The second clutch operates the third cam and measures the length of the spaces between the dashes. The counting of the dashes is accomplished by a bank of relays connected to form a counting chain.

The motor and timing cam mechanism is mounted upon its own independent base frame which, in turn, is mounted upon the hinged door of the selector cabinet by means of flexible mounting feet so that timing will not be affected through bending or mechanical displacement of the door. The counting relays are also mounted upon an independent base which in turn is fastened to the door.

A "Release Key" of the push-button type, on the front panel of the unit is used to release the alarm bell circuit after it has been set off by the proper sequence of alarm signals. It will not, however, release the alarm if the alarm has been set off through failure of the equipment and this fact is made use of to differentiate between the receipt of an alarm and the ringing of the alarm bells through failure of the equipment.

The motor has auxiliary contacts of the centrifugal type which will operate the alarm bells if the motor speed becomes too slow.

A voltmeter, mounted in the front panel, provides a constant check on the 24-volt battery voltage and reads the plate supply voltage when the voltage switch is turned to its non-locking position.

Since the slow-motion shaft of the selector unit revolves at the proper speed, a fourth cam has been mounted upon it to operate a pair of contacts which may be used to key the ship's radio transmitter and thus transmit a correctly timed alarm signal should the vessel be in distress. These contacts are placed in circuit and the motor operated independently of the rest of the autoalarm equipment by means of a switch on the front panel of the selector unit.

All parts entering into the construction of the selector have been treated to protect them from corrosion and the effects of moisture and heat. As in the receiver, the selector circuits are isolated from the chassis and cabinet except through grounding condensers.

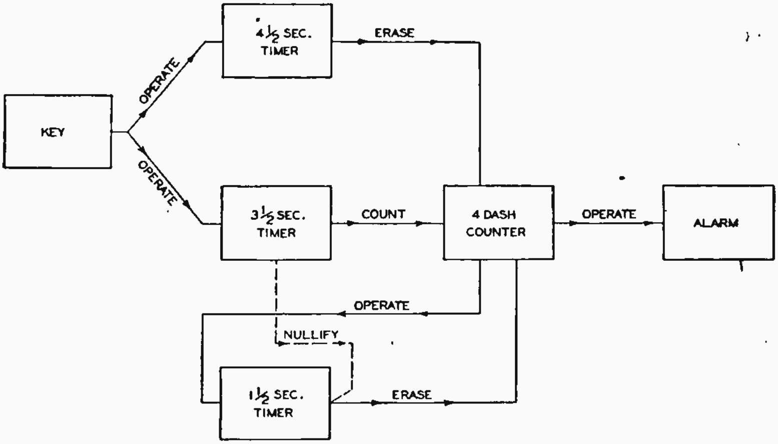
The operation of the selector can be best understood by considering an illustrative block diagram of figure 431.

This diagram represents a group of devices arranged so that their sequence of operations illustrates the fundamental scheme of the auto alarm selector.

In this diagram:

The Unit "KEY" represents some form of device which will energize the 3 1/2 second and the 4 1/2 second timer.

The 3 1/2 second timer is a device so arranged that after being energized continuously by the "Key" for a period of 3 1/2 seconds it will operate the "Counter" to partly record a dash, completing the record when the dash stops. This timing device, therefore, will select only those dashes which are 3 1/2 seconds or more in length, and will reject all dashes which are of shorter duration.



FUNDAMENTAL BLOCK DIAGRAM
M.R.& T. CO.
AUTO ALARM SELECTOR 101—A

FEDERAL TELEGRAPH CO
F-10044-2A

FIG. 431.

The 4 1/2 second timer is a device which starts simultaneously with the 3 1/2 second timer but is arranged so that when energized continuously for 4 1/2 seconds, it will erase any counts which may have been registered in the counter. This timing device, therefore, will act in conjunction with the 3 1/2 second timing device so that the combination of the two devices becomes a dash timer and will select and record only those dashes which are between 3 1/2 and 4 1/2 seconds in length.

The 1 1/2 second timer is a device which is energized by the counter at the termination of each complete recording of a dash. It is so arranged that after being energized for 1 1/2 seconds, it will erase, normally, all counts registered in the counter. This erasure will return the timer to zero, since it requires a recording in the counter to energize this timer.

This timer is associated with the 3 1/2 second timer in such a manner that this erasing power, which would have become effective after 1 1/2 seconds of operation, is made ineffective, or nullified, during such times that the 3 1/2 second timer is energized. The 1 1/2 second timer, therefore, will continue to operate for the first 3 1/2 seconds of the duration of the succeeding dash, since the previous count remains in the counter.

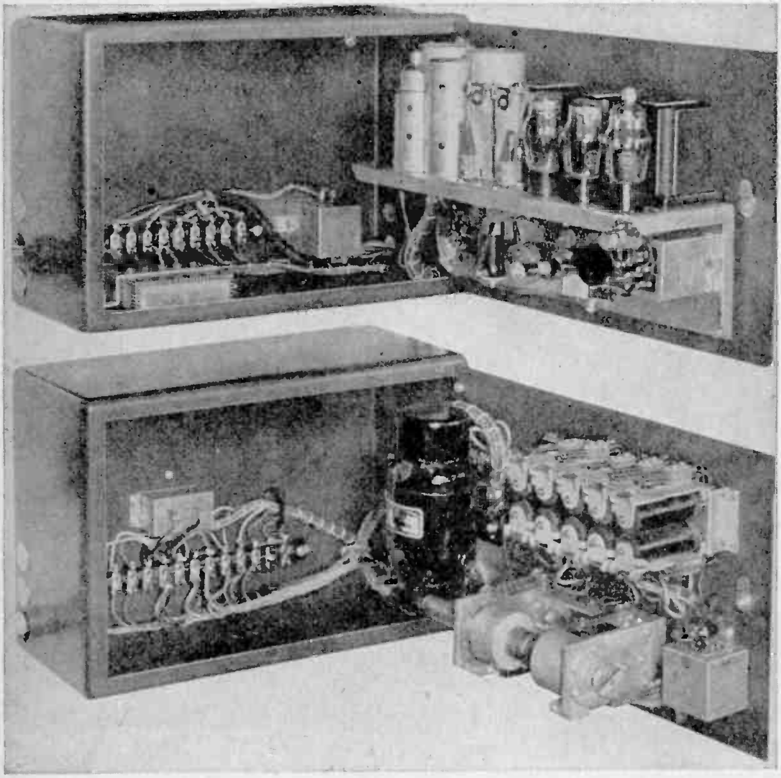


FIG. 432. Mackay Radio Auto Alarm Type 101A Receiver and Selector Units, Inside View.

In this manner we have arranged the 1 1/2 second or space timer so as to measure the space between two dashes and erase the count if the succeeding dash does not begin within the 1 1/2 second interval. Furthermore, the space between the dashes may contain intermittent interference without affecting the count in any way, because during this interval the space timer has no erasing power.

Now, in addition, it is so arranged that when the succeeding dash has existed for 3 1/2 seconds, the partial recording of that dash will release the space timer and reset it to zero. Should this dash be shorter than 3 1/2 seconds, therefore incorrectly timed, the nullifying power of the 3 1/2 second timer stops and the space timer will erase all records.

If the dash is correctly timed, the space timer will have been released after 3 1/2 seconds of the dash, and will be ready to start timing the space between this and the next dash, when the dash ends. If the dash is too long, the counts will be erased by the 4 1/2 second timer.

The "Counter" is a recording device energized by the 3 1/2 second timer, reset to zero by the 4 1/2 second and the 1 1/2 second timers, and arranged to operate the "Alarm" when four complete dashes have been recorded.

This group of units provides an arrangement whereby the counter will only record those operations of the "Key" which conform to the following requirements:

(1) The Key must be operated continuously for at least 3 1/2 seconds before any count will be recorded by the 3 1/2 second timer.

(2) The Key must not be operated for more than 4 1/2 seconds or all records will be erased by the 4 1/2 second timer.

The correct operation of the key for recording a count is, therefore, from 3 1/2 to 4 1/2 seconds.

(3) Each succeeding operation of the key must follow a correct operation within 1 1/2 seconds or all records will be erased by the 1 1/2 second timer.

(4) Four successive correct operations of the key are required to cause the counter to actuate the alarm.

(5) If the Key is operated in any other manner than that outlined above, there will either be no counts or such counts as are recorded, less than the total of four, will be erased.

It will be seen that these requirements placed upon the operation of the key coincide with the form specified for the International Auto Alarm Signal and its tolerances.

The above several illustrative units of the block diagram are to be found in the receiver and selector portions of the auto alarm equipment in the following physical forms:

Key—is Relay *B* in the receiver in conjunction with Relay *C* in the selector.

3 1/2 Second Timer—is the cam marked 3 1/2 in the selector together with its contacts III.

4 1/2 Second Timer—is the cam marked 4 1/2 in the selector together with its contacts II and relay *D*.

1 1/2 Second Timer—is the cam marked 1 1/2 in the selector together with its contacts IV.

Counter—is the bank of relays *E, F, G, H, J, K, L,* and *M,* relay *M* operating the alarm bells.

The operation of the selector will now be described in detail under the following conditions:

1. The First Dash.
2. Dash Too Long.
3. Space after the First Dash.
4. The Second Correct Dash.
5. The Third Correct Dash.
6. The Fourth Correct Dash.
7. Operation through Interference.

1—*The First Dash*

By the first dash is meant any dash which starts after an interval sufficiently long so that all the equipment is in its normal rest position. At the beginning of this dash relay *B* in the receiver is energized by the plate current of the last tube of the receiver. Relay *B* energizes relay *C* through the Circuit:

> Battery and charger, terminal 18, antenna switch, terminal 19, cam contact I, relay winding *C*, terminal 14, terminal 12, relay contacts *B*–1, terminal 11, terminal 15, back contact *M*2, terminal 16, to charger and battery.

The operation of relay *C* closes its contacts and the magnetic clutch *CL*–1 is energized through the Circuit:

> Battery and charger to 18, antenna switch, 19, back contacts *D*–2, contacts *C*–2, winding *CL*–1, 16, to charger and battery.

The cams 3 1/2 and 4 1/2 begin to revolve. Cam contacts I immediately open but have now been bridged by contacts *C*–1 and relay *C* remains closed. If the dash does not last for 3 1/2 seconds, then its termination opens relay *B*, breaking the circuit of relay *C* and thereby opening the circuit of the magnetic clutch *CL*–1 and the cams 3 1/2 and 4 1/2 return to their zero position. Relay *C* cannot be energized again until the cam 4 1/2 has reached its zero position and allowed cam contacts I to close.

When a dash has continued for 3 1/2 seconds cam 3 1/2 operates cam contacts III which operate relay *E* through the circuit:

> Battery and charger to 18, antenna switch, 19, back contacts *D*–2, contacts *C*–3, winding *E*, back contact *F*–3, cam contacts III–2, 16 to charger and battery.

The closing of contacts *E*–1 places the winding of relay *E* in series with the winding of relay *F* and both across the battery except that winding *F* is short circuited while the cam contacts III–2 are closed.

At the termination of the dash, provided its duration is between 3 1/2 and 4 1/2 seconds, the relays *B* and *C* are opened and clutch *CL*–1 is released, thus opening the cam contacts III–2. Current now flows through relay windings *E* and *F* in series through the circuit:

> Battery and charger, 18, antenna switch, 19, back contacts *D*–2, cam contacts IV–1, winding *E*, contacts *E*–1, winding *F*, back contacts *M*–2, 16 to charger and battery.

The closing of relay *F* energizes the magnetic clutch *CL*–2 through the circuit:

> Battery and charger, 18, antenna switch, 19, contacts *F*–1, winding *CL*–2, back cam contacts III–I, 16, to charger and battery.

The closing of relay *F* also connects relay *G* into the circuit to receive the next impulse from cam contacts III–2 through contacts *F*–2 and *H*–2.

2—*Dash Too Long*

If any dash lasts more than 4 1/2 seconds cam 4 1/2 operates its cam contacts II and closes the circuit of the winding of relay *D* through the circuit:

> Battery and charger, 18, antenna switch, 19, cam contacts II–1, winding of *D*, 14, 12, contacts *B*–1, 11, 15, back contacts *M*–2, 16, to charger and battery.

Relay *D* closes and locks up through its contacts *D*–1 to 19 and battery, by-passing the cam contacts II–1. The back contacts *D*–2 open the battery supply to the circuits of all counting relays and also clutch *CL*–1 which returns cams 4 1/2 and 3 1/2 to their zero position. Relay *D* remains closed as long as the dash continues but opens when the termination of the dash opens relay *B*. Back contacts *D*–3 energize the warning lights through the circuit:

> Battery and Charger, *X*, antenna switch, 24, lights, 13, contact *D*–3, chassis, *G*, 16, to charger and battery.

3—*Space After the First Correct Dash*

The battery side of the circuit of relays *E* and *F* has two optional paths, one through the cam contacts IV–1 to *D*–2 and battery, and the other through contacts *C*–3 to *D*–2 and battery. 1 1/2 seconds after the termination of the dash cam 1 1/2 opens it contacts IV–1. If the next dash has not yet started contacts *C*–3 are also open so that all counting relay circuits including the circuit of relays *E* and *F* are broken, thus placing all relays in their rest position. However, if a dash has started, contacts *C*–3 are closed and relays *E* and *F* remain closed. This dash, from the time it started, has caused cams 4 1/2 and 3 1/2 to be operated in the same manner as described for the first dash. If this second dash terminates or is interrupted at some time between the 1 1/2 and 3 1/2 second intervals required for the operation of cam contacts IV and III, respectively, then relays *E* and *F* are opened and the first dash is thereby uncounted or erased. It should be noted that the 1 1/2 second interval may be occupied by interference, relay *C* and cam 4 1/2 and 3 1/2 returning to their zero position at the termination of every dot, dash or static crash without erasing any counts.

4—*The Second Correct Dash*

This dash having started as described in the previous paragraph and having continued for 3 1/2 seconds, cam contacts III are operated. Cam contacts III–2 close relay *G* as they did relay *E* for the first dash, while cam contacts III–1 release clutch *CL*–2. Cam 1 1/2 then returns to rest or zero position, closing its cam contacts IV–1, thereby maintaining a closed circuit for the counting relays *E* and *F* even though the dash stops and relay *C* opens. If this second dash does not last for more than 4 1/2 seconds, it operates counting relays *G* and *H* in a similar manner to the operation of relays *E* and *F* by the first dash. After the cessation of the second dash, cam contacts III–1 close and start the 1 1/2 second timer whose contacts break the counting relay circuits if the third dash does not start within 1 1/2 seconds.

5—*The Third Correct Dash*

This dash results in the setting up of counting relays *J* and *K* through the same sequence as that described for the setting up of relays *G* and *H* after the second correct dash.

6—*The Fourth Correct Dash*

The actions during the third space are the same as during the first and second spaces. When the fourth dash has lasted 3 1/2 seconds it sets up relay *L*. At the termination of the fourth correst dash, relay *M* is operated and rings the alarm through the circuit:

> Battery and Charger, *X*, antenna switch, 24, alarm bells; Radio room bell to 21; Bridge and Cabin bells to 3 and 4, *SW*–3, 5, 21; Then all bells to contacts *M*–1, chassis, *G*, 16, to charger and battery.

Relay *M* also de-energizes relays *E, F, G, H, J* and *K* of the counting system, also relay *C*, by opening their circuits to battery. Clutches *CL*–1 and *CL*–2 are thus released, and this condition continues until relays *L* and *M* are released by the "Release" push-button, *SW*–6, which opens the circuit:

> Battery and charger, 18, antenna switch, 19, contacts *D*–2, cam contacts IV–1, winding of relay *L*, contacts *L*–1, winding of relay *M*, *SW*–6, 16, to charger and battery.

7—*Operation Through Interference*

The selector will operate to select the Auto Alarm Signal from a considerable amount of interference, caused either by other stations or by atmospherics, provided:

(*a*) The interference does not combine with the desired signal so as to actuate relay *B* for periods in excess of 4 1/2 seconds duration.

(*b*) The interference does not completely fill in the interval between the dashes of the Auto Alarm Signal.

The presence of interference immediately preceding or immediately following the dashes of the Auto Alarm Signal have the effect of lengthing those dashes. If the lengthened dash remains less than 4 1/2 seconds in duration, the selector will accept it as a dash of correct length. If lengthened beyond 4 1/2 seconds duration, it and any previous registered dashes will be rejected as described in paragraph 2.

Interference which exists during the interval between dashes of the Auto Alarm Signal, but does not completely fill that interval, will operate relay *B* which, in turn, operates relay *C* and starts the rotation of cams 4 1/2 and 3 1/2 as for a dash, paragraph 1. If the interference ceases before the 1 1/2 second period expires and before the end of the silent interval of the Signal, relay *B* will open releasing relay *C*, thus returning cams 4 1/2 and 3 1/2 to their rest or zero position, ready to receive the next dash. Since cam 1 1/2 has not yet operated its cam contacts IV, any record of previous dashes existing in the counter will remain intact.

Interference which completely fills the silent interval acts to prolong the preceding dash beyond its limit of 4 1/2 seconds.

The transmitting cam together with its cam contacts *V*–1 and one pole of the "Sig. Transmit" switch may be used in connection with a suitable keying relay to operate the ship's transmitter for the correct transmission of the Auto Alarm Signal. The other pole of the switch completes the motor circuit to battery removing the necessity of shifting the Antenna Switch.

There are auxiliary contacts on the motor governor which operate when the speed becomes too slow and operate the alarm bells through the circuits:

> Battery and charger, *X*, antenna switch, 24, alarm bells, Radio Room bell to 21; Bridge and Cabin bells to 3 and 4; *SW*–3, 5, 21; Then all bells to Motor contacts 4, chassis, *G*, 16 to charger and battery.

Spark suppressors have been incorporated across the terminals of the two clutch windings, to eliminate interference in the receiver from these circuits.

3. (2–C) Antenna Switch—An antenna switch is provided for transferring the ship's main antenna from the normal ship radio equipment to the Auto Alarm Receiver and for putting the auto alarm equipment into operation.

The blade of the antenna switch, insulated for high voltage, transfers the antenna. Auxiliary contacts, operated by the movement of the antenna blade, supply power to the receiver and selector units and also complete the circuit to the alarm bells.

No test whatsoever of the alarm equipment can be made without the antenna switch being closed on the auto alarm position, the closing of that switch completing automatically the power circuits of the entire apparatus.

4. (2–D) Alarm Bells—The three alarm bells necessary with this equipment are mounted one in the radio room, one on the bridge and one in the radio operator's quarters. The bells mounted on the bridge and in the operator's quarters may be temporarily cut out of circuit during routine tests by means of the non-locking push-button on the receiver marked "Bridge Bell Off."

5. (2–E) Warning Lights—Two warning lights, one mounted in the radio room and one on the bridge, serve to indicate that the equipment is inoperative due to prolonged noise or static, or both, or to the reception of a signal longer than 4 1/2 seconds duration, and which are of sufficient magnitude to maintain the signal relay in its "operated" position. These lights also indicate the failure of the ship's 115 volt power supply to the radio room during the time that the auto alarm equipment is in operation. Such failure of the ship's power will automatically transfer the receiver to the auxiliary 90-volt B battery and will also interrupt the charging of the storage batteries.

6. (2–F) **Auxiliary Equipment**—*A. Storage Batteries*—This equipment is normally supplied with two sets of 24-volt storage batteries which supply power for the operation of the heaters of the receiving tubes, the timing motor and clutches, the counting relays, the alarm bells and the warning lights. They are connected to the battery charger so that one set may be charged while the other set is being discharged. The normal drain from the batteries is 1.4 amperes, each set of batteries being rated at 60 ampere-hours capacity.

B. Battery Charger—The battery charger supplied with this equipment operates from the ship's 115 volt d.c. lines and charges the batteries at a 1.7 ampere rate. One 4 pole double throw switch is supplied on the charger panel by which the batteries may be alternately charged and discharged. The circuits of this switch are so arranged that the two sets of batteries discharge in reverse direction through the equipment although both are charged in the proper direction. This is done in order to reverse the direction of current flow through the motor governor contacts, thereby greatly reducing the tendency for those contacts to become pitted. A 2-pole single-throw switch, with fuses, is provided for controlling the charging current from the ship's d.c. lines. Separate fuses are provided for the discharge circuits, a 6-ampere fuse for the alarm bell circuit and a 3-ampere fuse for the rest of the equipment. When operation is to be from a 230 volt d.c. line, the charger is equipped with an additional series resistor to maintain the proper charging current value.

C. Receiver Power Supply Unit—Plate circuit power for the receiver is obtained from a Receiver Power Supply Unit which takes power from the ship's 115 volt d.c. lines and properly filters it for this use. A small toggle switch on the door of the unit is used to control the current applied to the unit. The pilot light, also on the door, indicates when the unit is in operation. The circuits are protected by one-ampere fuses within the unit. A relay is provided which is so adjusted and arranged that it will transfer the receiver circuits to operation from the auxiliary 90-volt dry B battery should the voltage of the ship's d.c. line fall below approximately 90 volts. When this transfer to B battery operation is made, this relay also completes the circuits of the warning lights on the bridge and in the radio room to indicate both that operation is from the auxiliary batteries and that the charging of the 24-volt storage battery has stopped or is greatly reduced through this lowering of the line voltage.

D. Auxiliary 90-Volt B Battery—Each installation is normally provided with a 90-volt dry B battery for use, as explained above, during such times that the ship's 110 volt d.c. power is not available in the radio room. This battery consists of two 45-volt units of the usual type generally available for this use.

3. Routine Operating Procedure

7. (3–A) To Place Auto Alarm Equipment On Watch—After the closing of the manual radio watch in the usual manner, the auto alarm shall be placed in operation by following the procedure herein outlined.

(1) Close the 4-pole switch on Battery Charger, to connect proper 24-volt battery to auto alarm equipment. Close 2-pole switch on battery charger to charge second battery. Turn "ON" Receiver Power Supply Unit.

(2) Transfer Auto Alarm Antenna Switch to Auto Alarm position, thereby transferring the ship's antenna to the auto alarm receiver and starting the auto alarm equipment.

(3) After allowing 30 seconds for the tubes to warm up, set the Sensitivity control at about 6 and test the Auto Alarm by depressing the "Test Buzzer" push-button on the receiver to form a series of dashes simulating the Alarm Signal, at the same time depressing the "Bridge Bell Off" push-button, thereby opening the bridge alarm bell circuit.

Note—Under conditions of no interference the alarm bell should operate after four dashes. Under conditions of interference it may require more than 4 dashes to operate the alarm bell.

Once every twenty-four hours the Auto Alarm shall be tested with the Bridge Bell *in the circuit.*

(4) Upon satisfactory indication that the auto alarm is in operating condition, i.e., sounding of the alarm bell in response to (3) above, adjust the sensitivity control to "Optimum."

(5) Notify the Officer on watch on the bridge that the Auto Alarm has been tested and is operating satisfactorily.

(6) Make appropriate entries in the ship's daily radio log and in the Auto Alarm Log to the effect that the Auto Alarm has been tested and put in operation and that the Officer on watch on the bridge has been notified, giving the time in each case.

(7) Make entries in the Auto Alarm Log giving the Sensitivity

Control setting and readings of the A and B voltages at the receiver panel meter.

8. (3–B) To Take Auto Alarm Equipment Off Watch—(1) Transfer the Auto Alarm Antenna Switch to the radio operating position, thereby stopping the auto alarm equipment.

(2) Turn Receiver Power Supply Unit "OFF" and take second battery off charge by opening 2-pole switch on charger, or continue either battery on charge depending on their condition.

(3) Resume manual watch in the usual manner, making appropriate entries in the ship's daily radio log and in the auto alarm log.

9. (3–C) On Sounding of the Alarm Bells—(1) *True Alarm*—Upon the reception of a true alarm, the bells will ring. The operator shall proceed immediately to the Radio Room and depress the "Release Key" on the Selector panel to stop the bells ringing. The auto alarm antenna switch should be transferred to the Radio Operating position and manual watch opened, carefully searching the 500 kc. band for indication of distress signals. Appropriate entries shall be made in the ship's daily radio log and in the auto alarm log and, in addition, the ship's radio log shall give details of the distress, including full text of the distress traffic heard or worked.

(2) *False Alarm*—Upon determining that the alarm bells have sounded a false alarm as determined by subsequent investigation of the 500 kc. band, the Auto Alarm shall again be placed in operation as previously outlined in 3–A, including the testing of the auto alarm and notification of the Officer on watch on the bridge. Appropriate entries shall be made in the logs.

(3) *Equipment Out of Order*—Should the Alarm bells ring because of failure of the equipment, as outlined in paragraph 5, previously, this alarm may be distinguished apart from a true alarm or a false alarm inasmuch as depression of the "Release Key" *will fail to stop the ringing of the alarm bells.* The Auto alarm should be taken out of operation and thoroughly checked for faults.

Upon location and correction of the trouble, the auto alarm shall again be placed in operation and on watch, as was outlined in 3–A, making appropriate entries in the logs and in addition, an entry in the auto alarm log covering the nature of the failure and the remedies applied.

10. (3–D) On Operation of Warning Lights—A continued burning of the warning lights on the bridge and in the radio room is an indication that:

(1) The signal relay has become locked up due to a sustained

signal or continuous static or noise of such high strength as to have the same effect, or indicates that,

(2) The ship's 115 volt d.c. supply to the radio room and receiver power supply unit has failed or has been reduced materially, thus transferring the receiver to operation from the auxiliary B batteries.

When (1) occurs, the sensitivity control should be reset to the "optimum" adjustment in accordance with paragraph 4, page 866.

When (2) occurs, steps should be taken to have the ship's power resumed.

An entry shall be made in the Auto Alarm log by the operator and in the ship's official log by the officer on watch on the bridge whenever adjustments are necessary to reduce the sensitivity of the Auto Alarm, giving all pertinent details.

11. **(3–E) Date Labels**—In accordance with Federal Communications Commission instructions all batteries and tubes used in Auto Alarms shall be date marked, showing their length of service. A number of gummed labels have been supplied for this purpose. Each tube and dry battery shall be labeled and marked with the date when it was actually placed in service (NOT when received aboard ship), and with the date it was removed from service.

12. **(3–F) Log Entries**—Entries should be made by the operator in the ship's daily radio log, and by the Officer on watch in the ship's official log,* of the daily tests of the Auto Alarm, giving the time and other pertinent details. In addition, an Auto Alarm log shall be maintained giving the times the alarm was placed on watch, taken off watch, and any incidents such as True Alarm, False Alarms, or other pertinent details.

Statements shall also be made in both logs whenever the warning lights remain lighted for a continuous period of five minutes, giving particulars as to the time the operator was called to make the necessary repairs or adjustments, the reason for the failure, the names of any parts removed, added or substituted and the time the alarm was restored to proper working conditions.

4. Operating Instructions

13. **(4–A) General**—(1) *How to Start Auto Alarm Equipment*—Close 4-pole switch on battery charger to position to discharge desired battery. Turn Power supply unit "ON" as indicated by the red pilot light on the cover. Shift the auto alarm antenna switch to the auto alarm position, seating the blade completely in place thereby transferring the antenna to the auto alarm

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* Entries in ship's official log not required by F.C.C.

receiver and completing the power circuits to the equipment. Close the 2-pole switch on the battery charger, thus charging the second 24-volt battery. After approximately 30 seconds, in order to allow the tube heaters to warm up, the auto alarm should be in operating condition.

Note—The charging rate has been adjusted to such a value that the batteries will be returned to the fully charged condition if they are charged one hour for every hour of discharge. The battery on discharge should be alternated every 24 hours rather than each time the equipment is placed on watch, unless this only occurs once per day, as this will result in a more equal division of operating time between the two sets.

(2) *How to Send Buzzer Test Signals*—Press the button marked "Test Buzzer" on the Receiver unit thus operating the buzzer which generates the signals.

(3) *How to Check Receiver Sensitivity*—Press the Test Buzzer button and turn the Sensitivity Control knob counter-clockwise until the meter on the receiver panel averages 5 milliamperes. The Sensitivity Control knob setting should be approximately 5. As the sensitivity of the receiver becomes less and less, due to weakening of the tubes, or for other reasons, the meter reading of 5 ma. will occur at higher and higher settings of the sensitivity control.

(4) *How to Adjust Sensitivity Control to "Optimum"*—The "optimum" setting of the sensitivity control is the highest to which the control can be turned toward maximum (scale reading of 10) under the existing conditions of noise or static, or both, and including the normal background of weak signals, without causing the milliammeter needle to hover at a higher reading than about 3 to 4 milliamperes. It is the adjustment of the sensitivity control at which the signal relay and the dash clutch are not energized except momentarily by the noise or static during periods of no-signal. Generally this adjustment will occur somewhere between the scale readings of 5 and 10. This adjustment will generally be at a higher value during daylight periods than at night.

Care must be taken that the setting of the sensitivity control is not **too low** as this will result in the receiver being insensitive and thereby less likely to receive an alarm signal. Continued operation of the receiver in an insensitive condition not only defeats the purpose of the auto alarm equipment, *but it might also subject the vessel and its officers to embarrassment should the equipment fail to respond to an alarm sent out by a nearby vessel in distress.*

The proper adjustment of the sensitivity control will be made considerably more easily with the aid of headphones plugged into the "phones" jack on the receiver.

(5) *How to Stop Alarm Bells*—If the alarm bells are ringing because of the reception of a **true alarm signal,** or from a false alarm signal, the bells will be stopped when the "Release Key" on the Selector Unit panel is pressed. If, however, the bells do *not* stop ringing when this button is pressed, their ringing is caused by some failure of the equipment and they will only cease when the failure is remedied or the auto alarm equipment is turned off. The failures of the equipment which will cause the bells to ring include:

(*a*) Burning out of a vacuum tube heater.
(*b*) Storage battery voltage becoming too low.
(*c*) Selector Fuse on Battery Charger Blown, or the 24-volt circuit to auto alarm equipment open.
(*d*) Motor stopped or running too slow.
(*e*) Vacuum tube heater circuit or 24-volt circuit to receiver open.
(*f*) Ground on alarm bell circuit.

(6) *When Warning Lights Operate for Extended Periods*—The warning lights operate whenever the signal relay is operated continuously for periods longer than 4 1/2 seconds and are again extinguished whenever the signal relay is released. Such operations of the relay can be due to the reception of a long dash but the relay can also be held in the operated position by strong noise or static conditions. The remedy is to reduce the sensitivity of the receiver to its "optimum" value as explained in paragraph 4 above.

These warning lights also operate when the ship's **d.c.** power to the receiver power supply unit (B battery eliminator) either fails or falls below 70 volts, thereby automatically switching the receiver to the auxiliary B batteries.

(7) *How to Read Battery Voltages*—The voltmeter on the Selector Unit panel is provided with a three position switch so that the voltages of the two sets of 24-volt batteries, the output of the receiver power supply unit and the auxiliary 90-volt B batteries can be measured.

Position "Minus *A*" indicates the voltage of Battery No. 1 when on discharge (positive side of battery *grounded*).
Position "Plus *A*" indicates the voltage of Battery No. 2 when on discharge (negative side of battery *grounded*).
Position "Plus *B*" (non-locking) indicates the voltage of the output of the receiver power supply unit when that unit is turned

"ON" and it is operating. If the meter reading for this position is *backward*, it indicates that the ship's 115 volt d.c. power to the radio room has been reversed and should be corrected.

Position "Plus *B*" (non-locking) indicates the voltage of the 90-volt auxiliary B battery when the receiver power supply unit is turned "OFF."

(8) *How to Stop Auto Alarm Equipment*—Shift auto alarm antenna switch from the auto alarm side to the opposite side, thus connecting the antenna to the normal radio equipment. Turn off the receiver power supply unit. Open 2-pole switch on battery charger to stop charging of battery unless it becomes necessary to continue charge for any reason.

(9) *General Operating Notes*—Allow approximately 30 seconds or more after starting the Auto Alarm equipment for the heaters of the tubes to warm up and the receiver thereby become operative.

When testing the alarm with dashes from the buzzer, headphones should be used to monitor the receiver in order to note any interference which may be present. With no interference present, the bells should ring after four correctly timed dashes have been applied to the receiver. During times of interference it may require more than the minimum of four dashes to operate the bells, depending upon the manner in which the interference combines with the alarm signal to spoil the timing of the latter.

This receiver has been designed for the specific purpose of operating a relay from the received signals. It was not designed for the aural reception of signals. Therefore, the signals heard in the headphones during monitoring will have a peculiar sound or quality, making the receiver somewhat inefficient for headphone use. Do not be misled, therefore, in judging its capabilities by what you hear in the phones.

14. (4–B) Maintenance—In order that electrical and mechanical equipment operate at its maximum efficiency it must be given attention periodically. The auto alarm is such a piece of equipment and should be cared for in the following manner:

(1) *General*—The entire equipment should be kept clean and free from dust and foreign matter. All connections and mounting screws should be checked periodically for tightness. Spares when used should be replaced as soon as possible. All routine tests should be faithfully performed with particular attention given to evidence of failure of any kind.

(2) *Tubes*—The operator in charge of the equipment should

make himself acquainted with the normal response of the receiver by means of headphones plugged into the phone jack in order that he may detect any subsequent weakening of the tubes in the receiver. In addition he should note the setting of the Sensitivity Control at which the milliammeter on the receiver panel averages a 5 milliampere reading on test buzzer signals when the line voltage is normal for the particular installation. Further check may be obtained by setting the sensitivity control in the above manner and then substituting a new tube in each position in rotation noting the milliammeter reading for each substitution. A pronounced increase in reading will then indicate when a weak or defective tube has been replaced.

(3) *Relays*—All relays and contact springs should be handled **with care** so as not to change their adjustment or tension. All relay and timing cam contacts should be polished with the burnishing tool supplied for this purpose once a month, or oftener should this prove desirable for particular installations.

Special attention should be given relays *B* and *C*. The process of burnishing is carried out in the following manner:—**Remove all power** by opening the 24 volt battery circuit at the 4-pole switch on the battery charger; turn OFF power supply unit and also open the B battery circuit by removing one lead from the battery. Otherwise a contact may be damaged by an accidental short circuit. Carefully insert the blade of the burnishing tool between the contacts to be polished and work the blade back and forth between the contacts 25 or more times while gently pressing the contacts against the blade with the fingers of the other hand. Do not exact too strong a pressure as this is a **polishing** process and *not a filing one.* **Do not use a file of any kind on any relay or cam spring contact.** Do not follow up the burnishing process with an attempt to clean the contacts with rags or paper strips, etc. To do so merely leaves lint or foreign particles on the contacts which will burn and cause future trouble. Relay contacts, when fully "made" should be deflected from their free position by about 0.005 inches. Observe the contact movement of a new or properly operating relay. Relay springs or armature adjustments should never be changed unless it is absolutely necessary for regaining proper operation.

(4) *Motor*—The motor is equipped with self oiling ball bearings and a reduction gear running sealed in grease. It should not require oiling except after extended use and then only by competent servicement from the service depots. **Never use**

any kind of abrasive whatever on the commutator or governor rings. Should they require any attention merely **clean them** with a cloth, together with the brushes and the brush-holders. A solvent, such as a small amount of carbon tetrachloride, benzine, or alcohol may be beneficial in some cases. However, care should be taken not to scratch the contact surface of the copper. If the governor contacts become pitted, they may be smoothed by a very fine file or a fine sand-paper, followed by a thorough burnishing with the burnishing tool to regain their polished surface. After doing this, it may be necessary to readjust the speed of the motor. This is done in the following manner:

The slow-motion shaft of the selector should revolve at a speed of 6 revolutions per minute, which is 1 revolution per 10 seconds or 1/2 revolution every 5 seconds. If the speed of the motor is correct, then, the transmitting contacts will be opened by the cam on the end of the slow-motion shaft every five seconds as observed by the seconds hand of the radioroom clock. If the speed is too **slow,** remove the cover of the governor compartment on top of the motor and turn the small spring contact adjusting screw IN one-quarter turn and re-check the speed. Adjust this screw until the motor speed is correct, which is that adjustment where the shaft makes 6 full revolutions in 59 to 61 seconds.

(5) *Cam Assembly*—The cam contacts should be burnished as specified for Relays in paragraph 3 above. *See that the small bakelite bushings between the ends of the contact springs are not displaced or lost.* A small oil hole is provided on the upper side of the two cams. **One drop** of light oil should be applied once every three months. The collector rings on the two clutches should be wiped clean with a clean cloth occasionally, and the brush springs examined for tension and for wear. **These brushes should bear firmly upon the rings.** The cam contact operating springs, with the **V** bend on the end which engages the cam, should be examined periodically for wear. The slow motion shaft bearings are sealed, self-lubricating, ball bearings and require no attention.

(6) *Receiver Power Supply Unit*—Requires no maintenance except the switching relay, which should be burnished in the manner specified in paragraph 3 above.

(7) *Storage Batteries*—The storage batteries of this equipment are similar to any other storage batteries used with radio equipment and should receive the same attention. They should be kept clean, filled with distilled water and properly charged. The charging rate has been set at 1.7 amperes, which is the correct value to

recharge the batteries in one hour for each hour of discharge. They should be given a periodic overcharge in order to equalize the batteries and keep them in proper condition. (Refer to manufacturer's instructions on page 890.)

(8) *Dry B Batteries*—The voltage of the dry B batteries should be checked each week **under load**, that is after being placed in operation by leaving the power supply unit switch "OFF" for a period of 5 minutes. Batteries should be replaced with fresh ones as soon as practical after their voltage, as measured above, drops to 75 volts.

15. (4–C) Correction of Faults—The following is an outline of faults which might occur in the Auto Alarm equipment, together with methods of correcting them. This outline is not intended as a complete listing but merely as a guide to aid in the servicing of this equipment and maintaining it in operation.

1. No Signals from receiver.
   Ship's d.c. reversed, thus placing negative side on plates. Check by turning Power Supply Unit "OFF" and noting action of voltmeter with its switch held on "*B*." R.f. amplifier tube grid lead off or grounded. Dirty contacts on relay "*A*."
2. Signals in phones but no relay action.
   Defective 89 rectifier tube.
   Shorted condenser, C_{11}.
   Open milliammeter.
3. High noise level locking up relay.
   If noise stops when antenna is disconnected, source is external to equipment and should be located and corrected if possible. If noise continues, source is in equipment or from ship's d.c. line.
   If noise continues when receiver power supply is turned "OFF" and 2-pole switch on battery charger opened, the source is in equipment. Check all connections for their tightness, clean motor commutator and brushes as per paragraph 4 under Maintenance.
4. Defective audio transformer.
   Temporary repairs may be made either by jumpering out the defective stage or by utilizing the remaining good winding of the transformer by using it as choke and reconnecting the stage as an impedance-coupled stage.
5. Signal Relay operates but no Selector operation.
   See that dash cam returns against its back stop and completely operates cam contacts below the cam. If necessary, increase cam return spring tension by loosening the three screws hold-

ing clamping ring around the knurled shoulder next to motor shaft coupling and then rotate knurled shoulder counter-clockwise a portion of a revolution, again tightening the clamping ring screws.

Examine these bottom cam contacts and see that they are "making" properly. These contacts must close before the signal relay can operate relay "*C*" and in turn the dash clutch. See description of operation under heading "The First Dash."

6. Space cam does not operate.
Contacts 111–1 of 3 1/2 second cam dirty, or not closing. Back contacts of relay *M*–2 dirty or not making. Contacts of relay *E*–1 dirty or not making. Clutch collector ring brushes dirty or not enough tension.
7. Counting relay operation OK but bells do not ring.
If relay *M* does not lock up, release key may be stuck. If relay does lock up, contacts *M*–1 may be dirty, alarm fuse on battery charger blown.
8. *Alarm does not ring after four test dashes.*
When the alarm receiver is connected to an antenna, external signals may combine with the test signals in such a manner that the combination will act to spoil the timing of the test signal. The headphones should be worn during test of the auto alarm equipment in order to make certain that when additional dashes, beyond the normal number of four, are required that it was because of the presence of interference.
9. Erratic registering of correctly timed signals.
If some correctly timed dashes may be registered in the counter while others are not, with no interference present, check motor speed, relay *B* contacts, relay *C* contacts, dash clutch collector rings and brushes for proper operation.
10. Motor speed suddenly much too high.
Governor contacts pitted and welded closed, governor contacts shorted out of circuit.
11. Motor speed much too slow.
Governor contacts dirty, governor brushes dirty, stuck in holder, worn too short.
12. Alarm bell does not operate.
Remove from housing and burnish contacts thoroughly.
13. Buzzer does not operate.
Dirty or burned contacts, contacts out of adjustment, series resistor open, buzzer button not making proper contact. Buzzer is adjusted by screw at bottom, backing it out at least 1/2

turn from point where it merely clicks, until a smooth note and steady meter reading is obtained.

14. Alarm Bells operate because of equipment failure.
The source of the trouble can be located most easily through the following procedure:
    (*a*) Observe voltmeter, if no indication of voltage on positions — *A* or + *A*, check Selector fuse on battery charger.
    (*b*) If voltmeter indicates some voltage on above position note whether it is normal 24 volt reading. Battery may be nearing complete discharge.
    (*c*) If voltmeter shows normal 24 volt reading, open Selector cabinet and note whether motor is operating at normal speed.
    (*d*) If so, open receiver cabinet and observe whether relay "*A*" is operated, indicating the heater circuit complete.
    (*e*) If above steps do not indicate location of failure, check bell circuits for grounding by removing the bell leads, one at a time from terminals No. 3, No. 4 and No. 21, a ground on any one of which leads will cause all bells to operate.
    (*f*) If the failure still remains, replace above leads and then remove lead from terminal No. 5. If bells continue to operate trouble is in receiver alarm bell circuit wiring or Relay *A*. If failure stops, trouble is in Selector Alarm Bell circuit wiring or in motor alarm contacts, or in Relay *M*.

A similar process of elimination, after a study of the circuit diagram, will assist in locating the source of any trouble which might appear with this equipment. The Bridge and Operator's Cabin Bells may be removed from the circuit and thereby prevented from ringing and causing unnecessary disturbance during the above tests (except for the tests of paragraph (14–*E*) above) by removing the leads from terminals No. 3 and No. 4 in the receiver cabinet.

15. If it becomes necessary to operate the Auto Alarm receiver from the auxiliary B Battery for any reason, the circuit from the Power Supply Unit relay to the Warning Lights should be opened by removing the lead from terminal No. 50 in the Power unit, taking care that the lead does not become grounded. This lead should be reconnected when operation from the Power unit is resumed.

5. Miscellaneous Information

16. (5–A) To Transmit an Auto Alarm Signal—Upon receiving orders from the Captain, or other authorized Officer of the vessel, to transmit an Auto Alarm Signal (which precedes the S O S Distress Signal) proceed as follows:

Place the ship's radio transmitter in operating condition on 500 kc. adjusted for a broad signal (in the manner called for in the Regulations for transmitting a distress signal), close the 4-pole switch on the auto alarm battery charger and turn "ON" the switch marked "SIGNAL TRANS," on the auto alarm selector panel. This starts the selector motor independently of the rest of the auto alarm equipment and completes a circuit to the wedge type plug which is inserted in the hand key. Contacts in the selector will then operate the transmitter keying relay to transmit correctly timed alarm signals of 4-second dashes and 1-second spaces between dashes. **To stop transmission** it is only necessary to remove the wedge plug and turn "OFF" the "Signal Transmit" switch on the Selector Panel.

Note—The transmitting contacts in the selector unit may only be used to key a transmitter through the medium of a relay. These contacts are not designed to handle over 50 to 75 milliamperes at 110 volts, and should never be used to handle any higher power. This feature of the Auto Alarm equipment, therefore, will only be wired-in on vessels provided with a suitable keying relay.

17. (5–B) List of Spare Parts—Each auto alarm installation is supplied with spare parts assembled in a suitable container. Whenever items are used from the box, the contents of the box should be replenished at the first opportunity.

18. (5–C) For Operation from 230 Volt D.C. Supply—When the Auto Alarm equipment is to be operated from a 230 volt d.c. power supply, the 115 volt battery charger type 106 and the receiver power supply unit type 103 should be omitted and the following units substituted in their place:

Battery Charger, type 106 in combination with Charger, type 112
Receiver Power Supply Unit, type 104.

Except for the above changes, the equipment and its operation remain the same as for 115 volt power supply.

ROUTINE BATTERY OPERATING INSTRUCTIONS

Batteries: Two 12 cell LX–7H Exide Batteries.
Full Charge Gravity when New—1.200–1.220.
Used For—Auto Alarm System.
Charged With—MRT Battery Charger 106A, at 1.7 amperes nominal charging current.

General—Keep all parts of battery clean and dry. When necessary wash cell covers with a rag dampened with fresh water. Keep connections clean and tight. Prevent corrosion by applying a thin coating of vaseline to brass or copper surfaces before bolting. Keep all filling plugs tightly in place except when adding water or reading gravity. Never add acid.

Select and mark a cell, called a " pilot " cell, in each battery for hydrometer readings. Every 6 months change the pilot cell to avoid lowering the gravity of one cell due to possible loss of electrolyte in taking readings. Using all cells spreads possible loss over all cells rather than have the loss taken by one cell.

Discharging—Alternately use each 12 cell battery to carry the 1.4 ampere load for the 16 hour Auto Alarm watch period, during which the specific gravity should drop about 65 points, as from 1.210 to 1.145. Only in an emergency should the discharge be carried further. There should be a regular changeover of the batteries once each 24 hours.

With full charge specific gravity of:					Hours to Charge Battery
1.200	1.205	1.210	1.215	1.220	
When specific gravity reads:					
1.135	1.140	1.145	1.150	1.155	16*
1.130	1.135	1.140	1.145	1.150	18
1.125	1.130	1.135	1.140	1.145	20
1.120	1.125	1.130	1.135	1.140	22
1.115	1.120	1.125	1.130	1.135	24

* If specific gravity readings are above those given in table, charge for normal Auto Alarm Period of 16 hours.

Example—Full charge specific gravity of pilot cell 1.210. Gravity as read on battery coming off discharge 1.140. Hours to charge—18.

Charging—The charging rate is proportional to the discharge so that if each battery when idle is charged for the full Auto Alarm watch period (normally 16 hours out of each 24) little additional charging will usually be required.

For good maintenance results proceed as follows: Once a week read the specific gravity of the pilot cell of each battery in the morning when it comes off discharge. At the succeeding Auto Alarm watch period charge the battery in accordance with the following table for this one charge, after which the normal (16 hour) charging periods should be resumed.

Replacing Water Loss—Once a month **after** reading specific gravity of battery coming off discharge add distilled or other approved water (never anything else) to all cells to bring top of electrolyte up to 3/8″ above tops of separators.

Equalizing Charge—Twice a year (every six months) charge each battery for a full 24 hour period. Be sure to water all cells before starting this charge and 15 minutes after the end of the charge read the specific gravity of all cells. Record these readings in the Auto Alarm Log Book and submit report to the Mackay Radio & Telegraph Company.

Radiomarine Corporation of America Model AR-8600 Auto Alarm

The model AR-8600 auto alarm has been designed to meet the following requirements.

Madrid, 1932, Telecommunication Convention, Paragraph 21 of Article 22 of the General Radio Regulations.

Federal Communications Commission auto alarm requirements and type tests, October 1, 1935, Document 14247. Federal Communications Commission Order No. 28, March 10, 1937.

20. Function of Auto Alarm—The fundamental purpose of the auto alarm is to stand a watch on the 500 k.c. distress frequency at all times when the radio operator is not on duty. The international auto alarm signal consists of a series of dashes four seconds in length, separated by spaces having a duration of one second. Twelve such dashes and spaces can be transmitted in one minute. Auto alarms designed to meet the requirements of the Federal Communications Commission are arranged to actuate warning bells when four correct dashes and spaces have been received. In cases of distress, transmission of the auto alarm signal is usually accomplished by using a radio room clock with a sweep second hand, this clock being designed with suitable markings on the dial to facilitate transmission of the correct dashes and spaces.

This clock is also to be used by the radio operator when he tests the auto alarm before going off watch.

21. Component Units—A complete auto alarm installation comprises the following component units.

Radio receiver and selector unit.
Junction box.
Master switch
Bridge bell and warning light.
Operator's room bell and warning light.
Six volt 75 ampere hour storage battery (1 amp rate).
Spare parts: 5 Type 1611 tubes.
2 Type 6K7 tubes.
1 Type 6H6 tube.
1 Type 6A8 tube.
3 Red warning lights (7 1/2 watt 120 volt).
1 Oven pilot light (6.3 volt).
8 Glass 6 ampere fuses.
6 Glass 1/2 ampere fuses.
6 Standard 10 ampere fuses.
1 Filament resistor (30 ohms).
1 Relay contact burnisher.

22. Power Supply Requirements—The main power supply for the AR-8600 auto alarm is the shipboard 110 volt d.c. line. A current of approximately 1.5 amperes is required. This 110 volt supply is used for all filament circuits, plate circuits, screen circuits, oven heater and warning lights of the auto alarm. A six volt storage battery is also used. This battery furnishes energy for ringing the alarm bells and for energizing the stepping relay and auxiliary relay in the auto alarm. The normal current required from the six volt battery is .4 amperes, except when all alarm bells are ringing when a current of approximately 3 amperes is required.

23. Construction of Radio Receiver-Selector Unit—The radio receiver-selector unit is constructed on a single panel which is hinged to a metal cabinet, the latter being designed for mounting vertically on the bulkhead. A hinged cover is also provided for the front panel to enclose the radio receiver, vacuum tubes, selector relays, and other parts. The receiver selector unit is 26 1/16" high, 15 1/8" wide and 11 3/4" deep. The weight is 63 pounds.

Five radio frequency transformer units are mounted in a row at the upper section of the front panel. Each of these units is constructed with impregnated Litz coils, and air dielectric tuning condensers. The coupling between the various r.f. coils is adjusted at the factory to secure the specified band width and selectivity.

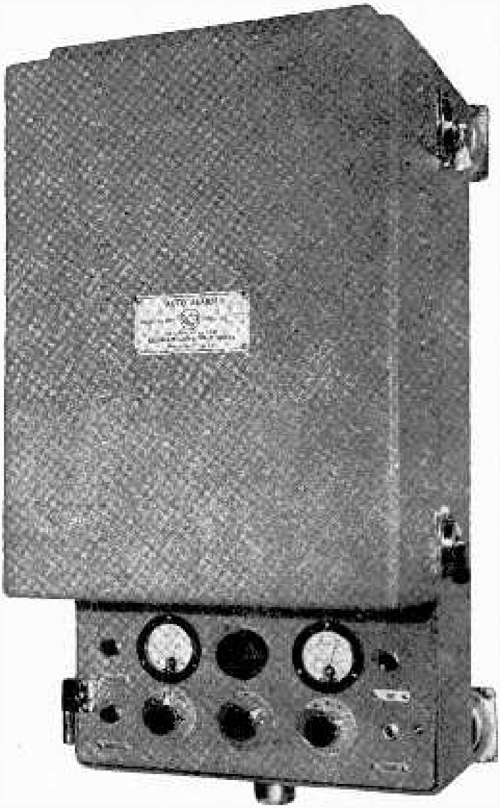

FIG. 433. R.M.C.A. Model AR–8600 Auto Alarm.

The first transformer unit in the upper left section of the panel contains the r.f. oscillator circuits. The next unit to the right is the 500 kc. input transformer. The next three units are the intermediate frequency transformers.

Directly beneath the r.f. units, viewed from left to right, are the following: One-half ampere plate fuse, 6–A–8 mixer-oscillator tube, 6K7 first intermediate amplifier, 6–K–7 second intermediate amplifier, 6H6 diode detector.

The next row of tubes, five type 1611, reading from left to right, are as follows: Voltage regulator tube, radio relay tube, first selector tube, second selector tube, Third selector tube.

Three selector relays are mounted in a thermostatically controlled oven which is located beneath the tubes. A suitable heater and bi-metallic thermostat are used inside this oven to maintain a temperature of approximately 55° Centigrade. The electric heater in this oven which is controlled by the thermostat, is permanently connected to the 110 volt line and operates at all times whether or not the auto alarm is in use. The heat from this oven is also used to maintain the component units of the auto alarm dry under marine conditions.

To the right of the oven there is located the stepping relay. This relay advances one position each time a correct dash and space are received. When the stepping relay reaches the fourth position, after four correct dashes *and* spaces, the bells are energized.

There are four relays mounted beneath the oven. The first relay to the left is the radio relay, which is actuated by incoming signals as explained further in this chapter. The next relay to the right is the filament burnout relay and is used to ring the warning bells in case the filament of any vacuum tube should burn out. The next relay to the right of the filament burnout relay is known as the bell ringing relay. This relay closes upon receipt of an alarm signal and stays closed, causing the bells to ring continuously until the reset button is depressed. The next relay (underneath the stepping relay) is known as the auxiliary relay is explained further in this text.

The reset push button will be seen below the radio relay. This push button is used to stop the bells from ringing after the correct alarm signal has been received. To the right of the reset button there is mounted a 0–15 d.c. milliammeter and below this meter a "current" selector switch. Positions 1, 2 and 3 of the current selector switch are used to read respectively the plate currents of selector tubes 1, 2 and 3. Position 4 of the current switch will permit the milliammeter to read the current through the coil of the radio relay. Position 4 is to be used, as hereinafter described, when adjusting the sensitivity control for optimum setting. Position 5 of the current switch is not used.

A test buzzer is mounted between the two meters. This buzzer is actuated by means of the test button so that a local signal may be induced into the auto alarm receiver for testing over-all operation. To the right of the buzzer there is located a 0–150 d.c. voltmeter and beneath this meter a "voltage" selector switch. Position 1 of the voltage switch will permit the voltmeter to read grid charging voltage from the voltage regulator tube. Position 2 of this switch reads bias voltage on the grids of selector tubes 1 and 2. Position 3 reads bias voltage on selector tube No. 3. Position 4 indicates the heater or filament voltage across all tubes, while position 5 permits the shipboard line voltage to be read.

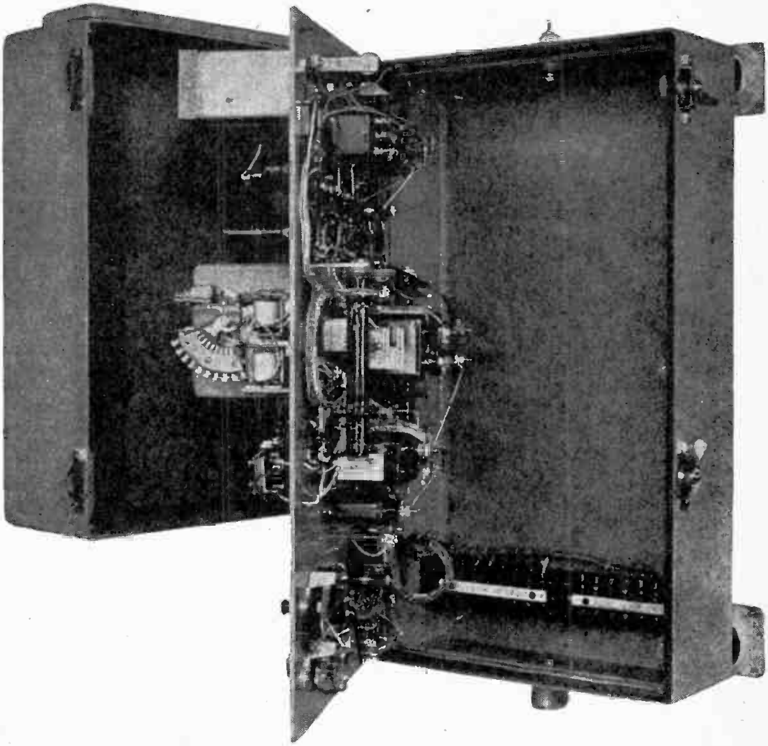

FIG. 434. R.M.C.A. Model AR-8600, Open View.

Typical readings of the milliammeter and the voltmeter for average shipboard conditions are given later in this chapter.

A sensitivity control is mounted beneath the test buzzer. This control adjusts the amplification of the radio receiver so that the optimum setting for the prevailing noise level may be obtained. This point is discussed in detail further in this chapter.

A push button switch to temporarily disconnect the bridge and operator's room bells is provided at the left of the current switch. This switch may be used by the operator to keep the bells from ringing during routine checking of the auto alarm.

A jack for the telephone receivers is mounted below the test button. Incoming signals may be monitored in this manner.

24. Operation of Radio Receiver-Selector Unit—The radio receiver circuits of the auto alarm utilize a five tube superheterodyne circuit which is shown in schematic diagram (figure 435). The antenna circuit after passing through the master switch connects to a tuned trap circuit (mounted back of the panel) which is adjusted at the factory for a frequency of 1100 kc. This is the intermediate frequency of the receiver and the trap circuit is provided to suppress interfering signals having a frequency of 1100 kc. After passing through the trap circuit the incoming signal is connected through a small condenser (50 mfd.) to a pair of broadly tuned circuits, which are adjusted to respond to 500 kc. plus or minus 12.5 kc. In other words signals having a frequency from 487.5 to 512.5 kc. are accepted. The first tube in the radio receiver is a type 6A8 mixer-oscillator. The oscillator portion of this tube is connected to a circuit which oscillates at a frequency of 1600 kc. This 1600 kc. energy is mixed with the incoming 500 kc. signal,

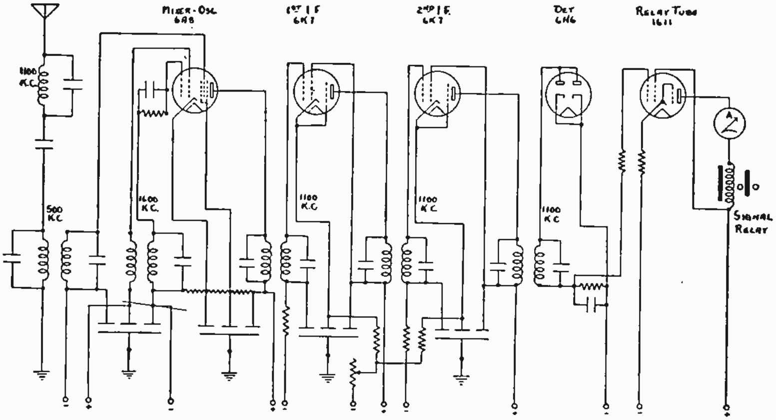

FIG. 435. Simplified Schematic, Auto Alarm Receiver, Radiomarine Corporation of America.

and produces in the plate circuit of the 6A8 the intermediate frequency of 1100 kc.

The 6A8 mixer-oscillator tube is followed by two stages of intermediate frequency amplification, each stage using a 6K7 pentode amplifier tube. The intermediate amplifier uses a total of six tuned circuits which are so coupled to enable the incoming signal to vary between 487.5 and 512.5 kc., without attenuation.

The fourth tube in the radio receiver is a type 6H6 diode detector. This tube has two plates which are connected in parallel and two cathodes which are connected in parallel. The radio signal, now at intermediate frequency, is rectified in the 6H6 detector stage and produces a d.c. voltage which appears across a one megohm resistor connected between the cathodes and one side of the third i.f. transformer secondary. This d.c. voltage from the diode stage is applied as a negative voltage to the grid of the fifth tube in the receiver, type 1611, which is known as the relay tube. This tube has connected in its plate circuit the coil of the

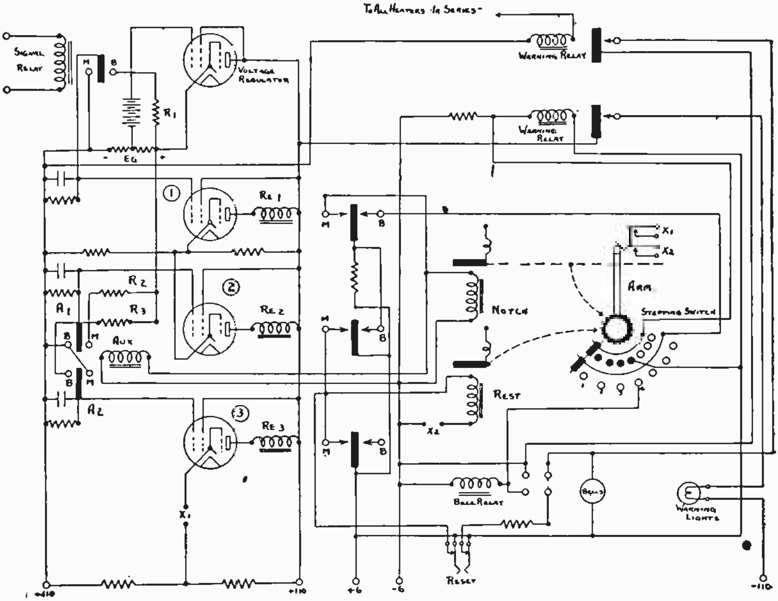

FIG. 436. Simplified Schematic Selector, Automatic Alarm, Radiomarine Corporation of America.

signal relay shown in both figures 435 and 436. Any incoming signal between 500 and 90,000 microvolts, and within the specified frequency band, will actuate the armature of the radio relay. The type 1611 relay tube, in the absence of signals, has a steady current (about 7.5 ma.) flowing through its plate circuit. This current is reduced upon the receipt of a signal causing the signal relay armature to make a contact. The action now moves to figure 436 in which the signal relay is shown once more. To understand this diagram it is necessary to know that on each relay the moving armature is shown as a black rectangle, the back contact is marked *B* and the "make" contact (closed when the relay is actuated) is marked *M*. The auxiliary relay "Aux." has two armatures, *A*1 and *A*2 in the diagram for clarity. Upon arrival of a signal, then, it is the *B* or back contact of the signal relay which closes. This connects *R*1 to the grid of tube 1, slowly charging the grid condenser positively (+) until approximately 3.5 seconds later the grid becomes positive enough to permit the plate current to rise sufficiently to operate relay *Re*–1. The *M* contact of *Re*–1 then energizes the "Notch" coil of the stepping switch, advancing this latter by one position. Connected across the notching coil is the winding of the auxiliary relay "Aux." which accordingly is also energized. Its *M* contact now connects *R*2 to the grid of tube 2 whose grid condenser begins to acquire a positive charge. If the incoming signal lasts too long (more than 4.5 seconds) this tube will close relay *Re*–2 whose *M* contact thereupon energizes the restoring coil "Rest." of the stepping switch, unlatching the detent and permitting the switch to return to zero. This is possible because at this time the gaps X_1 and X_2 do not exist since they are connected to switch X_1X_2 which is still closed. However if the dash does *not* last more than 4.5 seconds tube 2 does *not* operate and the switch is left advanced one position.

Spaces between dashes are checked as follows. When a dash of proper length (3.5–4.5 seconds) ceases the signal relay pulls up, closing its M contacts and grounding the grid of tube 1 which blocks and releases *Re*–1 whose *M* contact opens deenergizing not only the Notch coil but also the auxiliary relay "Aux." Thereupon contacts A_1M open, discontinuing the attempt to charge the grid of tube 2 while contacts A_1–B close and discharge this grid. At the same time the other back contact A_2–B of the auxiliary relay connects R_3 to the grid of tube 3 and begins to charge its condensers. The subsequent action depends upon the length of the silent period. Should another dash begin soon, tube 3 will take no part since the beginning of another dash will in addition to other actions operate the auxiliary relay and interrupt the charging or the grid condenser of tube 3. However if the pause is excessive the grid of tube 3 acquires sufficiently positive potential to permit the operation of *Re*–3 closing its *M* contact which also actuates the tripping coil "Rest." and returns the stepping switch to zero. Thus the equipment recognizes a false length in either dashes or spaces and upon their receipt immediately returns the stepping switch to zero. Thus only dashes of proper length can advance the switch at all and only those properly spaced can *continue* to do so. Each *proper* dash followed by a *proper* space leaves the switch one step further advanced. When it has advanced four steps two actions occur (1) the alarm circuits are closed and (2) the arm shown in figure 436 opens the switch, *X*1 and *X*2 thereby preventing subsequent signals from returning the switch to zero. The alarm therefore continues to ring until the operator has been advised and (preparatory to listening for the following distress message) pushes the "reset" button which causes everything to return to its initial condition.

The foregoing explanation may be difficult to follow. However if the actual auto alarm is operated with the test buzzer and the action of the various relays observed, as explained later in this chapter, it is possible to secure a clear understanding of the overall operation.

A voltage regulator tube (type 1611, top tube, figure 436), is used in the auto alarm. The purpose of this tube is to supply a regulated source of voltage under conditions of changing line voltage, so that timing of the selector circuits is not impaired.

The red warning lights are used to indicate when heavy static or other interference impairs operation. Each time the stepping relay advances one position a circuit is closed to the warning lights. These lights will remain lighted unless the static decreases or until a new adjustment is made on the sensitivity control.

25. **Junction Box**—The junction box used with the AR–8600 auto alarm is 14 7/16″ high, 12 7/16″ wide and 5 9/16″ deep. The weight is 23 pounds. The following units are mounted in the junction box. Two sockets are located at the top of the unit into which are screwed the six volt battery charging resistors. Below these sockets are two 30 ohm battery charging resistors. Below these sockets are two 30 ohm enameled resistors which are used in series with the filament circuits of the tubes. There are four radio frequency chokes below the filament resistors. One pair of these chokes is connected in series with the 110 volt line for filtering the power input to the auto alarm. The second pair

of chokes filter the input to the oven in the auto alarm. Four small mica filter condensers are mounted below the chokes. To the left of the filter condensers there is located a pair of fuse blocks for the incoming 110 volt line. Six ampere glass fuses are used in these fuse blocks. To the right of the filter condensers there is a single fuse block which uses a six ampere glass fuse and which connects to the positive side of the six volt storage battery. A special " C " battery delivering nine volts is mounted in the bottom of the junction box and held in place by means of a metal clamp. Numbered terminal blocks are provided for all incoming and outgoing circuits.

The following units are mounted on the inside of the door of the junction box.

Radio room bell and warning light.
Oven thermostat pilot light.
Line voltage relay.
Six volt battery relay.

A special 15 conductor lead-covered cable, color coded, is used to connect the radio receiver-selector unit to the junction box. A special 10 conductor, color coded, lead-covered cable connects the junction box with the master switch. The incoming bell and warning light circuits from the bridge and operator's room, as well as the incoming 110 volt and 6 volt circuits are also brought into appropriate terminals in the junction box.

The line voltage relay which is mounted on the rear of the cover of the junction box, to the left of the bell, is used to provide a warning whenever the shipboard line voltage is below or above predetermined values. If the line voltage falls below 90 volts the " low " or back contacts of the line voltage relay close. This will cause all three bells to ring until the line voltage has been restored to its normal value. The same action takes place if the line voltage exceeds 120 volts d.c. To provide a warning in case the six volt storage battery approaches discharge, a second relay mounted to the right of the bell on the back cover of the junction box is provided. The coil of this relay is connected across the six volt battery. If the battery voltage drops below approximately 4.5 volts, the bells will ring and will continue ringing until the battery voltage is restored to normal.

The high and low contacts on the line voltage relay are used to short circuit the coil of the six volt relay. In other words low or high 110 volt line voltage supply or low voltage from the six volt battery will cause the six volt relay contacts to close, ringing the bells.

26. **Master Switch**—The master switch is mounted on a base whose dimensions are approximately 6″ wide and 8 1/2″ high. Weight is 6 pounds. A large Isolantite insulator (7 1/8″ high) is mounted on the base of the switch and is designed to withstand the full voltage from the radio room transmitters. A contact arrangement is used at the top of the insulator to enable the antenna to be connected either to the auto alarm or to the other radio room equipment. When the master switch is placed in the "on" position, for auto alarm operation, the antenna circuit is carried through the long arm on the switch to the terminal marked *AA* and thence into the auto alarm receiver. A static leak and an adjustable spark gap are provided on the master switch between antenna and ground to prevent excessive voltages from reaching the auto alarm receiver. The spark gap should be adjusted so as not to exceed a spacing of one-thirty second inch. In the "on" position the master switch performs the following additional functions. Connects positive 110 volt line to the auto alarm. Connections positive and negative of the six volt storage battery to the auto alarm. When the master switch is placed in the "off" position it disconnects the antenna from the auto alarm receiver and connects the antenna to the other radio room equipment. It also places the six volt storage battery on charge and in addition closes an interlock circuit in series with the main transmitter key. This interlock circuit is to prevent the main transmitter from being used unless the auto alarm has been taken out of circuit.

27. **Bridge Bell and Warning Light**—The bridge bell and warning light are mounted in a metal box 7″ high, 6 5/16″ wide and 3 3/8″ deep. The weight is 5 pounds 4 ounces. The bell unit is designed to operate from the six volt storage battery. The warning light is a standard 7 1/2 watt 120 volt red lamp. The operator's room bell and warning light unit is similar to the bridge bell and warning light unit.

ADJUSTMENTS TO BE MADE BY RADIO OPERATOR BEFORE GOING OFF WATCH

On the front cover of the auto alarm there will be found printed instructions which read as follows:

28. **Important Instructions**—"*To Test Alarm*—Close master switch. Set sensitivity control to approximately 40. Using radio room clock transmit alarm signal with test push button on auto

alarm. Bells will ring after four correct dashes and spaces. See instruction book for further details."

"*Adjust Sensitivity Control*—Set scale at 0. Set current switch at 4. Meter will read about 7.5 ma. Turn sensitivity control to right until average meter reading due to noise, static, etc., is about 1 ma. less than maximum value. Listen with phones. Incoming signals will cause signal relay to chatter slightly and meter reading to fall toward zero. If sensitivity is set too high for prevailing noise level warning lights will indicate need for lower setting. Do not set sensitivity control lower than necessary as weak distress calls may not be received."

When testing the auto alarm with the test buzzer and push button the operator should observe that the milliammeter reading falls to zero or nearly so each time the test button is depressed. Close this button quickly several times and observe that the radio relay, whose armature click may be heard, follows the keying speed. Each time a correct four second dash and space are sent with the test buzzer, it may be observed that the stepping relay advances one position. If there is considerable radio interference or static during the time the alarm is being tested, it will be observed that the restore coil on the stepping relay is also energized, thereby preventing the stepping relay from advancing further. This condition will occur during testing whenever static or interference completely fills the spaces between dashes so that the normal auto alarm signal is distorted. The position of the sensitivity control, during the test of the auto alarm, may be used as an approximate check on the sensitivity of the receiver and the correct performance of all tubes. If it is found necessary to advance the sensitivity control beyond approximately 40 to 50 on the scale, it may be inferred that one of the tubes in the radio receiver part of the circuit is defective. After a little experience with the alarm, using the headphones plugged into the jack and by observing the operation of the radio relay on incoming signals, the operator may reach an approximate determination as to whether or not the receiver sensitivity is normal. In other words on the average shipboard antenna it should not be necessary to advance the sensitivity control to the extreme right in order to make the radio relay operate with the average incoming signal.

29. Sensitivity Control Adjustment—A clear understanding of the results to be expected from various settings of the sensitivity control is necessary in order to adjust this control to the optimum or most favorable position. For example if the sensitivity control is turned to the extreme right (100 on the dial) or nearly so, it may be found that the average noise level and static will cause the radio relay to hold over for long periods of time, or to chatter or vibrate steadily. When this occurs the adjustment is not a favorable one for not only will the warning light be illuminated frequently whenever static or noise persists for 3.5 seconds or more, but also a real alarm signal will be more apt to have its dashes prolonged and its spaces filled in, with such an adjustment. On the other hand if the sensitivity control is adjusted too far to the left, that is toward zero on the scale, then only very strong signals will operate the auto alarm, and a distress call from a distant ship might be missed. The optimum adjustment will be found to be that which gives a reading on the milliammeter (with no incoming signals) which is approximately one milliampere *less than* the reading obtained when the volume control is at zero. With such an optimum adjustment the radio relay may close occasionally from short bursts of static or from ordinary code signals. The operator should keep in mind that if the sensitivity control is set too high the radio relay will vibrate constantly, which is an undesirable adjustment. The officers on the bridge will have instructions to summon the radio operator whenever the warning light on the bridge is illuminated for periods of five minutes or more. When the sensitivity is set at 100 or maximum, a signal strength of approximately 200 microvolts will operate the auto alarm. At a dial setting of 50 (midscale) a signal of approximately 1000 microvolts is required. At 0 setting of the sensitivity control a signal strength of 20,000 microvolts is required.

30. Faults Which Will Cause Sounding of the Audible Alarm—1. *False alarm.* Accidental combination of static or other interference may occasionally cause the stepping relay to advance to its fourth position, which will lock in the bell ringing relay and cause the bells to ring continuously. Bells will stop when reset push button is depressed on auto alarm panel.

2. *Filament burnout.* If any one of the vacuum tube filaments (heaters) should burn out, or if one of the 30 ohm series filament resistors in the junction box should burn out, the *filament burnout relay* on the auto alarm panel will have its coil de-energized, which will close the back contacts, and cause the bells to ring. Bells can only be stopped from ringing by replacing the defective tube, or by opening the master switch.

3. *Low or high line supply voltage.* If the 110 volt shipboard supply is reduced below 90 volts or increased above 120 volts, the *line voltage relay* in the junction box will operate, which will short

out the coil on the six volt relay, causing the bells to ring. The bells will continue ringing until line voltage is restored to normal or until master switch is opened.

4. If the six volt battery approaches discharge and its voltage falls below about 4.5 volts, the back contacts will close on the *six volt relay,* causing the bells to ring continuously until a suitably charged battery is placed in circuit or until the master switch is opened.

5. If the one-half ampere fuse on the auto alarm panel or any of the fuses in the junction box should be blown, the bells will ring continuously until the fault is corrected or unless the master switch is opened. The one-half ampere fuse will blow in case of tube shorts or condenser breakdown in the receiver-selector unit.

31. **Operation of Warning Lights**—The purpose of the warning lights as explained previously is to provide a visual indication whenever prolonged static or other interference holds the radio relay open. After 3.5 seconds the stepping relay will advance one position and remain there as long as the interference is continuous. An auxiliary set of contacts on the stepping relay will close a circuit to the three warning lights to indicate this condition. The remedy is to readjust the sensitivity control to a slightly lower setting so that the stepping relay drops back to its normal or zero position.

32. **Procedure to Be Followed when Alarm Bells Ring**—1. If alarm bells ring momentarily, then stop ringing and repeat this cycle frequently, the difficulty is most likely due to low, high or variable line voltage. Go to the radio room, open the door of the junction box and observe the line voltage relay contacts. Also measure the line voltage by placing the voltmeter switch in position five on the auto alarm panel. If the voltage is approximately 90 or less, it will be observed that the line voltage relay "left" contact is closed, causing the bells to ring. Higher than normal line voltage will cause the "right" contact to make on the relay, also ringing the bells. This condition of low, variable, or high line voltage should be brought to the attention of the proper ship's officer.

2. Alarm bells ringing continuously. Go to the radio room and depress the reset button on the auto alarm. If this stops the bells from ringing a pair of phones should be immediately plugged into the phone jack to determine if an alarm signal has been transmitted by a vessel in distress. If the bells do not stop ringing when the reset button is depressed the fault may be low line voltage, high line voltage, low six volt battery supply, filament

burnout, or blown fuses. Filament burnout may be immediately determined by placing the voltmeter switch in position four, where a reading of 100 volts or more will be obtained instead of the normal reading of approximately 60 volts. A blown one-half ampere plate fuse or 110 volt line fuse may be quickly determined by observing if any reading is obtained on the voltmeter with the switch in position five. No reading will be obtained if these fuses are blown. If the six volt battery is low this should be checked with the three scale voltmeter carried in the radio room as a part of standard safety of life at sea equipment.

3. When troubles which cause the bells to ring continuously cannot be located quickly, it is desirable to disconnect the bridge bell and operator's bell temporarily to avoid undue annoyance to the ship's personnel. This may be done by removing the lead (blue with red tracer) which will be found on terminal 28 on the vertical right hand terminal block of the junction box. After the trouble has been corrected the operator should make certain that the lead to terminal 28 is firmly reconnected, and he should make a test with the bridge and the operator's room to insure that the bells are again functioning normally.

33. **Log Entries**—The following instructions with regard to log entries should be carefully observed, as they are required by the Federal Communications Commission.

1. While the ship is at sea the auto alarm shall be tested by means of the testing device supplied, at least once every 24 hours, the timing of the dashes to be made by reference to the sweep seconds hand of the station's clock. Bridge bell and warning light and operator's room bell and light must show correct operation when this test is made. A statement that the foregoing has been fulfilled must be inserted in the ship's official deck log * and the radio log daily.

2. If the warning light is illuminated for a continuous period of five minutes or more, the operator shall record in the radio log the time when he was called by the bridge, the time when he goes to the radio room to investigate the difficulty, the reason for the warning lights burning, and a statement as to the adjustments found necessary to restore normal operation.

3. If the bells ring, the operator should record in the radio log the time of the occurrence and the time when he arrives at the radio room to investigate the reason for the bells ringing. A record should also be made in the log to explain what caused the bells to ring, such as actual alarm, false alarm, filament burnout, low line voltage, low battery voltage, blown fuses, etc.

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* Entry in ship's official deck log not required by F.C.C.

4. Vacuum tube and battery information to be entered in log. Each vacuum tube initially supplied in the auto alarm is dated at the time of installation. If any tube becomes defective the operator should remove the tube and make an entry in the log to indicate the date the tube was removed and replaced and the tube socket from which it was taken. The defective tube should not be destroyed, but should be returned to the radio company responsible for the maintenance of the auto alarm. The new tube which is used to replace the defective tube should be dated by the operator. This may be done by scratching the date on the metal shell of the tube with the point of a knife or other sharp tool.

The 9 volt "C" battery (type D6BP) mounted in the junction box is provided with a label to record the date when installed, and also the date when it should be replaced. If for any reason the operator finds it necessary to replace the "C" battery with his spare "C" battery, he should enter this fact in the log, recording when the old "C" battery was taken out, when the new one was replaced and on the label of the new battery he should write the date when installed. The "C" battery should be replaced when it falls below 8.5 volts.

34. **General Maintenance and Repairs at Sea**—If normal operation of the auto alarm cannot be obtained, the radio operator should proceed as follows:

Important—Do not remove relay cover or oven cover on the auto alarm panel or work with tools around any of the parts unless the master switch is in the "off" position.

1. Check with three range radio room voltmeter to determine if the 110 volt line voltage and six volt battery power exists across the appropriate input terminals in the junction box. If correct readings are obtained make similar measurements across the proper terminals of the receiver-selector unit.

2. Make certain that all leads on the junction box terminals from number 1 to 32 inclusive are tight and making good connections.

3. Relay contacts should be checked and cleaned, if necessary, to insure proper contact. To clean contacts use the special burnishing tool which is furnished, taking care not to remove too much contact material with the burnisher.

4. If defective tubes are suspected, they should be replaced *one at a time*, starting with the 6–A–8 tube, always returning good tubes to the same socket from which they were removed. This will avoid confusion in locating a defective tube. Type 1611 tubes may be checked for emission by placing them successively

in the second socket from the left in the lower row of tubes. This is the radio relay tube socket and the plate current of this tube may be read by the milliammeter with the switch in position number four. Normal tubes with 100 volts line should show a plate current with no incoming signal of approximately 7 milliamperes or more. When checking tubes all tube sockets must be filled, otherwise bells will ring.

5. Each selector circuit may be checked by sending a test signal through the auto alarm and successively placing the "current" switch in position 1, 2 and 3. In position 1 after a long dash a current of approximately 8 to 10 milliamperes will be obtained. In position 2 after a long dash a similar value will be obtained. To check selector number 3 place the switch in position 3, send a 4 second dash with the test buzzer and then observe after about 5 seconds that the meter reads momentarily a value of approximately 6 milliamperes. The third selector tube shuts off its own plate current after it checks a space and for this reason only a momentary meter reading will be obtained.

6. It is possible to check various voltages in the junction box and on the various component units back of the auto alarm panel by using the three range voltmeter which is carried in the radio room. Such a voltage analysis will enable the operator to determine if open circuits or poor connections exist in various parts of the circuits.

7. The switch contacts on the master switch should be checked occasionally to insure that they are making good connection, removing any corrosion or oxidation which may have taken place.

8. Normal operation of the oven heater will be indicated by intermittent operation of the small pilot light mounted on the back of the junction box cover. This pilot light is provided to enable the radio operator to determine that the oven circuit is operating normally whether or not the auto alarm is on watch.

9. If for any reason the auto alarm 6 volt battery becomes discharged the operator should substitute one of the radio room 6 volt storage batteries temporarily. The auto alarm battery should then be placed on charge from the standard radio room "A" battery charger. The operator should determine why the auto alarm battery became discharged. The auto alarm master switch is arranged to place the 6 volt battery on charge at a rate of approximately 2 amperes whenever the master switch is in the "off" position. This charging rate is sufficient to keep the alarm battery fully charged if the alarm is "on watch" for a period of 18 hours daily. In other words 6 hours charging in each 24 hours will

keep the battery in good condition. If either or both battery charging resistors at the top of the junction box should become defective, standard 110 volt 100 watt lamps may be used as a substitute.

10. When replacing the 9 volt "C" battery, make certain that the green lead connects to the negative terminal and the brown lead connects to the positive terminal. No current is taken by the "C" battery, therefore if early "C" battery replacement is necessary look for shorts or leakage. A voltmeter connected to *series* with one of the "C" battery leads should show no reading for normal operation.

11. If plate current is obtained through each selector relay as explained under "5" above and the stepping relay does not operate, inspect the contacts on the selector relay in the oven. Remove oven cover screws and carefully withdraw the oven cover *straight out* to prevent breakage of the thermometer. Relay contacts may now be examined and cleaned if necessary.

12. Note that the 6 volt storage battery has two fuses in the positive side of the circuit, a 6 ampere glass fuse in the junction box and also an external 10 ampere fuse installed near the battery. Short circuits in the 6 volt circuits in the auto alarm or junction box will normally cause the 6 ampere glass fuses to blow. Short circuits in the wiring to the warning bells will cause blowing of the external 10 ampere fuse. This arrangement allows the warning bells to ring when the 6 ampere fuse is blown. Both fuses should be inspected in case of trouble. Always use the specified ratings when replacing fuses.

13. The line voltage relay will also cause the bells to ring if the polarity of the 110 volt shipboard line is reversed. The voltmeter on the receiver-selector unit in switch position 5 will also indicate this condition by reading in the reverse direction.

35. **Typical Readings of Current and Voltage for Normal Auto Alarm Operation**—The following readings are based on an average line voltage of 100 volts. Higher line voltages will give slightly higher readings.

Current Switch

Position 1—First selector relay closes at approximately 4 ma.
Position 2—Second selector relay closes at approximately 6.5 ma.
Position 3—Third selector relay closes momentarily at approximately 6.5 ma.

Position 4—Signal relay plate current is 7.5 ma. with no incoming signal. With signals, lower values, down to zero, will be obtained.
Postion 5—Not used.

Voltmeter Switch

Position 1—Grid charging voltage 52 volts.
Position 2—Grid bias on selector tubes 1 and 2, 29 volts.
Position 3—Grid bias on third selector tube, 29 volts.
Position 4—Heater voltage 60 volts.
Position 5—Reads ship's line voltage.

When going off watch the operator should always leave the " current " switch in position 1 and the " voltage " switch in position 5. If the current switch is left in position 4 the milliammeter will follow all incoming signals, causing unnecessary wear and tear on the instrument.

36. Testing Auto Alarm under Severe Static Conditions—Occasionally when static is very severe the sensitivity control cannot be advanced far enough to permit the test buzzer to actuate the receiver without causing the radio relay to " block " from the static. To test the alarm under these conditions place a temporary short circuit between the AA terminal and ground terminal on the master switch. After the test the short should be removed and the sensitivity control adjusted to optimum for prevailing noise level.

37. Understanding Selector Action by Observing Relays—1. Transmit ".V "s or other code signals with test buzzer. Radio relay will follow keying. The milliammeter in position 4 will show lower reading each time buzzer is operated. No other relays will operate.

2. Transmit one four second dash. Radio relay will operate instantly and after 3.5 seconds number 1 selector relay in oven will close, auxiliary relay will close, " notch " coil will be energized and stepping relay will advance one position. This checks if dash is long enough.

3. Transmit one dash of 5 seconds or more. Same action as under " 2 " above will take place and in addition number two selector relay in oven will close and " restore " coil on stepping relay will be energized. When long dash is broken stepping relay will return to zero or normal position. This checks overlong dashes.

4. Transmit one four second dash to advance stepping relay one

position and then break this dash. After approximately 5 seconds "restore" coil will click and stepping relay will return to zero. This checks spaces.

5. Transmit four correct 4 second dashes separated by 1 second spaces and watch the stepping relay move up with each dash, finally causing the bell ringing relay to lock in when the fourth dash is broken. Note that each dash, including the fourth dash must be followed by a space to lock in the bell ringing relay. If the fourth dash (or any other dash) is too long the restore coil is energized on the stepping relay.

CHAPTER 16

POLICE TRANSMITTERS AND RECEIVERS

1. Police Radio Communications *—State and Municipal police departments utilize radio communication for six purposes which may be summarized as follows:

1. By municipalities for one-way communication to mobile units and remote police stations.
2. By municipalities for 2-way communication with mobile units.
3. By states and municipalities for the radiotelegraphic exchange of police information.
4. By states in the general dispatching of state police units.
5. By harbor police in connection with the dispatching of harbor police boats and general policing of shipping.
6. By states for emergency radiotelegraphic use in the event of interruption of the wire teletype network.

Practically everyone is familiar with the operation of the first one-way system of communication by which messages are broadcast "blind" to mobile units associated with police work. After having accomplished their objective the crew of the car receiving the orders call back over the police telephone systems at the nearest call box.

The two-way system in which the cars are equipped with transmitters as well as receivers provides certain advantages as, for instance, the acknowledgment of calls and inquiries concerning cars which the patrolmen have regarded with suspicion. Two-way systems are operated in one of two ways; one system utilizes ultra-high frequencies (above 30,000 kilocycles) exclusively, while the other provides for transmission to cars by medium of high-frequencies and talk-back from the mobile units by ultra-high frequencies.

Two-way systems are divided into three classifications as follows:

1. Simplex operation: One frequency is used for both station and car transmitters. Only one can be on the air at a time,

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* See Chapter 19 for rules governing Emergency Radio Stations (police, marine fire and forestry).

direct car-to-car communication, when the cars are not separated too far.

2. Duplex operation: The station transmitter is on one frequency, the cars on another. Both can talk at once if necessary and operation is similar to ordinary telephone conversation. Car-to-car communications not possible except by rebroadcast through fixed station (sometimes called triplex).
3. Voice break-in operation: A system using voice operated relays that control transmitter and receiver. In this case one station can break in on the other during pauses in speech. Direct car-to-car communication is also possible in this method under the same conditions as specified in the first case.

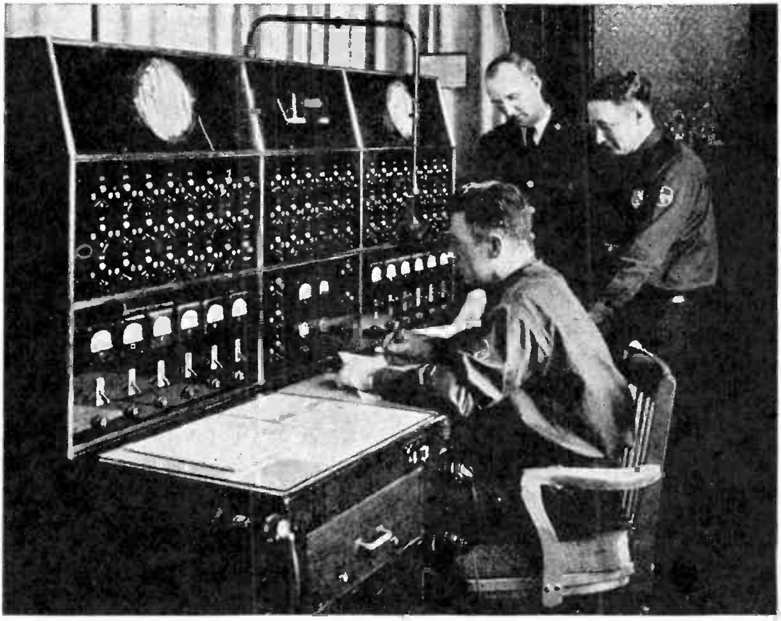
Transmitters and receivers employed for police communication require reliability of operation since they are used primarily for emergency transmissions and delays resulting from inoperative equipment cannot be tolerated.

It is not unusual to turn a police transmitter on and off a thousand times a day. Obviously the starting equipment relays, and in fact the component parts must be well designed to assure rapid and reliable operation under such rigorous requirements. Police departments realizing the importance of such requirements turn to commercial manufacturers for equipment and engineering advice when planning their radio communication systems. These manufacturers have at their command extensive research and development laboratories manned by engineers and technicians having years of experience in the design, manufacture and operation of radio equipment for the various radio services.

The description of equipment that follows is representative of such manufacturers and is published with their permission verbatim from the instruction books supplied with the equipment. One must, however, not assume that the equipment described in this Chapter is superior to that of other commercial manufacturers. Unfortunately space does not permit of a description of the equipment of each. However, by making use of the descriptions of one or two manufacturers the student is permitted to read himself into current practice.

Referring to the photograph of the Dispatching Room and Control Board of the Baltimore City Police Department. In the top panels are shown the speakers and in the center a clock. In the center panels control switches and lights are shown. Each switch bears a number corresponding to a particular scout car, detective cruiser or crash car. The switch may be thrown to any one of three lights namely, green, white or red.

When the green light is actuated it signifies to the operator that the car is cruising somewhere within its assigned district and is available for call. When a particular car is placed on an assignment and hence is not available for call, the white light is actuated. The white light is made to flash at short intervals to conspicuously mark the busy cars. A red light is actuated whenever a car is out of service, as for instance, in the case of a mechanical or electrical breakdown in either the car or the radio receiver.



Radio Dispatching Room and Control Board of the Baltimore City Police Department

In the lower portion of the center panel is the speech amplifier with overmodulation indicator. On the left and right are shown the selector switches by which the best remotely located receiver is chosen for reception from the mobile units equipped with ultra-high frequency transmitters on cars and fire boats. The meters indicate the relative strength of the received carrier at each receiving station. In addition to the meters a relay operated buzzer is sounded on each telephone line connecting the dispatcher's board with the remotely located receiver whenever a signal is above satisfactory level. This provision enables the dispatcher to readily select the output of any particular remotely located receiver without consulting the signal strength indicating meter mentioned above. This audible means for selecting the best receiver is an operating aid particularly valuable when traffic is heavy since it enables the dispatcher to make notes and obviates careful observation of meter indications.

The system was designed by Lieutenant William E. Taylor shown in the center and who is in charge of the Radio Division of the Police Department.

Western Electric Type 22A Police Transmitter *

2. Type 22A Transmitter—The 22A transmitter delivers 25 watts of carrier power into a coaxial transmission line over the frequency band 30–42 megacycles. Aside from the power output rating, the transmitter differs in many respects from other existing Western Electric transmitters for police service. A high-gain audio amplifier permitting the use of the low level, high quality, dynamic type of microphone; and an automatic gain control circuit reduces overmodulation and provides better coverage by keeping average modulation at a high level.

As can be seen from figure 437, the transmitter consists of a single chassis upon which all apparatus is mounted with the exception of the output current meter. The equipment mounted on the upper surface of the chassis is partitioned by means of three boxes having removable covers. Besides providing the necessary shielding, the compartments group the apparatus according to its function in the circuit. As viewed from the front, the left-hand compartment contains the power supply apparatus; the center compartment, the radio-frequency equipment; and the right-hand compartment, the audio-frequency equipment. The operating controls are located on the front of the transmitter and consist of a filament on-off switch with signal light, and a carrier control key which turns on the carrier when operated downward and provides a tone-signal attention call when operated upward. The radio-frequency output meter, located on the front panel, indicates the transmission line current.

* Abstracted from an article in Pick-Ups by Wm. K. Caughey, Bell Telephone Laboratories, and used by permission of Western Electric Co.

All connections to the transmitter are made through the bottom. The power supply and control conduits are run through holes in the table top and terminate underneath the transmitter. The wires are provided with sufficient slack beneath the transmitter so that it can be readily tilted back for inspection. The antenna transmission line connection presented an interesting problem due to the inflexibility of the 7/8-inch diameter transmission line and the requirement that this line must terminate very close to the output current meter, which in this case is located near the top of the transmitter. Any appreciable length of open lead to the meter would prevent it from indicating actual transmission line current. A satisfactory solution was obtained by terminating the antenna transmission line in a junction box mounted on the bottom side of the table top directly below the transmitter and employing a short removable section of transmission line between the box and the output current meter.

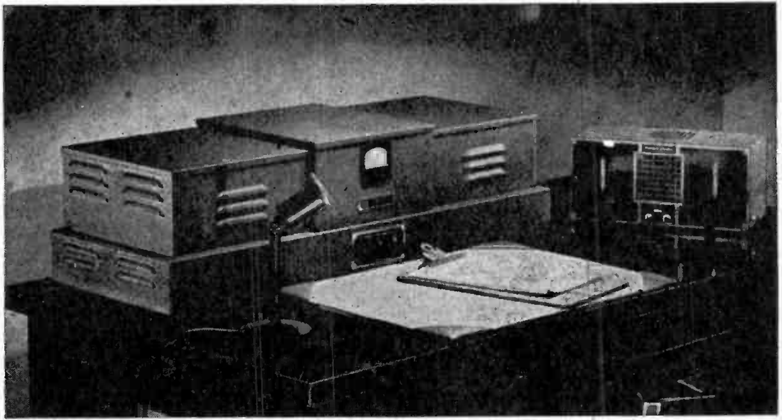


Fig. 437. Western Electric 22-A Ultra High Frequency Police Transmitter.

The audio amplifier section of the transmitter has a gain of approximately 100 db. Although this is considerably more gain than is used in the other existing police transmitters it was made possible without undue expense by the use of resistance coupled voltage amplifier stages employing high gain receiver type tubes and an a.f. power amplifier using beam type power tubes. The gain is sufficient for satisfactory operation with a dynamic microphone such as the No. 633A. In addition, a d.c. microphone supply is incorporated so that either a double-button carbon microphone or a single-button, high-level microphone can be used. Provision for telephone line input is also made.

Although automatic gain control circuits have been applied to radio receivers for many years, the 22A Radio Transmitter is the first commercial transmitter to incorporate such a device. In this transmitter, the control is effected in the audio amplifier and has the characteristic of varying the gain of the amplifier inversely with the applied signal for input levels exceeding a certain fixed amount. The circuit compensates to a large extent for excessive variations in speech level input, reduces distortion due to over-

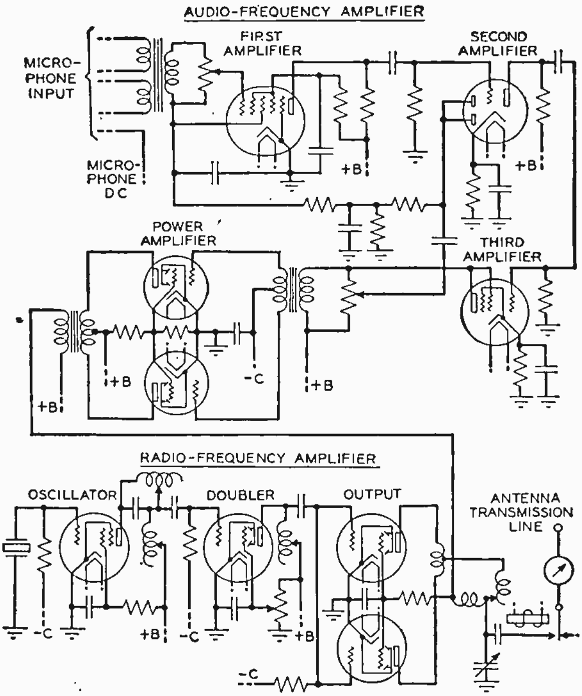


FIG. 438. Schematic Diagram of W.E. 22-A Transmitter.

modulation, and allows an increase in the average percentage of modulation. For police application where a monitoring operator is not ordinarily employed, this feature is a distinct advantage, since it enables the operator to pay less attention to how loud he speaks and to the distance he maintains from the microphone.

Figure 438 shows a simplified schematic of the transmitter. The audio-frequency amplifier shown in the top section of the diagram supplies the necessary audio power to completely modulate the carrier. It consists of four stages of amplification, two resistance-coupled and two transformer-coupled. The automatic gain control is effected by feeding back a portion of the a.c. voltage in the plate circuit of the third-amplifier tube, rectifying it in the diode section of the second-amplifier tube and applying the resultant d.c. voltage as a bias voltage to grids numbers 1 and 3 of the first-amplifier tube. The characteristics of this tube are such that the amplification can be varied over a large range without introducing excessive distortion simply by varying the bias voltage applied to the first and third grids. Figure 439 shows the automatic gain control characteristics of the transmitter. The diode rectifier in the second amplifier tube is biased by the voltage drop across the cathode resistor, so that rectification occurs only for signals having a peak amplitude in excess of this voltage. This produces the change in slope in the characteristic. The amplifier operates normally and at full gain until a signal sufficient to give a high level

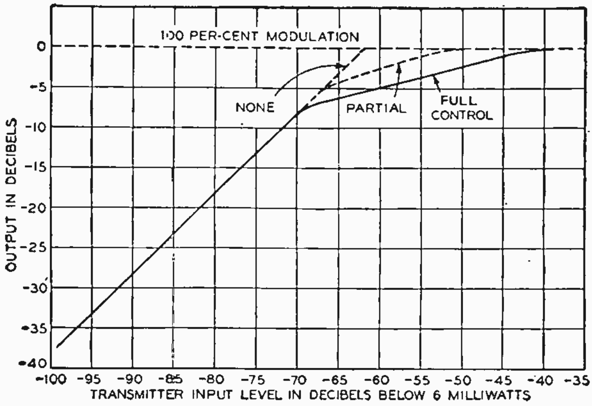


FIG. 439.

of modulation is applied, after which the gain of the amplifier is automatically reduced.

Provision is made in this transmitter for allowing the audio amplifier to act as an audio oscillator to transmit a distinctive tone-signal attention call. The circuit switching for this connection is performed by a relay which is operated either by the manual tone-carrier key located on the front of the transmitter or by a semi-remote control switch. When the relay is energized, a series resonant tuned circuit is connected between the cathode circuit of the second amplifier stage and the plate circuit of the fourth or a.f. power amplifier stage.

The radio-frequency amplifier equipment consists of a crystal-controlled oscillator employing a pentode type tube operating at one-fourth the carrier frequency, a doubler stage using a beam type power tube, and a r.f. output stage employing two beam-type tubes connected in parallel. Continuously variable inductances are used for tuning the various radio frequency circuits in order to maintain a high efficiency over the frequency range without the use of plug-in coils. These inductances are adjusted from the front panel by means of a screwdriver. A radio-frequency gain control is provided to compensate for output variations of the oscillator and consists of a potentiometer connected in the screen grid supply circuit of the doubler tube. Of interest, is the use of a center-tapped inductance between the plates of the parallel-connected tubes of the r.f. output stage to prevent parallel singing without introducing appreciable inductance or loss at the operating frequency.

The power supply equipment is of conventional design employing two separate rectifiers, one for the plate supply and the other for the grid bias, microphone and control circuits. The use of the grid bias supply for energizing the control circuit of the plate supply rectifier provides a simple safety method to insure grid bias voltage when the plate supply rectifier is operating.

One of the interesting features is the method of measuring tube currents for tuning the transmitter. Instead of incorporating milliammeters three pairs of pin jacks are mounted in the center compartment which accommodate the test prods of a standard Weston voltohmmeter. The pin jacks are connected to meter resistors in the essential circuits of the transmitter and are of such value that only the zero to three-volt range of the volt-ohmmeter is used and multiplication factors are employed to obtain actual current measurements. This arrangement provides a definite saving to the customer since a voltohmmeter is always on hand for serving any type of radio equipment.

3. **Carrier Control**—There are two methods of carrier control; namely, "Voice Automatic" and "Manual" (press switch to talk). Either method may be utilized at will by operating a switch in the transmitter chassis.

The control system includes an automatic antenna relay which switches a common antenna from the receiver to the transmitter circuit and incorporates a receiver cut-off device, both functions being vitally necessary in single frequency systems.

Carrier control materially reduces the average input energy required to operate the transmitter, since full plate and screen power are not required until actual transmission begins. Its principal value, however, is that it insures a rapid two-way circuit, permitting normal conversation. Power drain on the battery is further reduced because in routine police duty, two contacts are of short duration only, hence the radio transmitter adds very little to the average all day load on the car battery.

4. **Voice Automatic Control**—With voice automatic carrier control the operator simply talks into the handset microphone and simultaneously with his first uttered sound the transmitter is on the air and stays on the air during his announcement. If he pauses, the transmitter goes off the air (after a small fraction of a second).

As many police systems use a single operating frequency for headquarters and all car transmitters, it can easily be seen that "Voice Automatic" carrier control enables each car to send its message quickly and immediately go off the air, allowing other car transmitters (or headquarters) to break in during any slight pause in transmission. Thus the operating frequency is cleared for use by other cars or headquarters and a rapid two-way circuit is obtained—a feature that is also equally valuable in two-frequency or multiple frequency systems.

5. **Press-to-Talk Switch**—When the number of transmitters using a single frequency is limited and there is little likelihood of message congestion, it may be found desirable to use the manual method of carrier control. With this method, no radio frequency output is obtained until the operator presses a grip switch in the microphone handset handle. This grip switch allows the operator to go on or off the air at will.

This method of carrier control effectively conserves carrier power, because no high voltage plate power is required for the vacuum tubes during periods between transmission.

WESTERN ELECTRIC RADIO TRANSMITTER NO. 18A

6. General Description—The No. 18A Radio Transmitter is a low power radiotelephone transmitter suitable for mobile or fixed station operation in the frequency band of 30 to 42 megacycles. It will deliver 5 watts of high frequency energy to the load circuit, which may be either an antenna or a low impedance transmission line. A Western Electric quartz plate is used to maintain the frequency well within 0.025 percent of the nominal value. This transmitter is capable of approximately 90 percent modulation with good telephone quality.

An antenna transfer relay is included in this transmitter in order that the same antenna may be used on the radio receiver if desired. A choice of two methods of control is provided. In one a button on the external microphone is pressed while transmitting and released while receiving. In the other method, automatic voice-operated switching is used. When the operator speaks into the microphone, the transmitter is placed on the air, and held on until the speaker pauses. After a brief interval the circuits automatically drop back to the receiving condition.

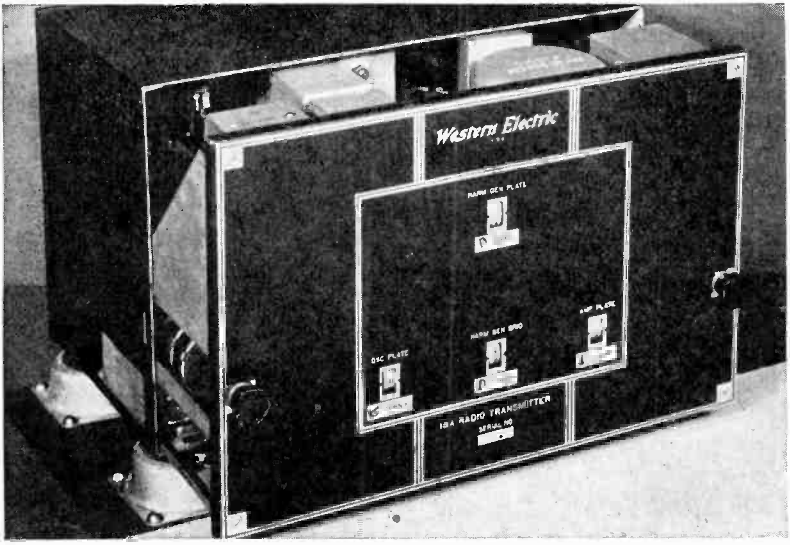


FIG. 440. Western Electric 5 Watt 18-A Police Radiophone Transmitter.

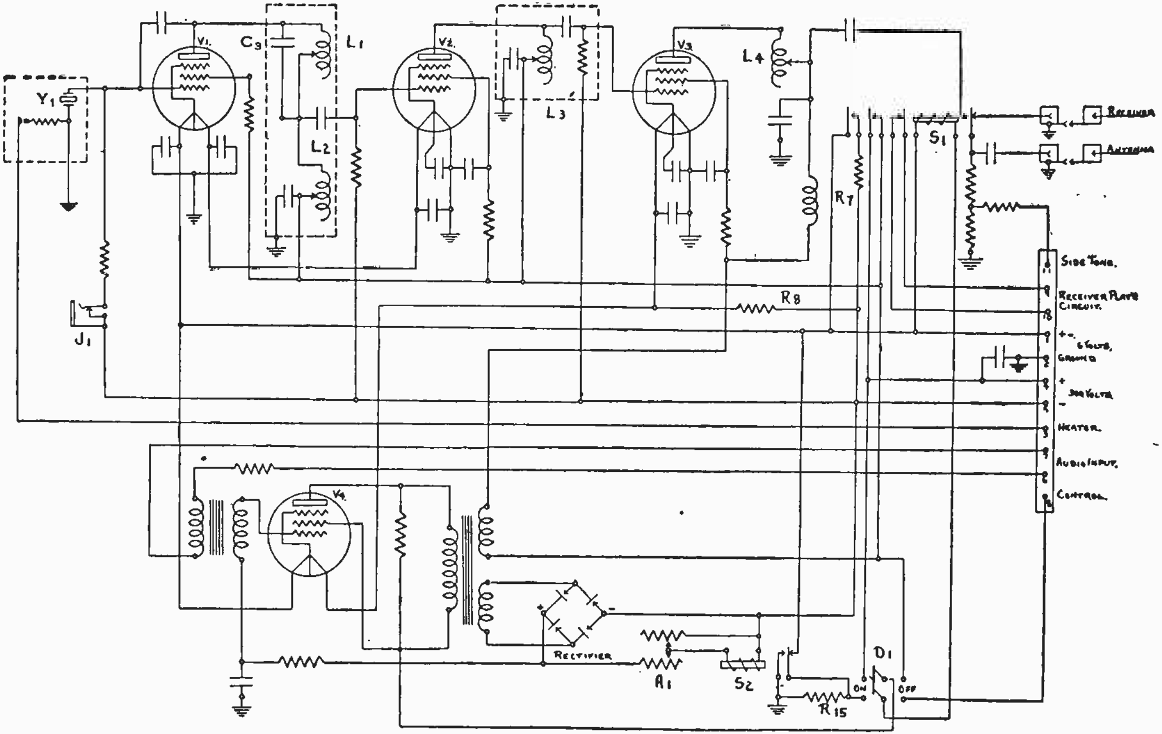


FIG. 441. Western Electric 18-A Transmitter Schematic Circuit.

For use in mobile applications, filament power is supplied directly from a 6-volt storage battery and plate power from a 300-volt dynamotor.

The general appearance of the No. 18A Radio Transmitter is shown in figure 440. The dimensions are approximately 11 inches wide, 7 inches high and 6 1/2 inches deep. The four tuning controls are accessible on the front panel. Electrical connections to the unit are all made by detachable plugs. The chassis carrying the apparatus is integral with the front panel and may be easily removed from the steel housing for inspection.

This transmitter employs four Western Electric No. 306A Vacuum Tubes, which are designed especially for this type of service. They perform the functions of oscillator, harmonic generator, modulating amplifier, and audio amplifier, respectively. A detailed description of their functions is given in the following sections.

7. **Oscillator**—Referring to the schematic circuit shown in figure 441, the quartz plate (*Y*1) is at the left of the diagram. This crystal oscillates at one-fourth or one-sixth of the desired output frequency and controls the grid circuit of the oscillator tube (*V*1). The plate circuit of the oscillator tube contains two tuned circuits in series. The first (*L*1*C*3 is adjusted by means of the variable coil *L*1 to present the high inductive load at the crystal frequency necessary for oscillation). The second tuned circuit (*L*2 shunted by the tube and wiring capacities) is adjusted to two or three times the crystal frequency. The voltage drop across this circuit is applied to the input of the following stage.

8. **Harmonic Generator**—The harmonic generator tube (*V*2) is normally operated as a doubler, that is, the plate circuit is tuned by *L*3 (shunted by the tube and wiring capacities) to twice the frequency applied to the grid. The voltage across *L*3 is, therefore, of four or six times the crystal frequency and is used to excite the last stage at the desired output frequency.

9. **Modulating Amplifier**—The plate circuit of the modulating amplifier (*V*3) is tuned to the desired output frequency by *L*4. The capacity for this tuned circuit consists of the load coupling condenser in series with the tube and stray capacity. Modulation is accomplished in this stage by superimposing an audio voltage on the plate and screen circuits.

10. **Audio Amplifier**—The audio amplifier (*V*4) receives its excitation from the microphone transformer *T*1. The plate circuit delivers audio power to the output transformer which in turn supplies the modulating voltage for *V*3. An auxiliary winding on

the transformer supplies a small part of the available audio output to the full wave copper oxide rectifier. The d.c. output of this rectifier is used for two purposes. One concerns the bias of *V*4, and the other is a circuit arrangement discussed in the next section. *V*4 is a class A Audio amplifier but when carrying no load is biased down to about one-third its normal plate current by the drop across the bias resistors. When the antenna relay is closed these resistors are effectively in parallel in the common plate return of all tubes. When audio input is applied to *V*4 a d.c. drop appears across attenuator *A*1. This drop is in series opposition with the regular bias for *V*4. As a result the net bias shifts down to normal value only when the tube is handling full load. Voice frequency ripple in the bias shifting voltage across *A*1 is kept from the grid of *V*4 by the resistance-capacity filter. The plate current of *V*4 therefore behaves much as if it were a Class B audio amplifier, increasing under load to its full value. With steady tone input the tube is a normal Class A amplifier and takes full plate current, but with voice input the maximum current is taken only in pulses at syllable frequencies, hence there is a considerable saving in average demand.

Description of Power and Control Circuits

11. **Filament Circuits**—The four Western Electric No. 306A Vacuum Tubes used in the No. 18A Radio Transmitter have a rated filament voltage of 2.75 volts. *V*1 and *V*2 are connected in series, as are *V*3 and *V*4. To insure a low filament impedance at very high radio frequencies, the center of the filament on the No. 306A Tube is brought out on a prong in the tube base. These taps are by-passed to ground on *V*2 and *V*3 in the transmitter.

12. **Crystal Heater Circuit**—The heater element in the quartz plate used in this transmitter is brought out on terminal 3 where it may be connected to a 6-volt source. This heater operates automatically in cold weather and keeps the crystal above 0° C. when the ambient temperature is as low as —20° C. Close control of the crystal temperature is not required because the crystals used have a very low temperature coefficient between 0° and 60° C.

13. **Manual Control Circuit**—When the voice control switch (*D*1) is in the "Off" position, the circuits in the transmitter operate in the following manner: The transmitter is put in the standby or ready condition by applying filament and plate voltages. The filaments reach operating temperature in about one second but no plate current flows because the positive side of the 300-volt supply is open at a pair of contacts on the antenna relay (*S*1).

When it is desired to put the transmitter "on the air," a button on the microphone or handset is pressed. This grounds terminal 8, operating *S*1 which in turn performs the following functions:

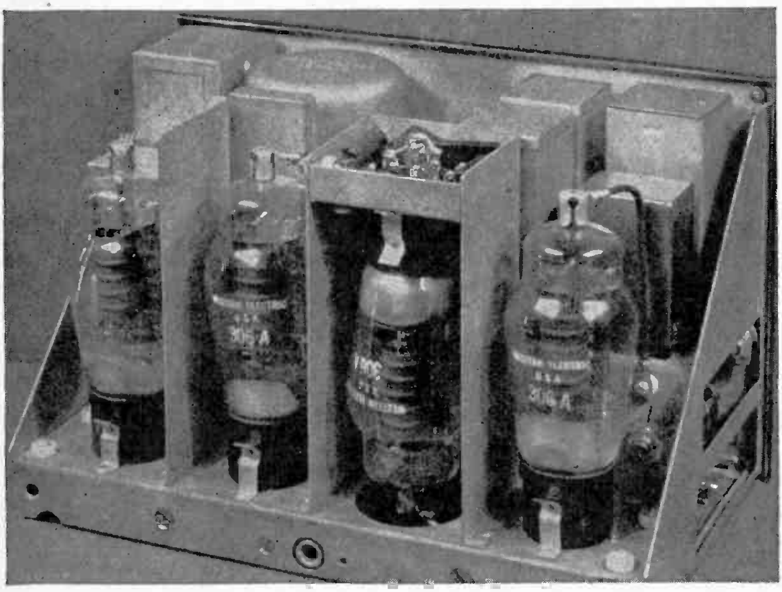


FIG. 442. Rear Open View of the Western Electric 18-A Ultra-high Frequency Radio Transmitter for Police Cars.

1. Transfers the antenna or transmission line from receiver to transmitter.
2. Closes the sidetone supply circuit.
3. Opens the plate circuit of the radio receiver to make it inoperative.
4. Closes the plate circuit of all four transmitter tubes.

When the button is released *S*1 drops out, restoring all circuits to the receiving condition.

14. **Automatic Control Circuits**—With *D*1 in the "on" position an automatic control is provided and the push button is not required. Under this condition the transmitter is made ready by applying power; the radio frequency tubes (*V*1, *V*2 and *V*3) remain idle as before, but the audio tube (*V*4) is energized. Now

when the operator speaks into the microphone the d.c. output from the copper oxide rectifier operates *S2* through the sensitivity control (*A1*). *S2* in turn operates *S1* by removing a short circuit from the winding of *S1*, then cutting out the series resistor *R15*. The transmitter is, therefore, placed on the air with the operator doing no more than speaking into the microphone. The relays are of the fast-operate slow release type and therefore hold the transmitter on the air during a phrase or sentence. When the operator pauses for a short interval the relays drop back to the receiving condition.

Under the operating condition just described the antenna relay (*S1*) performs another function which has not been mentioned. With the antenna relay released only *V4* is drawing plate current through the bias resistor *R7*, and with it closed all four tubes are drawing current. It is necessary, therefore, to add another bias resistor (*R8*) when *S1* operates. The filament ends of *R7* and *R8* are connected to opposite sides of the filament of *V4* to minimize the effect on the grid bias of reversing the filament supply polarity.

15. **Sidetone Circuit**—Sidetone energy is taken directly from the radio frequency output terminal in order that it may be obtained only when *S1* is operated and the transmitter is actually on the air. It is reduced to a suitable level by resistors *R9*, *R10*, and *R11*. *C16* prevents the sidetone from being short-circuited if there is a low frequency ground on the antenna.

16. **Installation**—The transmitter should be mounted in a location where it is conveniently accessible, and where there will be free ventilation space of several inches around it. When it is mounted in the trunk of an automobile it is not necessary to make special provision for ventilating the trunk as there is usually ample free space inside to prevent overheating.

The No. 18A Radio Transmitter can be removed from the housing by rotating the two locks to the left a turn or two and tilting the chassis forward. Four Western Electric No. 306A Vacuum Tubes should be inserted in their respective sockets, taking care that each is locked in place by the spring that snaps over the bayonet pin. A quartz plate of the correct frequency (see "**Apparatus List**") should be inserted in the three-pin socket.

The cables for antenna and power connections should be long enough so that they may be connected with the chassis outside of its housing during the initial tuning procedure and maintenance checking.

The external cables and antenna installation should be made according to information furnished for the particular radio telephone system to be used. Power connections should be made by use of a Jones Socket No. SS–12–CCT and antenna connections should be made by means of the plugs supplied with the set.

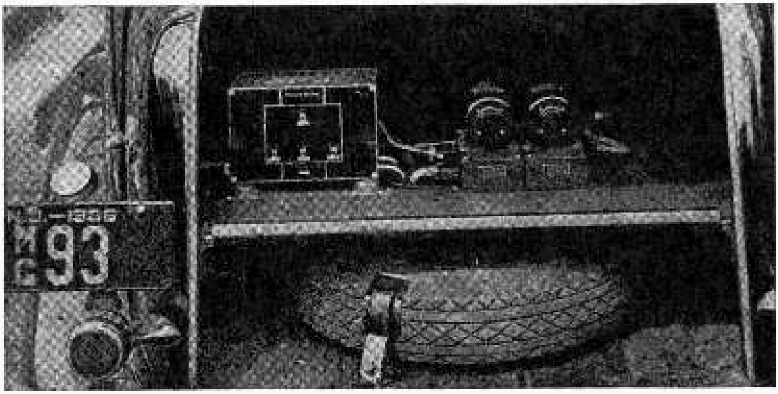


FIG. 443. Western Electric Type 18-A 5 Watt Police Transmitter Installed in One of the Police Radio Cars of the Westfield, New Jersey, Police Department. The two dynamotors shown at the right of the transmitter supply plate voltages for the car transmitter and receiver.

ADJUSTMENT

17. Relays—The two relays in the No. 18A Radio Transmitter are properly adjusted at the factory and should, in general, not be tampered with unless they are known to be causing trouble. The one exception to this rule is that it may be desirable to reduce the "holdover" time of *S*1 if push button or manual control is to be used exclusively. This adjustment is discussed in the section on "**Maintenance.**"

18. Tuning Controls—The four screwdriver-operated turning controls on the front panel of the No. 18A Radio Transmitter operate continuously variable coils in the oscillator plate, harmonic generator grid, harmonic generator plate, and amplifier plate circuits respectively. A calibration for the four controls is given which makes it possible to set all of them very nearly to their correct adjustment before power is applied to the transmitter. Each control has a dial marked in coil turns and the approximate number of turns for a particular frequency is given on the chart. The oscillator plate circuit should be adjusted to the crystal frequency, and the harmonic generator grid circuit to two or three times the crystal frequency as required. The harmonic generator plate and amplifier plate coils should be set to the desired carrier frequency which is twice the excitation frequency on the harmonic generator grid, and four or six times the crystal frequency.

19. Artificial Antenna—It will be found convenient to use an artificial antenna for a load during the initial adjusting procedure and also during maintenance checking. A radio frequency milliammeter with a range 0 to 500 ma. is required. The resistor may easily be made up from the small non-inductive resistors available in all radio stores. If the transmitter is to be operated directly into a quarter-wave antenna or into a 35-ohm line, the resistance should be about 35 ohms and may consist of six 200-ohm, one-half watt, units in parallel. Since they will be used only for brief intervals it is not necessary that they be capable of dissipating the transmitter output continuously. If the transmitter is to deliver power to a 70-ohm transmission line the artificial antenna resistor should be about 70-ohms and may consist of three 200-ohm units in parallel. In either case the resistor should be connected in series with the meter with the shortest possible leads. The combination should be wired with short leads to a plug which fits the antenna connector on the radio transmitter. This connector is a standard part widely used on automobile radio receivers. The meter should be connected to the outer or ground terminal and the resistor to the central terminal.

If no suitable radio-frequency meter is available, an artificial antenna may be made up from miniature Mazda lamps and the transmitter may be tuned by observing their brilliancy. For a 35-ohm load six standard radio panel dial lamps (6-volt Mazda No. 40), connected three in series, and two groups in parallel, may be used. For a 70-ohm load four Mazda T3, 14-volt, lamps connected in series parallel will be satisfactory. It is recommended that the lamps be connected together by soldering directly to their bases in order to keep the leads short.

The automatic control switch (*D*1) should be turned to the "Off" position. The 6-volt filament, and 300-volt plate, power should be applied. If there is no "Press-to-talk" button in the system being used terminal 8 is grounded in the external wiring, and the entire transmitter is energized when power is applied. If a "press-to-talk" button is used, it is necessary to operate this button in addition to applying power in order to turn on the transmitter.

After a second or two some antenna current should be observed.

All four tuning controls should now be adjusted to obtain the maximum antenna current. Some of these adjustments are not critical. In particular it will be found that the oscillator plate coil can be changed over a considerable range without much effect on the antenna current. It should be adjusted so that if a sustained sound should be made in the microphone the antenna current should rise. The harmonic generator plate coil should be readjusted slightly one way and then another until the rise in antenna current is the greatest.

20. **Checking Oscillator Adjustment**—It is desirable, although not essential, to check the oscillator adjustment by measuring the oscillator grid current. A jack (*J*1) is provided on the back of the chassis in order that a meter may be conveniently inserted in this circuit. A d.c. meter is required having a scale such that one-half milliampere may be read. The meter should be equipped with a cord and standard two-conductor telephone plug, the negative side of the meter being connected to the tip of the plug. As the oscillator plate coil turns are increased the oscillator grid current increases relatively slowly to a maximum, decreases slightly after the maximum is passed, then suddenly drops to zero at the point where oscillations cease. The correct operating point is on the slowly rising (with increasing coil turns) part of the curve at a point not exceeding one-half milliampere grid current. Too few coil turns giving very low grid current may result in insufficient excitation on the following stage. A very high grid current may damage the crystal. Near the maximum grid current point the crystal may not start quickly. The desired adjustment is, therefore, well below maximum on the proper side. At various frequencies with various crystals the current with proper adjustment will usually be between 0.2 and 0.5 milliamperes.

21. **Automatic Voice Control Switching**—If automatic voice control switching is to be used it will be well to check the adjustment of this facility while operating on the artificial antenna. Turn the voice control switch (*D*1) to the "On" position. Apply power to the transmitter and speak into the microphone. The antenna current should come up quickly when the operator speaks and should remain up during a phrase or sentence. When the operator pauses for a brief interval, the antenna current should drop to zero and remain there until the operator again speaks. The correct operation of this switching can be observed by listening to the sidetone in the handset receiver. Sidetone is obtained only when the antenna relay is in the transmitting position, hence it indicates just what goes out on the air.

The sensivity of the voice control is adjustable by means of the screwdriver-operated attenuator (*A*1). The sensitivity is increased by turning this control to the right. At full sensitivity the transmitter will pulse on and off without the operator speaking into the microphone. The sensitivity control must always be used well below the point where this pulsing ceases. The amount of sensitivity which can be used depends upon local conditions and must be determined by experiment. For example, if there is considerable extraneous noise reaching the microphone, or electrical noise in the microphone current supply, this may place the transmitter "on the air" while the operator is trying to receive. In such cases it is necessary to reduce further the sensitivity of the automatic control. On the other hand if the sensitivity is set too low, the initial delay or "clipping" at the start of a sentence will be greater than necessary, and also the transmitter may drop off the air between words or syllables.

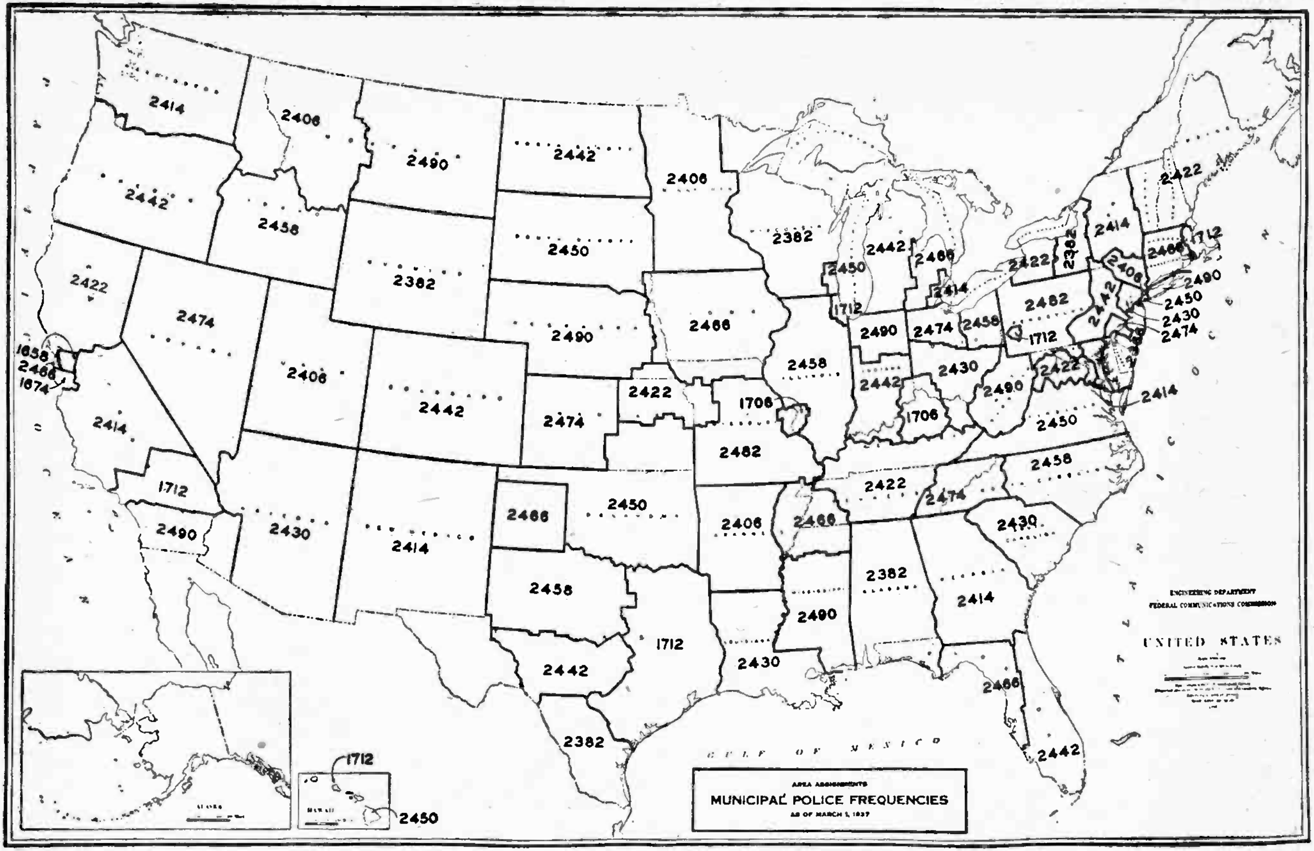
In order to obtained the maximum usefulness from the automatic switching it is necessary for the operator to become accustomed to talking at a uniform level fairly close to the microphone. In single frequency systems he should also regulate his phrases or sentences in such a way as to allow a brief pause at intervals to permit the other party to reply.

22. Connection to Antenna—After the transmitter is properly adjusted, it is ready for connection to the antenna. The artificial antenna should be removed and the chassis put into its housing. The antenna or transmission line should be connected. If a 0 to 500 ma. radio-frequency meter is available, it should now be temporarily connected in series with the antenna directly at the base of same. The transmitter should again be operated and if necessary the amplifier plate coil only may be readjusted to obtain maximum antenna current.

MAINTENANCE

23. General—The No. 18A Radio Transmitter should require little maintenance. However, the following suggestions will be helpful in preventing trouble and in locating troubles which might occur.

All parts of the transmitter should be kept clean. The chassis should be removed from its housing at regular intervals for inspection. Any dust which may have accumulated should be removed with a cloth or blown out with clean compressed air. All nuts and screws should be checked to see that they are tight. The



Frequency Assignments of Municipal Police Frequencies.

electrical connections should be examined to see that they are secure.

24. Test Bench—All large users of mobile radio equipment have found it convenient to establish a test bench at a central location for routine checking of their apparatus. It is recommended that the checking be done at regular intervals and that records be kept of the performance of the equipment each time it is on the test bench. By this means it should be possible to anticipate tube or other failures and make replacements, thereby avoiding interruptions in service.

The circuit for the test bench should simulate that in which the equipment is used and will readily suggest itself to the service man. In general for the No. 18A Transmitter it will consist of a 6-volt and a 300-volt d.c. supply, each equipped with suitable instruments for measuring the currents and voltages. With the transmitter operating these voltages and currents should be approximately as follows:

Low voltage supply	6 volts
Load	4.5 amperes
High voltage supply	300 volts
Load	150 milliamperes

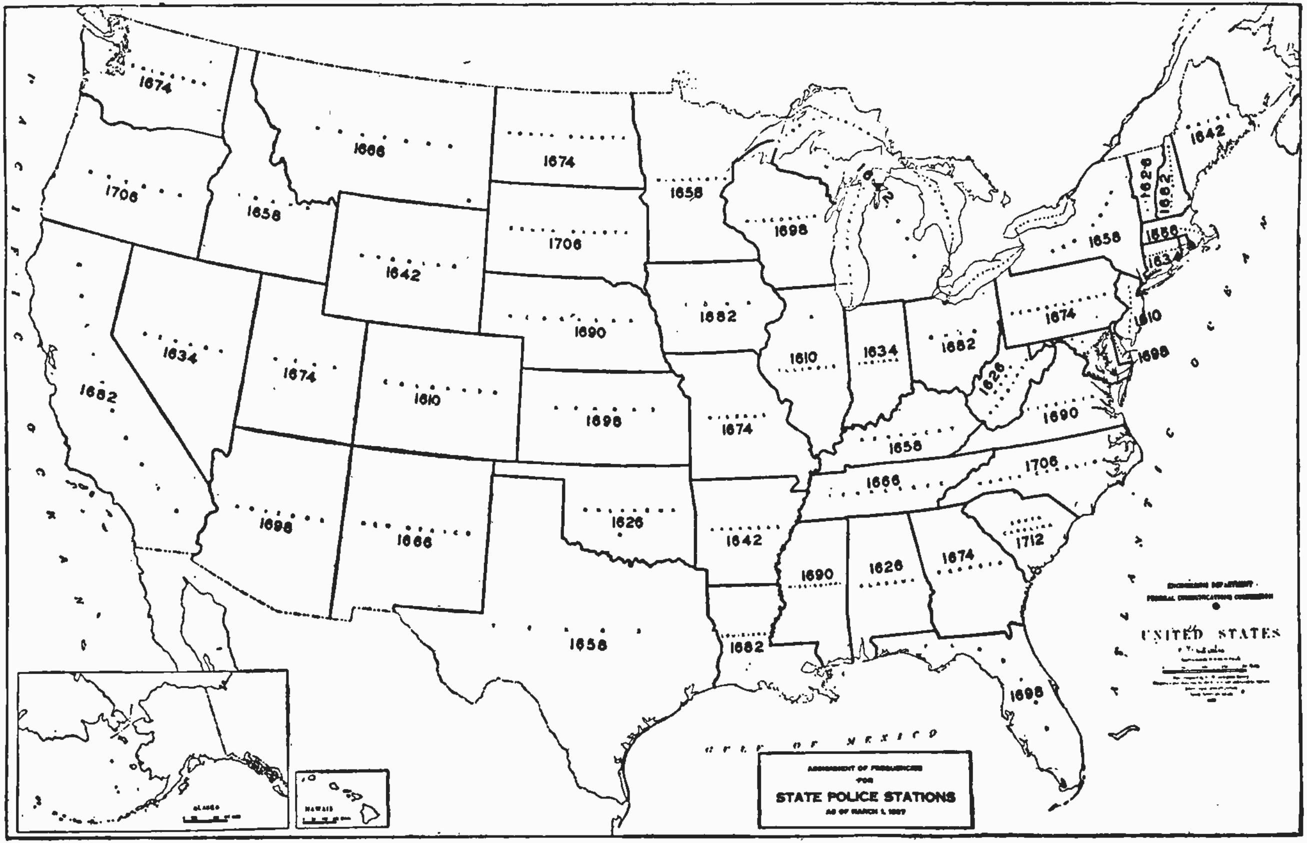
In addition to the instruments mentioned above the test position should be provided with an artificial antenna (described under "**Adjustment**"), a milliammeter equipped with cord and plug for measuring oscillator grid current, a portable 0–300 voltmeter with test leads, and an ohmmeter for checking circuits and resistors.

25. Location of Trouble—Trouble which might arise will, in general, usually be characterized by one of three conditions—no power output, low power output, or failure to modulate properly. Suggestions are made below which will be of assistance in locating trouble which would cause these conditions.

1. Check the voltages supplied to the set to see that they are approximately 6 volts and 300 volts.

2. Examine the four tubes to see that the filaments are heated to a dull red and that none of the other electrodes are unduly hot.

3. Check the tuning dials to see that they are properly set as described under "**Adjustment.**" As a further check, examine the rollers on the coils to see that their actual position agrees with the dial reading. If they do not, the roller can be moved to the correct position by lifting the bar held by a coil spring. Be sure the rollers are on and not between turns.



Frequency Assignments of State Police Stations.

4. Check the voltages within the chassis. They should be approximately as follows:

Bias voltage (from *J*1 to ground)	27 volts
Plate voltage (from any plate to ground)	280 volts
Oscillator screen voltage (from screen terminal of *V*1 to ground)	140 volts
Harmonic generator screen voltage (from screen terminal of *V*2 to ground)	200 volts
Amplifier screen voltage (from screen terminal of *V*3 to ground)	160 volts
Audio screen voltage (from screen terminal of *V*4 to ground)	280 volts

The above voltages are typical readings with the transmitter operating and the positive side of the 6-volt supply grounded. If the crystal is not oscillating, or the transmitter is not properly tuned, the screen voltages will be considerably higher as there will be less drop in the screen resistors.

5. Measure the oscillator grid current. It should be between 0.2 and 0.5 milliamperes and should vary as the oscillator plate coil is turned as described under "**Adjustment.**" If the oscillator is not operating examine *L*1 and *L*2 carefully to see that they are absolutely clean. A very small metallic sliver between turns may be causing the trouble.

6. Substitute a new oscillator tube and crystal if it is available.

7. If the oscillator is operating properly but the output from the transmitter is much below 5 watts, try raising the filaments above normal voltage. If the output rises appreciably one or more of the tubes needs replacing.

8. If no output is obtained but the total plate current is normal (150 milliamperes) examine the connections in the output circuit, the antenna relay springs, and check the artificial antenna for an open circuit.

9. If normal output is obtained but the set does not modulate check the microphone circuit and audio amplifier.

10. Check the audio grid bias between the positive terminal (the most accessible terminal near the head of the mounting screw) of *X*1 and ground. It should be about 27 volts but should shift down several volts when the operator speaks into the microphone.

26. Relays—The relay contacts may be polished if necessary, using a **Western Electric No. 265B Burnishing Tool.** Do not use oil or abrasive cloth or paper. If it is necessary to adjust relays, this may be done as follows:

1. *Antenna Relay* (*S*1)—

The armature of this relay should be free on its pivots and should have a small amount of lost motion before it begins raising the springs. The correct adjustment of the contact springs is determined by inserting a particular thickness gauge between the armature and pole piece, operating the relay or pushing the armature firmly against the gauge by hand, and forming the springs so they just make or break their respective circuits. Ordinary pliers and a machinist's thickness gauge can be used, but it will be found convenient to have the regular tools designed for this purpose. The No. KS–6909 Gauge is a thickness gauge for measuring the distance between armature and pole piece, and the No. 268 tool is a convenient device for bending the springs. The No. 68B Gauge is a simple tool for measuring contact pressure.

The total travel of the armature should be approximately 0.018 inch. To check the relay springs put a white card behind the springs and provide good light so the contacts can be closely watched. The antenna circuit springs on one side of the relay perform a transfer operation which consists of a "break" and a "make." The springs on the other side perform one "break" and two "make" operations. Both of the two "breaks" should just occur with a 0.010-inch gauge between the armature and pole piece.

The three "makes" should just occur with a 0.006-inch gauge. If the springs meet these position requirements, their forward or "make" contact pressures will also be correct. In the unoperated position the pressure on the back or "break" contacts should be about 15 grams. The holdover time, or release delay, of $S1$ is caused by the copper slug adjacent to the winding. For this slug to be effective the magnetic circuit of the relay must have practically no air-gap when the relay is closed. It is so adjusted at the factory that the air-gap between the armature and heel piece is just enough to prevent friction, and the brass residual screw is backed out so it is ineffective. With this adjustment the release time is of the order of 0.4 seconds, which has been found satisfactory for automatic switching. It may be desirable to reduce this delay if automatic switching is not used, or for other reasons. This is done by loosening the lock nut on the brass residual screw and turning it in a clockwise direction until the point projects a few mils from the armature. This prevents an iron to iron contact between armature and pole piece and reduces the delay. The lock nut should be tightened after this adjustment. The springs should be examined to see that they still perform their switching functions satisfactorily.

2. *Voice Control Relay* (*S*2)—

> **Caution**—Do not attempt to adjust this relay while the 6-volt power is on. After any adjusting be certain the back contact "breaks" before the front contact "makes." If the contacts are shorted they will be damaged when power is applied.

The same two gauges used in adjusting *S*1 can also be used for *S*2. In addition a small pair of pliers is required. The total armature travel measured between the armature and pole piece should be 0.010 inch or slightly more, and can be adjusted by means of the back contact screw. The pressure on the back contact should be about 5 grams and may be adjusted by means of the screw which bears against the retractile spring. The front or "make" contact should just make when the relay is operated by hand with a 0.003-inch gauge between the armature and pole piece.

CHAPTER 17

IMPORTANT EXTRACTS FROM THE COMMUNICATIONS ACT OF 1934, AS AMENDED BY PUBLIC 97, APPROVED MAY 20, 1937

1. License for Radio Communication or Transmission of Energy—SECTION 301. It is the purpose of this Act, among other things, to maintain the control of the United States over all the channels of interstate and foreign radio transmission; and to provide for the use of such channels, but not the ownership thereof, by persons for limited periods of time, under licenses granted by Federal authority, and no such license shall be construed to create any right, beyond the terms, conditions, and periods of the license. No person shall use or operate any apparatus for the transmission of energy or communications or signals by radio (*a*) from one place in any Territory or possession of the United States or in the District of Columbia to another place in the same Territory, possession, or District; or (*b*) from any State, Territory, or possession of the United States, or from the District of Columbia to any other State, Territory, or possession of the United States; or (*c*) from any place in any State, Territory, or possession of the United States, or in the District of Columbia, to any place in any foreign country or to any vessel; or (*d*) within any State when the effects of such use extend beyond the borders of said State, or when interference is caused by such use or operation with the transmission of such energy, communications, or signals from within said State to any place beyond its borders, or from any place beyond its borders to any place within said State, or with the transmission or reception of such energy, communications, or signals from and/or to places beyond the borders of said State; or (*e*) upon any vessel or aircraft of the United States; or (*f*) upon any other mobile stations within the jurisdiction of the United States, except under and in accordance with this Act and with a license in that behalf granted under the provisions of this Act.

2. Sec. 5—Paragraph (*m*) of section 303 of the Communications Act of 1934 is hereby amended to read as follows:

(*m*) (1) Have authority to suspend the license of any operator upon proof sufficient to satisfy the Commission that the licensee—

> (*A*) has violated any provision of any Act, treaty, or convention binding on the United States, which the Commission is authorized to administer, or any regulation made by the Commission under such Act, treaty, or convention; or

(*B*) has failed to carry out a lawful order of the master or person lawfully in charge of the ship or aircraft on which he is employed; or

(*C*) has willfully damaged or permitted radio apparatus or installations to be damaged; or

(*D*) has transmitted superfluous radio communications or signals or communications containing profane or obscene words, language, or meaning, or has knowingly transmitted—

(1) false or deceptive signals or communications, or

(2) a call signal or letter which has not been assigned by proper authority to the station he is operating; or

(*E*) has willfully or maliciously interfered with any other radio communications or signals; or

(*F*) has obtained or attempted to obtain, or has assisted another to obtain or attempt to obtain, an operator's license by fraudulent means.

(2) No order of suspension of any operator's license shall take effect until fifteen days' notice in writing thereof, stating the cause for the proposed suspension, has been given to the operator licensee who may make written application to the Commission at any time within said fifteen days for a hearing upon such order. The notice to the operator licensee shall not be effective until actually received by him, and from that time he shall have fifteen days in which to mail the said application. In the event that physical conditions prevent mailing of the application at the expiration of the fifteen-day period, the application shall then be mailed as soon as possible thereafter, accompanied by a satisfactory explanation of the delay. Upon receipt by the Commission of such application for hearing, said order of suspension shall be held in abeyance until the conclusion of the hearing which shall be conducted under such rules as the Commission may prescribe. Upon the conclusion of said hearing the Commission may affirm, modify, or revoke said order of suspension.

3. **Facilities for Candidates for Public Office**—Sec. 315. If any licensee shall permit any person who is a legally qualified candidate for any public office to use a broadcasting station, he shall afford equal opportunities to all other such candidates for that office in the use of such broadcasting station, and the Commission shall make rules and regulations to carry this provision into effect: *Provided,* That such licensee shall have no power of censorship over the material broadcast under the provisions of this section. No obligation is hereby imposed upon any licensee to allow the use of its station by any such candidate.

4. **Lotteries and Other Similar Schemes**—Sec. 316. No person shall broadcast by means of any radio station for which a license is required by any law of the United States, and no person operating any such station shall knowingly permit the broadcasting of, any ad-

vertisement of or information concerning any lottery, gift enterprise, or similar scheme, offering prizes dependent in whole or in part upon lot or chance, or any list of the prizes drawn or awarded by means of any such lottery, gift enterprise, or scheme, whether said list contains any part or all of such prizes. Any person violating any provision of this section shall, upon conviction thereof, be fined not more than $1,000 or imprisoned not more than one year, or both, for each and every day during which such offense occurs.

5. **Announcement that Matter Is Paid for**—Sec. 317. All matter broadcast by any radio station for which service, money, or any other valuable consideration is directly or indirectly paid, or promised to or charged or accepted by, the station so broadcasting, from any person, shall, at the time the same is so broadcast, be announced as paid for or furnished, as the case may be, by such person.

6. **Licensed Operator**—Sec. 318. The actual operation of all transmitting apparatus in any radio station for which a station license is required by this Act shall be carried on only by a person holding an operator's license issued hereunder, and no person shall operate any such apparatus in such station except under and in accordance with an operator's license issued to him by the Commission: Provided, however, That the Commission if it shall find that the public interest, convenience or necessity will be served thereby may waive or modify the foregoing provisions of this section for the operation of any station except (1) stations for which licensed operators are required by international agreement, (2) stations for which licensed operators are required for safety purposes, (3) stations engaged in broadcasting, and (4) stations operated as common carriers on frequencies below thirty thousand kilocycles: Provided further, That the Commission shall have power to make special regulations governing the granting of licenses for the use of automatic radio devices and for the operation of such devices.

7. **Construction Permits**—Sec. 319. (*a*) No license shall be issued under the authority of this Act for the operation of any station the construction of which is begun or is continued after this Act takes effect, unless a permit for its construction has been granted by the Commission upon written application therefor. The Commission may grant such permit if public convenience, interest, or necessity will be served by the construction of the station. This application shall set forth such facts as the Commission by regulation may prescribe as to the citizenship, character, and the financial, technical, and other ability of the applicant to construct and operate the station, the ownership and location of the proposed station and of the station or stations with which it is proposed to communicate, the frequencies desired to be used, the hours of the day or other periods of time during which it is proposed to operate the station, the purpose for which the station is to be used, the type of transmitting apparatus to be used, the power to be used, the date upon which the station is expected to be completed and in operation, and such other information as the Commission may

require. Such application shall be signed by the applicant under oath or affirmation.

(*b*) Such permit for construction shall show specifically the earliest and latest dates between which the actual operation of such station is expected to begin, and shall provide that said permit will be automatically forfeited if the station is not ready for operation within the time specified or within such further time as the Commission may allow, unless prevented by causes not under the control of the grantee. The rights under any such permit shall not be assigned or otherwise transferred to any person without the approval of the Commission. A permit for construction shall not be required for Government stations, amateur stations, or stations upon mobile vessels, railroad rolling stock, or aircraft. Upon the completion of any station for the construction or continued construction of which a permit has been granted, and upon it being made to appear to the Commission that all the terms conditions, and obligations set forth in the application and permit have been fully met, and that no cause or circumstance arising or first coming to the knowledge of the Commission since the granting of the permit would, in the judgment of the Commission, make the operation of such station against the public interest, the Commission shall issue a license to the lawful holder of said permit for the operation of said station. Said license shall conform generally to the terms of said permit.

8. **Designation of Stations Liable to Interfere with Distress Signals**—SEC. 320. The Commission is authorized to designate from time to time radio stations the communications or signals of which, in its opinion, are liable to interfere with the transmission or reception of distress signals of ships. Such stations are required to keep a licensed radio operaor listening in on the frequencies designated for signals of distress and radio communications relating thereto during the entire period the transmitter of such station is in operation.

9. **Ship Transmitter Adjustment**—SEC. 321. (*a*) The transmitting set in a radio station on shipboard may be adjusted in such a manner as to produce a maximum of radiation, irrespective of the amount of interference which may thus be caused, when such station is sending radio communications or signals of distress and radio communications relating thereto.

(*b*) All radio stations, including Government stations and stations on board foreign vessels when within the territorial waters of the United States, shall give absolute priority to radio communications or signals relating to ships in distress; shall cease all sending on frequencies which will interfere with hearing a radio communication or signal of distress, and, except when engaged in answering or aiding the ship in distress, shall refrain from sending any radio communications or signals until there is assurance that no interference will be caused with the radio communications or signals relating thereto, and shall assist the vessel in distress, so far as possible, by complying with its instructions.

10. **Exchange of Messages and Signals**—Sec. 322. Every land station open to general public service between the coast and vessels or aircraft at sea shall, within the scope of its normal operations, be bound to exchange radio communications or signals with any ship or aircraft station at sea; and each station on shipboard or aircraft at sea shall, within the scope of its normal operations, be bound to exchange radio communications or signals with any other station on shipboard or aircraft at sea or with any land station open to general public service between the coast and vessels or aircraft at sea: Provided, That such exchange of radio communication shall be without distinction as to radio systems or instruments adopted by each station.

11. **Interference between Government and Commercial Stations**—Sec. 323. (*a*) At all places where Government and private or commercial radio stations on land operate in such close proximity that interference with the work of Government stations cannot be avoided when they are operating simultaneously, such private or commercial stations as do interfere with the transmission or reception of radio communications or signals by the Government stations concerned shall not use their transmitters during the first fifteen minutes of each hour, local standard time.

(*b*) The Government stations for which the above-mentioned division of time is established shall transmit radio communications or signals only during the first fifteen minutes of each hour, local standard time, except in case of signals or radio communications relating to vessels in distress and vessel requests for information as to course, location, or compass direction.

12. **Use of Minimum Power**—Sec. 324. In all circumstances, except in case of radio communications or signals relating to vessels in distress, all radio stations, including those owned and operated by the United States, shall use the minimum amount of power necessary to carry out the communication desired.

13. **False Distress Signals; Rebroadcasting; Studios of Foreign Stations**—Sec. 325. (*a*) No person within the jurisdiction of the United States shall knowingly utter or transmit, or cause to be uttered or transmitted, any false or fraudulent signal of distress, or communication relating thereto, nor shall any broadcasting station rebroadcast the program or any part thereof of another broadcasting station without the express authority of the originating station.

(*b*) No person shall be permitted to locate, use, or maintain a radio broadcast studio or other place or apparatus from which or whereby sound waves are converted into electrical energy, or mechanical or physical reproduction of sound waves produced, and caused to be transmitted or delivered to a radio station in a foreign country for the purpose of being broadcast from any radio station there having a power output of sufficient intensity and/or being so located geographically that its emissions may be received consistently in the United States, without first obtaining a permit from the Commission upon proper application therefor.

(*c*) Such application shall contain such information as the Commission may by regulation prescribe, and the granting or refusal thereof shall be subject to the requirements of section 309 hereof with respect to applications for station licenses or renewal or modification thereof, and the license or permission so granted shall be revocable for false statements in the application so required or when the Commission, after hearings, shall find its continuation no longer in the public interest.

14. **Censorship; Indecent Language**—Sec. 326. Nothing in this Act shall be understood or construed to give the Commission the power of censorship over the radio communications or signals transmitted by any radio station, and no regulation or condition shall be promulgated or fixed by the Commission which shall interfere with the right of free spech, by means of radio communication. No person within the jurisdiction of the United States shall utter any obscene, indecent, or profane language by means of radio communication.

TITLE III—PROVISIONS RELATING TO RADIO

PART I—GENERAL PROVISIONS

(*b*) Such title III is further amended by adding at the end thereof a new part as follows:

PART II—*Radio Equipment and Radio Operators on Board Ship*

Ship Radio Installations and Operations

15. **Ships Subject to Amended Act**—Sec. 351. (*a*) Except as provided in section 352 hereof, it shall be unlawful—

(1) For any ship of the United States, other than a cargo ship of less than sixteen hundred gross tons, to be navigated in the open sea outside of a harbor or port, or for any ship of the United States or any foreign country, other than a cargo ship of less than sixteen hundred gross tons, to leave or attempt to leave any harbor or port of the United States for a voyage in the open sea, unless such ship is equipped with an efficient radio installation in operating condition, in charge of and operated by a qualified operator or operators, adequately installed and protected so as to insure proper operation, and so as not to endanger the ship and radio installation, as hereinafter provided, and in the case of a ship of the United States, unless there is on board a valid station license issued in accordance with this Act;

(2) For any passenger ship of the United States of five thousand gross tons, or over, to be navigated outside of a harbor or port, in the open sea, or for any such ship of the United States or any foreign county to leave or attempt to leave any harbor or port of the United States for a voyage in the open sea, unless such ship is equipped with

an efficient radio direction finder apparatus (radio compass) properly adjusted in operating condition as hereinafter provided, which apparatus is approved by the Commission;

(*b*) A ship which is not subject to the provisions of this part at the time of its departure on a voyage shall not become subject to such provisions on account of any deviation from its intended voyage due to stress of weather or any other cause over which neither the master, the owner, nor the charterer (if any) has control.

16. Exceptions—Sec. 352. (*a*) The provisions of this part shall not apply to—

(1) A ship of war;

(2) A ship of the United States belonging to and operated by the Government, except a ship of the United States Maritime Commission, the Inland and Coastwise Waterways Service, or the Panama Railroad Company;

(3) A foreign ship belonging to a country which is a party to the Safety Convention and which ship carries a valid certificate exempting said ship from the radio provisions of that Convention, or which ship conforms to the radio requirements of such Convention or Regulations and has on board a valid certificate to that effect;

(4) Yachts of less than six hundred gross tons not subject to the radio provisions of the Safety Convention;

(5) Vessels in tow;

(6) A vessel navigating solely on the Great Lakes, or on any bays, sounds, rivers, or protected waters within the jurisdiction of the United States, or to a vessel leaving or attempting to leave any harbor or port of the United States for a voyage solely on the Great Lakes, or on any bays, sounds, rivers, or protected waters within the jurisdiction of the United States.

(*b*) The Commission may, if it considers that the route or the conditions of the voyage or other circumstances are such as to render a radio installation unreasonable or unnecessary for the purposes of this part, exempt from the provisions of this part any ship, or any class of ships, which falls within any of the following descriptions:

(1) Passenger ships which in the course of their voyage do not go more than twenty nautical miles from the nearest land or more than two hundred nautical miles between two consecutive ports;

(2) Cargo ships which in the course of their voyage do not go more than one hundred and fifty nautical miles from the nearest land;

(3) Passenger vessels of less than one hundred gross tons not subject to the radio provisions of the Safety Convention;

(4) Sailing ships.

17. Operators, Watches, Auto-Alarm—Sec. 353. (*a*) Each cargo ship required by this part to be fitted with a radio installation and which is not fitted with an auto-alarm, and each passenger ship required by this part to be fitted with a radio installation, shall, for safety purposes, carry at least two qualified operators.

(*b*) A cargo ship, required by this part to be fitted with a radio installation, which is fitted with an auto-alarm in accordance with this title, shall, for safety purposes, carry at least one qualified operator who shall have had at least six months' previous service in the aggregate as a qualified operator in a station on board a ship or ships of the United States.

(*c*) Each ship of the United States required by this part to be fitted with a radio installation shall, while being navigated outside a harbor or port, keep a continuous watch by means of qualified operators: Provided, however, That in lieu thereof on a cargo ship fitted with an auto-alarm in proper operating condition, a watch of at least eight hours per day, in the aggregate, shall be maintained by means of a qualified operator.

(*d*) The Commission shall, when it finds it necessary for safety purposes, have authority to prescribe the particular hours of watch on a ship of the United States required by this part to be fitted with a radio installation.

(*e*) On all ships of the United States fitted with an auto-alarm, said apparatus shall be in operation at all times while the ship is being navigated outside of a harbor or port when the operator is not on watch.

18. Technical Requirements—Sec. 354. The radio installation and the radio direction-finding apparatus required by section 351 of this part shall comply with the following requirements:

(*a*) The radio installation shall comprise a main and an emergency or reserve installation: Provided, however, That on a cargo ship, if the main installation complies also with all the requirements of an emergency or reserve installation, the emergency or reserve installation may be omitted.

(*b*) The ship's radio operating room and the emergency or reserve installation shall be placed in the upper part of the ship in a position of the greatest possible safety and as high as practicable above the deepest load water line, and the location of such room or rooms shall be approved by the Bureau of Marine Inspection and Navigation, Department of Commerce.

(*c*) The main and emergency or reserve installations shall be capable of transmitting and receiving on the frequencies and types of waves designated by the Commission pursuant to law for the purpose of distress and safety of navigation.

(*d*) The main installation shall have a normal transmitting and receiving range of at least two hundred nautical miles, that is to say, it must be capable of transmitting and receiving clearly perceptible signals from ship to ship over a range of at least two hundred nautical miles by day under normal conditions and circumstances.

(*e*) Sufficient power shall be available at all times to operate the main radio installation efficiently under normal conditions over the range specified in subsection (*d*) of this section.

(*f*) The emergency or reserve installation shall include a source of energy independent of the propelling power of the ship and of any electrical system and shall be capable of being put into operation rapidly and of working for at least six continuous hours. For the emergency or reserve installation, the normal range as defined in subsection (*d*) of this section shall be at least one hundred nautical miles.

(*g*) There shall be provided between the bridge of the ship and the radio room, and between the bridge and the location of the direction finding apparatus, when the direction finding apparatus is not located on the bridge, an efficient means of communication independent of any other communication system of the ship.

(*h*) The direction finding apparatus shall be efficient and capable of receiving clearly perceptible radio signals and of taking bearings from which the true bearing and direction may be determined. It shall be capable of receiving signals on the frequencies prescribed for distress, direction finding, and radio beacons by the General Radio Regulations annexed to the International Telecommunication Convention in force and in new installations after the effective date of this part, such other frequencies as the Commission may for safety purposes designate.

19. Lifeboats—Sec. 355. Every motor lifeboat, required to be equipped with radio by treaty or convention to which the United States is a party, by statute, or by regulation made in conformity with a treaty, convention, or statute, shall be fitted with an efficient radio installation under such rules and regulations as the Commission may find necessary to promote the safety of life.

20. Approval of Installation—Sec. 356. (*a*) Insofar as is necessary to carry out the purposes and requirements of this part, the Commission shall have authority, for any ship subject to this part—

(1) To approve the details as to the location and manner of installations of the equipment required by this part or of equipment necessitated by reason of the purposes and requirements of this part.

(2) To approve installations, apparatus, and spare parts necessary to comply with the purposes and requirements of this part.

(3) To prescribe such additional equipment as may be determined to be necessary to supplement that specified herein, for the proper function of the radio installation installed in accordance with this part or for the proper conduct of radio communication in time of emergency or distress.

21. Transmission of Information—Sec. 357. (*a*) The master of every ship of the United States equipped with radio transmitting apparatus, on meeting with dangerous ice, a dangerous derelict, a tropical storm, or any other direct danger to navigation, shall cause to be transmitted all pertinent information relating thereto, to ships in the vicinity and to the appropriate authorities, in accordance with rules and regulations issued by the Commission, which authorities of the United States shall, when they consider it necessary, promptly bring the information received by them to the knowledge of those concerned and foreign authorities interested.

(*b*) No charge shall be made by any ship or station in the mobile service of the United States for the transmission, receipt, or relay of the information designated in subsection (*a*) originating on a ship of the United States or of a foreign country.

(*c*) The transmission by any ship of the United States, made in compliance with subsection (*a*), to any station which imposes a charge for the reception, relay, or forwarding of the required information, shall be free of cost to the ship concerned and any communication charges incurred by the ship for transmission, relay, or forwarding of the information may be certified to the Commission for reimbursement out of moneys appropriated to the Commission for that purpose.

(*d*) No charge shall be made by any ship or station in the mobile service of the United States for the transmission of distress messages and replies thereto in connection with situations involving the safety of life and property at sea.

(*e*) Notwithstanding any other provision of law, any station or carrier may render free service in connection with situations involving the safety of life and property, including hydrographic reports, weather reports, reports regarding aids to navigation and medical assistance to injured or sick persons on ships and aircraft at sea. All free service permitted by this subsection shall be subject to such rules and regulations as the Commission may prescribe, which rules may limit such free service to the extent which the Commission finds desirable in the public interest.

22. **Authority of Master**—Sec. 358. The radio installation, the operators, the regulation of their watches, the transmission and receipt of messages, and the radio service of the ship except as they may be regulated by law or international agreement, or by rules and regulations made in pursuance thereof, shall in the case of a ship of the United States be under the supreme control of the master.

23. **Certificates**—Sec. 359. (*a*) Each vessel of the United States to which the Safety Convention applies shall comply with the Radio and communication provisions of said convention at all times while the vessel is in use, in addition to all other requirements of law, and have on board an appropriate certificate as prescribed by the Safety Convention.

(*b*) Appropriate certificates concerning the radio particulars provided for in said convention shall be issued to any vessel of the United States which is subject to the radio provisions of the Safety Convention and is found by the Commission to comply therewith. Such certificates shall be issued by the Department of Commerce, or whatever other agency is authorized by law so to do, upon request of the Commission made after proper inspection or determination of the facts. If the holder of such certificate violates the provisions of the safety convention, or of this Act, or the rules, regulations, or conditions prescribed by the Commission, and if the effective administration of the safety convention or of this part so requires, the Commission, after hearing in accordance with law, is authorized to request the modification or cancelation of such certificate. Upon receipt of such request the Department of Commerce, or whatever other agency is authorized by law to do so, shall modify or cancel the certificate in accord therewith. The Commission is authorized to issue, modify, or cancel such certificates in the event that no other agency is authorized to do so.

24. Inspections—Sec. 360. (*a*) In addition to any other provisions required to be included in a radio station license, the station license of each ship of the United States subject to this title shall include particulars with reference to the items specifically required by this title.

(*b*) Every ship of the United States, subject to this part, shall have the equipment and apparatus prescribed therein, inspected at least once each year by the Commission. If, after such inspection, the Commission is satisfied that all relevant provisions of this Act and the station license have been complied with, that fact shall be certified to on the station license by the Commission. The Commission shall make such additional inspections at frequent intervals as may be necessary to insure compliance with the requirements of this Act.

25. Control by Commission—Sec. 361. Nothing in this title shall be interpreted as lessening in any degree the control of the Commission over all matters connected with the radio equipment and its operation on shipboard and its decision and determination in regard to the radio requirements, installations, or exemptions from prescribed radio requirements shall be final, subject only to review in accordance with law.

26. Forfeitures—Sec. 362. The following forfeitures shall apply to this part, in addition to the penalties and forfeitures provided by title V of this Act:

(*a*) Any ship that leaves or attempts to leave any harbor or port of the United States in violation of the provisions of this part, or the rules and regulations of the Commission made in pursuance thereof, or any ship of the United States that is navigated outside of any harbor or port in violation of any of the provisions of this part, or the rules and regulations of the Commission made in pursuance thereof, shall forfeit to the United States the sum of $500, recoverable by way of suit or libel. Each such departure or attempted departure, and in the case of a ship of the United States each day during which such navigation occurs shall constitute a separate offense.

(*b*) Every willful failure on the part of the master of a ship of the United States to enforce or to comply with the provisions of this Act or the rules and regulations of the Commission as to equipment, operators, watches, or radio service shall cause him to forfeit to the United States the sum of $100.

27. General Penalty—Sec. 501. Any person who willfully and knowingly does or causes or suffers to be done any act, matter, or thing, in this Act prohibited or declared to be unlawful, or who willfully and knowingly omits or fails to do any act, matter, or thing in this Act required to be done, or willfully and knowingly causes or suffers such omission or failure, shall, upon conviction thereof, be punished for such offense, for which no penalty (other than a forfeiture) is provided herein, by a fine of not more than $10,000 or by imprisonment for a term of not more than two years, or both.

28. **Violations of Rules, Regulations**—Sec. 502. Any person who willfully and knowingly violates any rule, regulation, restriction or condition made or imposed by the Commission under authority of this Act, or any rule, regulation, restriction, or condition made or imposed by any international radio or wire communications treaty or convention, or regulations annexed thereto, to which the United States is or may hereafter become a party, shall, in addition to any other penalties provided by law, be punished, upon conviction thereof, by a fine of not more than $500 for each and every day during which such offense occurs.

29. **Ship Act**—Section 602 of the Communications Act of 1934 is hereby amended by adding at the end thereof a new subsection to read as follows:

(*e*) Such part or parts of the Act entitled "An Act to require apparatus and operators for radio communication on certain ocean steamers," approved June 24, 1910, as amended, as relate to the ocean and to steamers navigating thereon, are hereby repealed. In all other respects said Act shall continue in full force and effect. The Commission is requested and directed to make a special study of the radio requirements necessary or desirable for safety purposes for ship navigating the Great Lakes and the inland waters of the United States, and to report its recommendations, and the reasons therefor, to the Congress not later than December 31, 1939.

30. **Unauthorized Publication of Communications**—Sec. 605. No person receiving or assisting in receiving, or transmitting, or assisting in transmitting, any interstate or foreign communication by wire or radio shall divulge or publish the existence, contents, substance, purport, effect, or meaning thereof, except through authorized channels of transmission or reception, to any person other than the addressee, his agent, or attorney, or to a person employed or authorized to forward such communication to its destination, or to proper accounting or distributing officers of the various communicating centers over which the communication may be passed, or to the master of a ship under whom he is serving, or in response to a subpoena issued by a court of competent jurisdiction, or on demand of other lawful authority; and no person not being authorized by the sender shall intercept any communication and divulge or publish the existence, contents, substance, purport, effect, or meaning of such intercepted communication to any person; and no person not being entitled thereto shall receive or assist in receiving any interstate or foreign communication by wire or radio and use the same or any information therein contained for his own benefit or for the benefit of another not entitled thereto; and no person having received such intercepted communication or having become

acquainted with the contents, substance, purport, effect, or meaning of the same or any part thereof, knowing that such information was so obtained, shall divulge or publish the existence, contents, substance, purport, effect, or meaning of the same or any part thereof, or use the same or any information therein contained for his own benefit or for the benefit of another not entitled thereto: *Provided*, That this section shall not apply to the receiving, divulging, publishing, or utilizing the contents of any radio communication broadcast, or transmitted by amateurs or others for the use of the general public, or relating to ships in distress.

31. **Short Title**—Sec. 609. This Act may be cited as the "Communications Act of 1934."

Approved, June 19, 1934.

CHAPTER 18

INTERNATIONAL TELECOMMUNICATION CONVENTION OF CAIRO—GENERAL RADIO REGULATIONS

(Revision of Cairo, 1938)

Summary of the General Radio Regulations as Revised by the International Telecommunications Conference of Cairo, 1938—The International Telecommunications Conference of Cairo, Egypt, 1938, revised the General Radio Regulations Annexed to the International Telecommunications Convention of Madrid. These regulations become effective as of January 1, 1939.[1] The following paragraphs are a summary of the major changes; however, prospective marine operators as well as those already in the service, should read the contents of the whole chapter thoroughly in order to become acquainted with all the changes. The applicant for an operator's examination is not expected to be able to quote the regulations verbatim, but should be able to state in his own words the substance and meaning of the regulations. The General Regulations in their entirety are not included in this chapter. Only those articles of the General Regulations with which operators must be familiar in the routine performance of their duties are published.

Under the new regulations, ships in regions of heavy radio traffic, equipped with break-in devices, may transmit only one short single message on 500 kc.; thus, coast stations and many ships will no longer be permitted to use this frequency for radio traffic for even short, single messages, as under the former rules. In other regions it may be used for traffic and radio direction finding, but with discretion.

The regulations now require that the radio watch on 500 kc. shall be compulsory only on types *A*-2 or *B* waves, which permits a watch also on *A*-1 waves by those who desire to do so.

Confusion, misunderstanding, and a possible violation of the secrecy provisions often resulted in the past when the general call CQ was used for certain restrictive purposes. In order to provide for this situation and to strengthen the secrecy provisions of the Convention, there was adopted the call CP as a call to several stations without request for reply to be followed by two or more call signals or by a code

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[1] The proceedings of the Conference must be ratified by the Senate of the United States. However, it will be found that the General procedure will be adhered to in the International Maritime Service effective as of January 1, 1939.

word indicating the group of receiving stations authorized to receive the transmitted material.

The new regulations require that the ship in distress transmit its call signals followed by the distress messages for a period sufficiently long to permit bearings to be taken.

It had become the habit for such stations, when hearing a distress call, to transmit immediately QRT over a considerable period of time, adding to the confusion and creating such interference. It was agreed that the use of this signal should be restricted, as far as practicable, to the ship in distress and the ship or station directing the distress traffic.

In addition to the list arranged alphabetically by signals as formerly given in the regulations, a new grouping by subject has been added to facilitate rapid selection of a signal to express a meaning. The former signal "QRK" has been changed to indicate "legibility" of signals as distinct from "signal strength," and it will now be followed by number 1 to 5 indicating degree of legibility. The call "QSA" for strength of signals was retained and will also be supplemented by a number from 1 to 5 indicating degree of signal strength. Two new signals "QUK" and "QUL" were added for the benefit of aircraft in requesting condition of sea and height of waves. The end of distress radio traffic will now be signaled by the abbreviation "QUM" and the signal "TU" will indicate thanks for cooperation.

There has been added to the requirements for obtaining a first and second class radiotelegraph certificate, a knowledge of direction-finding apparatus and the taking of radio bearings. A definite period of five minutes to cover the code test, both transmission and reception, and the knowledge of a language commonly used in the international correspondence of the mobile service. This latter requirement is intended to apply only to countries whose native language is not commonly used in international correspondence.

General Radio Regulations (Revision of Cairo 1938)

ARTICLE 1

Definitions

§ 1. *Telecommunication:* Any telegraph or telephone communication of signs, signals, writings, images, and sounds of any nature, by wire, radio, or other systems or processes of electric or visual (semaphore) signaling (see the annex to the Convention.)

General network of telecommunication channels: The whole of the existing telecommunication channels open to public service, with the exception of the radio channels of the mobile service.

Radio communication: Any telecommunication by means of Hertzian waves (see the annex to the Convention).

Radiotelegram: Telegram originating in or intended for a mobile station, transmitted on all or part of its route over the radio-communication channels of the mobile service (see the annex to the Convention.)

Telegraphy: Telecommunication by any system of telegraph signaling. The word "telegram" also covers "radiotelegram," except when the text expressly precludes such a meaning.

Telephony: Telecommunication by any system of telephone signaling.

Frequency assigned to a station: The frequency assigned to a station is the frequency occupying the center of the frequency band in which the station is authorized to work. In general, this frequency is that of the carrier wave.

Frequency band of an emission: The frequency band of an emission is the frequency band actually occupied by this emission for the type of transmission and for the signaling speed used.

Frequency tolerance: The frequency tolerance is the maximum permissible separation between the actual frequency of an emission and the frequency which this emission should have (frequency notified or frequency chosen by the operator).

Power of a radio transmitter: The power of a radio transmitter is the power supplied to the antenna. For the types of transmitters indicated hereinafter, the following data are applicable:

> *Continuous wave radiotelegraphy:* In the case of a transmitter employing type-*A*1 or -*A*2 emissions the power is that delivered to the antenna during the marking (key closed) condition.
>
> *Conventional double sideband type:* In the case of an amplitude-modulated wave transmitter of the conventional double sideband type the power in the antenna is represented by two numbers, one indicating the value of the carrier-wave power supplied to the antenna and the other indicating the actual maximum percentage of modulation used.[2]
>
> *Other types:* In the case of amplitude-modulated wave transmitters of other than the conventional double sideband type, the maximum power delivered to the antenna shall be given as the power of the transmitter.

§ 2. *Fixed service:* A service carrying on radio communnication of any kind between fixed points, with the exception of the broadcasting services and special services.

Mobile service: A radio-communication service carried on between mobile and land stations and by mobile stations communicating among themselves, excluding special services (see the annex to the Convention).

Aeronautical service: A radio service carried on between aircraft stations and land stations and by aircraft stations among themselves. This term shall also apply to fixed and special radio services intended to insure the safety of aerial navigation.

Broadcasting service: A service carrying on the broadcasting of

[2] This percentage shall be expressed in x per cent.

transmissions intended to be received by the general public; this service shall include exclusively:[3]

a) *radiotelephone service:* service carrying on the broadcasting of transmissions for reception at a distance of voice and music;

b) *television service:* service carrying on the broadcasting of transmissions for the visual reception at a distance of fixed or moving objects.[4]

Facsimile service: A service making transmissions for the reproduction at a distance of fixed images in a permanent form.[5]

Special service: A telecommunication service carried on especially for the needs of a specific service of general interest and not open to public correspondence, such as: a service of radiobeacons, radio direction finding, time signals, regular meteorological bulletins, notices to navigators, press messages addressed to all, medical notices (medical consultation by radio), standard frequencies, emissions for scientific purposes, et cetera.

§ 3. *Fixed station:* A station not capable of being moved and communicating by radio with one or more stations established in the same manner.

Land station: A station not capable of being moved, carrying on a mobile service.

Coast station: A land station carrying on a service with ship stations. This may be a fixed station assigned also to communication with ship stations; in this case, it shall be considered as a coast station only for the duration of its service with ship stations.

Aeronautical station: A land station carrying on a service with aircraft stations. This may be a fixed station assigned also to communication with aircraft stations; in this case, it shall be considered as an aeronautical station only for the duration of its service with aircraft stations.

Mobile station: A station capable of being moved and which ordinarily does move.

On-board station: A station on board either a ship which is not permanently moored, or an aircraft.

Ship station: A station on board a ship which is not permanently moored.

Aircraft station: A station on board any aircraft.[6]

Portable station: A station intended to be moved easily but which is not ordinarily used while in motion.

Radiobeacon station: A special station the emissions of which are intended to enable an on-board station to determine its bearing or a

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[3] See the exception "facsimile service."

[4] "Objects" is used here in the optical sense of the word.

[5] This facsimile service may be carried on by broadcasting stations, fixed stations or mobile service stations.

[6] "Aircraft" is a general term including: airplanes, dirigibles, free or captive balloons, et cetera.

direction with reference to the radiobeacon station, and in some cases also the distance which separates it from the latter.

Radio direction-finding station: A station equipped with special apparatus for determining the direction of the emissions of other stations.

Amateur station: A station used by an "amateur," that is, by a duly authorized person interested in radio technique solely with a personal aim and without pecuniary interest.

Private experimental station: A private station intended for experiments looking to the development of radio technique or science.

Private radio station: A private station, not open to public correspondence, which is authorized solely to exchange with other "private radio stations" communications concerning the private business of the license holder or holders.

ARTICLE 5

CLASSIFICATION OF EMISSIONS

§ 1. Emissions shall be classified below according to the purpose for which they are used; assuming their modulation or their possible keying to be only in amplitude.

1. *Continuous waves:*

Type A0. Waves the successive oscillations of which are identical under fixed conditions.

Type A1. Telegraphy on pure continuous waves. A continuous wave which is keyed according to a telegraph code.

Type A2. Modulated telegraphy. A carrier wave modulated at one or more audible frequencies; the audible frequency or frequencies or their combination with the carrier wave being keyed according to a telegraph code.

Type A3. Telephony. Waves resulting from the modulation of a carrier wave by frequencies corresponding to the voice, to music or to other sounds.

Type A4. Facsimile. Waves resulting from the modulation of a carrier wave by frequencies produced at the time of the scanning of a fixed image with a view to its reproduction in a permanent form.

Type A5. Television. Waves resulting from the modulation of a carrier wave by frequencies produced at the time of the scanning of fixed or moving objects.

(Note: The band-widths to which these emissions correspond are indicated in appendix 3.)

2. *Damped waves:*

Type B. Waves composed of successive series of oscillations the amplitude of which, after attaining a maximum, decreases gradually, the wave trains being keyed according to a telegraph code.

§ 2. In the above classification, the presence of a carrier wave is assumed in all cases. However, such carrier wave may or may not be transmitted.

ARTICLE 9

CONDITIONS TO BE OBSERVED BY MOBILE STATIONS

A. GENERAL

§ 1. (1) Mobile stations must be established in such a way as to conform, as regards frequencies and types of waves, to the general provisions forming the subject of article 7.

§ 2. The frequency of emission of mobile stations shall be verified as often as possible by the inspection service to which they are subject.

§ 3. Receiving apparatus must be such that the current which they induce into the antenna shall be as low as possible and shall not disturb neighboring stations.

§ 4. Transmitting and receiving sets of any mobile station must permit of making frequency changes as rapidly as possible. All installations must be such that, after the communication is established, the time necessary to change from transmission to reception and vice versa shall be as short as possible.

B. SHIP STATIONS

§ 6. (1) The transmitting apparatus used in ship stations working on type-*A2* or -*B* waves in the authorized band between 365 and 515 kc. (822 and 583 m.) must be provided with devices making it possible conveniently and appreciably to reduce the power thereof.

(2) This provision shall not be compulsory for type-*B* wave transmitters of which the power, at full load, measured at the terminals of the alternator, does not exceed 300 watts.

(3) All ship stations transmitting on frequencies in the band 100 to 160 kc. (3,000 to 1,875 m.) and on frequencies above 4,000 kc. (wavelengths below 75 m.) must be equipped with a wave meter having a precision at least equal to 5/1000 when the transmitter itself is incapable of being adjusted with this precision or better.

§ 7. Any station installed on board a ship compulsorily provided with radio apparatus as a result of an international agreement must be able to transmit and receive:

(*a*) on the wave of 500 kc. (600 m.), type-*A2* or -*B* and,

(*b*) in addition, on at least two other waves of type-*A2* or -*B* in the authorized band between 365 and 485 kc. (822 and 619 m.).

The provision set forth under (*b*) shall not apply to transmitters on lifeboats or to transmitters of emergency ship stations.

§ 8. In addition to the waves mentioned above, ship stations equipped to transmit type-*A1*, -*A2*, or -*A3* waves may use the waves authorized in article 7.[9]

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[9] Regarding the restriction upon the installation of type-*B* wave transmitters and the use of type-*B* waves on ships, see article 7, § 10, (1) to (3).

§ 9. All the ship station apparatus installed for the transmission of type-*A*1 waves in the authorized band between 100 and 160 kc. (3000 and 1875 m.) must permit of using at least two frequencies, selected in this band, in addition to the frequency of 143 kc. (2100 m.).

ARTICLE 11

Authority of the Master

§ 1. The radio service of a mobile station shall be placed under the supreme authority of the master or the person responsible for the ship, aircraft, or any other vehicle carrying the mobile station.

§ 2. The person holding this authority must require the operators to comply with the present Regulations.

§ 3. The master or responsible person as well as any persons who may have knowledge of the text or simply the existence of radiotelegrams, or of any information acquired by means of the radio service, shall be bound by the obligation to observe and insure the secrecy of the correspondence.

ARTICLE 12

Inspection of Stations

§ 1. (1) The competent governments or administrations of countries where a mobile station calls, may demand the production of the license. The operator of the mobile station or the person responsible for the station must submit to this verification. The license must be kept in such a way that it may be furnished without delay. However, the production of the license may be replaced by a permanent posting in the station, of a copy of the license certified by the authority which has granted it.

(2) The competent inspectors must have in their possession a card or badge of identification which they must show upon the request of the master or of his substitute.

(3) When the license cannot be produced or when manifest irregularities are detected, the governments or administrations may proceed to the inspection of radio installations in order to be assured that they satisfy the requirements of the present Regulations.

(4) Moreover, the inspectors shall have the right to demand the production of the operators' certificates although no proof of professional qualifications may be demanded.

§ 2. (1) When a government or an administration has found it necessary to resort to the measures provided for in § 1 above, or when it has not been possible to produce the operators' certificates, it shall be necessary immediately to inform thereof the government or the administration to which the mobile station in question is subject. In addition, the procedure specified in article 13 shall be followed should necessity arise.

(2) The representative of the government or of the administration which has inspected the station must, before leaving the latter, communicate his findings to the commander or to the responsible person (art. 11) or to their substitute.

ARTICLE 17

GENERAL RADIOTELEGRAPH PROCEDURE IN THE MOBILE SERVICE [10, 11]

§ 1. (1) In the mobile service, the following detailed procedure shall be obligatory except in the case of distress call or traffic to which the provisions of article 24 shall apply.

(2) In the exclusively aeronautical service, the procedure contemplated in the present article shall apply, except when special procedures, determined in regional agreements by the governments concerned, shall be in force.

(3) For the exchange of radio communications, stations of the mobile service shall use the abbreviations given in appendix 9.

Furthermore, in the maritime mobile services only those abbreviations given in appendix 9 may be used.

(4) In heavy traffic areas, ship stations shall take account of the provisions of § 2 (2) of article 21.

§ 2. (1) Before transmitting, any station must keep watch over a sufficient interval to assure itself that it will cause no harmful interference with the transmissions being made within its range; if such interference is likely, the station shall await the first stop in the transmission which it may disturb.

(2) If, however, even after taking these precautions, the emissions of this station should cause interference with a radio transmission already in progress, the following rules shall be applied:

(*a*) In the communication zone of a land station open to the public correspondence service or of any aeronautical station, the station whose emission produces the interference must cease transmitting at the first request of the above-mentioned land or aeronautical station.

(*b*) In the case where a radio transmission already in progress between two ships happens to be interfered with by an emission from another ship, the latter must cease transmitting at the first request of either of the other two.

(*c*) The station requesting this cessation must indicate the approximate length of the wait imposed upon the station whose emission it is suspending.

§ 3. Radiotelegrams of all kinds transmitted by ship stations shall

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[10] This procedure shall be applicable to short waves so far as possible.

[11] The provisions of §§ 2 and 8 shall be applicable to radiotelephone transmissions of the mobile service.

be numbered in daily series, assigning number 1 to the first radiotelegram transmitted each day to each land station separately.

§ 4. CALLING A STATION AND SIGNALS PREPARATORY TO TRAFFIC

(1) *Method of calling*

The call shall consist of the following:

not more than three times the call signal of the station called;
the word DE;
not more than three times the call signal of the calling station.

(2) *Wave to be used for the call and for preparatory signals*

To make the call as well as to transmit preparatory signals the calling station shall use the wave on which the station called is listening.

(3) *Indication of the wave to be used for the traffic*

The call, as indicated in subparagraph (1) above, must be followed by the regulatory abbreviation indicating the frequency and/or the type of wave which the calling station proposes to use to transmit its traffic.

When, as an exception to this rule, the call is not followed by the indication of the wave to be used for the traffic:

(*a*) if the calling station is a land station:

it shall mean that this station proposes to use its normal working-wave, as indicated in the nomenclature, for the traffic.

(b) if the calling station is a mobile station:

it shall mean that the wave to be used for the traffic is to be chosen by the station called.

(4) *Indication, when required, of the number of telegrams or of transmission by series*

When the calling station has more than one telegram to transmit to the station called, the preceding preparatory signals shall be followed by the regulatory abbreviation and by the figure specifying the number of these telegrams.

Furthermore, when the calling station wishes to transmit these telegrams in series, it shall so indicate by adding the regulatory abbreviation requesting the consent of the station called.

§ 5. REPLY TO CALLS AND SIGNALS PREPARATORY TO TRAFFIC

(1) *Method of reply to calls*

The reply to calls shall consist of the following:

not more than three times the call signal of the calling station;
the word DE;
the call signal of the station called.

(2) *Wave for reply*

To transmit the reply to calls and to preparatory signals, the station called shall use the wave on which the calling station must listen unless the calling station has specified a frequency for the reply.

As an exception to this rule, when a mobile station calls a coast station on the wave 143 kc. (2,100 m.). the coast station shall transmit the reply to the calls on its normal working-wave of the bands between 100 and 160 kc. (3,000 and 1,875 m.), as indicated in the nomenclature.

(3) *Understanding as to the wave to be used for the traffic*

A. If the station called has an understanding with the calling station, it shall transmit:

(*a*) the reply to the call;

(*b*) the regulatory abbreviation indicating that from that time on it is listening on the frequency and/or the type of wave announced by the calling station;

(*c*) in some cases, the indications mentioned in subparagraph (4);

(*d*) the letter K, if the station called is ready to receive the traffic of the calling station;

(*e*) in certain cases, if it is useful, the regulatory abbreviation and the figure indicating the strength of the signals received. (See appendix 12.)

B. If the station has no preliminary understanding, or if it must choose the wave to be used for the traffic, it shall transmit:

(*a*) the reply to the call;

(*b*) the regulatory abbreviation indicating the frequency and/or the type of wave requested;[1]

When an agreement is reached on the wave which the calling station must use for its traffic, the station called shall transmit the letter K after the indications contained in its reply.

(4) *Reply to the request for transmission by series*

The station called, replying to a calling station which has asked to transmit its telegrams in series [§ 4 (4)], shall indicate, by means of the regulatory abbreviation, whether it refuses or accepts and, in the latter case, if need be, shall specify the number of radiotelegrams which it is ready to receive in one series.

(5) *Difficulties in reception*

(*a*) If the station called is prevented from receiving, it shall reply to the call as indicated in subparagraph (3) above, but it shall replace the letter K by the signal • — • • • (wait), followed by a number

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[1] In the case where the choice of the wave to be used for the traffic falls to the station called, and if, in exceptional cases, the latter station does not give the corresponding indication, the traffic shall take place on the wave used for the call.

indicating in minutes the probable duration of the wait. If this probable duration exceeds 10 minutes (5 minutes in the aeronautical mobile service), a reason must be given therefor.

(*b*) When a station receives a call without being certain that this call is intended for it, it must not reply before the call has been repeated and understood. When, on the other hand, a station receives a call which is intended for it, but is doubtful about the call signal of the calling station, it must reply immediately, using the regulatory abbreviation instead of the call signal of the latter station.

§ 6. ROUTING OF TRAFFIC

(1) *Traffic wave*

(*a*) Each station of the mobile service shall transmit its traffic by using, in principle, one of its working-waves, as they are indicated in the nomenclature for the band in which the call was made.

(*b*) Outside of its normal working-wave which is printed in boldface type in the nomenclature, each station may use additional waves of the same band, in accordance with the provision of article 21, § 4 (2).

(*c*) The use of calling waves for traffic shall be governed by article 21.

(*d*) If the transmission of a radiotelegram takes place on another frequency and/or type of wave than that on which the call was made, the transmission of the radiotelegram shall be preceded by: not more than three times, the call signal of the station called; the word DE; not more than three times, the call signal of the calling station.

If the transmission is made on the same frequency and type of wave as the call, the transmission of the radiotelegram shall be preceded, in case of need, by the call signal of the station called; by the word DE, by the call signal of the calling station.

(2) *Long radiotelegrams*

(*a*) In principle, any radiotelegram containing more than 100 words shall be considered as forming a series or shall end a series in progress.

(*b*) As a general rule, long radiotelegrams, both in plain language and in code or cipher language, shall be transmitted in sections, each section containing 50 words in the case of plain language, and 20 words or groups in the case of code or cipher.

(*c*) At the end of each section the signal • • — — • • (?) meaning "have you received the radiotelegram correctly up to this point?" shall be transmitted. If the section has been correctly received, the receiving station shall reply by the letter K and the transmission of the radiotelegram shall be continued.

(3) *Suspension of traffic*

When a station of the mobile service transmits on a working-wave of a land station and thus causes interference with the said land station, it must suspend its work at the request of the latter.

§ 7. END OF TRAFFIC AND OF WORK

(1) *Signal for the end of transmission*

(*a*) The transmission of a radiotelegram shall be ended by the signal • — • — • (end of transmission), followed by the call signal of the transmitting station and the letter K.

(*b*) In the case of transmission by series, the end of each radiotelegram shall be indicated by the signal • — • — • and the end of the series by the call signal of the transmitting station and the letter K.

(2) *Acknowledgment of receipt*

(*a*) The acknowledgment of receipt of a radiotelegram shall be given by transmitting the letter R, followed by the number of the radiotelegram; this acknowledgment of receipt shall be preceded by the following formula: call signal of the station which has transmitted, word DE, call signal of the station which has received.

(*b*) The acknowledgment of receipt of a series of radiotelegrams shall be given by transmitting the letter R followed by the number of the last radiotelegram received. This acknowledgment of receipt shall be preceded by the above formula.

(*c*) The acknowledgment of receipt shall be made by the receiving station on the same wave as for the reply to the call [see § 5 (2) above].

(3) *End of work*

(*a*) The end of work between two stations shall be indicated by each of them by means of the signal • • • — • — (end of work), followed by its own call signal.

(*b*) For these signals, the sending station shall continue to use the traffic wave and the receiving station the wave for the reply to the call.

(*c*) The signal • • • — • — (end of work) shall also be used when the transmission of radiotelegrams of general information, meteorological information, and general safety warnings is ended and the transmission ends in the long-distance radio-communication service with deferred acknowledgment of receipt or without acknowledgment of receipt.

§ 8. DURATION OF WORK

(1) (*a*) In no case, in the maritime mobile service, must the work on 500 kc. (600 m.) exceed 5 minutes.

(*b*) In no case, in the aerial mobile service, must the work on 333 kc. (900 m.) exceed 5 minutes.

(2) On frequencies other than those of 500 kc. (600 m.) and 333 kc. (900 m.) the duration of the periods of work shall be determined:

(*a*) between a land station and a mobile station, by the land station,

(*b*) between mobile stations, by the receiving station.

§ 9. TESTS

When it is necessary to make test signals, either for the adjustment of a transmitter before transmitting the call, or for the adjustment of a receiver, these signals must not last more than 10 seconds, and they must be composed of a series of V's followed by the call signal of the station transmitting for the tests.

ARTICLE 18

GENERAL CALL "TO ALL"

§ 1. Two types of call signals "to all" shall be recognized:

1. the CQ call followed by the letter K (see §§ 2 and 3);
2. the CQ call not followed by the letter K (see § 4).

§ 2. Stations desiring to enter into communication with stations of the mobile service, without, however, knowing the names of the mobile stations within their range, can use the inquiry signal CQ, in place of the call signal of the station called, in the calling formula, this formula being followed by the letter K (general call to all mobile stations, with request for reply).

§ 3. In regions where traffic is heavy, the use of the CQ call followed by the letter K shall be forbidden, except in combination with urgent signals.

§ 4. The CQ call not followed by the letter K (general call to all stations without request for reply) shall be used before transmission of information of all kinds intended to be read or used by anyone who can receive it.

ARTICLE 19

CALL TO SEVERAL STATIONS WITHOUT REQUEST FOR REPLY

The call CP followed by two or more call signals or by a code word (call to certain receiving stations without request for reply) shall be used only for the transmission of information of any nature intended to be read or utilized by anyone who is authorized.

ARTICLE 20

CALLING

§ 1. The provisions of this article shall not apply to aircraft when special procedures, determined in regional agreements between the countries concerned, are in force. These provisions shall nevertheless always apply to aircraft entering into or wishing to enter into communication with a station of the radiomaritime service.

§ 2. (1) As a general rule, it shall devolve upon the mobile station to establish communication with the land station. It may call the land station for this purpose only after having arrived within the range of the latter.

(2) However, a land station having traffic for a mobile station which has not indicated its presence may call the latter if it has reason to assume that the said mobile station is within its range and is listening.

§ 3. (1) Furthermore, land stations may transmit their calls in the form of "lists of calls" consisting of the call signals of all mobile stations for which they have traffic on hand, at definite intervals, at least 2 hours apart, which have been established by agreements between the governments concerned. Land stations which transmit their calls on the wave of 500 kc. (600 m.) shall transmit them in the form of "lists of calls," in alphabetical order, to include only the call signals of mobile stations for which they have traffic on hand and which are within their range. To their own call signal they shall add the abbreviations to indicate the working-wave they wish to use in the transmission. Land stations which use continuous waves outside of the band of 365 to 515 kc. (822 to 583 m.) shall transmit the call signals in the order which is most convenient for them.

(2) The time at which land stations transmit their lists of calls, as well as the frequencies and types of waves which they use for this purpose, must be indicated in the nomenclature.

(3) Mobile stations which, during this transmission, hear their call signal, must answer as soon as they can, following, so far as possible, the order in which they were called.

(4) When the traffic cannot be disposed of immediately, the land station shall inform each mobile station concerned of the probable time at which the work can begin, as well as the frequency and the type of wave which will be used in the work with it, if this is necessary.

§ 4. When a land station receives calls from several mobile stations at practically the same time, it shall decide as to the order in which these stations may transmit their traffic to it, its decision being based only on the necessity for permitting each calling station to exchange with it the greatest possible number of radiotelegrams.

§ 5. (1) When communication is first established with a land station, every mobile station, if it deems it advisable on account of possible confusion, can transmit its name spelled out as it appears in the nomenclature. If the mobile station does not yet appear in the nomenclature, it may transmit its name fully spelled out.

(2) The land station can, by means of the abbreviation PTR, request the mobile station to give it the following information:

(*a*) approximate distance in nautical miles and bearing with reference to the land station, or else the position indicated by latitude and longitude;

(*b*) next port of call.

(3) The information covered by subparagraph (2) shall be furnished by authorization of the commander or the person responsible for the vehicle carrying the mobile station and only in case it is requested by the land station.

§ 6. In communications between land stations and mobile stations, the mobile station shall comply with the instructions given by the land station, in all questions relative to the order and the time of transmission, to the choice of frequency (wavelength) and/or of the type of wave and to the suspension of work. This provision shall not apply to cases of distress.

§ 7. In communications between mobile stations, and except for cases of distress, the station called shall control the work as indicated in § 5 above.

§ 8. (1) When a station called does not answer a call sent three times, at intervals of 2 minutes, the call must cease and it may be resumed only 15 minutes later. In the case of communications between a station of the maritime mobile service and an aircraft station, the call may be resumed 5 minutes later. The calling station, before resuming the call, must make certain that the station called is not in communication with another station at that time.

(2) The call may be repeated at shorter intervals if there is no danger that it will interfere with communications in progress.

§ 9. When the name and the address of the operating agency of a mobile station are not shown in the nomenclature or are no longer in accord with the data given therein, it shall devolve upon the mobile station, as a matter of routine, to furnish the land station to which it sends traffic with all the necessary information in this connection, using for this purpose the appropriate abbreviations.

ARTICLE 21

USE OF WAVES IN THE MOBILE SERVICE

A. RESTRICTIONS (TYPE B AND BROADCASTING)

§ 1. (1) The use of type-*B* waves shall be forbidden in all radio stations.

As an exception, it shall be permitted in ship stations on the following frequencies:

375 kc. (800 m.). for radio direction finding only.
425 kc. (706 m.) for traffic.
500 kc. (600 m.).

(2) Mobile stations at sea shall be prohibited from making radiotelephone broadcast transmissions intended to be received by the general public.

B. BAND OF 365–515 KC. (822–583 M.)

§ 2. *Calling and reply.* (1) The general calling wave which must be used by all ship stations and all coast stations working in radiotelegraphy in the authorized bands between 365 and 515 kc. (822 and 583 m.), as well as by aircraft wishing to enter into communication with a coast station or a ship shall be the wave of 500 kc. (600 m.) (*A*1, *A*2 or *B*).

(2) In order to reduce interference in the regions of heavy traffic, the administrations reserve the right to consider that the requirements of (1) are satisfied if the calling waves assigned to coast stations for the handling of public correspondence are not separated from the general calling wave of 500 kc. (600 m.) by more than 5 kc.

(3) The wave for the reply to a call transmitted on the general calling wave [see § 2, (1)] shall be the wave of 500 kc. (600 m.), the same as that for calling.

§ 3. *Distress.* (1) The wave of 500 kc. (600 m.) shall be the international distress wave; it shall be used for that purpose by ship stations and aircraft stations in requesting help from the maritime services. It may be used only for calls and replies, as well as for distress traffic, urgent and safety messages and signals.

(2) By way of exception, this wave may nevertheless be used for traffic under the conditions indicated in § 4 (3) below.

(3) Aside from the wave of 500 kc. (600 m.), the use of waves of all types between 485 and 515 kc. (620 and 583 m.), shall be forbidden.

§ 4. *Traffic.* (1) Coast and ship stations working within the authorized bands between 365 and 515 kc. (822 and 583 m.) must be able to use at least one wave besides that of 500 kc. (600 m.) when an additional wave is printed in heavy type in the nomenclature, this is the normal working-wave of the station. The additional waves thus chosen for coast stations may or may not be the same as those of ship stations. In any case, the working-waves of coast stations must be chosen in such a way as to avoid interference with neighboring stations.

(2) Besides their normal working-waves, printed in heavy type in the nomenclature, land and on-board stations may use, in the authorized bands, supplementary waves which shall be mentioned in the nomenclature in ordinary print. However, the band of frequencies from 365 to 385 kc. (822 to 779 m.) shall be reserved to the radio direction-finding service; it can be used by the mobile service, for radiotelegraph correspondence, only subject to the conditions set forth in article 7.

(3) As an exception, on condition that no interference will result therefrom for distress, urgent and safety, calling and reply signals, the wave of 500 kc. (600 m.) may also be used:

(*a*) in regions of heavy traffic, exclusively by ship stations and only for the transmission of a single and short radiotelegram;[12, 13]

(*b*) in other regions, for the transmission of radiotelegrams and for radio direction finding, but with discretion.

(4) In regions of heavy traffic of the European coasts, ship stations working with type-*A2* waves in the band of 365 to 550 kc. (822 to 545 m.), must use, to the extent possible, the frequencies of 425 kc. (706 m.) and 480 kc. (625 m.).

(5) No European coast station shall be authorized to use these frequencies.

§ 5. *Watch.* (1) In order to increase safety of life at sea (ships), and over the sea (aircraft), all the stations of the maritime mobile service which normally listen on the waves of the authorized bands between 365 and 515 kc. (822 and 583 m.) must, during their working hours, make the necessary provisions to insure the watch on the distress wave [500 kc. (600 m.)] twice per hour, for 3 minutes, beginning at *x*:15 and at *x*:45 o'clock, Greenwich Mean Time (GMT).

(2) During the intervals indicated above, outside the transmissions mentioned in article 24 (§§ 22 to 28):

1. Transmissions must cease in the bands of 480 to 520 kc. (625 to 577 m.);

2. Outside these bands:

(*a*) transmissions of type-*B* waves shall be forbidden;

(*b*) other transmissions of the mobile service stations may continue; stations of the maritime mobile service may listen to these transmissions on the express condition that these stations shall first insure the watch on the distress wave, as provided for in subparagraph (1) of this paragraph.

(3) Since calls in the authorized bands between 365 and 515 kc. (822 and 583 m.) are normally made on the general calling wave [§ 2 (1) above], maritime mobile service stations open to the service of public correspondence and using waves from these bands for their work must, during their hours of watch, remain on watch on the calling-wave of their service. The watch on 500 kc. (600 m.) shall of compulsory only on type-*A2* or -*B* waves. These stations, while observing the provisions of § 5 (1) and (2), and § 7 (4), shall be authorized to abandon this watch only when they are engaged in a communication on other waves.

C. BAND OF 100–160 KC. (3000–1875 M.)

§ 6. *Calling and Reply.* (1) The wave of 143 kc. (2100 m.) (type-*A1* only), shall be the international calling wave for use in long-

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[12] The regions of heavy traffic are indicated in the nomenclature of coast stations. These regions consist of the service areas of the coast stations indicated as not accepting traffic on 500 kc. (600 m.) (see appendix 9).

[13] In principle, such use shall be permitted only for ship stations provided with a break-in device or an equivalent apparatus.

distance communications of the mobile service in the bands 100 to 160 kc. (3000 to 1875 m.).

(2) Except for the wave of 143 kc. (2100 m.) the use of any wave between 140 and 146 kc. (2143 and 2055 m.) shall be forbidden.

(3) The wave for the reply to a call transmitted on the international calling-wave of 143 kc. (2100 m.) [see § 6 (1)] shall be:

> the wave of 143 kc. (2100 m.) for a mobile station; the normal working-wave, for a coast station.

§ 7. *Traffic.* The following rules must be followed in the operation of stations of the mobile service using type-$A1$ waves in the bands of 100 to 160 kc. (3000 to 1875 m.):

(1) (*a*) Any coast station carrying on a communication on one of these waves must listen on the wave of 143 kc. (2100 m.), unless otherwise indicated in the nomenclature.

(*b*) The coast station shall transmit all its traffic on the wave or on the waves which are specifically assigned to it.

(*c*) A coast station to which one or more waves within the band 125 to 150 kc. (2400 to 2000 m.) have been allocated, shall have a prior right to this or these waves.

(*d*) Any other mobile service station transmitting public traffic on this or these waves and thereby causing interference with the said coast station must discontinue its work at the request of the latter.

(2) (*a*) When a mobile station wishes to establish communication on one of these waves with another station of the mobile service, it must use the wave of 143 kc. (2100 m.), unless otherwise indicated in the nomenclature.

(*b*) This wave, designated as a general calling-wave, must be used exclusively in the North Atlantic:

1. for making individual calls and answering these calls;
2. for transmitting signals preliminary to the transmission of traffic.

(3) A mobile station, after having established communication with another station of the mobile service on the general calling wave of 143 kc. (2100 m.) must, so far as possible, transmit its traffic on some other wave of the authorized bands, provided it does not interfere with the work in progress of another station.

(4) As a general rule, any mobile station equipped for service on type-$A1$ waves in the band 100 to 160 kc. (3000 to 1875 m.) and which is not engaged in a communication on another wave, must, in order to permit the exchange of traffic with other stations of the mobile service, return each hour to the wave of 143 kc. (2100 m.) for 5 minutes beginning at x:35 o'clock Greenwich Mean Time, during the specified hours, according to the category to which the station in question belongs.

(5) (*a*) Land stations must, to the extent possible, transmit the calls in the form of calling lists; in this case, the stations transmit their calling lists at definite hours published in the nomenclature, on

the wave or on the waves which are allocated to them, in the bands of 100 to 160 kc. (3000 to 1875 m.), but not on the waves of 143 kc. (2100 m.).

However, if the flow of its traffic is facilitated thereby, a land station may be authorized by the authority to which it is subject to begin its calling lists by the following brief preamble transmitted on 143 kc. (2100 m.):

CQ from.....(land station call signal)
QSW........followed by the indication of the priority wavelength of the station on which the calling list will be immediately afterwards transmitted. Under no circumstances may this preamble be repeated.

(*b*) Land stations can, however, call individually mobile stations at any time, outside the hours fixed for the transmission of calling lists, according to the circumstances or the work to be done.

(*c*) The wave of 143 kc. (2100 m.) may be used for individual calls and will, preferably, be utilized to this end during the period indicated in § 7 (4).

D. AERONAUTICAL SERVICES

§ 8. (1) The general calling waves, for the aeronautical services, shall be the following, except in regions where regional agreements providing otherwise are in effect.

333 kc. (900 m.)
6210 kc. (48.31 m.) in addition to the use indicated in article 7, § 21 (1) (*c*).

Other frequencies may, in addition, be selected as calling waves by agreements between the interested governments. These frequencies, as well as the requirements for their use, shall be listed in the service documents published by the Bureau of the Union.

(2) The general waves for the reply in the aeronautical services shall be the following, except in regions where regional agreements providing otherwise are in effect:

333 kc. (900 m.)
6210 kc. (48.31 m.) in addition to the use as indicated in article 7, § 21 (1) (*c*).

Other frequencies may be selected as waves for the reply by agreements between the interested governments. These frequencies, as well as the requirements for their use, shall be listed in the service documents published by the Bureau of the Union.

(3) Radio communications of aeronautical stations shall be regulated by regional agreements between the governments concerned, except as otherwise provided for in these Regulations.

ARTICLE 22

INTERFERENCE

§ 1. (1) The transmission of unnecessary or unidentified signals or correspondence shall be forbidden to all stations.

(2) Tests and experiments shall be permitted in mobile stations if they do not interfere with the service of other stations. As for stations other than mobile stations, each administration shall judge, before authorizing them, whether or not the proposed tests or experiments are likely to interfere with the service of other stations.

§ 2. It is recommended that traffic relating to public correspondence be transmitted on type-*A1* waves rather than on type-*A2* waves, and on type-*A2* waves rather than on type-*B* waves.

§ 3. All stations of the mobile service shall be required to exchange traffic with the minimum of radiated power necessary to insure good communication.

§ 4. Except in cases of distress, communications between on-board stations must not interfere with the work of land stations. When this work is thus interfered with, the on-board stations which cause it must stop transmitting or change wave, upon the first request of the land station concerned.

§ 5. Test and adjustment signals must be selected in such a way that there will result no confusion with a signal, an abbreviation, etc., having a particular meaning defined by these Regulations or by the International Code of Signals.

§ 6. (1) When it is necessary to transmit test or adjustment signals, and there is danger of interfering with the service of the adjoining land station, permission must be obtained from that land station before such transmissions are made.

(2) Any station making transmissions for purposes of testing, adjusting, or experimenting, must, as far as possible, at frequent intervals in the course of these transmissions, transmit at low speed its call signal or, if need be, its name.

ARTICLE 23

EMERGENCY INSTALLATIONS

§ 1. The Convention for the Safety of Life at Sea shall determine which ships must be provided with emergency installations and shall define the conditions to be fulfilled by installations of this category.

§ 2. In the use of emergency installations, all the provisions of the present Regulations must be observed.

§ 3. Ships provided with a type-*A1* or -*A2* transmitting installation in operating conditions shall not use the type-*B* emergency installation to transmit any other than distress signals and traffic.

ARTICLE 24

DISTRESS TRAFFIC AND DISTRESS SIGNALS—ALARM, EMERGENCY, AND SAFETY SIGNALS

A. GENERAL

§ 1. No provision of these Regulations shall prevent a mobile station in distress from using any means available to it for drawing attention, signaling its position, and obtaining help.

§ 2. (1) When distress, emergency, or safety is involved, the telegraph transmission speed in general must not exceed 16 words per minute.

(2) The transmission speed for the alarm signal is indicated in § 21 (1).

B. WAVES TO BE USED IN CASE OF DISTRESS

§ 3. (1) *Ships.* (*a*) In case of distress, the wave to be used shall be the international distress wave, that is, 500 kc. (600 m.) (see art. 21); it must preferably be used in type *A2* or *B*. Ship stations which cannot transmit on the international distress wave shall use their normal calling-wave. (*b*) Low-power radiotelephone stations shall use, for this purpose, the calling and distress wave of 1650 kc. (182 m.), as indicated in article 31.

(2) *Aircraft.* Any aircraft in distress must transmit the distress call on the watching wave of the land or mobile stations capable of helping it; when the call is addressed to stations of the maritime service, the waves to be used are the distress wave or watching wave of these stations.

C. DISTRESS SIGNAL

§ 4. (1) In radiotelegraphy, the distress signal shall consist of the group • • • — — — • • •, transmitted as one signal, in which the dashes must be emphasized so as to be distinguished clearly from the dots.

In radiotelephony, the distress signal shall consist of the spoken expression MAYDAY (corresponding to the French pronunciation of the expression "m'aider").

(2) These distress signals shall announce that the ship, aircraft, or any other vehicle which sends the distress signal is threatened by serious and imminent danger and requests immediate assistance.

D. DISTRESS CALL

§ 5. (1) The distress call, when sent in radiotelegraphy on 500 kc. (600 m.), shall, as a general rule, be immediately preceded by the alarm signal as the latter is defined in § 21 (1).

(2) When circumstances permit, the transmission of the call shall be separated from the end of the alarm signal by a 2-minute silence.

(3) The distress call shall include:

the distress signal transmitted three times,
the word DE, and
the call signal of the mobile station in distress transmitted three times.

(4) This call shall have absolute priority over other transmissions. All stations hearing it must immediately cease all transmission capable of interfering with the distress traffic, and must listen on the wave used for the distress call. This call must not be sent to any particular station and does not require an acknowledgment of receipt.

E. DISTRESS MESSAGE

§ 6. (1) The distress call must be followed as soon as possible by the distress message. This message shall include the distress call followed by the name of the ship, aircraft, or the vehicle in distress, information regarding the position of the latter, the nature of the distress and the nature of the help requested, and any other further information which might facilitate this assistance.

(2) When, in its distress message, an aircraft is unable to signal its position, it shall endeavor to send its call signal long enough so that the radio direction-finding stations may determine its position.

§ 7. (1) As a general rule, a ship or aircraft at sea shall signal its position in latitude and longitude (Greenwich), using figures, for the degrees and minutes, accompanied by one of the words NORTH or SOUTH. and one of the words EAST or WEST. A period shall separate the degrees from the minutes. In some cases, the true bearings and the distance in nautical miles from some known geographical point may be given.

(2) A ship equipped with radiotelegraph apparatus, after having sent this distress message, shall transmit, to the extent practicable, the ship's call signal for a period long enough to enable the land and ship stations equipped with radio direction finders to determine its position.

(3) As a general rule, an aircraft flying over land shall signal its position by the name of the nearest locality, its approximate distance from this point, accompanied according to the case, by one of the words NORTH, SOUTH, EAST, or WEST, or, in some cases, words indicating intermediate directions.

§ 8. The distress call and message shall be sent only by order of the master or person responsible for the ship, aircraft, or other vehicle carrying the mobile station.

§ 9. (1) The distress message must be repeated at intervals until an answer has been received, and especially during the periods of silence provided for in article 21, § 5.

(2) The alarm signal may also be repeated, if necessary.

(3) The intervals must, however, be sufficiently long so that stations preparing to reply may have time to put their transmitters in operation.

(4) In case the on-board station in distress receives no answer to a distress message sent on the 500-kc. (600-m.) wave, the message may be repeated on any other available wave by means of which attention might be attracted.

§ 10. Furthermore, a mobile station which becomes aware that another mobile station is in distress, may transmit the distress message in either of the following cases:

(*a*) when the station in distress is not itself in a position to transmit it;

(*b*) when the master (or his relief) of the vessel, aircraft, or other vehicle carrying the station which intervenes, believes that further help is necessary.

§ 11. (1) Stations of the mobile service which receive a distress message from a mobile station which is unquestionably in their vicinity, must acknowledge receipt thereof at once (see §§ 18 and 19 below). If the distress call has not been preceded by an auto alarm signal, these stations may transmit this auto alarm signal with the authorization of the authority responsible for the station (for mobile stations, see article 11, § 1), taking care not to interfere with the transmission of the acknowledgment of the receipt of said message by other stations.

(2) Stations of the mobile service which receive a distress message from a mobile station which unquestionably is not in their vicinity, must wait a short period of time before acknowledging receipt thereof, in order to make it possible for stations nearer to the mobile station in distress to answer and acknowledge receipt without interference.[14]

F. DISTRESS TRAFFIC

§ 12. Distress traffic shall include all messages relative to immediate assistance needed by the mobile station in distress.

§ 13. Every distress traffic radiotelegram must include the distress signal transmitted at the beginning of the preamble.

§ 14. The control of distress traffic shall devolve upon the mobile station in distress or upon the mobile station which, by application of the provisions of § 10 (*a*), has sent the distress call. These stations may delegate the control of the distress traffic to another station.

§ 15. (1) When it considers it indispensable, any station of the mobile service in the proximity of the ship, aircraft, or vehicle in distress, may impose silence either to all the stations of the mobile service in the zone, or to any one station which may be causing interference with the distress traffic. In both cases, the regulatory abbreviation (QRT) shall be used, followed by the word DISTRESS; these indications shall be addressed "to all" stations or to one station only, as the case may be. The use of the abbreviation QRT must be reserved, as far

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[14] The provisions of § 11 shall also apply to any station working in the mobile service bands.

as possible, for the ship in distress and for the station which is directing the distress traffic.

(2) When the station in distress wishes to impose silence, it shall use the above-mentioned procedure, substituting the distress signal • • • — — — • • • for the word DISTRESS.

§ 16. (1) Any station hearing a distress call must conform to the provisions of § 5 (4).

(2) Any station of the mobile service which becomes aware of distress traffic must listen to this traffic even if it is not taking part in it.

(3) For the entire duration of distress traffic, it shall be prohibited for all stations which are aware of this traffic and which are not taking part in it:

(*a*) to use the distress wave [500 kc. (600 m.)] or the wave on which the distress traffic is taking place;

(*b*) to use type-B waves.

(4) A station of the mobile service which, while following distress traffic of which it is aware, is able to contitnue its normal service, may do so, when the distress traffic is well established, under the following conditions:

(*a*) the use of the waves specified in (3) shall be forbidden;

(*b*) the use of type-A1 waves, with the exception of those which might interfere with the distress traffic, shall be permitted;

(*c*) it shall be allowed to use type-A2 or -A3 waves only in the band or bands allocated to the mobile service and which do not include frequencies used for distress traffic [the band around 500 kc. (600 m.) extends from 385 to 550 kc. (779 to 545 m.)].

§ 17. When it is no longer necessary to observe silence, or when the distress traffic is ended, the station which has controlled this traffic shall send on the distress wave, and, where necessary, on the wave used for this distress traffic, a message addressed "to all," indicating that the distress traffic is ended. This message shall take the following form:

CQ call "to all" (three times),
the word DE,
call signal of the station transmitting the message,
distress signal,
time of filing of the message,
name and call signal of the mobile station which was in distress,
abbreviation "QUM"

G. ACKNOWLEDGMENT OF RECEIPT OF A DISTRESS MESSAGE

§ 18. The acknowledgment of receipt of a distress message shall be given in the following form:

call signal of the mobile station in distress (three times),
the word DE,

call signal of the station acknowledging receipt (three times),
group RRR,
distress signal.

§ 19. (1) Any mobile station acknowledging receipt of a distress message must, on the order of the master or his relief, give the following information as soon as possible, in the order indicated:

its name,
its position, in the form specified in § 7,
the maximum speed at which it is proceeding towards the ship (aircraft or other vehicle) in distress.

(2) Before transmitting this message the station must make sure that it is not interfering with the emissions of other stations in a better position to render immediate assistance to the station in distress.

H. REPETITION OF A DISTRESS CALL OR MESSAGE

§ 20. (1) Any station of the mobile service which is not in a position to render assistance and which has heard a distress message for which acknowledgment of receipt has not immediately been given, must take all possible steps to attract the attention of stations of the mobile service which are in a position to furnish help.

(2) For this purpose, with the permission of the authority responsible for the station, the distress call or distress message may be repeated; this repetition shall be preceded generally by transmission of the auto alarm signal as defined in § 21. A sufficient interval of time shall be provided between the transmission of the auto alarm signal and the repetition of the distress call (or message) so that mobile stations whose watch is not permanent and which are warned by the sounding of their automatic alarm apparatus may have time to go on watch. Repetition of the distress call (or message) shall be made at full power, either on the distress wave or on one of the waves which may be used in case of distress (§ 3 of this article); at the same time all necessary steps shall be taken to inform the authorities whose assistance may be advantageous.

(3) A station which repeats a distress call or a distress message shall transmit after it the word DE followed by its own call signal three times.

I. AUTOMATIC ALARM SIGNAL

§ 21. (1) The alarm signal shall consist of a series of 12 dashes sent in one minute, the duration of each dash being four seconds and the duration of the interval between two dashes, one second. It can be transmitted by hand or by means of an automatic instrument. Any ship station working in the band of 365 to 515 kc. (822 to 583 m.), and which is not provided with an automatic apparatus for the transmission of the auto alarm signal must be permanently equipped with a clock distinctly marking the seconds, preferably by means of a moving hand completing one revolution per minute. This clock must be placed at a point sufficiently visible from the keying table so that the operator may by watching it, easily and correctly time the different elements of the alarm signal.

(2) The only purpose of this special signal is to set into operation the automatic apparatus used to give the alarm. It must only be used either to announce that a distress call or message is to follow, or to announce the transmission of an urgent cyclone warning; in the latter case it can only be used by coast stations duly authorized by their government.

(3) In cases of distress, the use of the alarm signal is indicated in § 5 (1); in the case of urgent cyclone warnings, the emission of this warning must begin only 2 minutes after the end of the alarm signal.

J. URGENT SIGNAL

§ 22. (1) In radiotelegraphy, the urgent signal shall consist of the group XXX transmitted three times, with the letters of each group, as well as the consecutive groups well separated; it shall be sent before the call.

(2) In radiotelephony the urgent signal shall consist of three transmissions of the expression PAN (corresponding to the French pronunciation of the word "panne"); it shall be transmitted before the call.

(3) The urgent signal shall indicate that the calling station has a very urgent message to transmit concerning the safety of a ship, an aircraft, or another vehicle, or concerning the safety of some person on board or sighted from on board.

(4) In the aeronautical service, the urgent signal PAN shall be used in radiotelegraphy and in radiotelephony to indicate that the aircraft transmitting it is in trouble and is forced to land, but that it is not in need of immediate help. This signal should, as far as possible, be followed by a message giving additional information.

(5) The urgent signal shall have priority over all other communications, except distress communications, and all mobile or land stations hearing it must take care not to interfere with the transmission of the message which follows the urgent signal.

(6) In case the urgent signal is used by a mobile station, this signal must, as a general rule, and subject to the provisions of the above subparagraph (4), be addressed to a definite station.

§ 23. When the urgent signal is used the messages which this signal precedes must, as a general rule, be written in plain language, except in the case of medical messages exchanged between ships or between a ship and a coast station.

§ 24. (1) Mobile stations hearing the urgent signal must listen for at least 3 minutes. After this interval, and if no urgent message has been heard, they may resume their normal service.

(2) However, land and on-board stations which are in communication on waves other than those used for the transmission of the urgent signal and the call following it, may continue their normal work without interruption, unless the message is addressed "to all" (CQ).

§ 25. (1) The urgent signal may be transmitted only with the authorization of the master or of the person responsible for the ship, aircraft, or any other vehicle carrying the mobile station.

(2) In the case of a land station, the urgent signal may be transmitted only with the approval of the responsible authority.

(3) When the urgent signal has been used before the transmission of a message intended for all stations and including measures to be taken by stations which have received this message, the station responsible for the transmission must cancel it as soon as it knows that there is no longer necessity of acting upon it. This message of cancellation must likewise be addressed "to all" (CQ).

K. SAFETY SIGNAL

§ 26. (1) In radiotelegraphy, the safety signal shall consist of the group TTT, transmitted three times, with the letters of each group, as well as the consecutive groups, well separated. This signal shall be followed by the word DE and three transmissions of the call signal of the station sending it. It announces that this station is about to transmit a message concerning the safety of navigation or giving important meteorological warnings.

(2) In radiotelephony, the word SECURITY (corresponding to the French pronunciation of the word "sécurité") repeated three times, shall be used as the safety signal.

§ 27. The safety signal and the message which follows it shall be transmitted on the distress wave or on one of the waves which, in some instances, may be used in case of distress (see § 3 of this article.)

§ 28. (1) In the maritime mobile service, apart from messages transmitted according to a schedule, the safety signal must be transmitted toward the end of the first ensuing period of silence (art. 21, § 5), and the message shall be transmitted immediately after the period of silence; in the cases provided for in article 32,* *A*, § 4 (3) and § 5 (1), *B*, § 7, the safety signal and the message which follows it must be transmitted with as little delay as possible, but must be repeated, as has just been indicated, at the first ensuing period of silence.

(2) All stations hearing the safety signal must continue listening on the wave on which the safety signal has been sent until the message so announced has been completed; they must moreover keep silence on all waves likely to interfere with the message.

(3) The foregoing rules shall be applicable to the aeronautical service so far as they are not in conflict with regional arrangements providing aerial navigation with at least equivalent protection.

* Article 32 not published.

ARTICLE 25

WORKING HOURS OF STATIONS OF THE MOBILE SERVICE

§ 4. (1) Ship stations the service of which is not continuous may not close before having:

1. finished all operations called for by a distress call;
2. exchanged, as far as possible, all radiotelegrams originating in or destined to land stations which are within their range, and mobile stations which, being within their range, have signaled their presence before the effective cessation of work.

(2) A mobile station which has no fixed working hours must advise the land station with which it is in communication of the closing and reopening hours of its service.

(3) (*a*) Any mobile station which arrives in a port and the service of which is accordingly about to close, must so advise the nearest land station and, if necessary, the other land stations with which it generally communicates.

It must not close until it has cleared all traffic on hand, unless the regulations of the country where it calls prohibit.

(*b*) At the time of its departure, it must advise the interested land station or stations of its reopening, as soon as such reopening is permitted by the regulations in force within the country in which the port of departure is located.

ARTICLE 26

ORDER OF PRIORITY OF COMMUNICATIONS IN THE MOBILE SERVICE

The order of priority of radio communications in the mobile service shall be as follows:

1. distress calls, distress messages, and distress traffic;
2. communications preceded by an urgent signal;
3. communications preceded by a safety signal;
4. communications relative to radio direction-finding bearings;
5. government radiotelegrams for which priority right has not been waived;
6. all other communications.

ABBREVIATIONS TO BE USED IN RADIO COMMUNICATIONS

Q CODE

B. List of Abbreviations According to the Nature of Questions, Answers or Statements

Abbreviation	Question	Answer or Statement
	Name	
QRA	What is the name of your station?	The name of my station is . . .
	Route	
QRD	Where are you going and where do you come from?	I am going to . . . and I come from . . .
	Position	
QRB	At what approximate distance are you from my station?	The approximate distance between our stations is . . . nautical miles (*or* . . . kilometers).
QTH	What is your position in latitude and in longitude (*or according to any other indication*)?	My position is . . . latitude, . . . longitude (*or according to any other indication*).
	Quality of Signals	
QRI	Is the tone of my transmission regular?	The tone of your transmission varies.
QRK	What is the legibility of my signals (*1 to 5*)?	The legibility of your signals is . . . (*1 to 5*).
	Strength of Signals	
QRJ	Are you receiving me badly? Are my signals weak?	I cannot receive you. Your signals are too weak.
QRO	Must I increase the power?	Increase the power.
QRP	Must I decrease the power?	Decrease the power.
QSA	What is the strength of my signals (*1 to 5*)?	The strength of your signals is (*1 to 5*).
QSB	Does the strength of my signals vary?	The strength of your signals varies.
	Keying	
QRQ	Must I transmit faster?	Transmit faster (. . . words per minute).
QRS	Must I transmit more slowly?	Transmit more slowly (. . . words per minute).
QSD	Is my keying correct; are my signals distinct?	Your keying is incorrect; your signals are bad.

Q CODE—Continued

Abbreviation	Question	Answer or Statement
	Interference	
QRM	Are you being interfered with?	I am being interfered with.
QRN	Are you troubled by static?	I am troubled by static.
	Adjustment of the Wavelength	
QRG	Will you tell me what my exact frequency (wavelength) is in kilocycles (*or* meters)?	Your exact frequency (wavelength) is . . . kilocycles (*or* . . . meters).
QRH	Does my frequency (wavelength) vary?	Your frequency (wavelength) varies.
	Choice of the Wavelength and/or Type of Wave	
QSU	Must I transmit (*or* answer) on . . . kilocycles (*or* meters) and/or on waves of type-A1, -A2, -A3, or -B?	Transmit (*or* answer) on . . . kilocycles (*or* . . . meters) and/or on waves of type-A1, -A2, -A3, or -B.
QSV	Must I transmit a series of V's?	Transmit a series of V's.
QSW	Do you wish to transmit on kilocycles (*or* . . . meters), and/or on waves of type-A1, -A2, -A3, or -B?	I am going to transmit (*or* I shall transmit) on . . . kilocycles (*or* . . . meters), and/or on waves of type-A1, -A2, -A3, or -B.
QSX	Will you listen to . . . (*call signal*) on . . . kilocycles (*or* . . . meters)?	I am listening to . . . (*call signal*) on . . . kilocycles (*or* . . . meters).
	Change of Wavelength	
QSY	Must I shift to transmission on . . . kilocycles (*or* . . . meters), without changing the type of wave? *or* Must I shift to transmission on another wave?	Shift to transmission on . . . kilocycles (*or* . . . meters), without changing the type of wave, *or* Shift to transmission on another wave.
	Making Contact	
QRL	Are you busy?	I am busy (*or* I am busy with . . .). Please do not interfere.
QRV	Are you ready?	I am ready.
QRX	Must I wait? When will you call me again?	Wait (or wait until I have finished communicating with . . .). I shall call you again at . . . o'clock (*or* immediately).
QRY	Which is my turn?	Your turn is number . . . (*or according to any other indication*).
QRZ	By whom am I being called?	You are being called by . . .

Q CODE—Continued

Abbreviation	Question	Answer or Statement
QTQ	Can you communicate with my station by the International Code of Signals?	I am going to communicate with your station by the International Code of Signals.
	Time	
QTR	What is the exact time?	The exact time is . . .
QTU	What are the hours during which your station is open?	My station is open from . . . to . . .
	Charges	
QRC	By what private operating enterprise (or government administration) are the accounts for charges of your station settled?	The accounts for charges of my station are settled by the . . . private operating enterprise (*or* by the government administration of . . .).
QSJ	What is the charge to be collected per word to . . . including your internal telegraph charge?	The charge to be collected per word to . . . is . . . francs, including my internal telegraph charge.
	Transit	
QRW	Must I advise . . . that you are calling him on . . . kilocycles (*or* . . . meters)?	Please advise . . . that I am calling him on . . . kilocycles (*or* . . . meters).
QSO	Can you communicate with . . . directly (*or* through . . .)?	I can communicate with . . . directly (*or* through . . .).
QSP	Will you relay to . . . free of charge?	I will relay to . . . free of charge.
QUA	Have you any news from . . . (*call signal of the mobile station*)?	This is the news from . . . (*call signal of the mobile station*).
QUC	What is the last message you received from . . . (*call signal of the mobile station*)?	The last message I received from . . . (*call signal of the mobile station*) is . . .
	Exchange of Correspondence	
QRU	Have you anything for me?	I have nothing for you.
QSG	Must I transmit . . . telegrams (*or* one telegram) at a time?	Transmit . . . telegrams (*or* one telegram) at a time.
QSK	Must I continue the transmission of all my traffic; I can hear you between my signals?	Continue the transmission of all your traffic; I shall interrupt you if necessary.
QSL	Can you acknowledge receipt?	I am acknowledging receipt.
QSM	Must I repeat the last telegram which I transmitted to you?	Repeat the last telegram which you transmitted to me.

Q CODE—Continued

Abbreviation	Question	Answer or Statement
QSZ	Must I transmit each word or group twice?	Transmit each word or group twice.
QTA	Must I cancel telegram No. . . . as if it had not been transmitted?	Cancel telegram No. . . . as if it had not been transmitted.
QTB	Do you agree with my word count?	I do not agree with your word count; I shall repeat the first letter of each word and the first figure of each number.
QTC	How many telegrams have you to transmit?	I have . . . telegrams for you (*or* for . . .).
	Movement	
QTI	What is your true course?	My true course is . . . degrees.
QTJ	What is your speed?	My speed is . . . knots (*or* . . . kilometers) per hour.
QTO	Have you left dock (*or* port)?	I have left dock (*or* port).
QTP	Are you going to enter dock (*or* port)?	I am going to enter dock (*or* port).
QUG	Will you be forced to come down on water (*or* on land)?	I am forced to come down on water (*or* on land) at . . . (*place*).
QUK	Can you tell me the condition of the sea observed at . . . (*place or coordinates*)?	The sea at . . . (*place or coordinates*) is . . .
QUL	Can you tell me the surge observed at (*place or coordinates*)?	The surge at . . . (*place or coordinates*) is . . .
	Meteorology	
QUB	Can you give me, in the following order, information concerning: visibility, height of clouds, ground wind at . . . (*place of observation*)?	This is the information requested: . . .
QUH	Will you give me the present barometric pressure at sea level?	The present barometric pressure at sea level is . . . (*units*).
	Radio direction finding	
QTE [1]	What is my true bearing in relation to you? *or* What is my true bearing in relation to . . . (*call signal*) *or*	Your true bearing in relation to me is . . . degrees. *or* Your true bearing in relation to . . . (*call signal*) is . . . degrees at . . . (*time*). *or*

Q CODE—Continued

Abbreviation	Question	Answer or Statement
QTE [1]	What is the true bearing of . . . (*call signal*) in relation to . . . (*call signal*)?	The true bearing of . . . (*call signal*) in relation to . . . (*call signal*) is . . . degrees at . . . (*time*).
QTF	Will you give me the position of my station on the basis of bearings taken by the radio direction-finding stations which you control?	The position of your station on the basis of bearings taken by the radio direction-finding stations which I control is . . . latitude, . . . longitude.
QTG	Will you transmit your call signal during 50 seconds ending with a 10-second dash, on . . . kilocycles (*or* . . . meters) so that I may take your radio direction-finding bearings?	I will transmit my call signal during 50 seconds, ending with a 10-second dash, on . . . kilocycles (*or* . . . meters) so that you may take my radio direction-finding bearings.
QTM	Transmit radio signals and submarine sound signals to enable me to determine my bearing and my distance.	I am transmitting radio signals and submarine sound signals to enable you to determine your bearing and your distance.
QUJ [1]	Will you please indicate the proper course to steer towards you, with no wind?	The proper course to steer towards me, with no wind, is . . . degrees at . . . (*time*).
	Suspension of Work	
QRT	Must I stop transmission?	Stop transmission.
	Emergency	
QUD	Have you received the urgent signal transmitted by . . . (*call signal of the mobile station*).	I have received the urgent signal transmitted by . . . (*call signal of the mobile station*) at . . . (*time*).
	Distress	
QSR	Has the distress call received from . . . been attended to?	The distress call received from . . . has been attended to by . . .
QUF	Have you received the distress signal sent by . . . (*call signal of the mobile station*)?	I have received the distress signal sent by . . . (*call signal of the mobile station*) at . . . (*time*).
QUM	Is the distress traffic ended?	The distress traffic is ended.

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[1] In certain aeronautical services, "true course" and "true bearing" are called "geographic course" and "geographic bearing."

2. *Miscellaneous Abbreviations*

Abbreviation	Meaning
C	Yes.
N	No.
P	Announcing private telegram in the mobile service (*to be used as a prefix*).
W	Word *or* words.
AA	All after . . . (*to be used after a question mark to request a repetition*).
AB	All before . . . (*to be used after a question mark to request a repetition*).
AL	All that has just been transmitted (*to be used after a question mark to request a repetition*).
AS	Waiting period.
BN	All between . . . (*to be used after a question mark to request a repetition*).
BQ	Answer to RQ.
CL	I am closing my station.
CS	Call signal (*to be used in requesting that call signal be given or repeated*).
DB	I cannot give you a bearing, you are not in the calibrated sector of this station.
DC	The minimum of your signal is suitable for the bearing.
DF	Your bearing at . . . (*time*) was . . . degrees, in the doubtful sector of this station, with a possible error of two degrees.
DG	Please advise me if you find an error in the bearing given.
DI	Doubtful bearing due to the bad quality of your signal.
DJ	Doubtful bearing due to interference.
DL	Your bearing at . . . (*time*) was . . . degrees, in the uncertain sector of this station.
DO	Doubtful bearing. Request another bearing later, or at . . . (*time*).
DP	Beyond 50 miles, possible error of bearing can attain two degrees.
DS	Adjust your transmitter, your minimum signal is too broad.
DT	I cannot give you a bearing, your minimum signal is too broad.
DY	This is a two-way station, what is your approximate direction, in degrees, in relation to this station?
DZ	Your bearing is reciprocal (*to be used only by the control station of a group of radio direction-finding stations when addressing other stations of the same group*).
ER	Here . . . (*to be used before the name of the mobile station in the transmission of routing indications*).
GA	Resume transmission (*to be used more especially in the fixed service*).
JM	If I may transmit, make a series of dashes. To stop my transmission, make a series of dots [*not to be used on 500 kc (600 m)*].
MN	Minute *or* minutes (*to be used to indicate the duration of the waiting period*).
NW	I am resuming transmission (*to be used more especially in the fixed service*).
OK	We agree.
RQ	Announcing a request.

Miscellaneous Abbreviations—Continued

Abbreviation	Meaning
SA	Announcing the name of an aircraft station (*to be used in transmitting transit data*).
SF	Announcing the name of an aeronautical station.
SN	Announcing the name of a coast station.
SS	Announcing the name of a ship station (*to be used in transmitting transit data*).
TR	To announce sending of indications concerning a mobile station.
TU	Thank you for the cooperation given.
UA	Do we agree?
WA	Word after . . . (*to be used after a question mark to request a repetition*).
WB	Word before . . . (*to be used after a question mark to request a repetition*).
XS	Static.
YS	See your service notice.
ABV	Repeat (*or* I repeat) the figures in abbreviated form.
ADR	Address (*to be used after a question mark to request a repetition*).
CFM	Confirm (*or* I confirm).
COL	Collate (*or* I collate).
ITP	The punctuation counts.
MSG	Announcing a telegram concerning the service on board (*to be used as a prefix*).
NIL	I have nothing to transmit to you (*to be used after an abbreviation of code Q to show that the answer to the question asked is in the negative*).
PBL	Preamble (*to be used after a question mark to request a repetition*).
REF	Reference to . . . (*or* Refer to . . .).
RPT	Repeat (*or* I repeat) (*to be used in requesting or giving repetition of all or part of the traffic, the abbreviation to be followed by the corresponding indications*).
SIG	Signature (*to be used after a question mark to request a repetition*).
SVC	Announcing a service telegram concerning private traffic (*to be used as a prefix*).
TFC	Traffic.
TXT	Text (*to be used after a question mark to request a repetition*).

APPENDIX 12

SCALE USED TO EXPRESS STRENGTH OR LEGIBILITY OF SIGNALS

(See Article 17)

Strength

QSA 1 = scarcely perceptible.
QSA 2 = weak.
QSA 3 = fairly good.
QSA 4 = good.
QSA 5 = very good.

Legibility

QRK 1 = unreadable.
QRK 2 = readable now and then.
QRK 3 = readable, but with difficulty.
QRK 4 = readable.
QRK 5 = perfectly readable.

APPENDIX 15

PROCEDURE TO OBTAIN RADIO DIRECTION-FINDING BEARINGS

I. GENERAL INSTRUCTIONS

A. Before calling one or more radio direction-finding stations, the mobile station, in order to request its bearing, must refer to the nomenclature for:

1. The call signals of the stations to be called to obtain the radio direction-finding bearings desired.

2. The wave on which the radio direction-finding stations watch, and the wave or waves on which they take bearings.

3. The radio direction-finding stations which by means of special wire connections, may be grouped with the radio direction-finding station to be called.

B. The procedure to be followed by the mobile station depends on varying circumstances. Generally, the following must be taken into account:

1. If the radio direction-finding stations do not listen on the same wave, whether it be the wave on which bearings are taken or another wave, the bearings must be requested separately from each station or group of stations using a given wave.

2. If all the radio direction-finding stations concerned listen on the same wave, and if they are able to take bearings on a common wave—which may be a wave other than the listening wave—they must all be called together, in order that the bearings may be taken by all these stations at the same time, on one and the same transmission.

3. If several radio direction-finding stations are grouped by means of special wires, only one of them must be called, even if all are furnished with transmitting apparatus. In this case, the mobile stations must, however, if it is necessary, specify in the call by means of the

call signals, the radio direction-finding stations whose bearings they wish to obtain.

C. The data concerning: (*a*) the signal to be used to obtain the bearings, (*b*) the duration of the transmission to be made by the mobile station and (*c*) the time used by the radio direction-finding station in question, shall be given in the nomenclature.

II. RULES OF PROCEDURE

A. To obtain a bearing.

(1) The mobile station shall call the radio direction-finding station on the wave indicated, in the nomenclature, as being its watching-wave. The station calling shall transmit the abbreviation QTE? (followed, if the radio direction-finding station is a mobile station, by the abbreviation QTH?) and indicate, if necessary, the wave it is going to use to have a bearing determined. The station calling shall then await instructions.

(2) The radio direction-finding station called shall direct the calling station to transmit.

(3) After having prepared its new transmitting wave, wherever this is required, the calling station shall reply by sending its call signal sometimes combined with another signal, during a length of time sufficiently prolonged to take the bearing.

(4) The radio direction-finding station shall determine the direction and, if possible, the sense of the bearing, and transmit the information to the calling station in the following order:

(*a*) the abbreviation QTE;

(*b*) the true bearing in degrees from the radio direction-finding station;

(*c*) the time of observation;

(*d*) if the radio direction-finding station is a mobile station, its own position in latitude and longitude, preceded by the abbreviation QTH.

If the radio direction-finding station is not satisfied with the operation, it shall request the calling station to repeat the transmission indicated under (3).

(5) As soon as the calling station has received the result of the observation, it shall repeat the message to the radio direction-finding station. The latter shall then confirm the accuracy of the repetition or, when necessary, shall correct it by again repeating the message. When the radio direction-finding station is certain that the mobile station has received the message correctly, it shall transmit the signal "end of work." This signal shall then be repeated by the calling station, as an indication that the operation is completed.

B. To obtain a position from two or more direction-finding stations organized as a group.

If the calling station wishes to be informed of its position by the control station of a group of radio direction-finding stations, it shall call the control station as above and request a position, using the abbreviation QTF?.

The control station shall reply to the call and, when the radio direction-finding stations are ready, shall direct the calling station to transmit. When it has determined the position, it shall transmit it to the calling station as above, using the abbreviation QTF.

C. To obtain simultaneous bearings from two or more radio direction-finding stations organized as a group.

Upon receiving a request for bearings, the control station of a group of radio direction-finding stations shall proceed as in *B* above, and then transmit the bearings observed by each station of the group, each bearing being preceded by the call signal of the station which has taken it.

CHAPTER 19

F. C. C. RULES AND REGULATIONS

Introduction—In this chapter the professional licensed operator as well as the student operator will find rules and regulations applicable to the operation of radio stations of various services including, Ship, Broadcast, Aviation, Police, Fire, Forestry and those governing Commercial Operators.

The Commission has rules and regulations applicable to each service and certain general rules and regulations applicable to all services. In this chapter only those of importance to operators and to those preparing for operators' examinations have been chosen for publication.

Since the Commission may and does modify its rules and regulations for the purpose of securing enforcement of law and treaty, the rules as shown here cannot be guaranteed still to be in force at the time, and inquiry should always be made as to modifications or deletions.[1]

RULES OF PRACTICE AND PROCEDURE

Replies to Notices of Violation

Sec. 1.391. *Under Title III of the Act*—Any licensee receiving official notice of a violation of the terms of the Communications Act of 1934, any legislative act, Executive Order, treaty to which the United States is a party, or the Rules and Regulations of the Federal Communications Commission, shall, within three days from such receipt, send a written answer direct to the Federal Communications Commission at Washington, D. C., and a copy thereof to the office of the Commission originating the official notice when the originating office is other than the office of the Commission in Washington, D. C. *Provided, however,* That if an answer cannot be sent nor an acknowledgment made within such three-day period by reason of illness or other unavoidable circumstances, acknowledgment and answer shall be made at the earliest practicable date with a satisfactory explanation of the delay. The answer to each notice shall be complete in itself and shall not be abbreviated by reference to other communications or answers to other notices. If the notice relates to some violation that may be due to the physical or electrical characteristics of transmitting apparatus, the answer shall state fully what steps, if any, are taken to prevent future violations, and if any new apparatus is to be installed,

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[1] Rules in force as of March 1st, 1940.

the date such apparatus was ordered, the name of the manufacturer, and promised date of delivery. If the installation of such apparatus requires a construction permit, the file number of the application shall be given, or if a file number has not been assigned by the Commission, such identification as will permit of ready reference. If the notice of violation relates to some lack of attention or improper operation of the transmitter, the name and license number of the operator in charge shall be given.

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Sec. 1.411. *Order of suspension*—No order of suspension of any operator's license shall take effect until fifteen days' notice in writing thereof, stating the cause for the proposed suspension, has been given to the operator licensee who may make written application to the Commission at any time within said fifteen days for a hearing upon such order. The notice to the operator licensee shall not be effective until actually received by him, and from that time he shall have fifteen days in which to mail the said application. In the event that physical conditions prevent mailing of the application at the expiration of the fifteen-day period, the application shall then be mailed as soon as possible thereafter, accompanied by a satisfactory explanation of the delay. Upon receipt by the Commission of such application for hearing, said order of suspension shall be held in abeyance until the conclusion of the hearing which shall be conducted under such rules as the Commission shall deem appropriate. Upon the conclusion of said hearing the Commission may affirm, modify, or revoke said order of suspension.

Sec. 1.412. *Proceedings*—Proceedings for the suspension of an operator's license shall in all cases be initiated by the entry of an order of suspension. Respondent will be given notice thereof together with notice of his right to be heard and to contest the proceeding. The effective date of the suspension will not be specified in the original order but will be fixed by subsequent motion of the Commission in accordance with the conditions specified above. Notice of the effective date of suspension will be given respondent, who shall send his operator license to the office of the Commission in Washington, D. C., on or before the said effective date, or, if the effective date has passed at the time notice is received, the license shall be sent to the Commission forthwith.

GENERAL RULES AND REGULATIONS

Sec. 2.42. *Equipment test*—Upon completion of construction of a radio station in exact accordance with the terms of the construction permit, the technical provisions of the application therefor and the rules and regulations governing the class of station concerned and prior to filing of application for license, the permittee is authorized to test the equipment for a period not to exceed ten days: Provided that:

(*a*) The Inspector in Charge of the district in which the station is located, is notified two days in advance of the beginning of tests.

(*b*) In the case of all broadcast stations the Commission also shall be notified two days in advance of the beginning of tests, which shall be conducted in the case of Standard Broadcast Stations, only between 1:00 a.m., and 6:00 a.m., local standard time unless otherwise specifically authorized. Equipment tests shall not be conducted during the frequency monitoring period when the station is required to remain silent.

(*c*) The Commission may notify the permittee to conduct no tests or may cancel, suspend or change the date of beginning for the period of such tests as and when such action may appear to be in the public interest, convenience, and necessity.

Sec. 2.43. *Service or program test.*

(*a*) When construction and equipment tests are completed in exact accordance with the terms of the construction permit, the technical provisions of the application therefor, and the rules and regulations governing the class of station concerned, and after an application for station license has been filed with the Commission showing the transmitter to be in satisfactory operating condition, the permittee is authorized to conduct service or program tests in exact accordance with the terms of the construction permit for a period not to exceed thirty days: Provided that:

(1) The Inspector in Charge of the district in which the station is located, is notified two days in advance of the beginning of such tests.

(2) In the case of all broadcast stations the Commission also shall be notified two days in advance of the beginning of tests.

(*b*) The Commission reserves the right to cancel such tests or suspend, or change the date of beginning for the period of such tests as and when such action may appear to be in the public interest, convenience and necessity by notifying the permittee.

(*c*) Service or program tests will not be authorized after expiration date of the construction permit.

Sec. 2.44. *Authorization for tests not to be construed as license*—The authorization for tests embodied in Secs. 2.42 and 2.43 shall not be construed as constituting a license to operate but as a necessary part of the construction.

Sec. 2.48. *Station inspection*—The licensee of any radio station shall make the station available for inspection by representatives of the Commission at any reasonable hour and under the regulations governing the class of station concerned.

Sec. 2.52. *Operator license, posting of*—The original license of each station operator shall be posted at the place where he is on duty or kept in his possession in the manner specified in the regulations governing the class of station concerned.

Sec. 2.53. *Operators' place of duty*—*a.* Except as may be provided in the rules governing a particular class of station, one or more licensed operators of the grade specified by these rules and regulations shall be on duty at the place where the transmitting apparatus of each station is located and in actual charge thereof whenever it is being operated: *Provided, however,* That:

2. In the case of two or more stations, except amateur and broadcast, licensed in the name of the same person to use frequencies above 30,000 kilocycles only, a licensed radio operator of any class except amateur, radiotelephone third class, or holder of restricted operator permit who has the station within his effective control, may be on duty at any point within the communication range of such stations in lieu of the transmitter location or control point during the actual operation of the transmitting apparatus and shall supervise the emissions of all such stations so as to insure the proper operation in accordance with the station license.

Sec. 2.54. *Retention of radio station logs*—Logs of a radio station, when required elsewhere in these rules and regulations to be made or kept, shall be retained by the licensee for a period of one year unless otherwise provided by the rules governing the particular service or class of station concerned: *Provided, however.* That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee has been notified, shall be retained by the licensee until specifically authorized in writing by the Commission to destroy them: *Provided, further,* That logs incident to or involved in any claim or complaint of which the licensee has notice shall be retained by the licensee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

Sec. 2.55. *Logs, by whom kept*—Each log shall be kept by the person or persons competent to do so, having actual knowledge of the facts required, who shall sign the log when starting duty and again when going off duty. The logs shall be made available upon request by an authorized representative of the Commission.

Sec. 2.57. *Correction of logs*—No log or portion thereof shall be erased, obliterated, or wilfully destroyed within the period of retention provided by the rules. Any necessary correction may be made only by the person originating the entry who shall strike out the erroneous portion, initial the correction made and indicate the date of correction.

Sec. 2.58. *Rough logs*—Rough logs may be transcribed into condensed form, but in such case the original log or memoranda and all portions thereof shall be preserved and made a part of the complete log.

Sec. 2.59. *Distress messages*—Each station licensee shall give absolute priority to radio communications or signals relating to ships or aircraft in distress; shall cease all sending on frequencies which will interfere with hearing a radio communication or signal of distress and except when engaged in answering or aiding the ship or aircraft in distress; shall refrain from sending any radio communications or signals until there is assurance that no interference will be caused with the radio communications or signals relating thereto, and shall assist the vessel in distress, so far as possible, by complying with its instructions.

Sec. 2.60. *Control of distress traffic*—The control of distress traffic shall devolve upon the mobile station in distress or upon the station which by application of the provisions of Sec. 2.61 has sent the distress call. These stations may delegate the control of the distress traffic to another station.

Sec. 2.61. *Retransmission of distress message*—Any station which becomes aware that a mobile station is in distress may transmit the distress message in the following cases:

a. When the station in distress is not itself in a position to transmit the message.

b. In the case of mobile stations, when the Master or the person in charge of the ship, aircraft, or other vehicle carrying the station which intervenes believes that further help is necessary.

c. In the case of other stations, when directed to do so by the station in control of distress traffic or when it has reason to believe that a distress call which it has intercepted has not been received by any station in a position to render aid.

Sec. 2.62. *Resumption of operation after distress*—No station having been notified to cease operation shall resume operation on frequency or frequencies which may cause interference until notified by the station issuing the original notice that the station involved will not interfere with distress traffic as it is then being routed or until the receipt of a general notice that the need for handling distress traffic no longer exists.

Sec. 2.63. *Operation during emergency*—The licensee of any station, except amateurs, may, during a period of emergency in which the normal communication facilities are disrupted as a result of hurricane, flood, earthquake, or similar disaster, utilize such station for emergency communication service in communicating in a manner other than that specified in the station license, provided (1) that as soon as possible after the beginning of such emergency use notice be sent to the Commission in Washington, D. C., and to the Inspector in Charge of the district in which the station is located stating the nature of the emergency and the use to which the station is being put, and (2) that the emergency use of the station shall be discontinued as soon as substantially normal communication facilities are again available and the Commission in Washington, D. C., and the Inspector in Charge be notified immediately when such special use of the station is terminated. The Commission may at any time order the discontinuance of such service.

Sec. 2.75. *Frequency measurement*—The licensee of each station shall provide means for the measurement of the station frequency. The measurement of the station frequency shall be made by a means independent of the frequency control of the transmitter and shall be conducted in accord with the regulations governing the class of station concerned.

Sec. 2.80. *Operating power tolerance*—The operating power of all radio stations shall be maintained within the following tolerance of the assigned power:

1. When the maximum power only is specified, the operating power shall not be greater than necessary to carry on the service and in no event more than 5 percent above the maximum power specified.

2. When an exact power is specified, the operating power shall not be more than 5 percent above or less than 10 percent below such power.

SHIP RULES

WATCH

The following rules are extracts from the Rules Governing Ship Services.

§ 8.31. *Radio watch*—The term "radio watch" or "watch" means the service performed by a qualified operator when on duty in the radio room of a vessel listening for signals of other stations on the international calling and distress frequency, 500 kilocycles, and at all other times when such operator, in conformity with the International Radio Regulations in force and subject to authority of the master, is engaged in transmitting or receiving signals or messages on any authorized frequency, to or from any station in the maritime mobile service, or in receiving from any station time signals, weather reports, hydrographic reports, reports regarding aids to navigation, authorized press material, or information regarding the safety of life or property at sea.

OPERATING PROCEDURE

§ 8.41. *Interference to be minimized*—Before transmitting, a ship station shall make sure that it will not produce harmful interference with communications being carried on within its range. If such interference is likely, the station shall wait until the existing communications, which it may disturb, have been concluded; with due regard, nevertheless, for the priority of communications designated by section 8.42. The transmission of unnecessary or superfluous communications is forbidden.

§ 8.42. *Order of priority of communications*—The order of priority of radiotelegraph and radiotelephone communications in the maritime mobile service on any frequency used for this service shall be as follows:

(*a*) Distress calls, distress messages, and distress traffic.

(*b*) Communications preceded by an urgent signal.

(*c*) Communications preceded by a safety signal.

(*d*) Communications relative to radio direction-finder bearings.

(*e*) Government radiotelegrams for which priority right has not been waived.

(*f*) All other communications.

§ 8.43. *Mobile station in distress*—No provision of these rules or of any regulations shall prevent a mobile station in distress from using any means available to it for drawing attention, signalling its position, and obtaining help.

§ 8.44. *Transmission of alarm signal*—When a distress call has been transmitted and was not preceded by the international automatic alarm signal, a station in the maritime mobile service within the general vicinity of the station which transmitted the distress call, may transmit the alarm signal (using type A–2 or B emission) on the frequency 500 kilocycles upon authorization of the master or other person responsible for the station, provided every reasonable precaution is observed not to interfere with the acknowledgment of receipt of the distress call nor with distress traffic already in progress.

§ 8.45. *Repetition of distress call*—If a ship station has heard a distress call or distress message for which acknowledgment of receipt has not been given promptly, and the ship station itself is not in a position to render assistance, the ship station, subject to authority of the master, shall make every effort possible to attract the attention of any station in the maritime mobile service which appears to be in a position to render assistance, and for this purpose transmission of the distress call and distress message may be repeated on 500 kilocycles and on such other frequencies as may be deemed necessary. The ship station, if authorized by the master may transmit, for this purpose the international automatic alarm signal on the frequency 500 kilocycles (using type A–2 or B emission) prior to repetition of the distress call and message. In the event the alarm signal is transmitted, a sufficient period of time to allow operators warned by the alarm signal to go on watch shall be observed after transmission of the alarm signal and before retransmission of the distress message.

§ 8.46. *Repetition of alarm signal*—A ship station intercepting an international automatic alarm signal which appears to be not duly effective by reason of improper timing, improper type of emission, insufficient signal strength, interference, or excessive deviation from 500 kilocycles, if authorized by the master, may repeat the transmission of this signal on the frequency 500 kilocycles (using type A–2 or B emission) to be followed by a repetition of the distress call and distress message provided all reasonable precaution is taken by such station not to interfere with acknowledgment of receipt of the distress call nor with distress traffic already in progress.

§ 8.63. *Posting of licenses*—The original ship radio station license, and the original license of each operator of the ship station while he is on duty therein, shall be posted in a conspicuous place in the associated radio operating room on board the ship, except when any operator license has been submitted to the Commission in accordance with relevant provisions of § 13.72.

§ 8.118. *Tests of emergency installation*—On vessels required by law to be equipped with an emergency or reserve installation, the condition of this installation shall be determined by test and actual operation prior to the vessel's departure from each port[3] (but not necessarily more than once each day) and on each day the vessel is outside a harbor or port. When storage batteries are used as an emergency power supply or are used for the purpose of starting an emergency engine-driven generator, tests shall be made of the charging circuits for polarity and correct charging rate. Hydrometer reading of the electrolyte of a pilot cell and such other cells as are necessary to determine the state of charge of an emergency lead-acid storage battery, shall be taken. When an engine-driven generator is used as an emergency power supply, a check shall be made of the quantity of fuel in the supply tank.

§ 8.166. *Daily tests*—While the ship is being navigated outside a harbor or port, the auto-alarm shall be tested at least once every 24 hours by means of the testing device supplied as part of the alarm, the timing of the dashes to be made by reference to the second hand of the ship station clock. A statement that the foregoing requirement has been fulfilled must be inserted in the radio station log daily.

§ 8.204. *Inspection of lifeboat radio installation*—The lifeboat radio installation shall be inspected and tested by a qualified representative of the licensee of the ship radio station within 24 hours prior to departure to sea from each port (except not necessarily more than once each week) and at least once each year with the lifeboat afloat. The results of the inspection and tests shall be made known to the master of the vessel and shall be noted in the ship's radio station log. The annual inspection afloat shall include an actual test of the transmitter and receiver connected to the regular lifeboat antenna (erected) to determine that each is in effective operating condition. When testing with the lifeboat not afloat, the transmitter may be connected to an artificial antenna, in lieu of the regular lifeboat antenna, having electrical characteristics equal to those of the regular lifeboat antenna. To avoid interference transmission tests shall be conducted under the

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[3] It is recognized that in some cases, tank vessels cannot meet this requirement when in port because of the hazardous nature of the cargo being handled.

same procedure and regulations as prescribed for testing of the ship's regular radio-station transmitting equipment and in particular transmission tests shall not be made during the international silent period

§ 8.205. *Examination of lifeboat radio batteries*—When the vessel is under way, provision shall be made for the adequate charging of storage batteries and the routine inspection of all batteries, without removing them from the lifeboat. Such charging apparatus shall be arranged so as not to interfere with the launching of the lifeboat, and for this purpose shall be easily and quickly removable. Examination of the batteries shall be made at least once every 7 days by a qualified radio operator and a statement in regard to their condition and specific gravity in the case of a lead-acid battery, or voltage under normal load in the case of dry or Edison batteries, shall be reported to the master and entered in the ship's radio-station log. Dry batteries shall be replaced when it is found that the voltage under load has fallen 20 percent below the rated voltage of the battery.

REGULATION OF WATCH

§ 8.211. *Report to bridge*—On board a cargo vessel of the United States subject to title III, part II of the Communications Act which is fitted with an auto-alarm, the operator, when going off watch, shall report to the officer on watch on the bridge whether or not the auto-alarm has been placed in use and adjusted for effective operation.

§ 8.212. *Use of auto-alarm*—The auto-alarm shall be in operation and adjusted for normal efficiency, according to prevailing conditions of radio reception, at all times while the ship is being navigated outside a harbor or port when the operator is not on watch, and shall not be rendered inoperative when a radio direction finder, on board the same ship, is being used.

RADIO LOG

§ 8.221. *Radio log for safety purposes*—Each ship station operating on frequencies within the band 350 to 515 kilocycles, when required by law to keep a watch for safety purposes by means of a qualified operator, shall maintain an accurate radio log, as follows:

(*a*) Each sheet of the log shall be numbered in sequence, for each voyage, and shall include official call letters of the ship station and the name of the operator on watch.

(*b*) The entry "on watch" shall be made by the operator beginning a watch, followed by his signature. The entry "off watch" shall be made by the operator being relieved or terminating a watch, followed by his signature. All log entries shall be currently completed at the end of each watch by the operator responsible for the entries. The use of initials or signs is not authorized in lieu of the operator's signature.

(*c*) During the period a watch is maintained by an operator, all calls transmitted to or from the ship station and all replies transmitted or received shall be entered, stating the time and frequencies, and the call letters[4] of the station communicated with or heard. In addition, a notation of any messages exchanged shall be entered, stating the time, the frequency in kilocycles, and the call letters[4] of the station(s) heard, or communicated with. Insofar as possible, a positive entry with respect to reception on 500 kilocycles shall be made at least once in each 15 minutes. The entries required by paragraph (*e*) hereof shall be acceptable as positive entries provided operating conditions are such as to prevent additional entries being made.

(*d*)[5] The time of making an entry shall be shown opposite the entry and shall be expressed in Greenwich mean time (GMT), except that in the Great Lakes region the time shall be expressed in eastern standard time (EST) (counted from 00:00 to 24:00 o'clock, beginning at midnight).[6] The first entry in each hour shall consist of four figures; additional entries in the same hour may be expressed in two figures by omitting the hour designation. The abbreviation "GMT" (EST in the Great Lakes region) shall be marked at the head of the column in which the time is entered.

(*e*) During the period a watch is maintained by an operator, an entry shall be made twice per hour stating whether or not the international silent period was observed. In addition, entries shall be made indicating any signals or communications heard on 500 kilocycles during this period. If no signals are heard on 500 kilocycles, an entry to that effect shall be made. The use of rubber stamps for making entries to show observation of the silent period is not authorized.

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[4] If desired, the names of the stations or ships also may be entered.

[5] As amended by the Commission, effective November 14, 1939.

[6] For example, 7:01 p.m. eastern standard time would be entered as 0001 GMT; 7:30 a.m. eastern standard time would be entered as 1230 GMT; 6:45 p.m. eastern standard time and would be entered as 2345 GMT.

(*f*) All distress calls, automatic alarm signals, urgent and safety signals made or intercepted, the complete text, if possible, of distress messages and distress communications, and any incidents or occurrences which may appear to be of importance to safety of life or property at sea, shall be entered, together with the time of such observation or occurrence, and the position of the ship or other mobile unit in need of assistance, if it can be determined.

(*g*) Whenever harmful interference is experienced, an entry shall be made to that effect, stating the source of the interference, if known.

(*h*) The approximate geographical location of the ship, preferably the noon position, shall be entered each day of each voyage, either in terms of latitude and longitude, or as the distance in nautical miles and the direction from a known fixed point. For this purpose, the master of the ship shall furnish this information to the radio operator. The position report so furnished shall correspond to any entry of the same position made in other official records of the ship.

(*i*) An entry shall be made of the time of departure and arrival of the vessel at each port, including in each entry the name of the port.

(*j*) On a cargo vessel equipped with an auto-alarm, the entry "auto alarm on," "sensitivity set at ....,"[7] and the entry "auto alarm off," respectively, shall be made whenever the operator places the auto-alarm in and out of operation. Results of the required auto-alarm tests shall be entered daily, including the sensitivity-control setting and the minimum number of 4-second dashes from the testing device which were necessary to properly operate the alarm.

(*k*) On a cargo vessel equipped with an auto-alarm, an entry shall be made in the radio station log whenever the visual indicator installed on the bridge (to indicate when the alarm becomes inoperative due to prolonged atmospherics or other interference), remains actuated for a continuous period of 5 minutes. A statement shall be included giving particulars as to the time the operator was called to make the necessary repairs or adjustments; any reason for the failure; the names of any parts removed, added, or substituted; repairs effected; and the time the alarm was restored to proper operating condition.

(*l*) On a cargo vessel equipped with an auto-alarm, an entry shall be made in the radio station log whenever the auto-alarm becomes inoperative due to causes not indicated by the audible warning or the visual indicator, or whenever the audible warning is actuated. The entry shall include a statement showing the time the operator was called to make any necessary repairs or adjustments; the reason for

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[7] The actual setting of the sensitivity control, at the time the auto-alarm is placed in operation, should be designated.

the audible alarm being actuated or failing to be actuated, any parts removed, added, or substituted; repairs effected; and the time the auto-alarm was restored to proper operating condition.

(*m*) Entries shall be made of the results of tests of the emergency installation including transmitter antenna current, hydrometer readings of lead-acid storage batteries, voltage readings of other types of batteries, and quantity of fuel available for engine generators.

(*n*) An entry shall be made each time the emergency power supply is used (when the vessel is in the open sea) to carry on routine communication (other than a watch for safety purposes), stating the approximate period of time of such use.

(*o*) Results of inspections and tests of lifeboat radio equipment, when installed in compliance with requirements of law, prior to departure of the vessel from a harbor or port and the results of weekly inspections[8] of such lifeboat equipment shall be entered.

(*p*) A daily entry shall be made regarding comparison of the radio station clock with standard time, including an indication of any errors observed and corrections made. For this purpose, authentic radio time signals received from land or fixed stations shall be acceptable as standard time.

(*q*) Any failure of equipment to operate as required, any failure of power supply, any inability to obtain sufficient power to charge storage batteries or to properly operate the radio installation and any incidents tending to unduly delay communication shall be entered.

§ 8.222. *Radio log during hours of service*—(*a*) Each ship station, not required by law to keep a watch for safety purposes, but authorized to operate on frequencies within the band 350 to 515 kilocycles, shall maintain an accurate radio log in accordance with paragraphs (*a*) to (*g*), inclusive, of section 8.221, during its hours of service when operating on frequencies within this band. The radio log of such stations shall also contain the entries prescribed by paragraphs (*h*), (*i*), and (*p*) of section 8.221.

(*b*) Each ship station authorized to operate on any frequency or frequencies in the band 100 to 160 kilocycles or in any band(s) between 4000 and 30000 kilocycles, shall maintain an accurate radio log, with respect to operation on frequencies within these bands, in accordance with paragraphs (*a*), (*b*), (*d*), (*f*), (*g*), (*h*), (*i*), and (*p*) of section 8.221.

(*c*) Ship stations authorized to operate on any frequency or frequencies in the band 1500 to 3500 kilocycles, or in any band above

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[8] See section 8.204.

30000 kilocycles, are required to maintain an adequate record with respect to operation on frequencies within these bands, only insofar as prescribed by paragraph (*f*) of section 8.221, together with the name, call letters and position of the ship station, and the name of the radio operator making the record(s).

§ 8.223. *Disposition of logs*—Ship station logs shall be fully completed at the end of each voyage and before the operator(s) responsible leave(s) the ship. The radio log currently in use shall be kept by the licensed operator(s) of the station and during use shall be located in the radio operating room of the vessel. At the conclusion of each voyage terminating at a port of the United States,[9] the original radio log dating from the last departure of the vessel from a United States port (or a duplicate thereof) [10] shall be retained under proper custody on board the vessel for a sufficient period of time (not required to be retained for more than 24 hours) to be available for inspection by duly authorized representatives of the Commission. Thereafter, the original log (and the duplicate log, if provided) [10] may be filed at an established shore office of the ship station licensee, and shall be retained as stipulated by section 2.54 of part 2.

INSPECTION

§ 8.251 *Station available for inspection*—Pursuant to section 303 (n) of the Communications Act, the radio installation on board any ship of United States registry, or on board any foreign ship within the territorial jurisdiction of the United States, shall be available for inspection by duly authorized representatives of the Commission at any reasonable time and at such frequent intervals as within the discretion of the Commission will insure compliance with applicable regulations, laws, and treaties.

FREQUENCIES

§ 8.82. *International calling and distress frequency*—The international calling and distress frequency is 500 kilocycles. The provisions of the International Radio Regulations in force pertaining to the international calling and distress frequency 500 kilocycles shall apply in the Great Lakes region.

[9] Includes Hawaii, Alaska, Puerto Rico, and the Virgin Islands.

[10] Duplicate logs are not required by the provisions of this section, unless the original log is removed prior to opportunity for official inspection as explained.

§ 8.83. *Use of distress frequency*—The international calling and distress frequency 500 kilocycles shall be used by ship stations and aircraft stations in requesting help from the maritime services. In addition it may be used only for calls and replies, for distress traffic, for urgent and safety messages, and for operating signals.

RULES GOVERNING STANDARD BROADCAST STATIONS

DEFINITIONS [11]

§ 3.1. *Standard broadcast station*—The term "standard broadcast station" means a station licensed for the transmission of radiotelephone emissions primarily intended to be received by the general public and operated on a channel in the band 550 to 1600 kilocycles, inclusive.

§ 3.2. *Standard broadcast band*—The term "standard broadcast band" means the band of frequencies extending from 550 to 1600 kilocycles, inclusive, both 550 kilocycles and 1600 kilocycles being the carrier frequencies of broadcast channels.

§ 3.3. *Standard broadcast channel*—The term "standard broadcast channel" means the band of frequencies occupied by the carrier and two side bands of a broadcast signal with the carrier frequency at the center. Channels shall be designated by their assigned carrier frequencies. Carrier frequencies assigned to standard broadcast stations shall begin at 550 kilocycles and be in successive steps of 10 kilocycles.

§ 3.4. *Dominant station*—The term "dominant station" means a class I station, as hereinafter defined, operating on a clear channel.

§ 3.5. *Secondary station*—The term "secondary station" means any station except a class I station operating on a clear channel.

§ 3.6. *Daytime*—The term "daytime" means that period of time between 6 a.m. local standard time and local sunset.

§ 3.7. *Nighttime*—The term "nighttime" means that period of time between local sunset and 12 midnight local standard time.

§ 3.8. *Sunset*—The term "sunset" means, for each particular location and during any particular month, the average time of sunset as specified in the license of a broadcast station. (For tabulation of

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[11] Other definitions which may pertain to standard broadcast stations are included in sections 2.1 to 2.35 and the Communications Act of 1934, as amended.

average sunset time for each month at various points in the United States, see "Average Sunset Time.")

§ 3.9. *Broadcast day*—The term "broadcast day" means that period of time between 6 a.m. and 12 midnight, local standard time.

§ 3.10. *Experimental period*—The term "experimental period" means that period of time between 12 midnight and 6 a.m. This period may be used for experimental purposes in testing and maintaining apparatus by the licensee of any standard broadcast station, on its assigned frequency and with its authorized power, provided no interference is caused to other stations maintaining a regular operating schedule within such period. No station licensed for "daytime" or "specified hours" of operation may broadcast any regular or scheduled program during this period.

§ 3.11. *Service areas*—(*a*) The term "primary service area" of a broadcast station means the area in which the ground wave is not subject to objectionable interference or objectionable fading.

(*b*) The term "secondary service area" of a broadcast station means the area served by the sky wave and not subject to objectionable interference. The signal is subject to intermittent variations in intensity.

(*c*) The term "intermittent service area" of a broadcast station means the area receiving service from the ground wave but beyond the primary service area and subject to some interference and fading.

§ 3.12. *Main studio*—The term "main studio" means, as to any station, the studio from which the majority of its local programs originate, and/or from which a majority of its station announcements are made of programs originating at remote points.

§ 3.13. *Portable transmitter*—The term "portable transmitter" means a transmitter so constructed that it may be moved about conveniently from place to place, and is in fact so moved about from time to time, but not ordinarily used while in motion. In the standard broadcast band, such a transmitter is used in making field intensity measurements for locating a transmitter site for a standard broadcast station. A portable broadcast station will not be licensed in the standard broadcast band for regular transmission of programs intended to be received by the public.

§ 3.14. *Auxiliary transmitter*—The term "auxiliary transmitter" means a transmitter maintained only for transmitting the regular programs of a station in case of failure of the main transmitter.

§ 3.15. *Combined audio harmonics*—The term "combined audio harmonics" means the arithmetical sum of the amplitudes of all the separate harmonic components. Root sum square harmonic readings may be accepted under conditions prescribed by the Commission.

§ 3.16. *Effective field*—The term "effective field" or "effective field intensity" is the root-mean-square (RMS) value of the inverse distance fields at a distance of 1 mile from the antenna in all directions in the horizontal plane.

EQUIPMENT

§ 3.41. *Maximum rated carrier power; tolerances*—The maximum rated carrier power of a standard broadcast transmitter shall not be less than the authorized power nor shall it be greater than the value specified in the following table:

Class of station	Maximum power authorized to station	Maximum rated carrier power permitted to be installed*
		Watts
Class IV	100 or 250 watts	250
Class III	500 or 1,000 watts	1,000
	5,000 watts	5,000
Class II	250, 500, or 1,000 watts	1,000
	5,000 or 10,000 watts	10,000
	25,000 or 50,000 watts	50,000
Class I	10,000 watts	10,000
	25,000 or 50,000 watts	50,000

* The maximum rated carrier power must be distinguished from the operating power. (See Sections 2.18 and 2.19.)

§ 3.42. *Maximum rated carrier power; how determined*—The maximum rated carrier power of a standard broadcast transmitter shall be determined as the sum of the applicable power ratings of the vacuum tubes employed in the last radio stage.

(*a*) The power rating of vacuum tubes shall apply to transmitters employing the different classes of operation or systems of modulation as specified in "Power Rating of Vacuum Tubes," prescribed by the Commission.

(*b*) If the maximum rated carrier power of any broadcast transmitter, as determined by paragraph (*a*) of this section, does not give an exact rating as recognized in the Commission's plan of allocation, the nearest rating thereto shall apply to such transmitter.

(*c*) Authority will not be granted to employ, in the last radio stage of a standard broadcast transmitter, vacuum tubes from a manufacturer or of a type number not listed until the manufacturer's rating for the class of operation or system of modulation is submitted to and approved by the Commission. These data must be supplied by the manufacturer in accordance with "Requirements for the Approval of the Power Rating of Vacuum Tubes," prescribed by the Commission.

§ 3.43. *Changes in equipment; authority for*—No licensee shall change, in the last radio stage, the number of vacuum tubes to vacuum tubes of different power rating or class of operation, nor shall it change system of modulation without the authority of the Commission.[12]

§ 3.44. *Other changes in equipment*—Other changes except as provided for in these rules or "Standards of Good Engineering Practice," prescribed by the Commission, which do not affect the maximum power rating or operating power of the transmitter or the operation or precision of the frequency control equipment may be made at any time without authority of the Commission, but in the next succeeding application for renewal of license such changes which affect the information already on file shall be shown in full.

§ 3.45. *Radiating system*—(*a*) All applicants for new, additional, or different broadcast facilities and all licensees requesting authority to move the transmitter of an existing station shall specify a radiating system the efficiency of which complies with the requirements of good engineering practice for the class and power of the station. (Also see "Use of Common Antenna by Standard Broadcast Stations or Another Radio Station.")

(*b*) The Commission will publish from time to time specifications deemed necessary to meet the requirements of good engineering prac-

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[12] Formal application required. See "Standards of Good Engineering Practice" for form number.

tice. (See "Minimum Antenna Heights or Field Intensity Requirements" and "Field Intensity Measurements in Allocation," section A.)

(*c*) No broadcast station licensee shall change the physical height of the transmitting antenna, or supporting structures, or make any changes in the radiating system which will measurably alter the radiation patterns, except upon written application to and authority from the Commission.[13]

(*d*) The antenna and/or supporting structure shall be painted and illuminated in accordance with the specifications supplied by the Commission pursuant to section 303 (q) of the Communications Act of 1934, as amended. (See "Standard Lamps and Paints.")

(*e*) The simultaneous use of a common antenna or antenna structure by two standard broadcast stations or by a standard broadcast station and a station of any other class or service will not be authorized unless both stations are licensed to the same licensee. (See "Use of Common Antenna by Standard Broadcast Stations or Another Radio Station.")

§ 3.46. *Transmitter*—(*a*) The transmitter proper and associated transmitting equipment of each broadcast station shall be designed, constructed, and operated in accordance with the standards of good engineering practice in all phases not otherwise specifically included in these regulations.

(*b*) The transmitter shall be wired and shielded in accordance with good engineering practice and shall be provided with safety features in accordance with the specifications of article 810 of the current National Electrical Code as approved by the American Standards Association.

(*c*) The station equipment shall be so operated, tuned, and adjusted that emissions are not radiated outside the authorized band[14] which cause or which, in accordance with the Standards of Good Engineering Practice, are considered as being capable of causing interference to the communications of other stations. The spurious emissions, including radio frequency harmonics and audio frequency harmonics, shall be maintained at as low level as required by good engineering practice. The audio distortion, audio frequency range, carrier hum, noise level, and other essential phases of the operation which control the external effects shall at all times conform to the requirements of good engineering practice.

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[13] Informal application may be made, except in controversial cases or directional antenna; then formal application shall be made.

[14] See "Construction, General Operation and Safety of Life Requirements."

(*d*) Whenever, in this section, the term "good engineering practice" is used, the specifications deemed necessary to meet the requirements thereof will be published from time to time. (See "Construction General Operation and Safety of Life Requirements.")

TECHNICAL OPERATION

§ 3.51. *Operating power; how determined*—The operating power of each standard broadcast station shall be determined by:

(*a*) Direct measurement of the antenna power in accordance with section 3.54.[15]

(1) Each new standard broadcast station.

(2) Each existing standard broad[illegible]st station after July 1, 1940.

(*b*) Indirect measurement by means of the plate input power to the last radio stage on a temporary basis in accordance with sections 3.52 and 3.53.

(1) In the case of existing standard broadcast stations and pending compliance with paragraph (*a*) (2) of this section.

(2) In case of an emergency where the licensed antenna has been damaged or destroyed by storm or other cause beyond the control of the licensee or pending completion of authorized changes[13] in the antenna system.

(*c*) Upon making any change[16] in the antenna system, or in the antenna current measuring instruments, or any other change which may change the characteristics of the antenna, the licensee shall immediately make a new determination of the antenna resistance (see section 3.54) and shall submit application for authority to determine power by the direct method on the basis of the new measurements.

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[15] Program tests on equipment, including a new or different antenna system, will not be authorized unless application for authority to determine power by the direct method has been granted or is submitted simultaneously with the application for license to cover the construction permit and the application for license will not be granted until such time as the application for direct measurement is approved.

[16] Changes shall not be made except upon making proper request and obtaining approval thereof in accordance with sections 3.45 and 3.58.

§ 3.52. *Operating power; indirect measurement*—The operating power determined by indirect measurement from the plate input power of the last radio stage is the product of the plate voltage (E_p), the total plate current of the last radio stage (I_p) and the proper factor (F) given in the following tables: that is

$$\text{Operating power} = E_p \ x \ I_p \ x \ F$$

A. Factor to be used for stations employing plate modulation in the last radio stage *

Maximum rated carrier power of transmitter: †	*Factor (F) to be used in determining the operating power from the plate input power*
100–1,000 watts	0.70
5,000 and over watts	.80

* See "Power Rating of Vacuum Tubes."

† The maximum rated carrier power must be distinguished from the operating power. (See sections 2.18 and 2.19.)

B. Factor to be used for stations of all powers using low-level modulation *

Class of power amplifier in the last radio stage:	*Factor (F) to be used in determining the operating power from the plate input power*
Class B	0.35
Class BC †	0.65

* See "Power Rating of Vacuum Tubes."

† All linear amplifier operation where efficiency approaches that of class C operation.

C. Factors to be used for stations of all powers employing grid modulation in the last radio stage *

Type of tube in the last radio stage:	*Factor (F) to be used in determining the operating power from the plate input power*
Table C[1]	0.25
Table D[1]	0.35

* See "Power Rating of Vacuum Tubes."

§ 3.53. *Application of efficiency factors*—In computing operating power by indirect measurement the above factors shall apply in all cases, and no distinction will be recognized due to the operating power being less than the maximum rated carrier power. (See "Plate Efficiency of Last Radio Stage.")

§ 3.54. *Operating power; direct measurement*—The antenna input power determined by direct measurement is the square of the antenna current times the antenna resistance at the point where the current is measured and at the operating frequency. Direct measurement of the antenna input power will be accepted as the operating power of the station, provided the data on the antenna resistance measurements are submitted under oath giving detailed description of the method used and the data taken. The antenna current shall be measured by an ammeter of accepted accuracy.[17] These data must be submitted to and approved by the Commission before any licensee will be authorized to operate by this method of power determination.[18] The antenna ammeter shall not be changed to one of different type, maximum reading, or accuracy without the authority of the Commission. If any change is made in the antenna system or any change made which may affect the antenna system, the method of determining operating power shall be changed immediately to the indirect method. (See "Further Requirements for Direct Measurements of Power.")

§ 3.55. *Modulation*—(*a*) A licensee of a broadcast station will not be authorized to operate a transmitter unless it is capable of delivering satisfactorily the authorized power with a modulation of at least 85 percent. When the transmitter is operated with 85 percent modulation, not over 10 percent combined audio frequency harmonics shall be generated by the transmitter.

(*b*) All broadcast stations shall have in operation a modulation monitor approved by the Commission.

(*c*) The operating percentage of modulation of all stations shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice and in no case less than 85 percent on peaks of frequent recurrence during any selection which normally is transmitted at the highest level of the program under consideration.

(*d*) The Commission will, from time to time, publish the specifications, requirements for approval, and a list of approved modulation monitors. (See "Approved Modulation Monitors" and also "Requirements for Approval of Modulation Monitors.")

§ 3.56. *Modulation; data required*—A licensee of a broadcast station claiming a greater percentage of modulation than the fundamental

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[17] See Indicating Instruments Pursuant to section 3.58.

[18] Formal application required. See "Standards of Good Engineering Practice" for form number.

design indicates can be procured shall submit full data showing the antenna input power by direct measurement and complete information, either oscillograms or other acceptable data, to show that a modulation of 85 percent or more, with not over 10 percent combined audio harmonics, can be obtained with the transmitter operated at the maximum authorized power.

§ 3.57. *Operating power; maintenance of*—The licensee of a broadcast station shall maintain the operating power of the station within the prescribed limits of the licensed power at all times except that in an emergency when, due to causes beyond the control of the licensee, it becomes impossible to operate with the full licensed power, the station may be operated at reduced power for a period of not to exceed 10 days, provided that the Commission and the Inspector in Charge [19] shall be notified in writing immediately after the emergency develops. (See "Operating Power Tolerance.")

§ 3.58. *Indicating instruments*—Each broadcast station shall be equipped with suitable indicating instruments of accepted accuracy to measure the antenna current, direct plate circuit voltage, and the direct plate circuit current of the last radio stage. These indicating instruments shall not be changed or replaced, without authority of the Commission, except by instruments of the same type, maximum scale reading, and accuracy. (See "Indicating Instruments Pursuant to section 3.58.")

§ 3.59. *Frequency tolerance*—The operating frequency of each broadcast station shall be maintained within 50 cycles of the assigned frequency until January 1, 1940, and thereafter the frequency of each new station or each station where a new transmitter is installed shall be maintained within 20 cycles of the assigned frequency, and after January 1, 1942, the frequency of all stations shall be maintained within 20 cycles of the assigned frequency.

§ 3.60. *Frequency monitor*—The licensee of each standard broadcast station shall have in operation at the transmitter a frequency monitor independent of the frequency control of the transmitter. The frequency monitor shall be approved by the Commission. It shall have a stability and accuracy of at least 5 parts per million. (See "Approved Frequency Monitors" and also "Requirements for Approval of Frequency Monitors.")

§ 3.61. *New equipment; restrictions*—The Commission will authorize the installation of new transmitting equipment in a broadcast station

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[19] See "Field Offices of the Commission."

or changes in the frequency control of an existing transmitter only if such equipment is so designed that there is reasonable assurance that the transmitter is capable of maintaining automatically the assigned frequency within the limits specified in section 3.59.

§ 3.62. *Automatic frequency control equipment; authorization required*—New automatic frequency control equipment and changes in existing automatic frequency control equipment that may affect the precision of frequency control or the operation of the transmitter shall be installed only upon authorization[20] from the Commission. (See "Approved Equipment.")

§ 3.63. *Auxiliary transmitter*—Upon showing that a need exists for the use of an auxiliary transmitter[21] in addition to the regular transmitter of a broadcast station, a license therefor may be issued provided that:

(*a*) An auxiliary transmitter may be installed either at the same location as the main transmitter or at another location.

(*b*) A licensed operator shall be in control whenever an auxiliary transmitter is placed in operation.

(*c*) The auxiliary transmitter shall be maintained so that it may be put into immediate operation at any time for the following purposes:

(1) The transmission of the regular programs upon the failure of the main transmitter.

(2) The transmission of regular programs during maintenance or modification[22] work on the main transmitter, necessitating discontinuance of its operation for a period not to exceed five days.

(3) Upon request by a duly authorized representative of the Commission.

(*d*) The auxiliary transmitter shall be tested at least once each week to determine that it is in proper operating condition and that it is

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[20] Formal application required. See "Standards of Good Engineering Practice" for form number.

[21] All regulations as to safety requirements and spurious emissions applying to broadcast transmitting equipment shall apply also to an auxiliary transmitter. (See "Use of Frequency and Modulation Monitors at Auxiliary Transmitter.")

[22] This includes the equipment changes which may be made without authority as set forth elsewhere in the Rules and Regulations and the Standards of Good Engineering Practice or as authorized by the Commission by letter or by construction permit. Where such operation is required for periods in excess of 5 days, request therefor shall be made in accordance with section 1.365.

adjusted to the proper frequency, except that in case of operation in accordance with paragraph (*c*) of this section during any week, the test in that week may be omitted provided the operation under paragraph (*c*) is satisfactory. A record shall be kept of the time and result of each test operating under paragraph (*c*). Tests shall be conducted only between midnight and 9 a.m., local standard time.

(*e*) The auxiliary transmitter shall be equipped with satisfactory control equipment which will enable the maintenance of the frequency emitted by the station within the limits prescribed by these regulations.

(*f*) An auxiliary transmitter which is licensed at a geographical location different from that of the main transmitter shall be equipped with a frequency control which will automatically hold the frequency within the limits prescribed by these regulations without any manual adjustment during operation or when it is being put into operation.

(*g*) The operating power of an auxiliary transmitter may be less than the authorized power, but in no event shall it be greater than such power.

§ 3.64. *Duplicate main transmitters*—The licensee of a standard broadcast station may be licensed for duplicate main transmitters provided that a technical need[23] for such duplicate transmitters is shown and that the following conditions are met:

(*a*) Both transmitters are located at the same place.

(*b*) The transmitters have the same power rating.

(*c*) The external effects from both transmitters is substantially the same as to frequency stability, reliability of operation, radio harmonics and other spurious emissions, audio frequency range and audio harmonic generation in the transmitter.

OPERATION

§ 3.72. *Operation during experimental period*—The licensee of each standard broadcast station shall operate or refrain from operating its station during the experimental period as directed by the Commission in order to facilitate frequency measurement or for the determination of interference. (Stations involved in the after-midnight frequency monitoring programs are notified of their operating and silent schedule.)

[23] Such as licensees maintaining 24-hour schedule and needing alternate operation for maintenance, or development work is being carried on requiring such alternate operation.

§ 3.76. *Sharing time; experimental period*—If the license of a station authorized to share time does not specify the hours of operation, the station may be operated for the transmission of regular programs during the experimental period provided an agreement thereto is reached with the other stations with which the broadcast day is shared and further provided such operation is not in conflict with section 3.72. Time-sharing agreements for operation during the experimental period need not be submitted to the Commission.

§ 3.87. *Station license; posting of*—The station license and any other instrument of authorization or individual order concerning construction of the equipment or the manner of operation of the station shall be posted in a conspicuous place in the room in which the transmitter is located in such manner that all terms thereof are visible and the license of the station operator shall be posted in the same manner. (See sections 2.51 and 2.52.)

§ 3.88. *Licensed operator required*—The licensee of each station shall have a licensed operator or operators of the grade specified by the Commission on duty during all periods of actual operation of the transmitter at the place where the transmitting equipment is located. (See section 2.53.)

§ 3.89. *Licensed operator; other duties*—The licensed operator on duty and in charge of a standard broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another radio station or stations in accordance with the class of operator's license which he holds and by the rules and regulations governing such other stations: *Provided, however,* That such duties shall in no wise interfere with the proper operation of the standard broadcast transmitter.

§ 3.90. *Logs*—The licensee of each broadcast station shall maintain program and operating logs and shall require entries to be made as follows:

(*a*) In the program log,

(1) An entry of the time each station identification announcement (call letters and location) is made.

(2) An entry briefly describing each program broadcast, such as "music," "drama," "speech," etc., together with the name or title thereof, and the sponsor's name, with the time of the beginning and ending of the complete program. If a mechanical record is used, the entry shall show the exact nature thereof such as "record," "transcription," etc., and the time it is announced as a mechanical record.

If a speech is made by a political candidate, the name and political affiliations of such speaker shall be entered.

(3) An entry showing that each sponsored program broadcast has been announced as sponsored, paid for, or furnished by the sponsor.

(*b*) In the operating log,

(1) An entry of the time the station begins to supply power to the antenna, and the time it stops.

(2) An entry of the time the program begins and ends.

(3) An entry of each interruption to the carrier wave, its cause and duration.

(4) An entry of the following each 30 minutes:

(*i*) Operating constants of last radio stage (total plate current and plate voltage).

(*ii*) Antenna current.

(*iii*) Frequency monitor reading.

(*iv*) Temperature of crystal control chamber if thermometer is used.

(5) Log of experimental operation during experimental period. (If regular operation is maintained during this period, the above logs shall be kept.)

(*i*) A log must be kept of all operation during the experimental period. If the entries required above are not applicable thereto, then the entries shall be made so as to fully describe the operation.

§ 3.91. *Logs; retention of*—Logs of standard broadcast stations shall be retained by the licensee for a period of 2 years, except when required to be retained for a longer period in accordance with the provisions of section 2.54.

§ 3.92. *Station identification*—(*a*) A licensee of a standard broadcast station shall make station identification announcement (call letters and location) at the beginning and ending of each time of operation and during operation on the hour and half hour as provided below:

(*b*) Such identification announcement during operation need not be made when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or operatic production of longer duration than 30 minutes. In such cases the identification announcement shall be made at the first interruption of the entertainment continuity and at the conclusion of such program.

(*c*) In case of variety-show programs, baseball-game broadcasts, or similar programs, of longer duration than 30 minutes, the identification announcement shall be made within 5 minutes of the hour and half hour.

(*d*) In case of all other programs (except as provided in paragraphs (*b*) and (*c*) of this section) the identification announcement shall be made within 2 minutes of the hour and half hour.

(*e*) In making the identification announcement, the call letters shall be given only on the channel of the station identified thereby.

§ 3.93. *Mechanical records*—Each broadcast program consisting of a mechanical record, or a series of mechanical records, shall be announced in the manner and to the extent set out below:

(*a*) A mechanical record, or a series thereof, of longer duration than 30 minutes shall be identified by appropriate announcement at the beginning of the program, at each 30-minute interval, and at the conclusion of the program: *Provided, however,* That the identifying announcement at each 30-minute interval is not required in case of a mechanical record consisting of a single, continuous, uninterrupted speech, play, religious service, symphony concert, or operatic production of longer duration than 30 minutes.

(*b*) A mechanical record, or a series thereof, of a longer duration than 5 minutes and not in excess of 30 minutes, shall be identified by an appropriate announcement at the beginning and end of the program;

(*c*) A single mechanical record of a duration not in excess of 5 minutes shall be identified by appropriate announcement immediately preceding the use thereof;

(*d*) In case a mechanical record is used for background music, sound effects, station identification, program identification (theme music of short duration), or identification of the sponsorship of the program proper, no announcement of the mechanical record is required.

(*e*) The identifying announcement shall accurately describe the type of mechanical record used, i.e., where an electrical transcription is used it shall be announced as a "transcription" or an "electrical transcription," or as "transcribed" or "electrically transcribed," and where a phonograph record is used it shall be announced as a "record."

§ 3.94. *Rebroadcast*—(*a*) The term "rebroadcast" means reception by radio of the program[24] of a radio station, and the simultaneous or subsequent retransmission of such program by a broadcast station.[25]

(*b*) The licensee of a standard broadcast station may, without further authority of the Commission, rebroadcast the program of a United States standard broadcast station, provided the Commission is notified of the call letters of each station rebroadcast and the licensee certifies that express authority has been received from the licensee of the station originating the program.[26]

(*c*) No licensee of a standard broadcast station shall rebroadcast the program of any other class of United States radio station without written authority having first been obtained from the Commission upon application accompanied by written consent or certification of consent of the licensee of the station originating the program.[27, 28]

(*d*) In case of a program rebroadcast by several standard broadcast stations such as a chain rebroadcast, the person legally responsible for distributing the program or the network facilities may obtain the necessary authorization for the entire rebroadcast both from the Commission and from the person or licensee of the station originating the program.

Attention is directed to section 325 (*b*) of the Communications Act of 1934, which reads as follows:

"No person shall be permitted to locate, use, or maintain a radio broadcast studio or other place or apparatus from which or whereby sound waves are converted into electrical energy, or mechanical or physical reproduction of sound waves produced, and caused to be transmitted or delivered to a radio station in a foreign country for the purpose of being broadcast from any radio station there, having

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[24] As used in section 3.94, program includes any complete program or part thereof, or any signals if other than A–3 emission.

[25] In case a program is transmitted from its point of origin to a broadcast station entirely by telephone facilities in which a section of such transmission is by radio, the broadcasting of this program is not considered a rebroadcast.

[26] The notice and certification of consent shall be given within three (3) days of any single rebroadcast, but in case of the regular practice of rebroadcasting certain programs of a standard broadcast station several times during a license period, notice and certification of consent shall be given for the ensuing license period with the application for renewal of licnese, or at the beginning of such rebroadcast practice if begun during a license period.

[27] The broadcasting of a program relayed by a relay broadcast station (section 4.21) is not considered a rebroadcast.

[28] Informal application may be employed.

a power output of sufficient intensity, and/or being so located geographically that its emissions may be received consistently in the United States, without first obtaining a permit from the Commission upon proper application therefor." [29]

REBROADCAST OF NAVAL OBSERVATORY TIME SIGNALS

It is the policy of the Navy Department to consent to the rebroadcasting of the Naval Observatory Time signals in all cases where satisfactory assurance has been given that the following conditions will be complied with by the broadcast station concerned.

(1) Announcement of the time signal must be made without reference to any commercial activity;

(2) The time signal to be rebroadcast must be obtained by direct reception from a Naval radio transmitter which is broadcasting the time signal;

(3) The Naval Observatory time signals are intended to be sufficiently accurate for astronomical and other scientific purposes. No time may, therefore, be announced as a Naval Observatory time signal if any time lag has been introduced.

In order to avoid hereafter the necessity for each individual licensee to make application to the Navy Department for the consent to rebroadcast the Naval Observatory time signals, requests therefore may be made direct to the Commission under the provisions of Section 3.94 without being submitted to the Navy Department, provided appropriate representation is made with the request that the above conditions will be complied with in full. Representations of compliance with conditions 2 and 3 shall include such diagrams, descriptions and data as necessary to show that no time lag in excess of 0.04 second * has been introduced.

In addition to the above conditions, requests for such authorizations must be made for the full license term when accompanying an application for renewal of license or for the balance of the unexpired license period when made after the application for license has been granted.

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[29] Formal application required. See "Standards of Good Engineering Practice" for form number.

* This includes the time of transmission from the originating station to the point of reception by the rebroadcasting station assuming the speed of transmission to be 186,000 miles per second.

EXTRACTS OF F. C. C. STANDARDS OF GOOD ENGINEERING PRACTICE CONCERNING STANDARD BROADCAST STATIONS

PLATE EFFICIENCY OF LAST RADIO STAGE

Sec. 3.53 requires that in computing the operating power of standard broadcast stations by the indirect method the efficiency factors specified in Sec. 3.52 shall apply in all cases and no distinction will be recognized due to the operating power being less than the maximum rated carrier power.[30]

In compliance with this rule standard broadcast stations permitted to determine the operating power by the indirect method Sec. 3.51*b* and to employ greater daytime power that nighttime power shall maintain the same operating efficiency for both daytime and nighttime operation.

To determine whether this condition obtains, the following procedure should be used:

The apparent antenna resistance should be computed from the daytime (highest power) operating constants and then the nighttime power in the antenna determined from the I^2R using the apparent resistance previously determined. If this computed antenna power agrees with the nighttime operating power determined by the indirect method within plus or minus five percent, the station is considered as complying with the requirement of maintaining the same operating efficiency. In case the antenna current is subject to variation due to weather or ether conditions, an attempt should be made to arrive at an average value for the purpose of the computations referred to herein.

OPERATING POWER TOLERANCE

Sec. 3.57 requires that except in case of emergency beyond the control of the licensee, the operating power of each standard broadcast station shall be maintained within the prescribed limits of the licensed power.

Each station shall be operated at all times as near to the authorized power as practicable. However, in order to provide for variations in the power supply or other factors affecting the operating power which would necessitate continual adjustment to keep the operating power exactly the same as the authorized power, the operating power

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[30] See Sec. 3.52, Table A, page 1003.

may be permitted to vary from 5 percent above to 10 percent below the authorized power for periods of short duration.

In addition, to maintaining the operating power within the above limitations, broadcast stations employing directional antenna systems shall maintain the ratio of the antenna currents in the elements of the arrangement within 5 percent of that specified by the terms of the license or other instrument of authorization.

CONSTRUCTION, GENERAL OPERATION AND SAFETY OF LIFE REQUIREMENTS

Sec. 3.46 requires that the transmitter proper and associated transmitting equipment of each broadcast station shall be designed, constructed and operated in accordance with the standards of good engineering practice in addition to the specific requirements of the Rules and Regulations of the Commission.

The specifications deemed necessary to meet the requirements of the Rules and Regulations and good engineering practice with respect to design, construction and operation of standard broadcast stations are set forth below. These specifications will be changed from time to time as the state of the art and the need arises for modified or additional specifications.

A. Design—The general design of standard broadcast transmitting equipment [main studio microphone (including telephone lines if used as to performance only[31] to antenna output] shall be in accordance with the following specifications. For the points not specifically covered below, the principles set out shall be followed:

The equipment shall be so designed that:

1. The maximum rated carrier power (determined by Sec. 3.42) is in accordance with the requirements of Sec. 3.41.

2. The equipment is capable of satisfactory operation at the authorized operating power or the proposed operating power with modulation of at least 85 percent to 95 percent with no more distortion than given in (3) below.

3. The total audio frequency distortion from microphone terminals, including microphone amplifier, to antenna output does not ex-

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[31] In cases where telephone lines are not available to give the performance as required in these specifications a relay transmitter may be authorized to supersede the lines.

ceed 5 percent harmonics (voltage measurements of arithmetical sum or r.s.s.) when modulated from 0 to 84 percent, and not over 7.5 percent harmonics (voltage measurements of arithmetical sum or r.s.s.) when modulating from 85 percent to 95 percent (distortion shall be measured with modulating frequencies of 50, 400, 1000, 5000 and 7500 cycles).

4. The audio frequency transmitting characteristics of the equipment from the microphone terminals (including microphone amplifier) unless microphone frequency correction is included in which event proper allowance shall be made accordingly) to the antenna output does not depart more than 2 decibels from that at 1000 cycles between 100 and 5000 cycles.

5. The carrier shift at any percentage of modulation does not exceed 5 percent.

6. The carrier hum and extraneous noise (exclusive of microphone noises) level (unweighted r.s.s.) is at least 50 decibels below 100 percent modulation for the frequency band of 150 to 5000 cycles and at least 40 decibels down outside this range.

7. The transmitter shall be equipped with suitable indicating instruments in accordance with the requirements of Sec. 3.58 and any other instruments necessary for the proper adjustment and operation of the equipment.

8. Adequate provision is made for varying the transmitter power output between sufficient limits to compensate for excessive variations in line voltage, or other factors which may affect the power output.

9. The transmitter is equipped with automatic frequency control equipment capable of maintaining the operating frequency within the limit specified by Sec. 3.59.

    a. The maximum temperature variation at the crystal[32] from the normal operating temperature shall not be greater than:

    1. Plus or minus 0.1° Centigrade when an *X* or *Y* cut crystal is employed, or

    2. Plus or minus 1.0° Centigrade when low temperature coefficient crystal[33] is employed.

    b. Unless otherwise authorized, a thermometer shall be installed in such manner that the temperature at the crystal can be

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[32] Explanations of excessive frequency deviations will not be accepted when temperature variations in excess of the values specified below.

[33] See "Use of Low Temperature Coefficient Crystal."

accurately measured within 0.05° Centigrade for *X* or *Y* cut crystal or 0.5° for low temperature coefficient crystal.

c. It is preferable that the tank circuit of the oscillator tube be installed in the temperature controlled chamber.

10. Means are provided for connection and continuous operation of approved modulation monitor and approved frequency monitor.

a. The radio frequency energy for operation of the approved frequency monitor shall be obtained from a radio frequency stage prior to the modulated stage and the monitor circuits shall be such that the carrier is not heterodyned thereby.

11. Adequate margin is provided in all component parts to avoid overheating at the maximum rated power output.

B. Construction—In general, the transmitter shall be constructed either on racks and panels or in totally enclosed frames[34] protected as required by Article 810 of the National Electrical Code,[35] and as set forth below:

1. Means shall be provided for making all tuning adjustments, requiring voltages in excess of 350 volts to be applied to the circuit, from the front of the panels with all access doors closed.

2. Proper bleeder resistors shall be installed across all condenser banks to remove any charge which may remain after the high voltage circuit is opened (in certain instances the plate circuit of the tubes may provide such protection; however, individual approval of such shall be obtained by the manufacturer in case of standard equipment and the licensee in case of composite equipment).

[34] The final stages of high power transmitters may be assembled in open frames provided the equipment is enclosed by a protective fence.

[35] The pertinent sections of Article 810 of the National Electrical Code read as follows:

j. The transmitter shall be enclosed in a metal frame, or grill or separated from the operating space by a barrier or other equivalent means, all metallic parts of which are effectually connected to ground.

k. All external metallic handles and controls accessible to the operating personnel shall be effectually grounded. No circuit in excess of 150 volts should have any parts exposed to direct contact. A complete dead front type of switchboard is preferred.

l. All access doors shall be provided with interlocks which will disconnect all voltages in excess of 350 volts when any access door is opened.

3. All plate supply and other high voltage equipment, including transformers, filters, rectifiers and motor generators, shall be protected so as to prevent injury to operating personnel.

   a. Commutator guards shall be provided on all high voltage rotating machinery (coupling guards on motor generators, although desirable, are not required).

   b. Power equipment and control panels of the transmitter shall meet the above requirements (exposed 220 volt a.c. switching equipment on the front of the power control panels is not recommended, however, is not prohibited).

   c. Power equipment located at a broadcast station but not directly associated with the transmitter (not purchased as part of same), such as power distribution panels, control equipment on indoor or outdoor stations and the sub-stations associated therewith, are not under the jurisdiction of the Commission, therefore, Sec. 32.06 does not apply.

   d. It is not necessary to protect the equipment in the antenna tuning house and the base of the antenna with screens and interlocks, provided the doors to the tuning house and antenna base are fenced and locked at all times with the keys in the possession of the operator on duty at the transmitter. Ungrounded fencing or wires should be effectively grounded either directly or through proper static leaks. Lightning protection for the antenna system is not specifically required but should be installed as required.

   e. The antenna, antenna lead-in, counterpoise (if used), etc., shall be installed so as not to present a hazard. The antenna should be located close by or at a distance from the transmitter building. A properly terminated transmission line should be used between the transmitter and the antenna when located at a distance.

4. Metering Equipment [36]

   a. All instruments having more than 1000 volts potential to ground on the movement shall be protected by a cage or cover in addition to the regular case. (Some instruments are de-

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[36] In addition to the following requirements, instruments shall meet the requirements of Rule 33.11 and "Indicating Instruments Pursuant to Rule 33.11."

signed by the manufacturer to operate safely with voltages in excess of 1000 volts on the movement. If it can be shown by the manufacturer's rating that the instrument will operate safely at the applied potential, additional protection is not necessary.)

b. In case the plate voltmeter is located on the low potential side of the multiplier resistor with one terminal of the instrument at or less than 1000 volts above ground, no protective case is required. However, it is good practice to protect voltmeters subject to more than 5000 volts with suitable over-voltage protective devices across the instrument terminals in case the winding opens.

c. The antenna ammeters (both regular and remote and any other radio frequency instrument which it is necessary for the operator to read) shall be so installed as to be easily and accurately read without the operator having to risk contact with circuits carrying high potential radio frequency energy.

C. Wiring and Shielding—

1. The transmitter panels or units shall be wired in accordance with standard switchboard practice, either with insulated leads properly shielded to prevent the pickup of modulated radio frequency and protected.

2. Wiring between units of the transmitter, with the exception of circuits carrying radio frequency energy, shall be installed in conduits or approved fiber or metal raceways to protect it from mechanical injury.

3. Circuits carrying low level radio frequency energy between units shall be either concentric tube, two wire balanced lines or properly shielded to prevent the pickup of modulated radio frequency energy from the output circuits.

4. Each stage (including the oscillator) preceding the modulated stage shall be properly shielded and filtered to prevent feedback from any circuit following the modulated stage (an exception to this requirement may be made in the case of high level modulated transmitters of approved manufacture which have been properly engineered to prevent reaction).

5. The crystal chamber, together with the conductor or conductors to the oscillator circuit, shall be totally shielded.

6. The monitors and the radio frequency lines to the transmitter shall be thoroughly shielded.

D. Installation—

1. The installation shall be made in suitable quarters.

2. Since an operator must be on duty during operation, suitable facilities for his welfare and comfort shall be provided.

E. Spare Tubes—A spare tube of every type employed in the transmitter and frequency and modulation monitors shall be kept on hand. When more than one tube of any type are employed, the following table determines the number of spares of that type required:

Number of Each Type Employed	Spares Required
1 or 2	1
3 to 5	2
6 to 8	3
9 or more	4

F. Operation—In addition to the specific requirements of the rules governing standard broadcast stations, the following operating requirements shall be observed:

1. The percentage of modulation shall be maintained at as high level as practicable without causing undue audio frequency harmonics which shall not be in excess of 10 percent when operating with 85 percent modulation.

2. Spurious emissions, including radio frequency harmonics and audio frequency harmonics, shall be maintained at as low a level as practicable at all times in accordance with good engineering practice.

3. In the event interference is caused to other stations by modulated frequencies in excess of 7500 cycles or spurious emissions, including radio frequency harmonics and audio frequency harmonics outside the band plus or minus 7500 cycles of the authorized carrier frequency, the licensee shall install equipment or make adjustments which limit the emissions to within this band or to such an extent as to reduce the interference to where it is no longer objectionable.

4. The operating power shall be maintained within the limits of 5 percent above and 10 percent below the authorized operating power and shall be maintained as near as practicable to the authorized operating power.

5. Licensees of broadcast stations employing directional antenna systems shall maintain the ratio of the currents in the elements of the array within 5 percent of that specified by the terms of the license or other instrument of authorization.

6. In case of excessive shift in operating frequency during warm-up periods, the crystal oscillator shall be operated continuously. The automatic temperature control circuits should be operated continuously under all circumstances.

G. Studio Equipment—Studio equipment shall be subject to all of the above requirements except in case the installation is properly covered by an underwriter's certificate, it will be considered as satisfying the safety requirement.

INDICATING INSTRUMENTS PURSUANT TO SEC. 3.58

Sec. 3.58 requires that each standard broadcast station shall be equipped with suitable indicating instruments of accepted accuracy to measure the antenna current, direct plate circuit voltage, and the direct plate circuit current of the last radio stage.

The following requirements and specifications shall apply to indicating instruments used by standard broadcast stations in compliance with this rule:

A. Instruments indicating the plate current or plate voltage of the last radio stage (linear scale instruments) shall meet the following specifications:

1. Length of scale shall be not less than 2 3/10 inches.

2. Accuracy shall be at least two percent of the full scale reading.

3. The maximum rating of the meter shall be such that it does not read off scale during modulation.

4. Scale shall have at least 40 divisions.

5. Full scale reading shall not be greater than five times the minimum normal indication.

B. Instruments indicating the antenna current shall meet the following specifications:

1. Instruments having logarithmic or square law scales.
    (*a*) Shall meet same requirements as 1, 2 and 3 above for linear scale instruments.

(*b*) Full scale reading shall not be greater than three times the minimum normal indication.

(*c*) No scale division above one-third full scale reading (in amperes) shall be greater than 1/30 of the full scale reading. (Example: An ammeter meeting requirement (*a*) above having full scale reading of six amperes is acceptable for reading currents from two to six amperes provided no scale division between two and six amperes is greater than 1/30 of six amperes, 0.2 ampere.)

2. Radio frequency instruments having expanded scales.

(*a*) Shall meet same requirements as 1, 2 and 3 for linear scale instruments.

(*b*) Full scale reading shall not be greater than five times the minimum normal indication.

(*c*) No scale division above 1/5 full scale reading (in amperes) shall be greater than 1/50 of the full scale reading. (Example: An ammeter meeting the requirement (*a*) above is acceptable for indicating currents from one to five amperes provided no division between one and five amperes is greater than 1/50 of five amperes, 0.1 ampere.)

(*d*) Manufacturers of instruments of the expanded scale type must submit data to the Commission showing that these instruments have acceptable expanded scales, and the type number of these instruments must include suitable designation.

3. Remote reading antenna ammeters may be employed and the indications logged as the antenna current in accordance with the following:

(*a*) Remote reading antenna ammeters may be provided by:

1. Inserting second thermocouple directly in the antenna circuit with remote leads to the indicating instrument.

2. Inductive coupling to thermocouple or other device for providing direct current to indicating instrument.

3. Capacity coupling to thermocouple or other device for providing direct current to indicating instrument.

4. Current transformer connected to second thermocouple or other device for providing direct current to indicating instrument.

5. Using transmission line current meter at transmitter as remote reading ammeter. See paragraph (*h*) below.

(*b*) A thermocouple type ammeter meeting the above requirements shall be permanently installed in the antenna circuit. (This thermocouple ammeter may be so connected that it is short circuited or open circuited when not actually being read. If open circuited a make before break switch must be employed.)

(*c*) The remote ammeter shall be connected at the same point in the antenna circuit as the thermocouple ammeter or shall be so connected and calibrated as to read in amperes within two percent of this meter over the entire range above one-third or one-fifth full scale. See Sections B 1 (*c*) and B 2 (*c*) above respectively.

(*d*) The regular antenna ammeter shall be above the coupling to the remote meter in the antenna circuit so it does not read the current to ground through the remote meter.

(*e*) All remote meters shall meet the same requirements as the regular antenna ammeter with respect to scale accuracy etc.

(*f*) Calibration shall be checked against the regular meter at least once a week.

(*g*) All remote meters shall be provided with shielding or filters as necessary to prevent any feedback from the antenna to the transmitter.

(*h*) In the case of shunt excited antennas, the transmission line current meter at the transmitter may be considered as the remote antenna ammeter provided the transmission line is terminated directly into the excitation circuit feed line which shall employ series tuning only (no shunt circuits of any type shall be employed) and insofar as practicable, the type and scale of the transmission line meter should be the same as those of the excitation circuit feed line meter (meter in slant wire feed line or equivalent).

(*i*) Remote reading antenna ammeters employing vacuum tube rectifier are acceptable provided:

1. The indicating instruments shall meet all the above requirements for linear scale instruments.

2. Data are submitted under oath showing the unit has an overall accuracy of at least 2 percent of the full scale reading.

3. The installation, calibration and checking are in accordance with the above requirements.

(*j*) In the event there is any question as to the method of proving or the accuracy of the remote meter, the burden of proof of satisfactory performance shall be upon the licensee and the manufacturer of the equipment.

C. Stations determining power by the indirect method may log the transmission line current in lieu of the antenna current provided the instrument meets the above requirements for antenna ammeters, and further provided that the ratio between the transmission line current and the antenna current is entered each time in the log. In case the station is authorized for the same operating power for both day and nighttime operation this ratio shall be checked at least once daily. Stations which are authorized to operate with nighttime power different from the daytime power shall check the ratio for each power at least once daily.

D. No instrument indicating the plate current or plate voltage of the last radio stage, the antenna current or the transmission line current when logged in lieu of the antenna current shall be changed or replaced without written authority of the Commission, except by instruments of the same make, type, maximum scale reading and accuracy. Requests for authority to change an instrument may be made by letter or telegram giving the manufacturer's name, type number, serial number and full scale reading of the proposed instrument and the values of current or voltage the instrument will be employed to indicate. Requests for temporary authority to operate without an instrument or with a substitute instrument may be made by letter or telegram stating the necessity therefor and the period involved.

E. No instrument, the seal of which has been broken, or the accuracy of which is questionable, shall be employed. Any instrument which was not originally sealed by the manufacturer that has been opened shall not be used until it has been recalibrated and sealed in accordance with the following: Repairs and recalibration of instruments shall be made by the manufacturer, by an authorized instrument repair service of the manufacturer or by some other properly qualified and equipped instrument repair service. In either case the instrument must be resealed with the symbol or trade mark of the repair service and a certificate of calibration supplied therewith.

F. Since it is usually impractical to measure the actual antenna current of a shunt excited antenna system, the current measured at the input of the excitation circuit feed line is accepted as the antenna current.

G. Recording instruments may be employed in addition to the indicating instruments to record the antenna current and the direct plate current and direct plate voltage of the last radio stage provided that they do not affect the operation of the circuits or accuracy of the indicating instruments. If the records are to be used in any proceedings before the Commission, representation of operation with respect to plate or antenna current and plate voltage only, the accuracy must be the equivalent of the indicating instruments and the calibration shall be checked at such intervals as to insure the retention of the accuracy.

USE OF FREQUENCY AND MODULATION MONITORS AT AUXILIARY BROADCAST TRANSMITTERS

Sec. 3.60 and 3.55*b* require that each standard broadcast station have approved frequency and modulation monitors in operation at the transmitter.

The following shall govern the installation of approved *frequency* and *modulation* monitors at auxiliary transmitters of standard broadcast stations in compliance with these rules:

In case the auxiliary transmitter location is at a site different from that of the main transmitter, an approved *frequency* monitor shall be installed at the auxiliary transmitter except when the frequency of the auxiliary transmitter can be monitored by means of the frequency monitor at the main transmitter.

The licensee will be held strictly responsible for any frequency deviation of the auxiliary transmitter in excess of fifty cycles from the assigned frequency, even though exempted by the above from installing an approved frequency monitor. Furthermore, whenever the auxiliary transmitter is operated without a frequency monitor under this exemption, it must be monitored by means of the frequency monitor at the main transmitter.

Installation of an approved *modulation* monitor at the location of the auxiliary transmitter, when different from that of the main transmitter, is optional with the licensee. However, when it is necessary to operate the auxiliary transmitter beyond two calendar days, a modulation monitor shall be installed and operated at the auxiliary transmitter. The monitor (if taken from the main transmitter) must be reinstalled at the main transmitter immediately upon resumption of operation of the main transmitter.

In all cases where the auxiliary transmitter and the main transmitter have the same location, the same frequency and modulation monitors may be used for monitoring both transmitters, provided they are so arranged as to be readily switched from one transmitter to the other.

Standard broadcast stations not complying with these requirements cannot be considered as operating in compliance with the rules governing such operation.

EMERGENCY RADIO SERVICES

(Police—Fire—Forestry)

§ 10.71. *Equipment and service tests*—Equipment and service tests as authorized in sections 2.42 and 2.43 may be conducted provided that the necessary precautions are taken to avoid interference. The equipment tests authorized by section 2.42 may be conducted only during daylight hours on frequencies below 6000 kcs.

§ 10.72. *Routine tests*—The licensees of all classes of stations in the emergency service are authorized to make such routine tests as may be required for the proper maintenance of the station and communication network, provided that precautions are taken to avoid interference with any station in the particular service involved.

§ 10.82. *Posting fixed station licenses*—The station licenses of stations in this service, operated at fixed locations, shall be conspicuously posted at the place where the control operator is located.

§ 10.83. *Posting portable or mobile station licenses*—The licenses of portable and mobile stations, if separately issued, shall be readily available for inspection by authorized Government representatives. Either the original authorization or a photocopy of that document shall be available at the portable or mobile station involved.

§ 10.84. *Operator license*—The original license of each station operator shall be conspicuously posted at the place he is on duty, or, in the case of portable or mobile units, be kept in his personal possession.

LOGS [37]

§ 10.101. *Contents*—Each licensee shall maintain adequate records of the operation of the station including (*a*) hours of operation; (*b*) nature and time of each transmission; (*c*) frequency measurements; (*d*) name of operator on duty at the transmitter. In the cases of groups of stations, either fixed or fixed and mobile, operating as a single coordinated communication system controlled from a single point, a single log may be maintained at a central location, provided that such log records the required information with respect to all stations in the network.

INSPECTIONS

§ 10.111. *Inspection by Commission's representative*—All classes of stations in the emergency service shall be made available for inspection upon request of a representative of the Commission. However, if such station is actually engaged in an emergency which should not be interrupted, the Commission's representative may suspend the inspection and require the station to be made available for inspection immediately after conclusion of the emergency.

§ 10.124. *Modulation limits*—The transmitters of municipal police stations shall be modulated not less than 85 percent nor more than 100 percent on peaks.

§ 10.126. *Service which may be rendered*—Municipal police stations, although licensed primarily for communication with mobile police units, may transmit emergency messages to other mobile units such as fire department vehicles, private ambulances and repair units of public utilities, in those cases which require cooperation or coordination with police activities. In addition, such stations may communicate among themselves provided (1) that no interference is caused to the mobile service, and (2) that communication is limited to places between which, by reason of their close proximity, the use of police radiotelegraph

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[37] Additional provisions relating to logs may be found in Sections 2.54 to 2.58 of Part 2—General Rules and Regulations.

stations is impracticable. Municipal police stations shall not engage in point-to-point radio communication beyond the good service range of the transmitting station or transmit or handle communications requiring radiotelephone relay. Point-to-point communication between stations in the same local telephone exchange area is likewise prohibited unless the messages to be transmitted are of immediate importance to mobile units. The provisions of this rule are also applicable to state police stations.

AVIATION SERVICES

LICENSE

§ 9.21. *License periods*—The license period for all stations in the aviation service shall be for 1 year unless otherwise stated in the instrument of authorization. The date of expiration of license for all classes of stations operating in the aviation service, unless otherwise specified, shall be as follows:

(*a*) Stations in the aviation service, other than aircraft stations and all aviation stations in Alaska, shall be issued to expire March 1 of each year.

(*b*) Aircraft stations in the aviation service other than in Alaska shall be issued to expire April 1 of each year.

(*c*) All classes of aviation stations in Alaska shall be issued to expire January 1 of each year.

§ 9.22. *Posting station licenses*—The station licenses of stations in the aviation service shall be conspicuously posted at the place where the control operator is located except that in aircraft stations the license may be posted or kept at any convenient easily accessible location in the aircraft.

§ 9.23. *Posting operator licenses*—The original license of each station operator shall be conspicuously posted at the place he is on duty, or, in the case of mobile units either the license or verification card must be kept in his personal possession.

TESTS

§ 9.31. *Equipment and service tests authorized for aeronautical and aeronautical fixed stations*—Equipment and service tests as authorized in sections 2.42 and 2.43 may be conducted provided that the necessary precautions are taken to avoid interference.

§ 9.32. *Routine tests*—The licenses of all classes of stations in the aviation service are authorized to make such routine tests as may be required for the proper maintenance of the station provided that precautions are taken to avoid interference with any station. Tests on 3105 and 6210 kilocycles using a regular antenna system can be made only at such times when no interference will be caused and, if in range of an airport control station or Civil Aeronautics Authority station, only after permission is secured from such stations before commencing the tests.

LOGS

§ 9.41. *Information required in station logs*—All stations in the aviation service except aircraft stations must keep an adequate log showing (1) hours of operation, (2) frequencies used, (3) stations with which communication was held, and (4) signature of operator(s) on duty.

§ 9.42. *Station logs public aviation service*—In addition to all the requirements in section 9.41 above, all stations (both public service aircraft station and public service aeronautical station) in the public aviation service must keep a file of all record communications handled and a list of radiotelephone contacts established.

§ 9.43. *Required retention period*—The logs in the aviation service, other than public aviation service, may be destroyed after a period of 3 months except in those circumstances where retention of the logs for a longer period is specifically provided for in other rules.[38]

INSPECTIONS

§ 9.51. *Availability for inspections*—All classes of stations in the aviation service shall be made available for inspection upon request of an authorized representative of the Federal Government.

§ 9.52. *Responsibility of licensee*—It is the responsibility of the licensees of aircraft radio stations to submit their stations for inspection by a representative of the Commission at least once during the license period.

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[38] See also section 2.54 of Part 2, General Rules and Regulations.

COMMUNICATIONS

§ 9.61. *Methods of identification*—The aircraft name, company number, trip number, official registry number or other identification approved by the Commission may be used in lieu of the call letters; provided that adequate records are maintained to permit ready identification of individual aircraft. Also the name of the city or airport in which other classes of stations are located may be used in lieu of the call letters of the station when using telephony. In the case of stations using telegraphic emissions, the call letters designated in the license shall be used at the end of each sequence of communication to one or more stations.

§ 9.62. *Permissible communications*—All stations in the aviation service, except those stations licensed for public aviation service, shall transmit only communications relating to and necessary for aircraft operation and the protection of life and property in the air.

§ 9.63. *Priority of aviation communications*—(*a*) The regular routine communications of stations in the aviation service are essential to the safe operation of aircraft and shall have priority over the public aviation service stations.

(*b*) The radio operator in charge of the aircraft station shall suspend operations of aviation public service stations when such operations will delay or interfere with messages pertaining to safety of life and property or when ordered to do so by the captain of the aircraft.

(*c*) The operation of public aviation service stations shall in no way interfere with the radiocommunications of the aviation service.

(*d*) In cases where the aviation public service aircraft station license is issued to cover auxiliary equipment of the regular aircraft station, public communications shall be restricted to the extent necessary for the safe operation of aircraft as determined by the person in charge of the aircraft.

TOLERANCE

§ 9.82. *Measurement procedure*—The licensee of each station shall provide for measurement of the station frequency, or frequencies, regularly used in accordance with instructions issued from time to time by the Commission and establish procedure for regular checking.

These measurements of station frequency shall be made by means independent of the frequency control of the transmitter and shall be of such an accuracy that the limit of error is within the frequency tolerance allowed the station.

AIRCRAFT STATIONS

§ 9.91. *Aircraft stations*—Communications by an aircraft station shall be limited to the necessities of safe aircraft navigation and normally contacts with airport control stations shall not be attempted unless the aircraft is within the control area of the airport.[39]

AERONAUTICAL AND AERONAUTICAL FIXED STATIONS

§ 9.101. *Service aeronautical station*—Aeronautical stations shall provide non-public service without discrimination to all scheduled aircraft the owners of which make cooperative arrangements for the operation and maintenance of the aeronautical stations which are to furnish such service and for shared liability in the operation of stations. In addition, this class of station shall provide reasonable and fair service to non-scheduled aircraft in accordance with the provisions of these rules.

§ 9.104. *Emergency service*—The licensee of an aeronautical fixed station shall be required to transmit, without charge or discrimination, all necessary messages in times of public emergency which involve the safety of life or property.

AIRPORT CONTROL STATIONS

§ 9.111. *Receiving watch on 3105 kilocycles*—The licensee of an airport control station shall without discrimination provide non-public service for any and all aircraft. Such licensee shall maintain a continuous listening watch on the aircraft calling and working frequency 3105 kilocycles, and also be prepared to render a non-public communication service, during all hours of the day and night: *Provided, however,* That upon application therefor the Commission may exempt any station from the requirements of this provision when it

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[39] Approximately within 30 miles distance or 10 minutes' flight of the airport.

appears that in the preservation of life and property in the air the maintenance of a continuous watch by such station is not required.

§ 9.113. *Service to be rendered*—Communications of an airport control station shall be limited to the necessities of safe operation of aircraft using the airport facilities or operating within the airport control area [40] and in all cases such stations shall be in a position to render, and shall render, all airport control services.

§ 9.114. *Communications* must not be attempted with aircraft beyond the control area of the airport.[40]

(*a*) Localizer transmitters authorized to use the frequency 278 kilocycles may use power in excess of 15 watts provided that the power is limited so as not to produce a field strength of more than 1500 microvolts per meter at one mile from the transmitter location, in the direction of the maximum field.

(*b*) The power of airport control stations operating on other frequencies shall be limited to 100 watts.

Rules Governing Commercial Radio Operators

§ 13.1. *Licensed operators required* [41]—Unless otherwise specified by the Commission, the actual operation of any radio station for which a station license is required shall be carried on only by a licensed radio operator of the required class.[42]

§ 13.2. *Classes of licenses*—The classes of commercial operator licenses issued by the Commission are:

(*a*) Commercial radiotelephone group:

- (1) Radiotelephone second-class operator license.
- (2) Radiotelephone first-class operator license.

(*b*) Commercial radiotelegraph group:

- (1) Radiotelegraph second-class operator license.
- (2) Radiotelegraph first-class operator license.

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[40] Approximately within 30 miles distance or 10 minutes' flight of the airport.

[41] Wherever the term "license" is used generally to denote an authorization from the Commission, it includes both "license" and "permit."

[42] See section 13.61.

(*c*) Restricted commercial group:

- (1) Restricted radiotelephone operator permit.
- (2) Restricted radiotelegraph operator permit.

§ 13.3. *Dual holding of licenses*—A person may not hold more than one radiotelegraph operator license (or restricted radiotelegraph permit) and one radiotelephone operator license (or restricted radiotelephone operator permit) at the same time.

§ 13.4. *Term of licenses*—Commercial operator licenses are normally issued for a term of 5 years from the date of issuance.

APPLICATIONS

§ 13.11. *Procedure*—The application form in duplicate for operator license, properly completed and signed, shall be submitted in person or by mail to the office at which the applicant desires to be examined, which office will make the final arrangements for conducting the examination. If the application is for renewal of license,[43] it must be submitted during the last year of the license term and if the service requirements are fulfilled [44] the renewal license may be issued by mail. A renewal application shall also be accompanied by the license to be renewed.

§ 13.12.[45] *Special provisions, radiotelegraph first class*—An applicant for the radiotelegraph first-class operator license must be at least 21 years of age at the time the license is issued and shall have had an aggregate of 1 year of satisfactory service as a radiotelegraph operator manipulating the key of a manually operated radiotelegraph station on board a ship or in a manually operated coastal telegraph station.

EXAMINATIONS

§ 13.21. *Examination elements*—Written examinations will comprise questions from one or more of the following examination elements:

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[43] All outstanding radiotelegraph licenses bearing an endorsement granting privileges comparable with a radiotelephone license of any class shall be considered as two separate licenses and application for renewal thereof shall be made separately.

[44] See section 13.28.

[45] Radiotelegraph first-class licenses now held by persons under 21 years of age may be renewed without regard to the age limit provided by section 13.12.

(1) *Basic law*—Provisions of law and regulation with which every operator should be familiar.

(2) *Basic theory and practice*—Technical matters appropriate for every class of license except restricted radiotelephone operator permit.

(3) *Radiotelephone*—Additional matters, both legal and technical, including radiotelephone theory and practice.

(4) *Advanced radiotelephone*—Theory and practice applicable to broadcast station operation.

(5) *Radiotelegraph*—Additional matters, both legal and technical, including radiotelegraph theory and practice.

(6) *Advanced radiotelegraph*—Radiotelegraph theory and practice of wider scope, particularly with respect to ship radio matters (direction finders, ship radiotelephone stations, spark transmitters, etc.).

§ 13.22. *Examination requirements*—Applicants for original licenses will be required to pass examinations as follows:

(*a*) Radiotelephone second-class operator license:

(1) Ability to transmit and receive spoken messages in English.
(2) Written examination elements: 1, 2, and 3.

(*b*) Radiotelephone first-class operator license:

(1) Ability to transmit and receive spoken messages in English.
(2) Written examination elements: 1, 2, 3, and 4.

(*c*) Radiotelegraph second-class operator license:

(1) Ability to transmit and receive spoken messages in English.
(2) Transmitting and receiving code test of sixteen (16) code groups per minute.
(3) Written examination elements: 1, 2, 5, and 6.

(*d*) Radiotelegraph first-class operator license:

(1) Ability to transmit and receive spoken messages in English.

(2) Transmitting and receiving code test of twenty-five (25) words per minute plain language and twenty (20) code groups per minute.
(3) Written examination elements: 1, 2, 5, and 6.

(*e*) Restricted radiotelephone operator permit:

(1) Ability to transmit and receive spoken messages in English.
(2) Written examination element: 1.

(*f*) Restricted radiotelegraph operator permit:

(1) Transmitting and receiving code text of sixteen (16) code groups per minute.
(2) Writen examination elements: 1, 2, and 5.

§ 13.23. *Form of writing*—Written examinations shall be in English and shall be written by the applicant in longhand in ink, except that diagrams may be in pencil.

§ 13.24. *Passing mark*—A passing mark of 75 percent of a possible 100 percent will be required on each element of a written examination.

§ 13.25. *New class, additional requirements*—The holder of a license, who applies for another class of license, will be required to pass only the added examination elements for the new class of license.

§ 13.26. *Canceling and issuing new licenses*—If the holder of a license qualifies for a higher class in the same group, the license held will be canceled upon the issuance of the new license. Similarly, if the holder of a restricted operator permit qualifies for a first- or second-class operator license of the corresponding type, the permit held will be canceled upon issuance of the new license.

§ 13.27. *Eligibility for reexamination*—An applicant who fails an examination element will be ineligible for 2 months[46] to take an examination for any class of license requiring that element. Examination elements will be graded in the order listed,[47] and an applicant

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[46] A month after date is the same day of the following month, or if there is no such day, the last day of such month. This principle applies for other periods. For example, in the case of the 2-month period to which this note refers, an applicant examined December 1 may be reexamined February 1, and an applicant examined December 29, 30, or 31 may be reexamined the last day of Februaary, while one examined February 28 may be reexamined April 28.

[47] See Section 13.28.

may, without further application, be issued the class of license for which he qualifies.

§ 13.28. *Renewal examinations and exceptions*[48]—A license may be renewed without examination provided the service record on the license[49] shows at least 3 years satisfactory service in the aggregate during the license term and while actually employed as a radio operator under that license; or shows at least 2 years service in the aggregate, under the same conditions, of which 1 year must have been continuous and immediately prior to the date of application for renewal.

If the above requirements have not been fulfilled, but the service record shows at least 3 months satisfactory service in the aggregate, while actually employed as a radio operator under the license during the last 3 years of the license term, a license may be renewed upon the successful completion of a renewal examination which may be taken at any time during the last year of the license term.

Renewal examinations will consist of the same elements as for original licenses. However, the written examination will be directed toward a determination of the applicant's qualifications to continue to hold the license for which he has previously qualified. If the renewal examination is not successfully completed before expiration of the license sought to be renewed, or if the service is not acceptable, the applicant will be examined as for the original license.

CODE TESTS

§ 13.41. *Transmitting speed requirements*—An applicant is required to transmit correctly in the International Morse Code for 1 minute at the rate of speed prescribed in these rules for the class of license desired.

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[48] Paragraph (2) of rule 439 shall remain in effect with respect to renewals of 3-year licenses outstanding on July 1, 1939.

"RULE 439 (2) All operator licenses, except amateur, may be renewed without examination, provided—

(*a*) The applicant has had 90 days' satisfactory service during the 6-month period prior to the date the application for renewal of license is due to be filed, namely, 60 days prior to the expiration date, or

(*b*) The applicant has had at least 12 months' satisfactory service during the license term prior to the date the application for renewal of license is due to be filed."

[49] See sections 13.91 to 13.94, inclusive.

§ 13.42. *Transmitting test procedure*—Transmitting tests shall be performed by the use of the conventional Morse key except that a semi-automatic key, if furnished by the applicant, may be used in transmitting code tests of 25 words per minute.

§ 13.43. *Receiving speed requirements*—An applicant is required to receive the International Morse Code by ear, and legibly transcribe, consecutive words or code groups for a period of 1 minute without error at the rate of speed specified in the rules for the class of license for which application is made.

§ 13.44. *Receiving test procedure*—Receiving code tests shall be written in longhand either in ink or pencil except that in the case of the 25 words per minute code test, a typewriter may be used when furnished by the applicant.

§ 13.45. *Computing word or code groups*—Each five characters shall be counted as one word or code group. Punctuation marks or figures count as two characters.

SCOPE OF AUTHORITY

§ 13.61. *Operators' authority*—The various classes of commercial operator licenses issued by the Commission authorize the holders thereof to operate radio stations, except amateur, as follows:

(*a*) *Radiotelephone second-class operator license*—Any station while using type A–0, A–3, A–4, or A–5 emission except standard broadcast stations, International Broadcast stations, or ship stations licensed to use power in excess of 100 watts and type A–3 emission for communication with coastal telephone stations.

(*b*) *Radiotelephone first-class operator license*—Any station while using type A–0, A–3, A–4, or A–5 emission except ship stations licensed to use a power in excess of 100 watts and type A–3 emission for communication with coastal telephone stations.

(*c*) *Radiotelegraph second-class operator license*—Any station while using type B, A–0, A–1, A–2, A–3, or A–4 emission except—

(1) Any of the various classes of broadcast stations others than a relay broadcast station, or

(2) On a passenger[50] vessel required by treaty or statute to maintain a continuous radio watch by operators or on a vessel having con-

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[50] A ship shall be considered a passenger ship if it carries or is licensed or certificated to carry more than 12 passengers. A cargo ship means any ship not a passenger ship.

tinuous hours of service for public correspondence, the holder of this class of license may not act as chief operator.

(3) On a *vessel* (other than a vessel operated exclusively on the Great Lakes) required by treaty or statute to be *equipped* with a *radiotelegraph* installation, the holder of this class license may not act as chief or sole operator until he has had at least 6 months' satisfactory service as a qualified radiotelegraph operator on a vessel of the United States.

(*d*) *Radiotelegraph first-class operator license.*—Any station while using type B, A–0, A–1, A–2, A–3, or A–4 emission except—

(1) Any of the various classes of broadcast stations other than a relay broadcast station.

(2) On a *cargo vessel* (other than a vessel operated exclusively on the Great Lakes) required by treaty or statute to be *equipped* with a *radiotelegraph* installation, the holder of this class license may not act as chief or sole operator until he has had at least 6 months' satisfactory service as a qualified radiotelegraph operator on a vessel of the United States.

(*e*) *Restricted radiotelephone operator permit*—Any station while using type A–0, A–3, or A–4 emission: *Provided,* That—

(1) Such operator is prohibited from making adjustments that may result in improper transmitter operation.

(2) The equipment is so designed that none of the operations necessary to be performed during the course of normal rendition of service may cause off-frequency operation or result in any unauthorized radiation.

(3) Any needed adjustment of the transmitter that may affect the proper operation of the station are regularly made by or in the presence of an operator holding a first or second class license, either telephone or telegraph, who shall be responsible for the proper operation of the equipment.

Exceptions:

(1) The permit is not valid for the operation of any of the various classes of broadcast stations other than a relay broadcast station.

(2) The permit is not valid for the operation of a coastal telephone station or a coastal harbor station other than in the Territory of Alaska.

(3) The permit is not valid for the operation of a ship station licensed to use type A–3 emission for communication with coastal telephone stations.

(*f*) *Restricted radiotelegraph operator permit*—Any station while using type B, A–0, A–1, A–2, A–3, or A–4 emission: *Provided*, That, in the case of equipment designed for and using type A–3 or A–4 emission—

(1) Such operator is prohibited from making adjustments that may result in improper transmitter operation.

(2) The equipment is so designed that none of the operations necessary to be performed during the course of normal rendition of service may cause off-frequency operation or result in any unauthorized radiation.

(3) Any needed adjustments of the transmitter which may affect proper operation of the station are regularly made by or in the presence of an operator holding a first or second class license, either telephone or telegraph, who shall be responsible for the proper operation of the equipment.

Exceptions:

(1) The permit is not valid for the operation of any of the various classes of broadcast stations other than a relay broadcast station.

(2) The permit is not valid for the operation of a ship station licensed to use type A–3 emission for communication with coastal telephone stations.

(3) The license is not valid for the operation of a radiotelegraph station on board a vessel required by treaty or statute to be equipped with a radio installation.

(4) The license is not valid for the operation of any ship telegraph, coastal telegraph, or marine-relay station open to public correspondence.

§ 13.62. *Special privileges*—(*a*) Any operator may operate any station in the experimental service, while using frequencies above 300000 kilocycles.

(*b*) Subject to the limitations set forth herein,[51] the holder of any class radiotelephone operator license may operate a radiotelephone point-to-point station, a coastal harbor, or coastal telephone station while using A–1 or A–2 emission, for testing or other transmission entirely secondary and incidental to the service of such station.

§ 13.63. *Operator's responsibility*—The licensed operator responsible for the maintenance of a transmitter may permit other persons to adjust a transmitter in his presence for the purpose of carrying out tests or making adjustments requiring specialized knowledge or skill, provided that he shall not be relieved thereby from responsibility for the proper operation of the equipment.

MISCELLANEOUS

§ 13.71. *Issue of duplicate license*—An operator whose license or permit has been lost, mutilated, or destroyed, shall immediately notify the Commission. A sworn application for duplicate should be submitted to the office of issue embodying a statement attesting to the facts thereof. If a license has been lost, the applicant must state that reasonable search has been made for it, and further, that in the event it be found either the original or the duplicate will be returned for cancelation. The applicant must also give a statement of the service that has been obtained under the lost license.

§ 13.72. *Exhibiting signed copy of application*—When a duplicate operator license or permit has been requested, or request for renewal upon service has been made, the operator shall exhibit in lieu thereof a signed copy of the application for duplicate, or renewal, which has been submitted by him.

§ 13.73. *Supervision of examinations for permit*—Persons other than employees of the Commission may be authorized to supervise examinations for Restricted Radiotelephone Operator Permits for one or more employees of a division of local or State Government: *Provided*—

(*a*) That the absence of such employees for the purpose of taking an examination at a field office or designated examining city would interfere with the proper functioning of the division, and

(*b*) That the chief of police, director of public safety, or other official of equal responsibility furnish the names of the persons to be examined and designate an official by name and title to supervise the examination. The application for supervisory examination shall be

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[51] Section 13.61.

made to the inspector in charge of the district in which the applicants are located.

§ 13.74. *Verification card*—The holder of an operator license who operates any station in which the posting of an operator license is not required, may, upon filing application [52] in duplicate, accompanied by his license, obtain a Verification Card.[53] This card may be carried on the person of the operator in lieu of the original operator license: *Provided,* The license is readily accessible within a reasonable time for inspection upon demand by an authorized Government representative.

§ 13.75. *Posting license or verified statement*—The holder of a radiotelegraph or radiotelephone first or second class license who is employed as a service and maintenance operator at stations operated by holders of Restricted Operator Permits shall post at such station his operator license or a verified statement from the Commission [54] in lieu thereof.

SERVICE

§ 13.91. *Endorsement of service record*—A station licensee, or his duly authorized agent, or the master of a vessel acting as the agent of a licensee, shall endorse the service record appearing on said operator license, showing the call letters and types of emission of the station operated, the nature and period of employment, and quality of performance of duty.

§ 13.92. *Aviation service endorsement*—If the operator has operated more than three stations in the aviation service, the service may be shown by giving the name of the aviation chain or company in lieu of listing the call letters of the several stations.

§ 13.93. *Service acceptability*—Credit will be allowed only for satisfactory service obtained under conditions that required the employment of licensed operators, or when obtained at United States Government stations.

§ 13.94. *Statement in lieu of service endorsement*—The holder of a radiotelegraph license or a restricted radiotelegraph operator permit desiring an endorsement to be placed thereon attesting to an aggregate of at least 6 months' satisfactory service as a qualified operator on a vessel of the United States, may, in the event documentary evidence cannot be produced, submit to any office of the Commission a statement

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[52] Form 756.
[53] Form 758–F.
[54] Form 759.

under oath accompanied by the license to be endorsed, embodying the following:

(*a*) Names of ships at which employed;
(*b*) Call letters of stations;
(*c*) Types of emission used;
(*d*) Type of service performed as follows:

  (1) Manual radiotelegraph operation only; and
  (2) Transmitter control only; or
  (3) Combination of (1) and (2) running concurrently;

(*e*) Whether service was satisfactory or unsatisfactory;
(*g*) Name of master, employer, licensee, or his duly authorized
(*f*) Period of employment;
agent.

CHAPTER 20

AERONAUTICAL RADIO AND TELETYPE PROCEDURE

Introduction—The chapter is devoted entirely to the subject of radio procedure employed by the commercial air transport companies, the itinerant or sportsman pilot flying over a civil airway and operators in the service of the Bureau of Air Commerce, Department of Commerce.*

The first part of the chapter includes the radio procedure authorized for use by transport pilots and radio operators at ground stations and is taken directly from the Communications Manual of Aeronautical Radio, Inc., the licensee of the radio stations. Radio operators preparing to enter the aeronautical service and pilots training for the commercial transport service should study this procedure in detail.

The itinerant or private flyer will find information regarding radio procedure to be used when flying a civil airway since a regulation of the C. A. A. requires that if a pilot desires to do intentional instrument flying over a civil airway it will be necessary for him to have a licensed aircraft equipped with two-way radio and furnish the proper agency mentioned in the procedure with a flight plan.

Itinerant flyers are reminded that both radio station and operator's license are required from the Federal Communications Commission. In addition the itinerant aircraft must be submitted for inspection of the radio equipment once each year by arrangement with a field office of the Federal Communications Commission. Also, the frequency of the radio transmitter of the aircraft must be checked in accordance with the requirements of rule 206 as interpreted in the introductory paragraph of Chapter 8.

For the benefit of the professional radio operator preparing to enter the service of the Bureau of Air Commerce as Airway keeper and radio operator through civil service examinations, the teletypewriter and radio procedure employed in that service have been included as shown in the Bureau of Air Commerce Instruction Bulletin D–7.

The following material furnished through the courtesy of Aeronautical Radio, Inc. describes the standardized operating procedure employed by the major air transport lines in the United States. Aeronautical Radio, Inc. is the licensee of the radio stations and as such is responsible for the legal operation of the stations. The radio operator, in so far as technical operation of a station is concerned, is an employee of Aeronautical Radio, Inc. under ordinary conditions. All specific instructions covering station operation is issued by Aero-

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*On Aug. 23rd, 1938, the Civil Aeronautics Authority assumed jurisdiction of the authority formerly exercised by the Bureau of Air Commerce as referred to in this chapter.

nautical Radio, Inc. to the air transport company. The air transport companies issue additional operating procedure as is made necessary for their own flight operations.

Part I. Aeronautical Radio, Inc. Communications Manual

1. PURPOSE OF RADIO COMMUNICATIONS SYSTEM

(*a*) The primary purpose of the Radio Communications System in the interest of furthering the safety of life and property, is to properly control the operation of and furnish information to aircraft in flight.

(*b*) The secondary purpose of the system is to provide communication between ground stations whereby essential information may be quickly transmitted to stations concerned.

2. TYPES OF STATIONS IN THE AVIATION SERVICE

The Federal Communications Commission has defined four major classes of stations in the aviation service as follows:

(*a*) *Rule 244:* The term "aircraft station" means a radio station on board an aircraft. The aircraft are classified as transport, government and itinerant.

(*b*) *Rule 245:* The term "aeronautical station" means a station used primarily for radio communication with aircraft stations, but which may also carry on a limited fixed service with other aeronautical stations in connection with the handling of messages relating to the safety of life and property in the air.

(*c*) *Rule 246:* The term "aeronautical point-to-point station" means a station used primarily for fixed service in connection with the relay of messages destined for or originating on aircraft and relating solely to the actual aviation needs of the licensees.

(*d*) *Rule 247:* The term "airport station" means a station of low power used only for communication with aircraft in the vicinity of an airport and/or for the transmission of radio range signals for the locating of the aircraft, and/or runways.

3. TYPES OF EMISSIONS AUTHORIZED BY THE FEDERAL COMMUNICATIONS COMMISSION

The various types of station emissions of transmitters are classified as follows:

A1: CW Telegraphy, printer and slow speed facsimile.
A2: Tone modulated cw and ICW.
A3: Commercial Telephony.
A4: Visual Broadcasting and Special, High Speed Facsimile, Picture Tranmission and high quality Telephony.

5.* OPERATOR'S RESPONSIBILITIES FOR OBSERVANCE OF FEDERAL LAWS AND REGULATIONS

The licensed operator on duty at the station is responsible for the operation of the station and is subject to penalties, fines and imprisonments for violation of the act or regulations as follows:

(*a*) For violation of the Communications Act of 1934—For such offenses for which no specific penalty is provided, by a fine of not more than $10,000, or imprisonment for not more than two years or both.

(*b*) For violation of the Federal Communications Commission rules and regulations or the provisions of the telecommunicators' convention, a fine of $500.00 for each offense may be imposed.

(*c*) In addition to other penalties, an operator's license may be suspended for a period not exceeding two years for any of the following offenses:

(1) Failure to operate the station in conformity to the Communications Act, the rules and regulations of the Federal Communications Commission, and the license covering its operation.

(2) Failure to carry out the lawful orders of the master of the aircraft (when operating an aircraft).

(3) Wilfully damaging or permitting the willful damage of radio apparatus.

(4) Transmitting superfluous radio communications or obscene or profane language.

(5) Wilfully or maliciously interfering with other radio communications or signals.

(6) Uttering or transmitting false or fraudulent distress signals.

(7) Failure to hold secret all radio communications received or intercepted unless expressly authorized by the sender to divulge the contents or unless demanded by lawful authority. Exceptions—radio broadcasts, transmissions intended for the public, and distress communications.

Items (6) and (7) are in specific violation of the Communications Act of 1934. Suspension of license for two years is specifically provided in the Communications Act of 1934 for items (1) to (5) above.

6. GENERAL REGULATIONS BASED ON FEDERAL COMMUNICATIONS COMMISSION RULES AND REGULATIONS AND INTERPRETATIONS THEREOF AND REQUIRED AERONAUTICAL RADIO, INC. PROCEDURE

(*a*) Radio station license—No station may be operated without a license from the Federal Communications Commission and it must be

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* Section 4 has been purposely omitted.

operated under the terms of the license. The station's license must be framed and posted in a conspicuous place at the transmitter location. Framing not required on aircraft station and it may be posted with other licenses at one central place on the aircraft not necessarily with the transmitter.

(*b*) A construction permit from the Federal Communications Commission is required before apparatus may be connected to antenna in operable condition. It is also required before changes are made at the station which affect the maximum power rating, operating power of transmitter the operation or precision of frequency control equipment, the location of radiation system or its overall height. Exception—aircraft stations for which no construction permit is required.

(*c*) When station construction (other than aircraft) has been completed, and forty-eight hours before actual tests into antenna are made, the Superintendent of Communications must be notified. If the station is not specifically notified to the contrary, tests may be conducted. The station may be operated on the CP authority a total of forty days from date of originnal notice of intention to begin tests. At the expiration of forty days, operation is not authorized, unless the license has been posted at the station or an extension of this authorization has been granted by the Federal Communications Commission.

(*d*) A licensed operator of the proper grade, must be on duty, at the station at all times the station is in operation. Exception—if the license specifically provides for operation by remote control of the transmitter, the operator may be on duty at the control point. Authorized personnel of the transport company may talk over the circuits in emergencies and then only under the supervision of the operator on duty.

(*e*) At aeronautical, aeronautical point-to-point and airport stations, the operator's license must be posted during the time the operator is on duty. At aircraft stations, either the operator's license or form 758F (card issued by Federal Communications Commission certifying that a license has been issued) must be on the operator's person at all times while on duty.

(*f*) The public will not be admitted to the radio room unless on specific orders of proper authority. Authorized radio inspectors of the Federal Communications Commission, and other authorized government, airline and Aeronautical Radio, Inc., employees will be admittted when on official business. Courtesy will be shown to all. All apparatus will be kept clean and free from dust and dirt and the station will be maintained in a neat and efficient manner.

(*g*) There will be only one official clock and this will be kept synchronized with all other stations by methods prescribed in Section 2. Receiver(s) to cover the assigned frequencies must be installed and operated according to transport company requirements as outlined in Section 2. If the license requires a watch to be maintained on the itinerant frequency of 3105 kilocycles the receiver must be in operation when the station is open. A loud speaker may be used on the 3105 kilocycles' watch.

(*h*) Classification of messages—Only necessary messages will be sent by radio.

I. Authorized messages over aeronautical station circuits are as follows:
  1. Communications with aircraft.
  2. Weather.
  3. Operations pertaining to aircraft in flight.
  4. Messages relating to aircraft loads.
  5. Any emergency message relating to aircraft operation not specified above.
     When transmitting point-to-point over aeronautical stations, a break will be made during the first ten seconds of each minute.
  6. Unscheduled communication with other stations in the aviation service when necessary.

II. Unauthorized messages over aeronautical station circuits:
  1. Public correspondence.
  2. Personal.
  3. Messages of a private nature pertaining to individual passengers or intended for them.
  4. Rebroadcast (intended for).
  5. Amateur.

III. Authorized messages over aeronautical point-to-point circuits:
  1. Messages relating to the aviation needs of the licensee subject to provisions in Section 2.
  2. Messages relating to the aviation needs of itinerant or government aircraft.
  3. Unscheduled communication with other stations in the aviation service when necessary.

IV. Unauthorized messages over aeronautical point-to-point circuits:
  1. Public correspondence.
  2. Personal.
  3. Amateur.

V. Both aeronautical and aeronautical point-to-point stations may work government stations including aircraft.

(*i*) All aircraft and aeronautical stations will give absolute priority to distress calls from aircraft and aeronautical stations. The international distress call in telephone procedure is the spoken word "*Mayday.*" This can be supplemented by other words as necessary. The distress call does not have to be received by radio but may be relayed from any intercepting station, to other stations, by wire lines, messenger, or otherwise. It is the duty of the station or stations initiating a distress call to promptly notify those concerned when the distress period has ended. Full log entries must be made of all distress calls and answers. In the case of craft in distress, any class of station causing interference to the distress traffic may be requested to shut down, and is required to do so.

(*j*) Logs—The radio station log forms the record of station operation. Regulation requires that this record be preserved for three months under ordinary conditions and under conditions of disaster, etc., it must be preserved until its destruction is authorized by the Federal Communications Commission. Rule 255 of the Federal Communications Commission requires: "Each licensee of airport, aeronautical and aeronautical point-to-point stations licensed for non-public service shall keep a record of the operation of each station, showing *time* of operation, *frequency* used, and *stations communicated with.*" Log entries will be made chronologically immediately following the communication. During periods of emergency, however, the communications to and from aircraft, and the collection of information required by the aircraft, will not be neglected for the making of a log entry. Immediately following the emergency, an entry of the communications taking place during the emergency will be made. If company personnel other than the operator on duty, are present in the station, during the time of emergency, they should verify the log entries made at the end of the emergency period by initialing same. Operators will follow these instructions regarding log keeping. These instructions are in addition amplified in Section 2.

1. If information in addition to that required by Rule 255 is incorporated in the log it must be accurate. Erasures must never be made. Any necessary changes shall be made by drawing a line through the undesired material. The deletion to be initialed by the operator making it.
2. Time of transmission on log entries.
    - (*a*) Time shown shall be time of completion of message for both radio telephone and radio telegraph procedure.
    - (*b*) In radio telephone procedure the start and finish time will be shown if the total elapsed time exceeds one minute.
    - (*c*) In radio telegraph procedure if the messages are sent at other than normal manual speeds the start and finish time will be shown.
    - (*d*) Time occupied by message transmission is the complete sequence, call, text and acknowledgment.
    - (*e*) If communications are held substantially simultaneously with a number of stations, such as for example, a number of aircraft in the vicinity of an airport, a single log entry may be made, showing the sense of communication held with each aircraft.
3. The message file is part of the log and must be shown to authorized inspectors.
4. If the operator goes off watch for a temporary period and is relieved, the relief operator will endorse the log showing time on duty. If no relief operator is available, the operator going off watch will close the station notifying other stations, and if aircraft

are in the sector, arrange to have them covered by other stations, *making full* log entry of facts.

5. Operators will sign the log with time indicating the beginning and end of their watch.
6. A log entry will be made each time aircraft stations are released from aeronautical station to airport station control.
7. Frequency measurement reports must be sent to station measured.
8. If the message file forms the complete log and no running log sheet is kept it must show the complete chain of events at the station such as operators going on and off duty, opening and closing of the station, interference received, and everything that would be normally entered on a log. This is usually done by entries on message blanks in chronological order.

(*k*) Communications received direct from the Federal Communications Commission concerning station operation, such as "discrepancy reports," etc., must be forwarded immediately in accordance with instructions in Section 2.*

7. Radio Telephone Procedure

(*a*) Be brief and talk as fast as good reception permits. Release microphone button momentarily at approximately every dozen words, permitting receiving station to break you, if it is having trouble receiving. A full ten-second break will be made at the beginning of each minute on each point-to-point transmission. This break will be announced by words "ten seconds."

(*b*) Call letters will not be used. Aeronautical stations are identified by their geographic locations, aircraft stations by the company or trip number, which ever is indicated in Section 2 of this Manual. Additional identification of aircraft stations such as pilots or company name may be used if required in Section 2.

(*c*) Technically an aeronautical station's sector extends to one-half the air-line distance from its location on the route to the next aeronautical station on the route.

(*d*) A log record must be kept by aeronautical stations of transmitted messages. See Log Part 6, pp. J, this Section. No log is required of aircraft stations.

(*e*) Reporting schedules for aircraft are assigned in Section 2. If necessary calls may be made off schedule otherwise schedules must be adhered to.

(*f*) If repeats are necessary, do not give reason, merely request "Repeat," anything else is superfluous.

(*g*) Approved procedure in calling aircraft include the name of aeronautical station (geographic) and the approved aircraft identification and must be as brief as possible. For exact procedure see Section 2.

(*h*) Approved procedure for aircraft calling or answering aero-

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* See page 1041.

nautical station will include approved aircraft identification and aeronautical station name (geographic). For exact procedure see Section 2.

The procedure indicated in (*i*), (*j*), (*k*) and (*l*) is considered good practice and will be adhered to unless amplified or changed in Section 2.

(*i*) The PX report from aircraft to aeronautical stations usually includes in the order given the following. See Section 2 for additional information.

1. Aircraft number (or flight number as indicated in Section 2).
2. Position.
3. Altitude.
4. Cloudiness.
5. Ceiling.
6. Visibility.
7. Air temperature.
8. Air conditions.
9. General.
10. Go ahead.

(*j*) The aeronautical station will acknowledge as follows: This acknowledgment serves to confirm the position report and is also for the benefit of other aircraft—" O. K. 343 over Helmar 6000 Chicago."

(*k*) When an aircraft makes an off-schedule call it will not wait for an acknowledgment before beginning transmission of message. The correct procedure is as follows: " 343 to Chicago. What is South Bend weather. Go ahead."

(*l*) Off-schedule calls may be made by aircraft stations at any time. It is the duty of all stations to give absolute priority to distress calls. The exact procedure and words to be used for distress calls are indicated in Section 2. See also Part 6, pp. I (Eye) of this Section.

(*m*) All attempted contacts will be recorded in the log. If the aeronautical station does not receive answer from aircraft station, at time of scheduled contact it will repeat call at ten-second intervals during the time alloted to contact, unless otherwise instructed in Section 2.

(*n*) Special messages to and from aircraft stations will be written on regular forms.

(*o*) All test transmissions including checks made with aircraft on the ground prior to take-off must be logged.

(*p*) Messages will not be repeated back to the transmitting station as check against error. If in doubt about all or part of a message ask for a repeat of the portion of which you are in doubt, as: " Repeat all before (certain word) "; " repeat all after (certain word) "; " repeat all between (certain words) "; when more than one message is to be sent, say: " I have two," etc.

(*q*) All information transmitted over the circuit must be in message form. No operator will accept for transmission any *verbal message* regardless of its nature except in emergency, when protection of life and property may make such verbal or conversational message necessary, in which event a written record must be made of the text immediately following the transmission.

(*r*) When transmitting figures, they shall be repeated, as for example, say, " eight eighteen "—repeat, " eight one eight."

(*s*) Code for spelling words in radio messages:

A—Adams
B—Boston
C—Chicago
D—Denver
E—Edward
F—Frank
G—George
H—Henry
I—Ida
J—John
K—King
L—Lincoln
M—Mary
N—New York
O—Ocean
P—Peter
Q—Queen
R—Robert
S—Sugar
T—Thomas
U—Union
V—Victor
W—William
X—X-Ray
Y—Young
Z—Zero

(*t*) If aeronautical station operator is unable to establish contact with the aircraft station, he will make use of all available facilities, including Department of Commerce facilities to get necessary information to the pilot. For exact procedure to be followed see Section 2.

(*u*) When a special form is used at aeronautical stations for transcribing position reports from aircraft (usually called the PX form) one copy constitutes a part of the station log. If no special form is used the log record should show all position reports received.

8. Radio Telegraph Procedure Aeronautical Point-to-Point Service

(*a*) All messages given to radio operators for transmittal must be in written form carrying signature of originator.

(*b*) All messages will be numbered serially.

(*c*) Receipt and delivery of messages to and from the radio room will be by methods prescribed in Section 2.

(*d*) Accuracy is essential and takes precedence over speed.

(*e*) Call stations by full call letters followed by DE and full call letters of station calling. At the close of the sequence the full call will be used followed by VA.

(*f*) The form to use in transmitting messages is as follows unless otherwise specified in Section 2.

(Preamble)

1. Message number.
2. Station call letters.
3. Transmitting operator's sine.
4. Check (word count).
5. City of origination.

6. Time filed and date (only day of month)

Break
(address)
Break
(Text)
Break
(Signature)

Example: "7 WSDI ZG 10 Chicago 1010A 2
Bryan Cleveland (Text) Jones"

(*g*) Service Marks—The transmitting operator will service the messages as follows, showing on same the information below. These service marks must be accurate as the message blank is the log record.

1. Frequency of transmission—This may be in code if so indicated in Section 2.
2. Time of transmission—This will be finish time if the transmission has been at normal speed.
3. Call letters of receiving station which may be shortened to last two letters of call.
4. Receiving and transmitting operator's sine.

(*h*) Filing time is the time the message reaches operator's desk.

(*i*) The receiving operator will write the message, example in pp. (*f*) as follows:

7 WSDI ZG AB 10 Chicago 1010A January 2, 1936.
Bryan Cleveland
Text
Jones—1011A

He has added AB, his sine, to the transmitting operator's sine ZG, and filled in the full date and the received time after signature.

(*j*) Service messages will be used between radio stations to obtain necessary information. They will carry the letters RQ ahead of the message number.

(*k*) Multiple addresses will not be transmitted unless the receiving station is to retransmit the message to another station.

(*l*) Relayed messages are to be handled exactly the same as an originated message.

(*m*) Teletype stations are designated by the Department of Commerce by call letters and these can be used in aeronautical point-to-point in lieu of station name. As they are not pronouncable, this would not be true in radio telephone procedure.

(*n*) The transmitting operator will endorse on the back of any message the reason for any unusual delay in its transmission. Unless the endorsement appears, the delay will be charged directly to the operator.

(*o*) The file copies of all transmitted messages are a part of the log and will be shown to authorized inspectors.

(*p*) The abbreviations and codes listed in the Manual will be used.

9–10. AIRPORT RADIO STATION AND ITINERANT PROCEDURE

(*A*) Under ordinary conditions the aircraft will work the airport station when within the airport zone which is considered to be approximately a 30 mile zone around the airport.

(*B*) Radio stations charged with the responsibility for aircraft flying within their sector will make a log entry when the aircraft is turned over to the control of an airport station.

(*C*) Aircraft working airport stations will, under ordinary conditions, use the opposite frequency to that in use on the airway at the time, providing the aircraft station is equipped with quick frequency shift.

(*D*) *Itinerant Procedure—" Intentional Instrument Flight Plan:* (*a*) Before the departure of any aircraft making an intentional instrument flight on a civil airway (except a flight for training purposes as provided in paragraph (*D*) of part (1) immediately above), or when visibility on said airway is less than one mile on the route to be flown, or whenever a flight can only be continued as an intentional instrument flight, the person in command of said aircraft shall present a flight plan, for forwarding to the point of destination, directly or by telephone or telegraph, to one of the following agencies (whichever is nearest or most available, but in the order listed if equally available):

(1) Airway traffic control station,
(2) Airport control tower,
(3) Department of Commerce teletype station, or
(4) Air line radio station.

(*b*) The flight plan aforementioned shall contain the following information:

(1) Proposed time of departure,
(2) Proposed cruising altitude,
(3) Type of equipment, and
(4) Estimated flying time between stops and destination."

(2) Instrument Bulletin D–3, issued by the BAC Air Navigation Division, contains detailed procedure for the handling and forwarding of itinerant flight plan dispatches, PX reports, etc., over government and commercial circuits.

(3) The purpose of the entire procedure is to regulate, keep track and disseminate information regarding all flight traffic on the airways so that all concerned may be informed about flights on the airways.

(*a*) Personnel receiving flight plan messages from itinerants must put these into the BAC hands at once, so that the information may be disseminated to all aircraft flying the airway which the flight plan covers. At points covered by "Airways Traffic Control" the flight plan would be communicated to same. Otherwise, to BAC radio or teletype station. If none of these are available at point of departure the message should be relayed via company radio, if the traffic permits or by commercial telegraph (collect), to the BAC station at the first stop mentioned in the plan. The message would read, as follows:

> (The message would be addressed to the BAC facility at the first stop)
> "Proposed departure 8:30 Altitude 3000, Estimate Arrival Cincinnati 10:30, Cleveland 12:45 WACO NC–4337 Confirm (signed) Smith (pilot's name)."

In reply the message would read:

> (Addressed to the pilot at the point of origin)
> "Your flight plan confirmed." The signature would include the last name of the person authorizing the flight. Variations from this confirmation would occur such as different altitude, or departure delays, etc.

(4) In equipping the aircraft to conduct two-way radio between aircraft and ground the itinerant has the choice of:

(*a*) Equipping his aircraft to transmit on 3105, 3120, 6210 Kcs. working BAC and airport stations, or
(*b*) Contracting with Aeronautical Radio, Inc. to use the combined Aeronautical Radio, Inc. air line stations and frequencies.
(*c*) Using both of the above services.

(5) Under the rules and regulations of the Federal Communications Commission you are required to handle communications with itinerant aircraft exactly the same as you handle scheduled air transport communications. The fact that you receive a call from aircraft on any of the frequencies on which you maintain a listening watch is prima facie evidence that the aircraft has a right to be on this frequency and should be handled in the regular manner. The instructions below have been issued to all itinerants using aeronautical frequencies. Report any irregularities noted to communication headquarters:

(*a*) The aeronautical stations with which you communicate are licensed to Aeronautical Radio, Inc., Washington, D. C., and jointly operated by Aeronautical Radio, Inc., and the transport company along whose route you fly.

(*b*) An aeronautical station is defined in the Federal Communications Commission's regulations as follows:

> "The term 'aeronautical station' means a station used primarily for radio communication with aircraft stations, but which may also carry on a limited fixed service with other aeronautical stations in connection with the handling of messages relating to the safety of life and property in the air."

(*c*) It is obvious from the foregoing that the stations are operated primarily for safety and handle messages relating primarily to the safety of the aircraft and cargo. Aeronautical stations do not handle paid or toll messages, or messages that do not relate directly to the safety of the aircraft.

(*d*) When you are flying along any route and your station is tuned to the chain frequency assigned to that route, you are actually on the equivalent to a party line telephone. There is one difference, however, because you are using a radio channel and because two radio stations tuned to approximately the same frequency create interference to each other when transmitting simultaneously (a beat note in receiver equivalent to the difference in cycles between the frequency of the two stations, and cross-talk), it is necessary that you(except in emergency):

(1) Listen before starting a transmission and do not transmit if other stations are working.
(2) Work your scheduled contacts on a schedule which will be assigned by the first aeronautical station you contact.

(*e*) It is most important that the channel be open so that emergency calls can be heard at any time. Be brief and conform to transport procedure, as follows:

(1) Call aeronautical stations by their geographic location. That is if you want to raise the Chicago Brown Chain station just call "Chicago."
(2) The five letter aircraft calls are easily misunderstood. Use your aircraft number and company identification. A correct procedure would therefore be as follows:

(*f*) *Call:* Plane 13329 Standard Oil to Chicago go ahead.
Answer: Chicago to Standard Oil 13329 go ahead.
The Message: Over Helmar at 3000 feet estimated arrival Chicago 2:18 P.M.
Acknowledgment: Acknowledges message—gives Chicago Airport weather.

(*g*) If repeats are necessary ask for them. Do not give a long reason why.

(*h*) Remember that emergency calls are in order at any time. You can secure absolute priority by the telephone "SOS" call of "MAYDAY." This call should not be given unless the craft is in actual distress and you are prepared to substantiate the facts in event of inquiry.

(*i*) The Department of Commerce has special regulations and clearances for itinerant flights under minimum ceilings and visibility. Always conform to these regulations, remembering that there are others on the airways.

(*j*) When within airport zones work the airport control tower and tune your low frequency receiver to 278 kilocycles.

(*k*) Different frequencies are assigned to different chains to avoid congestion and information will be furnished by Aeronautical Radio, Inc., on request. Frequency and station lists will be issued from time to time.

(*l*) To get full benefit of chain operations and to keep track of other aircraft on the airway you are on, keep your communication receiver tuned to the chain on which you are flying.

Part II. Instructions for Airway Meteorological Service

Operators desirous of learning about weather observations, and their application to airways should obtain from the Superintendent of Documents, Government Printing Office, Washington, D. C., a booklet compiled by the Weather Bureau, U. S. Department of Agriculture, entitled "Instructions for Airway Meteorological Service." This booklet contains instructions for accepting, filing for transmission, and entry on forms of airway weather observations. The cost of the booklet is twenty-five cents.

BUREAU OF AIR COMMERCE
AIR NAVIGATION DIVISION *

INSTRUCTION BULLETIN D-7
REVISED

TELETYPE AND RADIO COMMUNICATION PROCEDURE

Section 1

1. *Abbreviations and Phrase Contractions*—(*a*) The Weather Bureau of the U. S. Department of Agriculture will issue and revise from time to time a list of abbreviations for use in connection with the transmission of meteorological information. These abbreviations shall be utilized by operating personnel in the transmission of meteorologicaal information by means of the communication facilities of the Air Navigation Division.

1. (*b*) The following abbreviations are authorized for use in the transmission of administrative dispatches and shall be utilized in the transmission of service dispatches and PX reports. They will be counted as one word each (unless otherwise noted) whether used in singular or plural form:

MON	Monday	JAN	January	AUG	August
TUE	Tuesday	FEB	February	SEPT	September
WED	Wednesday	MAR	March	OCT	October
THURS	Thursday	APR	April	NOV	November
FRI	Friday	MAY	May	DEC	December
SAT	Saturday	JUN	June		
SUN	Sunday	JUL	July		

* See footnote on page 1046.

Alabama	ALA
Arizona	ARIZ
Arkansas	ARK
California	CALIF
Colorado	COLO
Connecticut	CONN
Delaware	DEL
District of Columbia	DC (2 words)
Florida	FLA
Georgia	GA
Idaho	IDA
Illinois	ILL
Indiana	IND
Iowa	IA
Kansas	KAN
Kentucky	KY
Louisiana	LA
Maine	ME
Maryland	MD
Massachusetts	MASS
Michigan	MICH
Minnesota	MIN
Mississippi	MISS
Montana	MONT
Nebraska	NEB
Nevada	NEV
New Hampshire	NH (2 words)
New Jersey	NJ (2 words)
New Mexico	NM (2 words)
New York	NY (2 words)
North Carolina	NC (2 words)
North Dakota	ND (2 words)
Ohio	OHIO
Oklahoma	OKLA
Oregon	OREG
Pennsylvania	PA
Rhode Island	RI (2 words)
South Carolina	SC (2 words)
South Dakota	SD (2 words)
Tennessee	TENN
Texas	TEX
Utah	UTAH
Vermont	VT
Virginia	VA
Washington	WASH
West Virginia	WVA (2 words)
Wisconsin	WIS
Wyoming	WYO

AM (Ante Meridian) (2 words)
BL (Bill(s) of Lading—2 words)
CAPT (Captain)
CO (Commanding Officer—2 words)
COL (Colonel)
COMDR (Commander)
COMDT (Commandant)
CS (Central Standard (time)—2 words)
DEPT (Department)
ENGR (Engineer)
ETC (Etcetera)
ES (Eastern Standard (time)—2 words)
FT (Fort, Foot, Feet)
GOVT (Government)
KC (Kilocycl(s))
KW (Kilowatt(s))
LT (Lieutenant)
LT.COMDR (Lieut. Commander—2 words)
MAJ (Major)
MS (Mountain Standard Time—2 words)
MR (Mister)
MRS (Mistress)
PARA (Paragraph)
PO (Post Office—2 words)
PS (Pacific Standard (Time)—2 words)
PM (Post Meridian) (2 words)
RE (Reference)
SGT (Sergeant)
SQDN (Squadron)
ST (Street or Saint)
STP (Stop)

In addition, but only if desired by sender, the first letter of each word in the name of any well known company or office, such as "UAL—United Air Lines," "GAO—General Accounting Office," "FERA—Federal Emergency Relief Administration," etc., each letter of which shall be counted as one word, transmitted without spaces may be used. The sender will be expected not to file traffic containing such abbreviations whenever there is doubt as to whether the abbreviation will be correctly interpreted by the recipient. NOTE: The abbreviations authorized for special purposes, as for example the addresses of dispatch traffic or the transmission of meteorological information, are not authorized for use in the text of administrative dispatches. Abbreviations appearing in an example constitutes authority to utilize the abbreviation for the purpose indicated in the example, see page 1064, subparagraph 19 under 5 (*g*): The abbreviation IFN for "information" is authorized for use in accordance with the example.

1. (*d*) The five letter groups listed below are authorized for use as *phrase contractions* in the transmission of dispatches and shall be counted as one word each:

ADCON (Issue instructions to or advise all concerned)
ADEDA (Advise effective date)
ADVOF (Advise this office)
ASSAP (As soon as practicable)
AUGRA (Authority granted)
AUZRE (Authority is requested)
BAFAK (Bids acceptable from Asst. Airway keepers)
BAFAR (Same—Asst. Radio Operator)
BAFKE (Same—Airway keeper)
BAFJU (Same—Jr. Radio Operator)
BAFOC (Same—Operator in Charge)
BAFRO (Same—Sr. Radio Operator)
BULET (Bureau letter)
COREQ (Confirming requisition follows)
CLOTO (Close this office)
DILET (District letter)
DIREP (Dispatch reply)
EXREP (Expedite mail reply)
EXSHI (Expedite shipment)
FOCOR (Forward confirming requisition)
INREQ (Information requested)
LETFO (Letter follows)
NACOS (National Communication schedule)
NORXP (No reply received)
NOTAM (Notice to Airmen)
POAKE (Position open Airway keeper)
POASK (Same—Asst. Airway Keeper)
POJUN (Same—Jr. Radio Operator)
POOIC (Same—Operator in Charge)
PORAK (Same—Relief Asst. Keeper)
PORRO (Same—Relief Radio Operator)
POSAR (Same—Asst. Radio Operator)
POSRO (Same—Sr. Radio Operator)
RACFI (Radio and communication facilities inoperative)
RACFO (Radio and communication facilities operative)
REBUL (Reference instruction bulletin)
RECOK (Recommend approval)
RECON (Reference contract)
REDIS (Reference dispatch)
REFEN (Reference endorsement)
REINV (Reference invoide)
RELET (Reference letter)
REMAG (Reference mailgram)
RENOA (Reference Notice to Airman)
REPRO (Reference proposal)
REREQ (Reference requisition)
RERQD (Reply requested)
RETEL (Reference telegram)
ROCON (Reference this office contract)
RODIS (Reference dispatch from this office)
ROEND (Reference endorsement from this office)
ROINV (Reference invoice from this office)
ROLET (Reference letter from this office)
ROMAG (Reference mailgram from this office)
RONOA (Ref. this office Notice to Airmen)
ROREQ (Reference requisition from this office)
ROTEL (Reference telegram from this office)
RUCON (Reference contract from your office)
RUDIS (Reference dispatch from your office)
RUEND (Reference endorsement by your office)
RUINV (Reference invoice from your office)
RULET (Reference letter from your office)
RUMAG (Reference mailgram from your office)
RUNOA (Reference Notice to Airmen from your office)
RUREQ (Reference requisition from your office)

RUTEL	(Reference telegram from your office)
SUREQ	(Submit requisition)
TAGEX	(Transfer approved travel at Government expense)
TAWOG	(Transfer approved travel without expense to Government)
URAUZ	(You are authorized)
URECA	(Your recommendation is approved)
URIZR	(Your recommendation is requested)
WIBOD	(Will be ordered)

2. *Acceptable and Non-acceptable Traffic*—(*a*) Communications of the following type are acceptable for transmission by means of the communication facilities of the Air Navigation Division:

1. Meteorological information.
2. Government traffic relative to the air services, when mail will not serve the purpose.

2. (*b*) Dispatches relative to the following subjects will be acceptable if offered for transmission because of emergencies resulting from the failure of ordinary communication services and the facilities of the Air Navigation Division are the only means of communication available:

1. Accidents.
2. Transfers of materials, supplies, and spare parts.
3. Emergency improvements to be made in flying equipment for added safety to air navigation.
4. Information relative to conditions at terminal fields, intermediate fields, and along the airways that affect safety to air navigation.
5. Dispatching aircraft and aircraft personnel.
6. Passenger reservations and cancellations.
7. Personnel transfers necessitated by service requirements.
8. The furnishing of passengers with lunches and other conveniences.
9. Employees requests for leave of absence.

2. (*c*) Dispatches relative to personal business or subjects not connected with official duties or official movements of the writer are *not* acceptable.

2. (*d*) If dispatches relative to subjects which are not approved for transmission by means of the communication facilities of the Air Navigation Division are offered for transmission, the sender should be quoted the regulations but if the sender does not cancel the dispatch the operator should accept and forward the traffic to its destination. A copy of the dispatch shall be forwarded by mail through channels to the office of the Assistant Director of Air Commerce with a complete explanation of the circumstances, including the name and address of the sender.

2. (*e*) Dispatches addressed to destinations not served by the communication facilities of the Air Navigation Division will be accepted for transmission by radio or teletype to the point on the radio or teletype circuits nearest the destination, providing that the delivery of

traffic not relative to official business of the Air Navigation Division is completed without cost to the Air Navigation Division.

3. *Accidents*—When an aircraft accident occurs near a station operated by Air Navigation Division personnel, a short dispatch, preferably not over ten words in length, should be immediately forwarded by means of the communication facilities of the Air Navigation Division, or, if none is available, by commercial telegraph facilities to the Supervising Aeronautical Inspector of the Inspection District, Air Regulation Division, in which the accident occurred. The location of headquarters of the Supervising Aeronautical Inspectors should be furnished to each station by the Air Navigation Division District Offices. The following information relative to the accident should be supplied:

Aircraft license number
Pilot's name
Kind of accident (minor or major)
Location of accident
Cause of accident.
Any information relative to injuries to pilot or passengers.

Example:

CHICAGO
AERO INSP CHICAGO STP AIRCRAFT NC123 JONES MINOR WRECK
GOSHEN BROKEN WHEEL NO INJURIES 100010
(Signature)

Note: The text is completed by the six figure time group and is explained in paragraph 17 (*d*).

4. *Acknowledgments*—(*a*) All numbered traffic shall be acknowledged. Upon receiving a numbered communication the receiving station will call the transmitter station and transmit the letter "R" (Received) and the number of the communication, in accordance with the following examples:

CG DE GO R1	(Straight number dispatch)
CG DE GO R1ALCKT	(All circuit dispatch)
CG DE GO R1ALSXN	(All section dispatch)
CG DE GO R1AN	(All District stations dispatch)
CG DE GO R1DC	(All Air Navigation Division stations dispatch)
CG DE GO R3-5	(Serial numbers of the first and last communications sent in an unbroken series)

4. (*b*) The transmitting stations will enter the acknowledgment on the sent file copy or, if an unbroken series has been transmitted to one station, will enter the acknowledgment on the file copy of the first and last dispatch of the series.

4. (*c*) Acknowledgments should not be sent until the receiving operation has compared the check of the dispatch with the actual number of words received and is positive that the dispatch is correct so far

as he can determine. "ALSXN," "ALCKT" and other dispatches transmitted to a group of stations shall be acknowledged in weather sequence order.

4. (d) Acknowledgments for any class traffic may be transmitted within the period allocated to any other class traffic *provided* that the circuit is not required for the transmission of traffic of the class scheduled for that period. Example: An acknowledgment for a class "D" dispatch may be transmitted shortly after the start of a "Star" schedule when it is apparent that no class "P" traffic is on hand for transmission.

5. *Addresses*—(*a*) The address (or destination) of all dispatches except those intended for specific groups such as "All Circuit" dispatches will be the name of the City or Town where delivery will be made.

5. (*b*) No addresses will be shown when the dispatch is intended for the operator or keeper in charge or acting in charge of an Air Navigation Division station.

5. (*c*) The addressee of dispatches not intended for delivery to the operator or keeper in charge or acting in charge of the station will be indicated by the abbreviation hereinafter shown.

5. (*d*) The last name of the addressee shall be utilized to indicate delivery to an individual not regulary attached to the station addressed. If there are offices other than the Air Navigation station at the address shown, the word "Care" and the abbreviation of the office where the addressee can be reached shall also be shown.

5. (*e*) The abbreviation NDS (Navigation Division Station) shall be utilized to indicate delivery to the operator or keeper in charge or acting in charge of the Air Navigation Division station when one or more other addressees are indicated and the dispatch is also intended for delivery to the person in charge of the station.

5. (*f*) Abbreviations indicating addressees shall be transmitted on the same line as the beginning of the text and shall be separated from the text by the abbreviation STP (Stop).

5. (*g*) Examples—

	Address	*Addressee*	*Delivery to*
(1)	WASHINGTON	DIRECTOR STP	(Director of the Bureau of Air Commerce, Washington, D. C.)
(2)	WASHINGTON	AIR STP	(Assistant Director, Bureau of Air Commerce, Air Regulation Division—Washington, D. C.) (AIR—1 word)
(3)	WASHINGTON	AN STP	(Assistant Director, Bureau of Air Commerce, Air Navigation Division—Washington, D. C.) (AN—2 words)
(4)	CHICAGO	AN STP	(District Manager. Note: The addressee AN when utilized with the address WASHINGTON denotes delivery to the Assistant Director, Bureau of Air Commerce, Air Navigation Division; when

	Address	Addressee	Delivery to
			utilized with addresses Newark, Atlanta, Chicago, Ft. Worth, Salt Lake, Oakland, the office of the District Manager is indicated.) (AN—2 words)
(5a)	CHICAGO	INSP STP	(Airline Inspector) (INSP—1 word)
5(b)	CHICAGO	AERO INSP STP	(Aeronautical Inspector) (AERO INSP—2 words)
(6)	WASHINGTON	WB STP	(U. S. Weather Bureau City Office) (WB—2 words)
(7)	CLEVELAND	AWO STP	(U. S. Weather Bureau Airport Station) (AWO—3 words)
(8)	CLEVELAND	(No Addressee indicated)	(Operator in charge or acting in charge Cleveland Air Navigation Division Station)
(9)	CHICAGO	LAB STP	(Radio Laboratory Chicago) (LAB—1 word)
(10)	WASHINGTON	NAVY STP	(Delivery to Navy Department Air Service Headquarters) **Note:** The use of "Navy STP" and "WAR STP" is authorized when arrangements have been made to deliver communications to certain acceptable addresses. These addressees should be interchanged by Air Navigation Division Districts with the view of avoiding long military addressees.
(11)	SELFRIDGE	WAR STP	(Delivery to War Department Air Service Headquarters.) **Note:** See **Note** for NAVY above.
(12)	CHICAGO	AMO STP	(Air Mail Operations, Post Office Department excepting Superintendent) (AMO—3 words)
(13)	WASHINGTON	SUPT AMO STP	(Superintendent of Air Mail Operations, Post Office Department.) (SUPT AMO—4 words)
(14)	BUFFALO	ALL CONCD STP	(For delivery to all concerned in accordance with list prearranged by the District Office.) If any exceptions state, example ALL CONCD EXCEPT INSP STP.
(15)	NEWARK ATLANTA CHICAGO FORT WORTH SALT LAKE OAKLAND	ALL AN STP	(All District Offices)
(16)	WASHINGTON CLEVELAND	AN WASHINGTON JONES CARE NDS CLEVELAND STP	(Multiple address dispatch showing a copy to be delivered to a person not regularly attached to the Cleveland station.)
(17)	NEWARK ATLANTA	AN STP	(More than one District office when the sender does not desire to notify each

	Address	*Addressee*	*Delivery to*
	CHICAGO		addressee what other addressees have received the same dispatch.)
(18)	NEWARK ATLANTA FORT WORTH	AN NEWARK ATLANTA FORT WORTH STP	(Dispatch to more than one office when the sender desires to notify each addressee what other addressees *have* received the same dispatch.)
(19)	NEWARK CHICAGO	AN NEWARK IFN AN CHICAGO STP	(Action to be taken by District Manager, Newark; copy to District Manager, Chicago, for information.)
(20)	CHICAGO CLEVELAND	AN WB CHICAGO NDS AWO CLEVELAND STP	(Chicago operator responsible for delivery to District Office and downtown Weather Bureau office, Chicago; Cleveland operator responsible for delivery to Operator In Charge and Airport Weather Bureau, Cleveland.) **Note:** A dispatch to any one point may only carry one address regardless of how many offices or persons at that point are to receive a copy of the dispatch.
(21)	ALL SL RP SXN	ALL SL RP SZN STP	(All stations on a circuit between two points under the supervision of a given District office where the circuit extends through more than one District) (May be modified by word except in accordance with example 23)
(22)	ALL CO KC SXN CHICAGO	ALL CO KC SXN AN CHICAGO STP	(Delivery to all stations on the section of the circuit named plus the office of the District Manager, Chicago.)
(23)	ALL CG NA CKT	ALL CG NA CKT STP	(All stations on a circuit.) **Note:** Teletype circuit designators are usually the teletype calls of the stations at the terminals of the circuit. The eastermost or northermost designator should be transmitted first. (**Note:** All circuit addresses shall be modified when necessary by the word "EXCEPT" to denote subtraction of any station or stations. Example: "ALL WA CV CKT EXCEPT KY AND SV." KY and SV shall then receipt for and file the dispatch without further action. This procedure is necessary to insure complete number records of ALSXN AND ALCKT dispatches at all points.)
(24)	ALL ANI	ALL ANI STP	(All stations within the First District) **Note:** This address may be modified when

	Address	*Addressee*	*Delivery to*
			necessary by the word *except* to denote subtraction of any station or stations.
(25)	ALL DC6	ALL DC6 STP	(All Department of Commerce stations in the Sixth District) **Note:** To facilitate the handling of dispatches addressed to stations operated by Air Navigation Division personnel when there are a number of exceptions necessary when using the address ALL AN6.

5. (*h*) The use of the phrase contraction ADCON (Advise all concerned) with or in place of abbreviations of addressees is not approved. When appropriate, ADCON may be utilized at the end of the text preceded by the abbreviation STP (Stop). The use of ADCON in Notices to Airmen in dispatch form is not approved.

5. (*i*) When the location of the District headquarters is included in the address of all circuit (or all section) dispatches, example, ALL CVMR. CKT, the use of the abbreviation " AN " to indicate delivery to the District office is not necessary when the abbreviation ADCON appears as the last word of the text. The district office will be included in the list of " all concerned " posted in the Air Navigation Division station at the location of the District office.

5. (*j*) When the location of the District headquarters is not included in the address of " All Section " dispatches (example, ALL CO KC SXN) delivery to the District office, when necessary, shall be indicated by the addition of the District Office address in accordance with Para. 5. (*b*), example 22. In some cases of this nature the serial number to the ALL CKT address will be different from the serial number to the District Office address. Because of the difference in the number of words, the check to the all circuit address will be more than the check to the District office address.

6. *Bell Signals*—(*a*) The following bell signals shall be utilized as indicated:

1 bell—end of transmission.
3–3–3 bells—precede transmission of S S S traffic.
10 bells—precede transmission of special weather reports and constitute general call order to connect allswitch lines and reperforators on the circuit. Wait 5 seconds before starting transmission to give time for necessary connections.

6. (*b*) Each bell signal, excepting one bell indicating end of transmission, shall be preceded by the transmission of 3 figure shift impulses.

6. (*c*) If the bell signal is composed of a combination such as 1 space 3, one figure shift impulse shall be transmitted between the bell signals, example; one bell, one figure shift, three bells.

6. (*d*) Signals composed of a continuous number of bells (example 10 bells) shall be sent as rapidly as the circuit will permit.

6. (*e*) Call bell signals shall be assigned to each teletype drop by the office of the District Manager.

6. (*f*) Transmission of 10 bell signal before starting scheduled communications, for which a definite period is provided by the National Communication Schedule, is not approved. Examples: 10 bells signal not approved preceding upper schedules, weather sequence collections, airway forecasts, State forecasts, and similar material transmitted on Schedule.

7. *Calls*—Teletype call letters and designators shall be utilized for heading sequence weather collections and identifying weather reports.

8. *Code*—(*a*) The following identifying code is authorized for use when required to prevent garbling during receipt or delivery of a dispatch by telephone:

A	Adams
B	Boston
C	Chicago
D	Denver
E	Edward
F	Frank
G	George
H	Henry
I	Ida
J	John
K	King
L	Lincoln
M	Mary
N	Noble
O	Ocean
P	Peter
Q	Queen
R	Robert
S	Sugar
T	Thomas
U	Union
V	Victor
W	William
X	Xray
Y	Young
Z	Zebra

8. (*b*) Service message code—

CODE	Meaning.
CANCEL	Cancel and file.
DUPE	Duplicate quickly from origin or verify from sender original not understood.
GBA	Give better address, unknown at address given, not in directory.
GQA	Get quick answer.
SRS	See our service.
SUBFIX	We forward subject to correction.
SYS	See your service.
DFS	Disregard former service.

9. *Communications, Subject of*—Employees are instructed to include only *one* subject in each dispatch.

10. *Checking Dispatches*—(*a*) "CHECK" is the number of words in the dispatch. Only those words in the address, text and signature are counted.

10. (*b*) The six figure time group is not counted in the check.

10. (*c*) In "svc" dispatches there is no check, nor time group.

10. (*d*) With exceptions shown in this bulletin, words are counted as written in the station dictionary, compounds words being checked by the number of component words. If not found in the dictionary and questionable as to whether they are compound words, they should be counted one word. Groups of code letters and such groups as OK, AM, PM, count one word per letter, unless the station is supplied with a code book such as is the case with U. S. Weather Bureau code when

the code groups shall be counted one word per group as written in the code book. Teletype call letters and designators appearing in dispatches shall be counted one word per letter. The word "RE" should be counted one word when used in the sense of "About" or "Concerning," for example, "RE INSTRUCTIONS," but is not counted separately when used as a prefix, for example "REDESIGN."

10. (*e*) The following are to be counted as one word each, in all their various forms, singular and plural, endings in ing, etc.:

Airplane
Airline
Antifreeze
Antifriction
Blueprint
Carload
Caretaker
Decoded
Landplane
Layout
Payroll
Retrained
Retransmit
Wavemeter

10. (*f*) Such words as "Can't" and "Doesn't" should be spelled in full, changing "can't" to "can not" (2 words) and "doesn't" to "does not" (2 words), etc., on the dispatch copy before transmission.

10. (*g*) The text of a portion of the dispatches transmitted by means of the teletype and radio communication facilities of the Air Navigation Division will consist of five letter code words which do not appear in any authorized list of abbreviations, example: EDBIA. For the purpose of determining the check of these dispatches, each group of five letters shall be counted as one word.

10. (*h*) The names of cities or towns shall be counted as one word each whether utilized in the address or text of dispatches, example: FT WORTH OR FORT WORTH count as one word.

11. *Classification of Dispatches*—(*a*) All traffic must be in the form of numbered dispatches excepting when emergencies involving life and property require the immediate use of the circuit. The following procedure will be utilized when it becomes necessary to stop all operations on the teletype circuit:

Transmit bell signals—3 space 3 space 3 space followed by typing of three letters "s," example:

3 bells 3 bells 3 bells s s s (Follow with call letters of station called, if practicable) DE (Call of station calling) (Information desired to impart.)

11. (*b*) Communications transmitted by means of the teletype or radio facilities of the Air Navigation Division shall be divided into four classes as follows: (**Note:** When two or more communications of the same class are on hand, the priority of transmission within the class shall conform to the order in which the communications are herein listed, example: Assume a station to have on hand for transmission a dispatch relative to the failure of a radio range, a special weather report, and a dispatch reporting an aircraft movement. The

special weather report would be transmitted at the first opportunity followed by the dispatch relative to the range failure and the dispatch reporting the aircraft movement.)

1. "S S S" Class.

Dispatches involving the safety of life or property and requiring the immediate use of the circuit in accordance with the example in Para. 11 (*a*) concerning S S S transmissions.

2. "P" (Priority) Class.

Dispatches to be broadcast to aircraft in flight.

Dispatches to other points when relating to the safety of life or property.

Special (SPL) weather reports.

Dispatches relating to the failure of air navigational radio aids and the return of such aids to normal operation.

Delayed weather information required for scheduled radio broadcast.

Dispatches reporting the failure and return to normal of airways aids other than radio, such as light beacons, information relative to landing fields, etc.

Special (SPL) weather forecasts.

PX reports.

Dispatches reporting aircraft movements.

Note—Delayed weather information required for broadcast purposes shall be preceded by the prefix "P" and the abbreviation "DW" (Delayed weather).

3. "D" Class.

Delayed weather information not required for scheduled radio broadcast.

Note—May include sequence weather reports, 6-hourly weather reports, upper air reports, APOBS, forecasts, delayed map signals, etc. Delayed weather information of this class shall be preceded by the prefix "D" and the abbreviation "DW" (Delayed weather).

Dispatches that are of such urgent nature that they can not be classed with the "W" group. (Includes meteorological information in dispatch form.)

4. "W" Class.

Dispatches not included in other classes and not of urgent nature, transmitted only between 9 P.M. and 9 A.M., E.S.T.

11. (*c*) In the absence of knowledge of the circumstances concerning each dispatch and unless otherwise classified by the sender, dispatches should be transmitted as "W" traffic.

11. (*d*) Relay and traffic centers shall supply themselves with suitable files having three partitions labeled respectively "P," "D," and "W," where traffic bearing the corresponding prefix may be kept in times of congestion while awaiting transmission.

11. (*e*) Traffic bearing the prefix "P" shall be cleared before "D" traffic is sent, and "D" traffic shall be cleared before "W" traffic is sent.

11. (*f*) All concerned shall be notified that class "W" traffic may suffer delay to such an extent that in some cases use of the mails would result in quicker delivery. Dispatches should not be transmitted with the "D" prefix late in the afternoon when there is no likelihood of their reaching the addresses before the morning of the following business day. Correspondence that can be handled by mail without injury to the interest of the Government shall not be made the subject of dispatches. Communications destined for over-night mail points should be handled by mail when action cannot be taken until the following business day. Attention is invited to the utility of mailgrams for short communications which need not be made the subject of a letter and which do not require transmission by teletype or radio facilities to serve the intended purpose. Mailgrams may contain the abbreviations utilized in dispatches and may be written on dispatch forms but should bear the word "MAIL," preferably marked in red. When writing dispatches, particular attention should be given to the omission of all superfluous words. The words "of," "on," "in," "the," "that," "by," "please," etc., can usually be omitted without destroying the meaning of the text.

12. *Duplications*—If a dispatch is duplicated for any reason, the word "DUPE" will appear immediately after the check. A dispatch duplicated on the same day shall carry its original serial number. Dispatches duplicated later shall carry a new serial number and in all other respects be transmitted as though just originated. A regular dispatch when duplicated will, of course, retain its original reference group. SVC dispatches when duplicated will retain their original date of origin at end of dispatch, but bear the present time of dispatch. Example of duplicated dispatch:

CV WI TL 36 DUPE TOLEDO
CLEVELAND
(TEXT) 183030
(signature)

13. *Emergency Dispatches to Be Broadcast to Aircraft*—(*a*) All air Navigation Division stations equipped with radiotelephone facilities are authorized to accept and forward by radio broadcast emergency dispatches to pilots of aircraft in flight, or down at points isolated from regular commercial communication facilities. Acknowledgment of receipt shall be obtained from the aircraft, if possible, so that the broadcasting of the dispatch may be discontinued.

13. (*b*) In order to insure prompt transmission of dispatches to the radio stations concerned and delivery in the desired manner, all dispatches shall be filed in the form shown below; this form shall be strictly adhered to as it will be the broadcasting stations authority for broadcasting the dispatch without further instructions:

IX KC P1 CG 14 CHICAGO
IOWA CITY
KANSAS CITY
NC 408 UNTIL ADVISED STP RETURN TO KANSAS CITY IMMEDIATELY
191510
SMITH

"NC408" is the Department of Commerce number of the ship to which the dispatch is to be broadcast. (In some cases it may be desirable to show the pilot's name with or instead of the number.)

"UNTIL ADVISED" indicates that the sender desires that the dispatch be broadcast until he advises that it should be discontinued. Stations receiving this request shall ask for further orders if no instructions to discontinue the broadcast are received within one hour; transmission, however, shall continue until receipt of the order to stop, or until an acknowledgment has been received from the aircraft.

Designations which may appear in routing instructions (Instructions to the broadcasting station for handling the dispatch) are:

Name of route, as, CHICAGO TO KANSAS CITY.
Location of ship, when down, as, DOWN AT ————.
"RETURN TO KANSAS CITY IMMEDIATELY" is the text.

"191510" shows the time (twenty-four hour clock system) and the date the dispatch was actually filed with the Air Navigation Division station.

"SMITH" is the name of the contractor's responsible agent.

13. (*c*) When a dispatch is requested broadcast "UNTIL ADVISED," a dispatch in the following form should be sent when it is desired to discontinue broadcast:

IX KC P2 CG 11 CHICAGO
IOWA CITY
KANSAS CITY
FILE OURS DATE TO NC 408 200010
SMITH

14. *Errors*—(*a*) If an error is noticed when made the teletype operator shall teletype XXX then repeat the group as it should be and proceed with the balance of the teletyping, example:

SL E 35⊕O XXX E35⊕10 69/75 ← 20 957

14. (*b*) If an operator fails to receive any portion of a dispatch due to any cause, that portion shall be requested from the sending operator by using QXKQ. Example:

Request for repetition—WA DE CV QXKQ W17 UV Q DATE 104605
Repetition— CV DE WA QXK W17 UV 851 TUBES WERE SHIPPED TO ALBUQUERQUE DATE 104605

14. (*c*) Example of request for repetition of a weather report:

CG DE GO QXKQ 2230 WEA (Use 24-hour time).

14. (*d*) Traffic shall not be delayed because of questionable words or an incorrect check. Such traffic should be sent promptly, checked "subfix" (Subject to correction) and an "svc" dispatch requesting correction or verification should be sent to the station of origin by operator who finds error or apparent error, otherwise *each* operator who relays the dispatch in its incorrect form will be held responsible for the error.

14. (*e*) Service (svc) dispatches correcting errors in relay traffic shall be addressed to the station that made the inquiry and to the destination of the dispatch referred to and not to stations along the line through which the original dispatch was relayed.

14. (*f*) Both sending and receiving operators are responsible for mistakes in handling communications. Every effort shall be made to discover errors by checking and rechecking.

14. (*g*) Personnel should practice diligently to attain maximum speed in teletyping as the efficiency of the circuit depends to a great extent on the time required for teletyping. This does not mean that accuracy should be sacrificed for speed. A minimum average speed of 35 words per minute (Counting 5 letters or characters and 1 space per word will be required of personnel at drops on the long lines teletypewriter circuits).

14. (*h*) After teletyping weather reports each operator or keeper shall carefully compare the teletype report with the observation as written on Weather Bureau Form 1130-Aer. or 1130-Aer. to make sure no errors have been made. If an error has been made, the operator or keeper shall, immediately upon completion of sequence, transmit CQN (Correction) and the correct item, example: CQN RP VSBY 25.

15. *Failure of Lights and Other than Radio Aids to Air Navigation*—(*a*) Failure and return to normal of obstruction lights, light beacons, and other than radio aids to air navigation (landing T, wind cones, etc.) shall be reported to all concerned by Notice to Airmen in dispatch form and by mail when necessary. When the failure is reported by other than an Air Navigation Division employee the source of the information shall be indicated in the text of the dispatch in accordance with the following:

LOCAL FIELD MANAGER REPORTS SALT LAKE MUNICIPAL AIRPORT BEACON INOPERATIVE UNTIL FURTHER NOTICE 091027

The source of the information and time of receipt shall be indicated on the station file copy of the dispatch. When the information is received at a communication station direct from any employee of the Air Navigation Division, dispatch shall not show the source of the information but shall contain definite advice, example:

BEACON SITE 8 DALTON RESUMED NORMAL OPERATION 1645CS 170225

The time of receipt and source of information shall be indicated on the station file copy if other than by actual observation of the operator or keeper on watch. The appearance of the operator's initials alone on the file copy will indicate that he is the originator of the information. The dispatches shall be signed in accordance with the instructions provided in paragraph 17 (*e*).

15. (*b*) The address of NOTAMS re-lighting aids and other facilities for whose condition airway mechanicians are responsible shall include the headquarters station of the mechanician concerned. If the headquarters of the mechanician is at the station where the NOTAM originates, the words MECHANICIAN ADVISED shall be included as the last words of the text. It will be the responsibility of the operator on duty at the mechanicians headquarters station to notify the mechanician of the failure by the most appropriate means. The NOTAM concerning return of the facilities to normal operation shall be addressed to all points which were addressed in the NOTAM which reported the failure.

15. (*c*) The text of the Notice to Airmen described in paragraph 15 (*a*) shall be broadcast in accordance with the procedure provided for use in connection with radio range failures. (Refer to Instruction Bulletin D–5.) If weather reports do not originate at the location of light beacon or other facilities which are made the subject of Notices to Airmen, in addition to other destinations when required, the notices shall be addressed to and broadcast by the broadcast stations on the same airway or airways adjacent to the facility described.

16. *Form and Example of Dispatch Notice to Airmen* (*a*) In accordance with current instructions, Notices to Airmen in dispatch form shall be broadcast by all radio stations which broadcast weather reports which originate at the point where the inoperative radio aid or other than radio aid to air navigation is located. It is the responsibility of the operator or keeper in charge or acting in charge of each facility to prepare and post in his station and keep corrected to date a list of the stations that broadcast reports from his station. Notices to Airmen in dispatch form shall be addressed to the stations on this list, to the Office of the Manager of the District in which the station is located and to any other address or addresses specified by the District Manager.

16. (*b*) "ALL CONCD" shall be shown as the addressee of Notices to Airmen in dispatch form. Delivery to "all concerned" at each address will be made in accordance with the list posted in the station.

16. (*c*) The character of the dispatch shall be indicated by the use of the phrase contraction NOTAM (notice to Airmen) placed after the abbreviation STP which follows the addressee.

16. (*d*) The following example represents a Notice to Airmen in dispatch form sent by Washington concerning return to normal of the Washington range:

RW PG DY NK CV PI WA 21 WASHINGTON
RICHMOND
PITTSBURGH
CINCINNATI
NEWARK
CLEVELAND
ALL CONCD STP NOTAM WASHINGTON RANGE RESUMED OPERATION 2345ESTH 001525 GM

Note that the time of resumption of operation is indicated on the 24-hour clock system and that the date is also indicated in addition to the usual six figure time group. It will not be necessary to show the date if the facility is restored to service on the date indicated by the 6 figure time group. Some time may elapse between the actual restoration of the facility to operation and the transmission of the Notice to Airmen. It may be advisable to observe the operation of a facility for a short interval before issuance of a Notice that normal operation has been resumed.

16. (*e*) The form of the example in the foregoing paragraph applies to all Notices to Airmen in dispatch form and supersedes all other examples of this form.

17. *Form and Component Parts of Dispatches*—(*a*) Dispatches transmitted by means of the communication facilities of the Air Navigation Division consist of the following five principal parts:

1. The preamble.
2. The address.
3. The addressee.
4. The text.
5. The signature.

17. (*b*) 1. The preamble of a single address dispatch consists of the call letters of the station to which the dispatch is sent, the traffic classification letter and serial number, the call letters of the sending station, the check and the name of the station where the dispatch originates. These component parts shall be transmitted in accordance with the following example:

CG WI GO II GOSHEN

17. (*b*) 2. Dispatches shall be numbered serially at each station starting with No. 1 at midnight, Central Standard Time (or any time after midnight that the first dispatch is sent). The number series shall continue through each 24-hour day with a separate set of numbers to and from each station. ALL, AN, ALL, DC, ALCKT and ALSXN dispatches shall carry daily individual number series separate from each other and from the regular number series. The ALL AN and ALL DC DISPATCHES will carry one series of numbers within the District; ALCKT dispatches will be numbered in one number series instead of each station assigning its own station serial number to ALCKT dispatches.

Similarly, a separate number series will be used for ALSXN dispatches but the same number series will be used by all stations in that section. Numbers shall be marked off the number sheet immediately after receipt of the dispatch for record purposes and to detect missing numbers.

17. (*b*) 3. Dispatches forwarded by means other than Air Navigation Division communication facilities to Air Navigation Division stations shall bear numbers of the regular series. At the time of the daily number sheet comparison a service dispatch shall be addressed to the station concerned stating the number of dispatches sent by other than airways facilities and describing the facility (telephone or telegraph) utilized. Dispatches forwarded by telephone or telegraph should bear complete service data similar to that entered on dispatches transmitted in the usual manner.

17. (*b*) 4. The month, day and year are not included in the preamble. The station to which a dispatch is addressed will, upon receipt, write or stamp the word RECEIVED, the month, day and year and the initials of the receiving operator on the dispatch in the upper right hand corner. Teletype record stations will also write the time transmission was completed on each communication.

17. (*b*) 5. The preamble of a multiple address dispatch will differ from a single address dispatch in several particulars. The following represents an example of the preamble addresses and addressees of a dispatch to all District Managers transmitted by Washington:

NK W16 AG CV W5 FW W2 WA 50 OH W1–2 WA 51 WASHINGTON
NEWARK
ATLANTA
CHICAGO
FT WORTH
SALT LAKE OAKLAND
ALL AN STP etc

When the serial number or check is the same to more than one destination, it is unnecessary to repeat these items with the call letters of each destination. This is indicated in the foregoing example where the serial number to Atlanta and Cleveland is the same and the check to Newark, Atlanta, Cleveland and Fort Worth is the same. When two or more numbers are given to one station they should be separated by a dash as in the case where numbers 1 and 2 are given to Omaha. The call letters of the sending station will precede each check. The first station to receive a serial number will accept the first address, the second station the second address, etc.

17 (b) 6. The preamble of ALCKT, ALSXN, ALL AN (number) and ALL DC (number) dispatch shall conform to the following example:

ALL AN3W1AN CG 15 CHICAGO

17. (*c*) Addresses and addressees are described in some detail in Para. 5. Addresses shall be transmitted on separate lines except when

two or more addresses are given to one station they shall be shown on the same line. Refer to the example in Para. 17 (*b*) 5.

17. (*d*) The text is completed by the six figure time group which is made up as follows: The first two figures indicate the hour of the day by 24 hour clock, the third and fourth figures indicate the number of minutes past that hour and the last two figures indicate the date. Example: 10:00 A.M. on the 24th day of the month is written 100024; 1:00 P.M. on the third day of the month is 130003; 10:35 P.M. on the 17th day of the month is 223517. The time group indicates the time and date the message is filed with operator or the time at which he writes it if he is the sender of the dispatch.

17. (*e*) Dispatches from the Bureau to District Offices and field stations will be signed by the initials instead of the last name of the sender, examples, RM instead of MARTIN and CIS instead of STANTON. No spaces shall be transmitted between the initials. A similar procedure will be effective for the signature of dispatches sent from District headquarters to this office and to field offices. Dispatches addressed to this office by other than District headquarters personnel shall not be signed by initials but by the last name of the sender spelled in full. Dispatches from field stations addressed to District headquarters and other field stations should be signed by initials when the sender is a district headquarters employee temporarily away from headquarters or when the sender is regularly assigned to the station from which the dispatch is sent. In other cases, the signature of the dispatch should be the last name of the sender spelled in full. The foregoing applies to Notices to Airmen in dispatch form and all except service dispatches.

17. (*f*) In SVC dispatches the office of origin, the check and the six figure time group are omitted. The signature is always the office at which the SVC originated followed immediately by the day of the month and preceded by the time of transmission, example:

CG W2 CV SVC
CHICAGO
(TEXT IN DETAIL)
1625 CLEVELAND 10

SVC dispatches are authorized for use between all teletype and radio stations and shall be given the same classification letter as the dispatches to which they refer except that in exceptional circumstances SVC dispatches relative to "D" traffic may be given the "P" classification and SVC dispatches relative to "W" traffic may be given the "D" classification.

18. *Number Sheet Comparison*—(*a*) Number sheet comparison shall be made at midnight C.S.T. by stations between which traffic has been numbered during the previous 24 hours utilizing authorized signals QXF and QAU. Comparison shall be made in sequence order of stations as designated by the Managers of the districts in which the teletype

circuit operates or, in the absence of specific instructions, in sequence order from North to South and from East to West, example:

(Two carriage return and five line feed impulses)
NK DE BW QXF NK 2 QAU NK 3
AZ DE BW QXF AZ 1 QAU AZ 0
CV DE BW QXF CV 3 QAU CV 1

Note—Two carriage returns and five line feed impulses shall be sent at the beginning of the transmission by each station that enters the sequence.

No confirmation is necessary if the numbers are correct. In the event that a discrepancy is noted the missing number or numbers shall be duplicated as soon as practicable. The station transmitting the number sheet comparison shall enter the time of transmission in the station log. The station receiving the comparison shall enter the time of reception in the log with the notation " Numbers correct " or " Numbers comparison incorrect " as the case may be.

18. (*b*) An operator leaving a watch shall check the traffic handled by him against the number sheet and shall note on the log " Numbers correct " or explain any discrepancy to the operator taking the watch.

19. *Information and Public Inquiries*—(*a*) When inquiries concerning aeronautical information in general and pertaining to radio and communication facilities in particular are made of Air Navigation Division personnel, replies should be based on the current instruction bulletins.

19. (*b*) Inquiries relative to subjects not covered by written instructions on file at the station shall be referred to the office of the District Manager for reply.

20. *Monitoring*—The teletype circuits are constantly monitored by telephone company personnel and by a Department of Commerce monitoring station on each circuit and it is therefore practicable to promptly ascertain violations of Air Navigation Division instructions. Conversation, remarks, and unauthorized transmissions on teletype circuits are prohibited. This applies to all stations regardless of whether the personnel is under the jurisdiction of the Department of Commerce or of other organizations. Violations of this ruling will result in cautionary letters to Department of Commerce personnel with possible separation from the service. Violation by other personnel will be cause for notification to Department heads, or possible discontinuance of service at the point where the violation occurs.

21. *Recopying*—When dispatches are recopied, the copy shall be checked against the original, immediately, word for word. Dispatches shall not be recopied unless parts are illegible, as the practice of recopying is dangerous.

22. *Records*—Each day's traffic and reports shall be carefuly inspected by the operator designated to check for errors. The traffic shall then be filed for future reference. Except at teletype record sta-

tions, only copies of traffic handled by the station need be retained in the station files. The office of the district Manager will designate one teletype station on each long lines circuit as a teletype record station. This station so designated will retain a record of all communications handled on the circuit. These records will cover each 24 hour period and shall be dated and stored for reference purposes.

23. *Responsibility of Receiving Operators for Delivery of Dispatch Traffic*—(*a*) The receiving operator is held responsible for delivery of traffic to the addressee through authorized channels. In the event the dispatch cannot be delivered within 24 hours of receipt either in person, by telephone, by messenger, or through other means, the sender shall be advised by means of an "svc" message that the dispatch remains undelivered and further instructions are requested. Attempts to effect delivery shall not be discontinued until advice to "cancel and file" has been received from the sender. In no case shall any dispatch be filed prior to delivery until the sender has authorized such action.

23. (*b*) When a dispatch intended for delivery to a single addressee is transmitted to more than one destination, all of which are to attempt delivery the station completing delivery shall so advise the other stations which received the dispatch in order that they may file the dispatch without further action after attaching a copy of the message reporting delivery.

23. (*c*) At stations where the original received copy of a dispatch is delivered by messenger, no copy is retained in the station files. Where this practice is in effect a suitable entry shall be made on the station number sheet indicating the disposition of the dispatch. If, at a later date, a question arises concerning a dispatch of which no copy was retained in the file of the station where delivery was made, information or a copy of the dispatch may be obtained from the files of the tape record station.

24. *Secrecy of Communications*—Contents of communications shall not be divulged excepting through authorized channels.

25. *Servicing Data*—The following data relative to the transmission of a dispatch shall be entered on the "Sent" file copy. The call letters of the station or stations to which the dispatch was sent, the serial number or numbers, the classification letters, and check. An explanation of any unusual delay in handling the dispatch should be shown. The file copy shall bear the sign of the operator who transmitted the dispatch and the sign of the operator in charge or operator who performed the daily traffic check. The time of the end of transmission on the 24-hour clock basis without the time zone indicator shall be entered by the teletype record stations on all communications.

26. *Sequence Weather Collection and Meteorological Information Transmission Procedure*—(*a*) Teletype monitor stations shall start sequence weather report collections in accordance with the National Communication Schedule by means of the following transmissions:

1. One letters shift impulse.
2. Two carriage return impulses.
3. Five line feed impulses.
4. The sequence designator.
5. One bell.
6. One letter shift impulse.
7. Two carriage return impulses.
8. One line feed impulse.

The sequence designator is composed of the teletype call letters of the first and last reports in the sequence, the time of the sequence collection on the 24-hour clock system, and the abbreviations of the time zone, example:

WA AG 2242ES

26. (*b*) The stations whose reports comprise the sequence collection shall enter the sequence in the order directed by the District Manager. Each station shall start its transmission with its call letters and shall complete its transmission with one bell (signifying end of transmission) one letter shift impulse, two carriage return impulses and one line feed impulse. No space impulse shall be transmitted between the line feed impulse which terminates the transmission of the preceding station and the call letters of the following station as the impulses which perform carriage return and line feed functions on the page model machines will space out tape on the tape model machines which will separate the items on the tape.

26. (*c*) If a station is unable to start teletyping its report within 5 seconds of the time that the preceding station has completed its transmission the station next in order in the sequence shall proceed with its report. The tardy station shall not break in on the circuit but shall enter its report immediately after the last station in the sequence has completed its transmission.

26. (*d*) Upon completion of the transmission of the last report in the sequence and any corrections which are promptly transmitted, the monitor station shall request repetitions or additional corrections if necessary. When the sequence collection is correctly completed the teletype monitor station shall acknowledge for the sequence by the transmission of the letter R, the call letters of the monitor station and one bell. Sequence weather collections will not be considered complete until acknowledged by the monitor station. The personnel who enter reports in sequence collections shall remain at their teletypewriters until the sequence has been acknowledged in order that corrections or repetitions may be promptly furnished unless scheduled broadcast duties require their immediate attention.

26. (*e*) If a station has made an error in the transmission of a weather report which was not noticed in time to correct it before the following station in the sequence started its transmission, the error should be corrected at the end of the sequence by typing the letters CQN

(correction), the call letters of the station making the correction, and the corrected item, example:

CQN VK BRM 998
CQN GO TMP 68

26. (*f*) 1. The instructions issued by the Weather Bureau contained in Circular N, Third Edition, 1935, and supplementary instructions relative to weather reporting procedure are approved and shall govern weather observation duties performed by Air Navigation Division personnel. Meteorological information shall be transmitted by means of the teletype communication facilities of the Air Navigation Division in accordance with the examples contained in Weather Bureau Circular N, Third Edition, 1935.

26. (*f*) 2. If the items comprising a complete weather report exceed a total of 76 characters and spaces, it will be necessary to complete the transmission of the report on the second line as not more than 76 characters and spaces shall be transmitted on one line.

26. (*f*) 3. The abbreviation "M" for "missing" shall be transmitted in place of any item of a report which is missing or is obviously incorrect. Example: If a report is received in which the sky condition is indicated by a broken cloud symbol not followed by a slant symbol and no ceiling height is indicated, the abbreviation "M" for "missing" shall be transmitted in place of the ceiling height.

26. (*g*) Special weather reports other than those transmitted in sequence weather collections shall be preceded by the transmission of 5 line feed impulses. Example of the transmission of a special weather report:

One letters shift impulse.
2 carriage return impulses.
5 line feed impulses.
1 figure shift impulse.
10 bell signal.
1 letters shift impulse.
QXB SPL 1637CG 15 R⊕ ETC

At teletype circuit junction points when a special weather report becomes available for transmission at the time of the usual record weather observation report, it shall, if practicable, be transmitted on all circuits including the local circuit in the usual form of a special weather report prior to the start of the scheduled sequence weather collection in which the record weather observation report would normally be entered. If the special weather report cannot be transmitted on one or more circuits prior to the start of a scheduled sequence weather collection it shall be entered in the place in the sequence or sequences where the record observation would normally appear. Under these circumstances the letters QXB and the time of observation shall not be transmitted and the abbreviation SPL shall follow the call letters of the reporting station. The abbreviation SPL is necessary to call the attention of all concerned to the fact the report represents a decided change in conditions since the previous report. The transmission of the time of observation is not necessary as the time of the observation is established by the designator of the sequence. Example of the form of transmission of a special weather report in a scheduled sequence weather collection:

CG SPL 15 R⊕ ETC

At intermediate teletype weather reporting stations special weather reports becoming available at the time of a record observation shall be transmitted in accordance with the foregoing instructions.

27. *Teletype Discrepancies*—The following items are defined as discrepancies in teletype operating procedure:

27. (*a*) *Late*—Late reports are those which, failing to appear in a sequence, appear immediately at the end of the sequence after the last station in the sequence finishes its transmission.

27. (*b*) *Out of Sequence*—Reports out of sequence are those which appear in the weather sequence but are out of their proper place. Reports which appear at the end of a sequence are not considered out of sequence; they are considered *late*.

27. (*c*) *Missing*—Missing reports are those which do not appear at any time during a sequence nor at the end of the sequence.

27. (*d*) *Slow*—A station will be charged with being slow when it allows the preceding station in the sequence collection more time than the allotted 5 seconds before proceeding with its own report.

27. (*e*) *Errors in Typing*—Where the wrong key is struck and no correction is made or the correction is improperly made, operators will be given the benefit of doubt when garbling of transmission appears to result from line failures but errors occasioned by machine failures will be counted.

27. (*f*) *Unauthorized Abbreviations*—Unauthorized abbreviations are those which are not shown in the authorized lists of abbreviations or subsequent additions to these lists.

27. (*g*) *Failure to Utilize Authorized Abbreviations*—Failure to utilize authorized abbreviations in the transmission of meteorological information.

27. (*h*) *Incorrect Procedure*—Incorrect procedure pertains to the use of unauthorized forms in the transmission of dispatches and weather reports, or any transmission not strictly in accordance with the instructions contained in existing instruction bulletins with additions and corrections thereto, *except that this will not be considered as extending to the actual meteorological significance of the elements of airways weather reports.* For example, the use of 'Remarks' in airways weather reports, as authorized by Weather Bureau Circular N, 1935, permits great latitude in the form of such expressions. A transmission should not, therefore, be changed in these cases, except for incorrect transmission procedure. Examples of remarks quoted in Circular N are only intended as examples and not as being the only remarks that may be transmitted. Incorrect use of "Q" signals, use

of plain language instead of authorized "Q" signals, incorrect method of requesting fill-ins or repeats, incorrect form in transmitting dispatches and PX reports, etc., are examples of incorrect procedure.

27. (*i*) *Incomplete*—Incomplete reports are those which do not contain all items necessary for a complete report, examples, temperature missing, barometer missing or field condition missing when it should be included in the report.

27. (*j*) *Failure to Observe the National Communication Schedule*—Transmission of any communication in other than the periods provided by the National Communication Schedule.

27. (*k*) *Incorrect Classification of Traffic*—Transmission of traffic in Classes D, P, or S S S in violation of the authorized classification.

27. (*l*) Failure to promptly supply repetition or correction of an item of weather report requested prior to acknowledgment of the sequence collection by the monitor station.

28. *Time Signals*—(*a*) In order to insure all stations having the correct time one Air Navigation Division on each circuit will be designated by the District Manager to transmit time as follows once each day: Example, Promptly at 30 seconds of the hour of noon each day the designated station will transmit 10 bells and type out the words "STAND BY TIME" and all stations on this circuit will prepare to set clocks. The station will ring *one* bell exactly on the hour and all stations will set their clocks accordingly. This signal has precedence over all traffic, excepting S S S communications.

NAA TIME SIGNAL SCHEDULES

Time E. S. T.	Frequency (Kilocycles)
0055–0100	113
0155–0200	113
0255–0300	113, 4015, 8030, 9050
0355–0400	113
0455–0500	113
0555–0600	113
0655–0700	113
0755–0800	113
0955–1000	113, 8870; **Note**—8870 not used on Sunday
1155–1200	64. 3. 690. 8410, 12045, 12615, 16820
1255–1300	113
1355–1400	113
1455–1500	113
1555–1600	113, 9050
1655–1700	113
1755–1800	113
1855–1900	113, 9050
1955–2000	113
2155–2200	113, 690, 8030, 9050, 12045
2355–2400	64, 113, 4525

28. (*b*) The signal consists of the transmission of a dot (.) for every second, omitting the 29th, 51st, 56th, 57th, 58th, 59th seconds during the first minute, the 29th, 52nd, 56th, 57th, 58th, 59th seconds during the second minute, the 29th, 53rd, 56th, 57th, 58th, 59th seconds during the third minute, the 29th, 54th, 56th, 57th, 58th, 59th seconds during the fourth minute, the 29th, 51st, 52nd, 53rd, 54th, 55th, 56th, 57th, 58th, and 59th seconds during the fifth minute. At the sixtieth second a 1-second dash (—) will be sent, the beginning of which is the time signal.

29. *Traffic Transmission Procedures*—(*a*) All model 15 (page) teletype machines shall be set for single line feed.

29. (*b*) Where figures or groups of figures and letters occur in dispatches to be transmitted by teletype, these figures shall be transmitted as figures and not spelled in word form. Each figure and letter shall count as one word; example of transmission:

	Check
TYPE UV851 TUBES	7 words
PLANE NC947Y WILL BE	9 words
EFFECTIVE APR 15	4 words

29. (*c*) Carriage return and line feed impulses shall invariably be transmitted with the carriage in the letters position on both 14 model (tape) and 15 (model page) teletypewriters. Two carriage return impulses shall be successively transmitted to effect the carriage return function. When both carriage return and line feed impulses are to be transmitted, the line feed impulse shall in all cases follow the carriage return impulse.

29. (*d*) Delivered dispatch copies received on page model teletypewriters shall have a minimum length of approximately 5 1/2 inches. To secure this uniform size the following described procedure shall be followed:

> The first items of a dispatch transmission shall be a letters shift impulse and two carriage return impulses following by the transmission of the plus sign on the upper case letter z. This sign shall be placed at the extreme left side of the paper. After this sign one letters shift, two carriage return, and eight consecutive line feed impulses shall be transmitted followed by the preamble; one letters shift, two carriage return and two line feed impulses shall then be transmitted; then the address; then letters shift, two carriage return and two line feed impulses, followed by the text. One letters shift, two carriage return and two line feed impulses shall be transmitted at end of each line of 65 to 76 characters and spaces throughout the text. After the time group one letters shift and two line feed impulses should be transmitted followed by the signature placed to the right of the end of the text when there is sufficient room, otherwise, a letters shift and two carriage return impulses shall be transmitted followed by the signature placed at

the left margin. One letters shift and consecutive line feed impulses shall then be transmitted until the plus sign at the start of the dispatch is eight lines beyond the edge of the glass cover of the teletypewriter. Two carriage return impulses followed by one figure shift impulse and a second plus sign shall then be transmitted followed by one bell signifying end of the dispatch. Subsequent dispatches shall be sent in the same manner. The plus signs will then serve as guides when separating the dispatches for delivery.

Exact example of the form of a dispatch transmitted on a page model teletypewriter:

Example:
NK W 16 AG CV W5 FW W2 WA 50 OH WI–2 WA 51 WASHINGTON
NEWARK
ATLANTA
CHICAGO
FORT WORTH
SALT LAKE OAKLAND
ALL AN STP INDICATED DISTRICT HEADQUARTERS AND FIELD STATIONS TRANSMITTING NUMBER OF DISPATCHES THAT SHOULD BE MAILED STP UTILIZE MAILS EVERY CASE PRACTICABLE AND ELIMINATE UNNECESSARY WORDS FROM DISPATCH TRAFFIC STP INSPECTOR WILL BE DETAILED FROM THIS OFFICE TO CHECK MONITOR AND DISPATCH RECORD STATION FILES
170028
RM

If a dispatch contains so many words that the first plus sign has passed beyond the edge of the glass cover of the teletypewriter before the signature is reached, a minimum of eight line feed impulses shall be transmitted before the second plus sign is struck.

29. (*e*) The instructions provided in Para. 29 (*d*) from the start of the transmission to and including the transmission of the signature apply also to the transmission of traffic from a tape model teletypewriter. Following the signature, the transmission shall be completed by the transmission of sufficient line feed impulses to bring the total number of line feed impulses transmitted in the dispatch to 34. Following the transmission of the 34th line feed impulse one figure shift impulse shall be transmitted followed by transmission of the character plus mark on the upper case of the letter Z, and one bell signifying the end of the dispatch. If there are 34 or more line feed impulses utilized during the transmission to and including the signature, at least 5 line feed impulses shall be transmitted before the plus sign is struck.

29. (*f*) When dispatch traffic is prepared on local perforators for transmission, the same procedure as that followed when sending from a tape model teletypewriter will apply.

Section 2

Radio Communication Procedure

1. *Operation*—The instructions relative to teletype operating procedure shall apply to radio communication procedure wherever practicable with the exceptions herein provided.

2. *Calling and Answering*—(*a*) The calling station shall call once and sign once at a rate of twenty words per minute, except that the call may be made twice if conditions are such as to require the transmission of words twice in handling traffic or when it is difficult to contact the station called.

2. (*b*) The station calling shall indicate at the end of the call the prefix of the highest class traffic on hand for transmission; example:

WWAV DE WWAW D

if PX traffic is on hand, this may be indicated by the calling station in the following manner:

WWAV DE WWAW PX

If additional traffic is on hand after completion of the first dispatch, the transmitting station shall indicate the prefix of the highest class of traffic remaining before sending "K." If the receiving station or stations have traffic, they shall indicate the prefix of the highest class traffic on hand when acknowledging, but shall wait for the invitation to transmit before sending.

2. (*c*) A station when called shall answer immediately, calling once and signing once advising the calling station to "K" PROVIDED the called station has no traffic on hand of a higher grade than the calling station; examples:

(Calling Station) WWAV DE WWAU D
(Called Station) WWAW DE WWAV K

If the station called has on hand traffic of a higher grade than the calling station it shall state the prefix of the class at the end of the call instead of answering "K"; example:

(Calling Station) WWAV DE WWAW D
(Called Station) WWAW DE WWAV P

The calling station shall then accept the class "P" traffic from the called station before proceeding to clear his traffic.

2. (*d*) After contact has been established in the usual manner between two or more stations, it is unnecessary for the stations to utilize their full radio calls in the ensuing communications. Contractions consisting of the last two letters of 3 or 4 letter radio calls may be utilized, example:

AW DE AV Instead of WWAW DE WWAV

The complete radio calls will continue to be utilized in connection with the transmission of sequence weather collections and other meteorological information.

2. (*e*) The transmission of special weather reports, airways forecasts and other information intended for several stations shall be preceded by the transmission of the signal QST repeated three times, example,

QST QST QST DE WWHS

3. *Fill-ins and Verifications*—(*a*) When a portion of the text of a message has been lost through interference or other causes and a fill-in is required, the receiving operator shall repeat the words correctly received on either side of the missing portion separated by a question mark: example, "PLANE? ARRIVED K." The transmitting operator would then repeat the word plane and continue through the word arrived: example, "PLANE NS 15 ARRIVED K." If the entire first part of the message has been lost the fill-in shall be requested as follows: example, "AB PLANE K", meaning "REPEAT ALL BEFORE 'PLANE.'" The transmitting operator would then repeat the entire message to and including the word "plane." If the entire last part of a message has been lost the receiving operator shall repeat the last word correctly received followed by a quotation mark and the word "END"; example, "ARRIVED'? END K." The transmitting operator would then repeat the word "ARRIVED" and continue to the end of the message.

3. (*b*) When it is desired to obtain verification of doubtful words or phrases the receiving operator shall repeat the questionable portion followed by four dashes indicating doubt. Example, a message has been sent containing the words "MORRISSEY" and "LABIN" which the receiving operator wishes to verify. He would then send "MORRISSEY—LABIN—K." If there is no question, the transmitting operator would reply "OK"; if doubt as to the accuracy of the reception still exists the words may be repeated until the uncertainty is removed.

4. *Dispatch Transmission Procedure*—The break signal (BT) shall be transmitted between the end of the preamble and the address, *and* between the six figure time group and the signature. The short comma (AA) shall be transmitted between the address and the addressee, and between the end of the text and the six figure time group. In multiple address dispatches the short comma shall be transmitted after each address.

5. *Number Sheet Comparison*—At the end of each 24-hour period (midnight C.S.T.) service messages shall be exchanged between stations which have handled numbered traffic, for the purpose of confirming the number of dispatches handled during the previous 24 hours. The "number services" shall be carefully checked against number sheets and any discrepancy in numbers shall be promptly corrected. Stations should transmit their "number services" in the order in which they enter sequence weather collections.

6. *Equipment*—Communication by using sets not part of the station equipment and communication with stations not in the Air Navigation Division must be specifically approved by this office.

7. *Interruptions*—In case of communication failure, a continuous watch shall be maintained within the assigned hours, utilizing radio, telegraph, telephone, or local messenger service to serve the intended purpose of the traffic. The radio circuit monitor station shall be advised of the probable time that communication will be resumed. Weather reports shall be forwarded during the failure period in accordance with Weather Bureau instructions unless different procedure has been approved by this office.

8. *Prevention of Errors*—(*a*) The following transmission procedure is provided to facilitate transmission and reduce errors in radio communication:

Transmit one dash instead of five dashes for 0 (zero) when the 0 is part of any figure except 10. When the figure 0 (zero) appears alone, it shall be transmitted ZERO.
Transmit I—for one.
Transmit FR—for four.
Transmit SV—for seven (regular speed)
Transmit Ten, tenth, with dash sent longer in order to prevent losing this number in static.
Transmit Six, half speed.
Transmit Thirteenth, half speed.

8. (*b*) In the radio transmission of weather reports the abbreviations ETD for Estimated and HZ for Hazy shall be *transmitted* instead of the abbreviations utilized on the teletypewriter circuits. The word EAST shall not be abbreviated on the radio circuits. The abbreviations ETD and HZ shall be *copied* E and H respectively.

9. *Responsibility for Communication*—The sending radio operator is responsible for the proper and judicious transmission of traffic and if it is seen that traffic cannot get through in time by the radio circuit to serve the intended purpose, the sending operator may send the traffic by the method required to serve the intended purpose at the expense of the Air Navigation Division, excepting that Weather Bureau traffic shall be handled in accordance with their regulations governing transmission at U. S. Weather Bureau expense during failures.

10. *Sequence Weather Collection Transmission Procedure*—(*a*) The installation of typewriters of type pallets carrying the symbols utilized in the transmission of weather reports by teletype has made possible the delivery of weather information in the same form irrespective of whether radio or teletype communication facilities are employed. To eliminate the delay incidental to the conversion of symbols to abbreviations and the transmission of the abbreviations by radio the symbols and characters utilized in the transmission of weather reports by teletype shall be transmitted by radio utilizing the following radio code:

Symbol or Character	*Radio Code Equivalent*
+ (Plus sign)	• — • — • (AR)
/ (Slant)	— • • — • (DN)
○ (Clear)	— — — • (German o)
⦶ (Scattered Clouds)	— — • • — — (Exclamation point)
⊕ (Overcast)	— — — — • • — (OX)
○ (Broken Clouds)	— • • • — • — (BK)
— (Dash)	— • • — • • — (DX)

The radio characters representing symbols shall be transmitted without space, i.e., ⊕ shall be transmitted — — — — • • —; not — — — — • • —.

10. (*b*) Weather sequences shall be started promptly at the scheduled time. The station starting a sequence weather collection shall, first, make its own radio call twice; second, transmit the sequence designator; third, transmit its own teletype call letter or designator; fourth, proceed directly with the weather report; fifth, upon completion of the report the station shall transmit its own radio call once.

The succeeding stations in the sequence shall, first, make own radio call twice; second, transmit its own teletype call letters or designator; third, proceed directly with the weather report; fourth, transmit own radio call once, example,

WWAW WWAW CS○8 76/72NW6 027 WWAW

The number "10" when appearing in ceiling, visibility, wind velocity, temperature or dew point shall be transmitted as "TEN." This does not apply to barometer figures; 3010 shall be sent 010 (the number 10 shall be written when the word "ten" is transmitted, example,

WWAW WWAW CS⊕/TEN NW TEN 010 WWAW

10. (*c*) Repetitions shall not be supplied until the sequence has been completed but shall be furnished before any other business is handled. If a station is asked for repetitions by two or more stations, they shall be supplied in the order in which the requests were received. Example of request procedure: Assume that the portion from the wind to the end of the Charleston report (which precedes Jacksonville in the sequence) has not been received at Jacksonville. The Jacksonville report should be transmitted in the usual manner with the request for repetition of the Charleston items transmitted as follows:

WWAV WWAV JX○ 9 83/71SW6 987 BT CS WIND ? END WWAV

If the report was received correctly except for the visibility, the repetition should be requested as follows:

BT CS VSBY ? WWAV

APPENDIX 1

AERONAUTICAL RADIO OPERATOR'S EXAMINATION

The following questions are a specimen of an examination conducted by an air transport company for applicants for positions as ground station operators. The material which has been included in chapter 20 as well as previous ones will be helpful in answering the questions. It should of course be understood that applicants for such positions must hold a valid operator's license of the proper grade issued by the Federal Communications Commission.

QUESTIONS FOR RADIO OPERTORS EXAMINATION

1. What is the law regarding secrecy of radio messages and penalty for violation?
2. Who can legally operate radio apparatus?
3. What matter is unlawful to transmit by radio under any circumstance?
4. What are the penalties for violation of the licensing authority? (FCC)
5. Name five misdeeds that constitute grounds for suspension of operator's license.
6. What class of station does your license permit you to operate?
7. When a new operator's license is received what acts are necessary before the license becomes valid?
8. What is the penalty for operating a station without a license? (Station License)
9. What is the rule regarding posting of operator's and station license?
10. Where can you find regulations concerning operator's license?
11. What is the penalty for an unlicensed operator operating a licensed station?
12. How many days prior to expiration must you apply for renewal of your license?
13. What is the FCC requirement in regard to the Station Log of aeronautical stations?
14. How long must the Log be kept in file at the station?
15. What constitutes a radio Log for our stations?
16. What class of messages are authorized over aeronautical stations?
17. What class of messages are unauthorized over aeronautical stations?
18. What class of messages are authorized over aircraft stations?
19. What class of messages are unauthorized over aircraft stations?

20. What is the rule regarding time entries on message and PX reports?
21. Contact may be made with what class of stations?
22. If an amateur station should interfere with your operating, what would be your procedure?
    (*a*) If on your frequency and called you, would you answer him?
    (*b*) Any exceptions?
23. What is the rule regarding "Attempted Contacts"?
24. What is the rule regarding requesting repeats on all or part of a message after it has been acknowledged and how should this be logged?
25. What entries are required in the equipment log books?
26. What is the international radio telephone distress signal?
    (*a*) What is the urgency signal?
    (*b*) What is the emergency signal on our circuit?
27. What is the penalty for transmitting fraudulent distress signals?
28. During an "Emergency" period, what transmissions may be made?
29. During an "Emergency" period a message is sent you that should not be handled, how should it be acknowledged? Any further action?
30. Some messages and PX's are heard which indicate a condition that may develop into an "Emergency."
    (*a*) What record would you make of these?
    (*b*) Would such record receive any special handling?
31. When a pilot calls "Emergency," what is the operator's procedure?
32. If you heard a plane in some other sector in your division in distress or experiencing trouble of any kind, what would you do?
33. What disposition is made of all messages and PX reports copied during an emergency?
34. What action would you take if operations are normal and an operator of another service calls you by 'phone and tells you there is an "emergency" on his circuit, that your signals are interfering and requests you shut your stations down till further advised?
    (*a*) What action would you take if the weather at your station was unfavorable and you had a plane or planes approaching that had to be kept posted on conditions at your stations?
35. Assume there is an emergency on your circuit and you are receiving interference from a broadcast, aeronautical, commercial, amateur or other station, you call the interfering station explaining the circumstance and request them to shut down and they refuse or ignore your request, what action would you take?
    (*a*) What log entry would you make?
36. What is meant by "Suspension of Message Traffic"?
    (*a*) During a "Suspend Message Traffic" period, what transmismissions may be made?
    (*b*) Under conditions above, what disposition is to be made of traffic not falling in those classifications?

(*c*) By a sending operator?
(*d*) By receiving operator?

37. What is the purpose of the "ten second period"?
    (*a*) A pilot has requested a weather sequence and some winds aloft, should the ten second period be observed in transmitting this information?
    (*b*) If you were transmitting a message and broke for the ten second period in what manner would you continue the message at the end of the silent period?
38. What is the rule regarding signatures on messages?
39. What is the rule on messages requesting material by radio?
40. How should messages concerning mechanical difficulties with planes be handled?
41. What is the rule regarding acceptance of "Verbal Messages" by an operator?
42. When an operator receives a message which he believes should not have been handled by radio, what disposition should be made?
43. What entry is required on all messages written by a person other than the radio operator?
44. How long may a message be delayed in the radio room and what entry is required if the delay exceeds this period?
45. Give examples of correct procedure in calling a station for transmittal of a message.
    (*a*) Messages of different classifications.
    (*b*) What is proper procedure in case station called does not answer immediately?
46. What is correct procedure in acknowledging a message?
47. What would you do if a station on one side of you called a station on your other side in an attempt to work direct, but is unable to effect a contact for some reason?
48. Can you handle any classification of message or make any transmissions without verbatim written record? When?
49. Can personal messages be handled on the circuit? If so, what is the procedure for handling?
50. Who will make final determination as to whether a message will be handled by radio or wire?
51. Can messages pertaining to aircraft mechanical troubles be handled over the radio circuit?
52. Has an operator the authority to change a poorly constructed message?
53. Suppose you received a message and had copied it solid but was just a trifle doubtful of one word. How would you verify that you had received it correctly?
54. How should figures be read in messages?
55. In view of the fact that contacts with airplanes take precedence over all others, is there any restriction concerning the type of message which can be handled between planes, or between planes and ground stations?

56. What information is to be included in the servicing of a message?
    (*a*) Give example of message received by you.
    (*b*) Sent by you.
    (*c*) Received and relayed by you.
    (*d*) Received by you for relay but copied direct by next other stations.
57. If an error is made on a PX or message, how is the copy to be corrected?
58. Decode the following message:
    THUOC ILABA SMITH JOHNSON BROWN ACCBC OLCOA MOCCO XOOBZ YAIOB BOOCO ASFCG FRIOB ACXSL SECOB THUOC DELPA CLEARED CHOH TCGIY CDAO.
59. What is the code for spelling words by radio?
60. When are we permitted to transmit Reservations advice to planes in flight?
61. What is the rule in regard to OFF Schedule calls to planes when you have a long message to give the pilot?
62. When and where may a loud speaker be used?
63. Would you handle messages relating to an accident by radio under any circumstances?
    (*a*) If so, explain.
64. Who is responsible for traffic put on the air?
65. What is the rule regarding operators leaving the microphone?
66. Suppose you received a message for transmission that you knew definitely should not be handled by radio. You return the message marked "NOT FOR RADIO" and the message writer, who is your superior, insists the message be transmitted what would you do?
    (*a*) Suppose the above message is sent and we are cited by the FCC, who would be responsible, the operator or the writer?
    (*b*) Suppose the writer is also a licensed operator, who would be responsible?
67. Should landing instructions be written up before transmitting? Explain.
68. When a pilot calls for landing instructions, what routine information do you give?
69. When may a pilot be assisted through an overcast by two-way radio?
70. In case of failure of plane's two-way radio in flight during unfavorable weather, what steps would you take to get important information to the pilot?
71. When a pilot in flight advises by radio of the failure of a Department of Commerce Airway aid, what action do you take?
72. You have a very urgent message—one that could practically be called an emergency—for a ship approaching your station. You have been unable to hear or raise the ship for the last 45 minutes, what would you do to insure that every available means of getting that message across had been used?

73. What is the ground station calling routine in respect to position reports?
74. If a windshift line was approaching your station, outside of the weather coming in on the teletype, what would you watch very carefully and give to trips approaching your station?
75. If a pilot reported he was running on one motor what would be your first question to him and what precautions would you take, as no emergency had been sent. Would you call this an emergency? If so, why?
76. If a PX report is missed while a ship is in your sector, due to the fact that you were busy working another section on the field, would you ask the next station for a repeat on this PX? If so, why?
77. Another station in your PX sector is heard giving landing instructions.
    Part is unreadable at your station. What PX record would you make, would you request a repeat on the part missed?
78. You have been unable to copy a PX report of a plane in your sector, interference completely broke up the contact stations repeat.
    (*a*) Under what general conditions would you request a repeat?
    (*b*) Would the request have to be in message form?
    (*c*) If you did not request a repeat, what entry in the PX log would you make?
79. Are we permitted to communicate with government planes?
80. A trip approximately 10 minutes out requests land instructions, in 20 seconds 2 other planes are scheduled to report, what would be your procedure?
81. The weather is somewhat unfavorable—what parts of a pilot's PX report should be repeated in acknowledging?
82. When it is evident that a plane's transmitter has failed, what is operator's procedure?
83. When a plane's long wave receiver fails under unfavorable weather conditions what is operator's procedure?
84. When a message is received from or sent to a plane, where shall this message be filed?
85. If a pilot reported "Will be in Saugus in three minutes, put us in at 855A," how would you enter this on the PX report?
86. What is the correct sequence for the information given in PX reports?
87. What radio tests are required before a plane is dispatched from a station where sections are originating or when plane or pilot is changed?
88. When a pilot calls in for apron check, what information do you give him?
89. What is the responsibility of the station in regard to planes taking off?
90. How should coverage be provided to privately owned planes operating on your division frequency?

91. The weather sequence for your sector, including that of your own station, comes on the tape at 41 minutes past the hour. Conditions at your station are poor and variable. The ceiling has been varying up and down between say, 600 and 2000 feet, and the visibility about one half to two miles. At about five minutes past the hour the pilot of a trip approaching your station asks what your weather is. What would you do?
92. The pilot of an approaching trip wants the weather at the first Department of Commerce reporting stations on either side of you. It is impossible to get it by teletype inside of at least ten to fifteen minutes. The pilot is in a hurry for it. What would you do?
93. If all or part of your radio went out, and you couldn't get it back on the air within a reasonably short time, what steps would you take?
94. At terminal stations where dispatchers are on duty, what are the operator's duties when assisting a plane through the overcast?
95. What are frequency monitor reports?
    (*a*) How often are they made out?
    (*b*) What stations are monitored by your station?
    (*c*) What disposition is made of frequency monitor reports received from other stations?
    (*d*) How is the monitoring done?
96. On what frequency does the transmitter at your station operate and how is the frequency controlled?
97. What is meant by "working break-in"?
98. What type antenna is used?
99. What action would you take if advised by another station that your transmitter was "OFF FREQUENCY"?
100. Give the location and type, power of all DC radio facilities in your PX sector.
101. Name the regular on course weather reporting stations in your PX sector.
102. What off course stations are generally used in your division?
103. From what points do you have occasion to secure special reports and how do you secure this information?
104. What is the type and power output rating of our ground station transmitters?
105. Name the type and purpose of all tubes used in the transmitter and rectifier?
    (*a*) SW Receiver.
    (*b*) LW Receiver (if used).
    (*c*) Constant level mike amplifier.
    (*d*) A-Power supply.
    (*e*) B-Power supply.
    (*f*) Remote control telephone line amplifier (if one is used).
    (*g*) Teletype rectifier (if one is used).
    (*h*) Teletype repeater (if used).
    (*i*) Public address system amplifier (if used).

107. What is the normal readings of the meter on the rectifier with mike button off? With mike button pressed?
108. What are the normal readings of all meters on the transmitter with mike button off? With button pressed?
109. What relays operate when the mike buton is pressed, and what is the function of each?
110. On what frequencies will the following equipment at your station operate:
    (*a*) Transmitter.
    (*b*) SW Receivers.
    (*c*) Long Wave Receiver (if any).
    (*d*) Airport localizer (if any).
111. During what hours must a station that has an airport localizer maintain a watch on 3105 KC?
112. During what hours must airport localizers be in operation?
113. Assume another station reports your carrier rough. Checking the transmitter meters you find the output plate and R.F. current is low. All rectifier meters normal, no load, under load the 2500 volt rectifier meter drops to 1800 to 2000 volts. What are the probable causes of this trouble?
114. If a vacuum tube fails and is replaced what entries are made on the "sticker" attached to each tube? What entries are made on the tube which is removed? What entries are made in the station equipment log? What disposition is made of a defective tube?
115. If you were required to replace a defective tube from your spare stock and the new tube had no sticker attached, what would you do in order that a record of the tube life might be recorded accurately?
116. If a casual visitor should touch the transmission line ("lead-in") on your transmitter while you were transmitting and received a serious burn or shock what would you do?
117. If a radio serviceman were "knocked out" by an electrical shock while adjusting your transmitter what would you do? If he should fall into the transmitter and continue to be shocked what would you do?
118. If a properly identified FCC radio inspector told you to stop transmitting because of an alleged license infringement what would you do?
119. Assume you get a complaint on the quality of your transmitter, you find the following conditions: Output plate and R.F. current normal; osc. and Mod-Amp. grid low; Mod-Amp. and audio plate low; 2500 volt rectifier and bias meters normal; 1000 volt rectifier drops to about 700 volts under load. What are the probable causes of this trouble?
120. Assume your transmitter fails and on checking the meters you find the following conditions: All rectifier meters read normal, transmitter meters all read zero except audio plate which reads normal. What are the probable causes?

121. Assume your transmitter fails and on checking the meters you find them all normal except there is no output plate or R.F. current. What are the probable causes?

122. Assume the 1A–1000 volt fuse blows, what are the indications on the transmitter and rectifier meters and the probable causes?

123. (*a*) Assume the 1A–2500 volt fuse blows, what are the indications on the rectifier and transmitter meters, and the probable causes.

124. Assume the 1000 volt vacuum relay fails to operate, what are the indications on the rectifier and transmitter meters and how would you make temporary repairs?
    (*a*) Assume the 2500 vacuum relay fails, what are indications on the rectifier and transmitter meters and the probable causes?

125. Assume your rectifier is running no load (the transmitter is not on the air) and suddenly the relays all kick out. Inspection shows one or more 1A–4 AG fuses in the 2500 volt rectifier anode leads blown. Assume you replace the fuses and press the start button. As soon as the relays kick in the fuses blow again and all relays kick out, what are the probable causes of this trouble? Describe step by step how you would proceed to localize it.

126. Assume that every time you press the mike button the 1A fuse in the 2500 volt circuit blows. What are the probable causes?
    (*a*) Assume that the 1000 volt circuit fuse blows under the same circumstances. What are the probable causes?

127. How do you test the 1A–1000 volt and 2500 volt fuses for continuity?

128. Make a sketch of the back rectifier showing the location, purpose and value of all fuses. Show the location and purpose of all relays.

129. Make a sketch of the rectifier looking from the top front showing the location and purpose of all tubes and fuses.

130. Make a sketch of the transmitter looking from the back. Show type, location and purpose of all tubes.

131. Make a sketch of the front of the rectifier and transmitter showing the location and purpose of all meters.

132. Assume your transmitter relays fail to operate when you press the mike button. What are the probable causes for this trouble?

133. Assume your receiver goes out, what are the most likely causes of trouble?

134. What are the meter indications on the transmitter if the
    (*a*) Oscillator tube goes dead.
    (*b*) Doubler tube goes dead.
    (*c*) Mod-Amp tube goes dead.
    (*d*) Output tube goes dead.

135. Assume your transmitter is operating satisfactorily as far as all reports from stations are concerned. All meter readings are normal except output plate, which reads zero. What are the probable causes of trouble?

136. How many spare fuses of each size do you have in stock, and where are they kept?
137. Why is it necessary that failed tubes be packed and handled as carefully as new stock.
138. Where are the spare 249–B rectifier tubes kept? Why?
139. What procedure is necessary before the plate voltage is applied to a new 249–B rectifier tube?
140. If stations called do not answer and upon observation of transmitter meters, no indication of modulation is found, what is proable trouble and how could temporary correction be made quickly?
141. What size fuses should be installed in all units or relay rack and in units at remote receiver locations?
142. Why should any fuse be of a definite rating?
143. If a local ES 192 receiver fails to shift frequency, what is the probable cause of difficulty and how corrected?
144. Should meter glasses be washed with damp cloth while power is on? Why?
145. When transmitter and rectifier are apparently "off" because doors have been opened, are any parts of the apparatus still "alive" and what precautions should be taken before working on the units?
146. If any of the rectifier meter circuits are "open" what precautions should be taken before touching any parts within the rectifier?
147. If a 251A power tube or associated circuits fail to function, how could limited range operation be continued quickly?
148. If an ES 192 receiver blocks to an unusual extent on transmissions from nearby ship stations what tube in the receiver probably needs replacement?
149. Define the following terms as used in weather reports:
    (*a*) Clear.
    (*b*) Scattered clouds.
    (*c*) Broken clouds.
    (*d*) Overcast.
150. What is the height above ground of clouds referred to as "high"—in weather reports as "HIGH OVERCAST—LOWER BROKEN EST. 8H."
151. Define the following:
    (*a*) Mild thunderstorm.
    (*b*) Moderate thunderstorm.
    (*c*) Severe thunderstorm.
152. Define the following:
    (*a*) Hazy.
    (*b*) Thick haze.
    (*c*) Blowing snow.
    (*d*) Fog.
    (*e*) Ground fog.
    (*f*) Ice fog.

153. Define the following:
    (*a*) Temperature.
    (*b*) Dewpoint.

154. How many points of the compass are used in reporting wind directions on weather printers?

155. Define the following:
    (*a*) Variable.
    (*b*) Fresh gusts.
    (*c*) Strong gusts.

156. What are the teletype symbols for the following sky conditions?
    (*a*) Clear.
    (*b*) Scattered clouds.
    (*c*) Broken overcast.
    (*d*) Overcast.
    (*e*) High scattered clouds.
    (*f*) High broken clouds.
    (*g*) High overcast.
    (*h*) High overcast, lower broken clouds.
    (*i*) High overcast, lower scattered clouds.
    (*j*) High broken, lower broken clouds.
    (*k*) High broken, lower scattered clouds.
    (*l*) High scattered, lower scattered clouds.
    (*m*) High scattered, lower broken clouds.
    (*n*) Overcast, lower broken clouds.
    (*o*) Overcast, lower scattered clouds.
    (*p*) Broken, lower scattered clouds.
    (*q*) Broken, lower broken clouds.
    (*r*) Scattered, lower broken clouds.
    (*s*) Scattered, lower scattered clouds.

157. Decode the following symbols:

F+
IF+
S+
R+
ZR+
SL+
HL+
MI+
ZMI+
BS+
BD+
BSA+
K+
H+
D+

In what portion of the weather report do they occur?

158. Decode the following:

R—
R
R+
S—
S
S+
ZR—
ZMI—
SMI+
SL—
SL
SL+
HL—
HL

ZR
ZR+
SP
MI—
MI+
HL+
T—
T
T+

In what part of the weather report are they used?

159. Decode the following:

F—
F
F+
GF—
GF
GF+
H
H+
K
K+
D
D+
BS
BS+
BD
BD+
BSA
BSA+
IF—
IF
IF+

In what part of the weather report do they occur?

160. What is the proper order of information appearing in weather reports?

161. Code the following report:
Estimated 1,200; overcast; 2 miles; severe thunderstorm; heavy rain; heavy hail; temperature 75; dewpoint 73; wind west 30, severe gusts; barometer 29.91; field flooded; thunderstorm moving east.

162. Code the following report:
Estimated 1,500; high overcast; lower broken; five, hazy; twenty three; twenty one, east eight; thirty zero two.

163. What is the operators' responsibility in regards to keeping pilots informed of weather along the route?

164. What part of the following PX report would you repeat to the pilot for confirmation?

.JONES—UNITED FIVE—OVER GOSHEN—TWO ZERO FIVE—SIX THOUSAND—HIGH OVERCAST ESTIMATED TEN THOUSAND—BROKEN BELOW TOP ESTIMATED FOUR THOUSAND—TEMPERATURE SIX FIVE—SLIGHTLY ROUGH—ESTIMATE MCCOOL TWO FIVE FIVE FOUR THOUSAND CHICAGO THREE TWO FOUR—GO AHEAD.

(*b*) How would you copy the above report on the PX form?

165. (*a*) On what dates is the kollsman altimeter at your station replaced?
(*b*) What other equipment is replaced at the same time?

166. What is the altitude of the Kollsman at your station?

167. What is the altitude of the field at your station?

168. What is the code for the days of the week?

Days
Sunday ____________
Monday ____________
Tuesday ____________
Wednesday ____________
Thursday ____________
Friday ____________
Saturday ____________

169. What is the code for the months?

Months
January ____________
February ____________
March ____________
April ____________
May ____________
June ____________
July ____________
August ____________
September ____________
October ____________
November ____________
December ____________

170. What is the code for clouds?

Clouds
Cirrus ____________
Cirro-Stratus ____________
Cirro-Cumulus ____________
Alto-Stratus ____________
Alto-Cumulus ____________
Alto-Cumulus-Castellatus ____________
Strato-Cumulus ____________
Mammato-Cumulua ____________
Cumulus ____________
Nimbus ____________
Cumulo-Nimbus ____________
Stratus ____________
Fracto-Stratus ____________

171. What is the code for directions and variations?
Directions and Variations

North (ern) (erly) (ward) ____________
North northeast (ern) (erly) (ward) ____________
Northeast (ern) (erly) (ward) ____________
East Northeast (ern) (erly) (ward) ____________
East (ern) (erly) (ward) ____________

East southeast (ern) (erly) (ward)
Southeast (ern) (erly) (ward)
South southeast (ern) (erly) (ward)
South (ern) (erly) (ward)
South southwest (ern) (erly) (ward)
Southwest (ern) (erly) (ward)
West southwest (ern) (erly) (ward)
West (ern) (erly) (ward)
West northwest (ern) (erly) (ward)
Northwest (ern) (erly) (ward)
North northwest (ern) (erly) (ward)

172. What is the code for the following air transport lines?

Scheduled Air Transport Lines

American Airlines
Braniff Airways
Canadian Airways
Chicago & Southern
Eastern Air Lines
Hanford Airlines
National Parks Airways
Northwest Airlines
Pan American Airways
Pennsylvania Central Airlines
TWA, Inc.

174. What is the code for the following root endings of words?

Endings

able
al
ally, erly, ly
ance, ence
der
ed, ied
ening
er, ier
ern
ically
iest
iness, ness
ing
ity
ive
ment
ous
s, es, ies
tion, ation
ward

APPENDIX 2

The UNITED STATES COAST GUARD being vitally interested in promoting SAFETY OF LIFE AT SEA, recommends that RADIO EQUIPPED VESSELS:

WHEN IN DISTRESS:

Approximately 10 minutes after transmitting your distress message, giving *all information* which will leave no doubt as to your trouble and position, do not fail to transmit slowly on the distress frequency *own ship's call and "mo"* for 3 minutes to enable direction finding equipment to be used, thereby permitting assistance to come to you without difficulty or delay.

WHEN ANOTHER IS IN DISTRESS:

1. Give *absolute priority* to distress call and messages relating thereto.
2. *Cease all transmissions* capable of interfering with the conduct of distress communications.
3. Maintain *absolute silence* if within range and not actually taking part in the conduct of distress communications.
4. Concentrate attention on the distress case and *intercept all information possible.*
5. If unquestionably in vicinity of distressed vessel, *acknowledge receipt* of the distress message, if received, *giving your position* to the vessel in distress, stating action being taken.
6. Be extremely careful *not to interfere* with stations more favorably situated to handle the case.
7. *Do not* try to silence other units, i.e. "Q R T," *unless you are in control.*

REMEMBER THAT THE VESSEL IN DISTRESS CONTROLS

Permit *him* to handle the situation without being interfered with. The vessel in distress *may* delegate this control to some other station *more favorably situated. Do not interfere* with the station lawfully controlling the situation.

In Minor Cases of Distress or Other Trouble

Use the urgent signal (XXX), or the general call for any Coast Guard Unit (NCU).

U. S. COAST GUARD FORM 800–D

APPENDIX 3

U. S. COAST GUARD FORM 800–M
APPROVED BY U. S. PUBLIC
HEALTH SERVICE.

MEDICAL AID BY RADIO TO VESSELS AT SEA

In order for a doctor to properly diagnose a request for medical aid all pertinent information is necessary. Before sending a radio message for medical advice the sender should carefully examine the patient and obtain all information possible and embody the data in one message. The following is presented as a guide for obtaining data:

(1) How long has the patient been sick? Was he taken sick suddenly, or did the sickness come on slowly?
(2) Has the patient a fever, and if so, how much?
(3) What is the patient's pulse rate per minute?
(4) How many breaths does the patient take per minute?
(5) What is the general appearance of the patient? Is the flesh in any part of the body swollen?
(6) Is the sickness thought to be due to poison or to poisoned food?
(7) Is the sickness thought to be due to a communicable disease, such as cholera, smallpox, etc.? To what diseases have the crew been exposed? Name and how long out of port of departure?
(8) Are other members of the crew suffering from the same sickness, or have other members been sick and recovered, or died?
(9) Mention all the symptoms or complaints of the patient.

The following is a list of common symptoms which may be used to aid in bringing out all the information:

(1) Headache.
(2) Chills.
(3) Fever.
(4) Pain, location and character.
(5) Nausea.
(6) Vomiting.
(7) Diarrhea.
(8) Constipation.
(9) Appearance of tongue, coated or swollen.
(10) Colic.
(11) Urine, increased, decreased.
(12) Consciousness.
(13) Unconsciousness.
(14) Labored breathing.
(15) Convulsions.
(16) Bleeding from any part of body, as mouth, bowel, or skin.
(17) Rash, jaundice, or any discoloration of the skin.
(18) Swelling of any part of the body.
(19) Areas of tenderness.
(20) Paralysis in any part.
(21) Injury to any part of body.
(22) The treatment that has been given.

The following are examples of good radio messages:

(*a*) "Man, aged 30, deck hand, sick for past 24 hours, with severe pains and cramps in lower right side of abdomen, which is hard and tender to touch. There is nausea and some vomiting. Temperature is 99 1/2; pulse, 120 per minute; breathing 25 per minute. Have given no medicine."

(This information will inform the physician that the patient is probably suffering from an acute attack of appendicitis and he will therefore advise treatment accordingly.)

(*b*) "Man, aged 20, fireman, became sick three days ago with chill, and headache, followed in few hours by high fever, which does not go down.. Fever is 104; pulse, 140, breathing, 50 per minute. Has severe pains in chest when he breathes. Face flushed. Lies on left side, coughs; sputum rusty or blood colored. Has hot water bottle to side."

(This formation conveys to the physician the idea that this patient is perhaps suffering from pneumonia and he will outline the treatment accordingly.)

(*c*) "Man, aged 45, cook, fell and broke both bones right leg, apparently near middle. Bones protrude through skin."

(The physician receiving such a message will have no difficulty in understanding the nature of this fracture and will advise proper treatment.)

Vessels seeking medical advice from U. S. Coast Guard may contact its units by calling N C U *(general call for all Coast Guard units), on the International calling and distress frequency of 500 kilocycles (600 meters).*

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